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IMPROVING PLANT NUTRIENT MANAGEMENT FOR BETTER FARMER LIVELIHOODS, FOOD SECURITY AND ENVIRONMENTAL SUSTAINABILITY

Proceedings of a Regional Workshop

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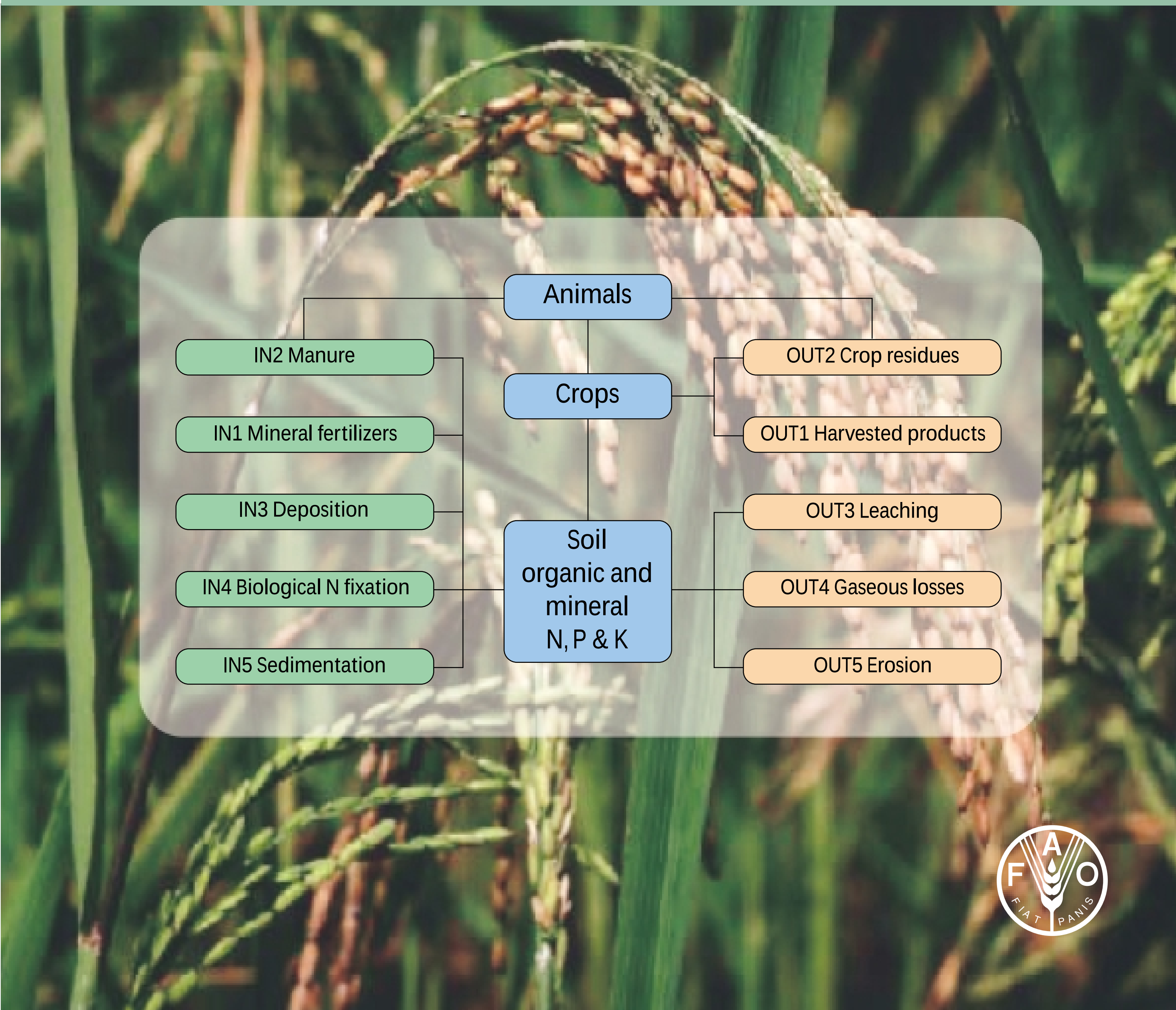

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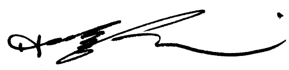
Foreword

Agricultural development in Asia and the Pacific has had its bright spots in terms of research and development in securing basic food needs and food reserves. The last decades have been marked by the continuing development of new hybrids and many open pollinated, high yielding varieties that double if not triple yields per unit area. This breakthrough provided alternative technologies for countries that had limited arable lands (generally Pacific Island countries, particularly the Small Island States) and countries that had been losing their lands to unabated high population growth, urbanization, industrialization and even pollution (generally Asian countries like China, Indonesia, the Philippines and others). Unfortunately, because of the urgency of improving food security, agricultural policy and infrastructure support in many Asian and Pacific countries were generally built around two basic short-term objectives with short-term benefits: improving crop yields and improving the incomes of small and resource poor farmers, with minimal measures to ensure that high yielding plants be provided with adequate and balanced plant nutrients to avoid serious soil fertility depletion. Thus, glaring enough in many countries in the region, despite the availability of high yielding plants and irrigation, is the stagnation of yields and decline of soil fertility brought about by (a) unsound fertilizer policies and (b) inadequate national efforts in monitoring and evaluating the combined impacts of fertilizer use and high yields on soil degradation, particularly fertilizer-induced soil nutrient deficiencies.

In most instances, government policy-makers focused on providing support in the form of subsidies for high yielding seeds and irrigation, but rarely provided adequate support for proper and balanced plant nutrition. Fertilizers, wherever they are a part of government support, are heavily in favour of Urea, the main fertilizer whose impact on the physical appearance of the plants is easily recognizable by the farmers. The net result was the excessive use of Urea which eventually created an unfavourable balance of nitrogen (N) with phosphorous (P) and potassium (K) nutrients. This nutrient imbalance has been recognized as the emerging major culprit in the decline and stagnation of food crop production and the general decline in soil fertility and production capacity in practically all countries in Asia and the Pacific region. A case in point was cited by the experience in India, which reported that as food production increased with time, the number of elements becoming deficient in soils and crops also increased. Micronutrient deficiencies in soils over long periods of nutrient supply imbalance in intensively used croplands are also emerging as yield limiting factors. Nutrient imbalances in intensively used agricultural lands can create a time-bound domino effect on the emergence of deficiencies of secondary and micronutrients.

As a way to strengthen awareness and improve common understanding of the complex dynamics of sustainable crop production, soil nutrient management and soil stability between and among scientists and land use practitioners in Asia-Pacific, FAO conducted a three day "Regional Workshop on Improving Plant Nutrient Management for Better Farmer Livelihoods, Food Security and Environmental Sustainability". Participants from 17 countries in the region discussed, elaborated on and identified country-relevant issues and gaps, and exchanged ideas and recommendations to collectively formulate technical and policy measures with particular focus on developing both country and regional options and actions for making Integrated Plant Nutrient Management (IPNM) the alternative technology for sustainable crop production and soil fertility management.

As a result of the thorough exchange of information and experiences on IPNM by the participants, the workshop opened up a new agenda that, in addition to ensuring food security, recognized the emerging role of the agricultural sector in promoting soil and land use stability. This will, therefore, require creation of an enabling agricultural policy environment that will incorporate social and environmental responsibility in overall crop production to ensure that all lands put into cultivation shall not in any manner lead to the degradation of human health, biodiversity and the environment. It is hoped that the result of this workshop will lead to greater awareness of and capacity building for farm level nutrient management, more specifically in enhancing the capacity of farmers to use organic and inorganic fertilizers safely, and in protecting the regions' soil resources.



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Food and Agriculture Organization of the United Nations

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The workshop was ably hosted by the China Agriculture University (CAU) under the effective coordination of Dr Fan Mingsheng with the full support of Dr N. Mona, the FAO Representative in China and CAU's eminent agricultural scientists, led by Professor Zhang Fusuo.

Sixteen experts and practioners from various institutions in Asia and the Pacific made substantial contributions to the active and practical exchange of applicable technologies, knowledge and lessons learned in Integrated Plant Nutrition Management. The participants represented five South Asian countries (Bangladesh, India, Nepal, Pakistan, and Sri Lanka), six Southeast Asian countries (Cambodia, Lao People's Democratic Republic, Myanmar, the Philippines, Thailand and Viet Nam); three Pacific Island countries (Fiji, Papua New Guinea and Tonga) and two East Asian countries (China and Democratic People's Republic of Korea).

Special mention should be given to the full support, unqualified contributions and effective participation provided by eminent scientists from different colleges and universities in China. This includes the College of Resources and Environment Science China Agriculture University; College of Resource and Environmental Sciences, Nanjing Agricultural University; State Key Laboratory of Soil and Sustainable Agriculture Institute of Soil Science, Chinese Academy of Sciences; Soil and Fertility Institute, Sichuan Academy of Agriculture Science; Northwest Sci-tech University of Agriculture and Forestry, Institute of Soil and Water Conservation; Northwest Sci-tech University of Agriculture and Forestry Resource and Environment College Shanxi, Institute of Soil and Fertilizer; and Institute of Atmospheric Physics, Chinese Academy of Sciences.

Much of the facilitation and guidance in the lively discussions on issues and solutions to the problems related to integrated nutrient management were provided by FAO experts led by Dr Rabindra Roy, Mr Hiroshi Hiraoka and Dr Yuji Niino.

Additional and very valuable experiences and insights into China's efforts on INM were enhanced by field visits arranged and sponsored by the China Agricultural University and with the help of Dr Fan Mingsheng whose active participation in the workshop was highly appreciated by the workshop participants.

We wish to thank Dr Fan Mingsheng and Professor Zhang Fusuo for compiling and Dr Rogelio Concepcion for editing of these proceedings.

Table of Contents

Table of Contents *(continued)*

Page

Part I. The workshop

A. Objectives

The workshop brought together various senior scientists of Asia and the Pacific countries to freely interact and exchange information and knowledge gained in research and development on Integrated Nutrient Management (INM) and its impact on soil fertility and farmers' yields and income. The workshop and ensuing discussions were designed to satisfy the following key objectives:

- Review the latest progress on integrated nutrient management;
- Identify integrated nutrient management issues and technical gaps;
- Formulate potential technical and policy measures and options for Integrated Nutrient Management, including methods and modalities in each country; and
- Identify common technical issues for regional action on integrated nutrient management.

B. Participants

The workshop was attended by senior soil and plant nutrition specialists from Bangladesh, Cambodia, China, DPR Korea, Fiji, Indonesia, Lao PDR, Myanmar, Nepal, Pakistan, Papua New Guinea, the Philippines, Sri Lanka, Thailand, Tonga and Viet Nam including experts and staff of FAO and China Agricultural University.

C. General design and scope of discussions

Individual country papers were presented by senior scientists from Asia and the Pacific region. Paper presentations were followed by a workshop which reviewed fertilizer use, soil fertility, and nutrient flow situations, lessons learned and shared experiences of the countries in research, technology development and transfer of knowledge and information on integrated nutrient management. The participants, likewise, recognized that rapid urbanization is a common barrier to long-term sustainable land management and agricultural land use development. The workshop participants discussed ways and means to promote close collaboration within Asia and the Pacific region for future exchanges of information, data, expertise and experiences in integrated nutrient management. There was a convergence of agreement for the adoption of South-South Cooperation and to strengthen future partnership with the FAO global network as the region's common platform to promote interregional exchanges of country experts, enhance sharing of knowledge and experiences in research, development and extension on integrated nutrient management and other aspects of sustainable soil and land management technologies.

Part II. Synthesis of Asia and the Pacific region's perspective on nutrient management and soil productivity

The 1996 World Food Summit established a strong linkage between Sustainable Agricultural and Rural Development (SARD) and food security. SARD has identified sound management and use of available natural resources and the environment as both a prerequisite and a means of achieving the objective of food security.

The participants recognized that Asia and the Pacific region has the highest share of global land resources and at the same time the highest population. The participants, likewise, confirmed that many production areas in the region have been suffering from a rapid and continuous decline in the man-arable land ratio. This decline in productive land predisposes the remaining intensively-used farmlands to a high incidence of soil erosion and rapid decline in soil fertility, which altogether leads to a decline in the capacity of their natural resources to sustain their respective country's future food needs.

Agriculture in the region has undergone notable transformations during the last four decades. The global success of the Green Revolution programme provided the initial global consciousness of the strategic value of making sustained improvements in the individual country's food self reliance and likewise provided the foundation for the role of science and modern technologies in meeting present and future challenges.

Over the years, yield improvements were obtained through increased area of irrigated lands, development and use of improved varieties, and increased use of oil-based fertilizers. Asian cereal production registered more than a 260 percent increase from 386 million tonnes in year 1965 to 1 009 thousand tonnes in year 2004, with similar trends for other agricultural commodities. Furthermore, the region's average yield of paddy rice doubled from 2.0 t/ha in 1965 to 4.1 t/ha in 2004, while that of wheat more or less tripled from 0.97 t/ha to 2.87 t/ha.

The increasing competition between farming and urbanization for use of agricultural land creates the condition for a paradigm shift to the conscious campaign to develop and promote the awareness that Integrated Plant Nutrient Management System as a national, regional and global strategy to combat loss of farm productivity is a profitable investment for sustainable rural livelihood, food security and the environment.

In recent years, gains in technology-driven crop production were challenged and threatened by the increasing pressure from the external environment, extreme climate changes and global oil market situation and its impact on cost and availability of Urea, the most preferred fertilizer by small farmers in the region. The last decades were marked by research and development of new super-hybrids, environment-friendly pest and disease management, introduction of better use of fertilizers and increased investment in irrigation development. However, a parallel event in the form of an increasing incidence of regional drought and flooding as well as increasing deforestation and use of fragile marginal lands jointly contributed to an accelerated erosion and massive loss in soil organic matter in Asia and the Pacific region. Furthermore, in recent years and perhaps in unforeseen periods into the future, the unstable global oil situation and its direct impact on the doubling of the cost of inorganic fertilizers, particularly that of Urea, shall be the dominant barrier to the sustainability of food and agricultural production, incomes and livelihood of small, vulnerable poor farmers in the region.

The dramatic improvements in yields in many Asia and Pacific countries have, likewise, led to larger problems of soil nutrient mining, aggravated by the fact that this complex process of soil fertility loss remained unknown to many farmers and local field extension technicians. Soil nutrient mining is a phenomenon where the withdrawal of nutrients by crops exceeds the combined external nutrient supply and the mobilization of soil nutrients, which over time results in the exhaustion of native soil nutrient reserves and induction of deficiencies in some micronutrients. These situations have had large impacts on the incomes of small, poor farmer's, which has definitely translated into a decline in their capacity to continue the adoption of modern agricultural production technologies. If soil nutrient mining is not addressed properly and immediately, serious impairment of soil productivity will result in irreversible soil degradation and permanent loss of income, which altogether will greatly weaken farm-level self-reliance and national capacities for food self-sufficiency.

Fertilizer subsidies resulted in increased fertilizer importation and utilization and dramatic increases in country's production of cereals and other food crops. However, even as the country enjoyed the bonanza of low cost fertilizers and the consequent improvement in food security, researchers noted a continuing decline in soil fertility and yield increments and increasing requirements of fertilizers per unit area, including a phenomenal loss in soil productivity and deterioration of water quality.

The general trend in fertilizer importation in most Asia and Pacific countries indicated a general preference for Urea and very minimal for Potash. Senior scientists from India indicated that this is because Urea is the preferred and main source of nitrogen because it is cheaper, easily available and provides rapid response. They further provided information on the increased nutrient gap where nutrient exports, in the form of farm products consumed as food medicine and other products, exceed the net nutrient imports in the form of applied fertilizers.

The widening gap between the withdrawal of soil nutrients to produce food and the provision of fertilizer supplements to prevent the total depletion of native soil nutrients is becoming an important common concern in Asia and the Pacific region. This situation is highly relevant, critical and time sensitive since the only and perhaps the quickest alternative mitigation measure to compensate for the decline and loss of arable land is the sustained development and provision of yield improving technologies, such as early-maturing hybrids and irrigation, which encourage huge and fast withdrawal of soil nutrient reserves in short periods. When soil nutrient and fertilization management is faulty in these time-sensitive yield improvement initiatives, there are serious negative consequences on the terrestrial and coastal environment and long-term food production programme. Over time, the unabated loss of soil fertility will trigger the silent and undetected process of desertification and eventually lead to the total and irreversible loss of land productivity and population carrying capacity in the region.

The inadequate management of applied nutrients has also created an undesirable flow of nutrients, with most of the unused fraction released to the rivers, groundwater, lakes and other freshwater bodies or released to the air in gaseous forms contributing to air pollution. At the farm household level, the cost-benefit of farm input has declined. At the national and regional level, the plant nutrient balance has been negatively affected and so has the food production potential.

The common barriers to sustainability of food security efforts in the region, including countries with successful food production programmes such as Bangladesh, China, India, Pakistan, Republic of Korea and Viet Nam, are summarized below:

- *Declining trends in soil fertility and mining of soil nutrients.* The adoption of intensive cultivation and short duration high yielding varieties and the blanket application of plant nutrients without the benefit of proper and timely soil analysis are proving to be inadequate to sustain the loss of soil nutrient reserves to sustain long-term and cost-effective high crop production.
- *Decline in soil organic matter levels.* Poor on-farm management of soil organic matter along with sub-optimal use of organic and biological nutrient sources, combined with the concurrent soil nutrient mining, poor water management and poor soil cover have collectively caused the rapid degradation/decline of soil organic matter. The general absence of comprehensive national programmes on organic-based farming, nutrient recycling, and composting along with poor land management practices has led to a loss of soil infiltration capacity and soil erosion that eventually has resulted in the rapid removal of surface soil organic matter by run off. Furthermore, while poor on-farm management could be attributed to a lack of proper information and technology transmission to the farmers in some areas, the reduced availability and access to organic resources, compounded by

undefined socio-economic factors are the outstanding constraints and barriers to the use of adequate amounts and proportion of organic and inorganic fertilizers.

- *Overuse and inefficient utilization of mineral fertilizers and resulting deterioration of environmental quality.* Many areas in the region witnessed both the conditions of inadequate availability and affordability of key agricultural inputs like mineral fertilizers. There is a serious concern about the overdose of fertilizers as shown by the general trend for some farmers to misuse and apply excessive amounts of inorganic fertilizers, especially Urea. Country reports from the China, India, the Philippines and other countries indicates that in recent years there has been a tremendous increase in the importation of Urea in disproportionate volume against phosphorous and Potash fertilizers. Inadequate awareness concerning efficient fertilizer use and appropriate practices have resulted in inefficient releases of soil nutrients with respect to the actual needs of the plant for optimum growth and production into the already weakened ecosystem, causing water and soil pollution.

Participants clearly showed a regional convergence regarding policy and technical measures to combat the decline in soil fertility and food supplying capacity of agricultural lands. Scientists in the region are in common agreement on the need for the efficient and balanced use of nutrients by plants and the need to apply scientific measures to ensure that soil fertility is sustained while engaging farmers to improve their yields through the use of short maturing, proper water management and use of IPM.

Despite complex differences in sizes of population, socio-economic conditions and land areas, scientific communities, land use policy-makers and practitioners in Asia-Pacific countries have committed themselves to strengthening regional cooperation and national capacities to develop a more rational integrated approach to nutrient and natural resources management and sustainable land management that link food production with rural livelihood, environmental protection and biological diversity improvement. In terms of combating problems of declining production and yields among small poor farmers, Asia-Pacific countries have adopted a common approach, albeit with differing efficiency and success, involving organic-based fertilization following balance fertilization principles and methods.

In response to the global search for cost-effective fertilization measures, farm waste recycling and accelerated compost production, the oldest yet relevant alternative technologies have become the region's consensus for the convergence of socially acceptable cost reduction measures that help stabilize soil productivity, farm income and livelihood of poor farming communities in Asia and the Pacific region.

While some Asia-Pacific countries are at the crossroads to industrialization, agriculture generally remained steadfast as the region's primary industry to combat growing population and food security needs and environmental degradation. China and India, for instance, which have both the largest land area and population in the region and have moved successfully towards urban development and industrialization, still consider agriculture the primary area of development and investment. In the recent years, China, along with most Asia-Pacific countries, has mobilized its scientific communities to address concerns about Integrated Nutrient Management to support sustainable agricultural development for food security and securing rural areas against the vagaries of global and national economic development.

Part III. Highlights of common country-level issues on integrated nutrient management

The summary of the lessons learned, policies and constraints in implementing integrated nutrient management in Asia-Pacific countries are presented in the Annexes to Part VII (Tables 1 through 17).

Knowledge gaps in IPNS management between scientists and farmers remain a major factor in the complex dynamics of soil-plant nutrient management to effectively sustain the balance between soil nutrient reserves with actual plant nutrient uptake and nutrient export or removal from the farm.

The increasing collective participation of the private sector and local and international academic institutions in the region to provide agricultural producers with early maturing hybrid seeds that need to be fed with huge amounts of nutrients within short periods (110 to 120 days) is a big challenge for soil and plant nutrition scientists. The shortened time for soil nutrient mobilization to meet the phenologically-related food demands of the plants make readily soluble/available chemical fertilizers a major consideration in the campaign for improving yields and food supplies to support a rapidly growing population.

The nutrient budgets in the agro-ecosystem as shown in some papers indicated the growing negative trends for potash and phosphates and increasing trends for nitrogen. China, as corroborated by the senior scientist from Bangladesh, reported that in the "1950s there was a small surplus of N with deficits of P and K and then N and P became more balanced in the mid-1970s. The N and P budgets then show a surplus with K still in deficit. The nutrient surpluses of arable land reached 154 kg N/ha and 31 kg P/ha in 2004. The increasing surpluses of N and P can be attributed mainly to increasing fertilizer inputs and steady application of organic manures from 1980 to 2003. Although the K deficit decreased from -1.89 mt in 1979 to -1.34 mt in 2004, there was still a serious shortage of K. In addition, nutrient inputs from the environment, especially N inputs, have also contributed to the nutrient surpluses, accounting for 18.6 percent of N, 1.7 percent of P, and 12.7 percent of K of total inputs in 2004."

A. INM issues for Asian countries

Asian agriculture is under persistent pressure to narrow the gap between food supplies and demand by the ever increasing human population, aggravated by significant loss of arable land from urbanization and pollution. As a consequence of this negative trend in the food supplying capacity of the regions natural resource base, Asian countries have mainstreamed into their national policies the promotion and use of genetically improved short food crops, including livestock and fishes, as the foundation of their food security programmes. This is further enhanced and fully supported by policy support for fertilizer subsidies to encourage farmers to use more and higher rates of fertilizers to ensure high crop yields.

Common barriers and root causes of the decline in agricultural land productivity and the ensuing threat to food security in Asian countries include, but are not limited to the following:

1. Soil mining or internal loss of soil nutrient reserves to the plant and the groundwater induced by the imbalanced use of fertilizers, mostly through the excessive use of Urea;
2. Poor rationalization of chemical fertilizer importation to ensure easy access to appropriate, suitable and affordable fertilizer grades. In most cases, the importation and supply of Urea exceeded phosphates and potash;
3. Inadequate understanding and absence of dedicated national programmes for organic-based fertilization and balanced fertilization based on a sound soil testing programme;

4. Policy support for short maturing, high yield varieties (hybrid) without appropriate integrated nutrient management practices to avert the incidence of soil mining and soil/water degradation;
5. Fertilizer subsidies that are not based on the soil and plant nutrient needs of the country (e.g. Bangladesh, China, India, Pakistan and Sri Lanka);
6. High population and rapid urbanization and declining man-arable land ratio; and
7. Global oil issues and uncontrolled increases in the price of chemical fertilizers.

B. INM issues for Pacific Island countries

Pacific Island countries, in contrast to their Asian counterparts, have dedicated much of their agricultural development to serving the needs of farm families and are built around the organization and success of a network of home gardens.

In contrast to the capital intensive character of Asian agriculture, agricultural development in the Pacific Island countries is basically based on low external input, small-scale farming systems, supported by traditional and indigenous technologies. They are largely dedicated to home self-reliance composed of networks of small home gardens generally using simple tools and indigenous technologies to serve farm family needs and local markets. Compared to the predominance of chemical fertilizers in the more advanced Asian countries, farmers in the Pacific Islands are mainly dependent on natural fertilizer sources, recycling crop residues and natural soil fertility.

Some island countries have started to experience the pressures of increasing population and rapid urbanization and declining land availability per capita, which in the long-term could become a major barrier to a long-term, sustainable agricultural development programme for food security. Increasing areas of sloping farmlands are contributing to a higher incidence of erosion and long-term loss of land productivity of scarce arable lands, particularly in coastal areas.

Common issues in nutrient management and barriers to food security in Pacific Island countries, because of the very nature of small backyard or home gardens, are listed below, to wit:

1. The natural ecological convergence of upland agriculture with coastal agriculture and fishery areas justify the unique and critical role of soil erosion control and management in developing an inter-landscape transboundary INM strategy for a watershed-wide soil fertility management programme;
2. Dependence on natural soil fertility and natural fertilizer sources and traditional plants and varieties;
3. Soil erosion resulting from decreasing fallow periods, subsistence farming and increasing human demand for land and food;
4. Land use policy that protects scarce agricultural lands is in important consideration in the formulation of food security increasing population;
5. While low external inputs and multi-cropped home gardens, characterized by natural nutrient recycling and low nutrient demands, result in low food outputs, they help farmers preserve native soil nutrient reserves; and
6. Declining man-arable land ratio due to increased population and urbanization.

Additional discussions prior to formulation of recommendations

A collective review of lessons learned and knowledge about integrated nutrient management was conducted by the senior scientists to define the measures needed to combat complex problems of soil nutrient mining and the decline in soil productivity. The self-review provided insights on the modalities adopted in packaging information and technologies. Critical gaps were identified to improve the efficiency of delivery of services from various country institutions to the different stakeholders, farmers, policy-makers and extension agents.

The participants recognized the need to distinguish among three kinds of stakeholders and the manner in which information and substantive contents are packaged and delivered. The results of these exercises are summarized below:

For the farmers:

- Provision and packaging of appropriate and farmer-friendly extension materials (sketches and drawing illustration techniques, conduct of pilot on-farm demonstrations, preparation of easy-to-read soil fertility maps/charts, fertilizer recommendation charts, etc.);
- Establishment and promotion of Farmer Field Schools for community-based learning and development of Soil Doctors (adopted from Thailand's experience) to facilitate farmer-to-farmer exchanges of knowledge and acquired technologies; and
- Elaboration and proper communication of monetary and environmental benefits of IPNS.

For the decision-makers:

- Mainstreaming of principles of nutrient management and elaboration of environmental and economic benefits derived from sound IPNS. This includes the preparation of policy briefs and position papers to elaborate the substantive economic and environmental benefits of adopting IPNS;
- Illustration of IPNS benefits through presentation of national nutrient balance analysis;
- Conduct of pilot techno-demos to showcase the impact of IPNS on yield increases supported by simple audience-friendly graphic illustrations of environmental benefits, and cost/return analysis;
- Brief on both positive and negative scenarios of IPNS adoption to address poverty and food security and long-term sustainable development; and
- Conduct and preparation of briefing materials on the environmental impacts of sound nutrient management practices.

For support institutions and change agents:

- Review of the extension approach (number of extension agents, extension methods);
- Promotion of the adoption of participatory approaches by all stakeholders (NGOs, the private sector, industry, researchers, academics, etc.);
- Provision of knowledge management to support IPNS networking (model, knowledge, scenario, scientific document); and
- Local campaign and support to IPNS.

Table 1. Technical options, needs and information gaps in transfer of information on nutrient management practices

Technical issues and options	Do we have reliable guidelines, manuals, economic analysis?	What are the technical gaps?
Farmer awareness on soil fertility issues	Yes	Lack site and nutrient information
Accurate soil data	Yes, not enough	Expensive to acquire; not shared and properly circulated
Crop potential	Yes, not enough	May need to develop and provide crop and agro-ecosystem specific pilot demonstration (crop models by ecosystem)
Farmers' practices	Yes	Varying farmers attitudes towards changes in technology packages
Climatic data (variation risk)	Yes, not enough	Need to have farmer-level data and higher accuracy in local climate forecasting
Technical information	Yes, not enough	Need to improve packaging, networking, interpretation for wider awareness and easier understanding by stakeholders at all levels (farmers, policy-makers and extension agents)
Fertilizer availability/use	No	Unreliable statistics and restricted regulation on fertilizer (entry into the country)
Farmer knowledge	Partially	More effective methods of communication and integration of local and acquired knowledge and technologies
Cost-benefit analysis	Not enough	Not updated, market changes, difficulty in including quantified values of environmental services (e.g. C-sequestration value)

The gaps and responses of the participants in the meeting are summarized in table (Table 1).

The participants, likewise, addressed the issue of availability and sufficiency of technical information on IPNS. They put into proper context the discussion by defining the composition of policy-makers at various levels of the government. The nature and category of information are summarized below:

- National level information in the form of broad guidelines for national policy-makers composed of various country offices and Ministries (e.g. Agriculture, Environment, Finance, Science & Technology, etc.); Secretaries (e.g. Agriculture research policy-makers, Director-General of MOA/DOA); academic sectors; farmer organizations and councils and including national NGOs (e.g. NGOs in Bangladesh, Thailand and Viet Nam);
- Provincial level information in the form of specific guidelines and monitoring activities for the provincial levels of policy-makers, composed of Secretary of Agriculture, Provincial Councils; and
- District or field level information in the form of specific technical knowledge management composed of district level administrators and agriculture extension groups.

The participants collectively agreed on the benefits associated with the FAO programme for South-South Cooperation (SSC). The discussion covered a wide variety of issues for possible consideration by technology providers and technology recipient countries. The areas of cooperation cover the topics of IPNS, Balanced Fertilization, Crop and IPNS Modeling, enhanced compost production and demonstration, site specific nutrient management, application of GIS technology in mapping, data management, sharing and utilization, Sustainable Land Management (SLM) for land degradation, and various forms of Information Technologies.

Table 2 summarizes the results of the initial discussions on the proposed SSC showing potential technology providers and recipient countries. The initially identified activities, however, need to be refined and further discussed by the concerned participating countries during the actual South-South Cooperation country mission.

Table 2. Selected topics and potential country partners for South-South Cooperation

Technology Needs	Potential technology providers	Potential recipient countries
IPNS practices (model farm) at different land holding size levels – Showcase demo plots	China, Indonesia, Lao PDR, Philippines	Bangladesh, Cambodia, DPR Korea, SIDS (SAPA, Maldives)
Balanced nutrient management	China, Philippines, Viet Nam	Bangladesh, Myanmar, Nepal
DSS for P and K fertilizer recommendation	Indonesia	
Soil and plant tissue analysis	China, Indonesia, Philippines, Sri Lanka, Thailand, Viet Nam	Bangladesh, Cambodia, DPR Korea, Nepal
Slow Release Fertilizer	China	Bangladesh, Fiji, Nepal, Philippines, Thailand, Viet Nam
Decomposition of crop residue by microorganism and compost making	China, Philippines, Thailand	Bangladesh, DPR Korea, Fiji, Indonesia, Myanmar, Sri Lanka
Rapid soil test kit, including micro and secondary nutrients (Zn, B, S, Ca, Mg)	China, Indonesia, Philippines, Thailand	Bangladesh,Cambodia, DPR Korea, Fiji, Myanmar, Nepal, Sri Lanka, Viet Nam
Precision agriculture	Thailand	Bangladesh, Indonesia, Nepal, Sri Lanka, Viet Nam
GIS for National Nutrient Mapping and Management	Thailand	
Sloping Land Management technologies	China, Indonesia, Philippines, Sri Lanka, Thailand, Viet Nam	Bangladesh, Lao PDR
Community-based extension	China, Thailand (Soil Doctor)	Fiji
Land use planning and extension	Philippines, Viet Nam	

Part IV. Recommendations

1. Further strengthen the promotion, dissemination, packaging of IPNS information, lessons learned and results of research on IPNS to farmers, policy-makers and field extension agents.
2. Strengthen exchanges of information between and among scientists and institutions in Asia and the Pacific region through FAO sponsored South-South Cooperation.
3. Establishment of Regional Network: Asia-Pacific Network on IPNM for Food Security and Environmental Sustainability (APIPNM).

Part V. Conclusions

1. The participants collectively expressed interest in the immediate formulation of programme to support the implementation of South-South Cooperation to improve the transfer of knowledge and information and strengthen capacity building within Asia and the Pacific region.

2. The participants, with the full support of China and FAO, likewise recommended the formation and implementation of the Asia-Pacific Network on IPNM for Food Security and Environmental Sustainability (APIPNM). The following interim arrangements were agreed upon:

   a. That there will be contribution either in cash or in kind from China and that this can be done through a Memorandum of Agreement that will cover a period of five (5) years. Some potential donors and partners were identified:

      - Donor institutions from Australia Germany and perhaps ADB,
      - FAO may be able to support in the formulation and packaging of the formal proposal.

   b. That the Chinese Agricultural University volunteered to initially act as secretariat to perform, among other relevant actions, some initial activities involving preparation of a regional background paper for addressing policy-makers and in the preparation of a draft network proposal.

Part VI. Country papers

South Asian Country

Paper Number 1

Integrated nutrient management for sustaining crop productivity and improvement of soil fertility in Bangladesh agriculture*

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Upazilla Agriculture Office, Kutubdia Cox's Bazer, Bangladesh

Summary

Bangladesh is the fifth most populous country in Asia and the 18^{th} in the world who has successfully attained self-sufficiency in food despite the decline in per capita land and increase in population. The country has opted for an agricultural development policy that gradually moved farmers away from the traditional and rather static agriculture dependent on native soil fertility to a dynamic judicious fertilizer dependent farming. In the last three decades, food grain production has considerably increased due to substantial intensification of cropping, introduction of high yielding varieties (HYVs), and expansion of irrigated area and use of chemical fertilizers. However, this has also led to widespread soil fertility depletion caused by fertilizer nutrient imbalance and serious nutrient gap between plant use and fertilizer application and mining out scarce native soil nutrients to support increases in yields of food crops. The use of chemical fertilizers mainly for N, P, K and S has been increasing steadily but they are not applied in balanced proportion. Continously cropped areas were observed to have problems of decline in organic matter and those associated with imbalance use of fertilizers were found, aside for its impacts on P and K fertilization, to have emerging deficiencies of micronutrients like Zn, B, Mn, Mo. Bangladesh adopted a strategy for balanced fertilization to promote soil building to support sustainable land use system and ensure stable supply of food grains from existing agricultural lands. In this context and as a further response to economic recession, as well as to conserve and improve soil fertility, the concept of integrated nutrient management (INM) system has been adopted.

1. Introduction

Bangladesh is situated between 20º34′ and 26º38′ north latitude and 88º01′ and 92º41′ east longitude. It is the fifth most populous country in Asia and ranks eighteenth in the global context. The country has a land area of 14.83 million hectares (m ha), population over 135 million with a density of more than 800 person km^{-2}, which is one of the highest in the world.

Primarily, the country is deltaic floodplain. The topography is flat with elevation not exceeding 10 meters above mean sea level. The non-undulated topography is broken in the southeast by the Chittagong Hill Tracts and hills in the northeastern part of the country. Floodplain and piedmont plains occupy almost 80 percent of the land area. Slightly uplifted fault blocks (terrace) occupy about 8 percent and hills occupy about 12 percent of the land.

* This country report has not been formally edited and the designations and terminology used are those of the author.

The effective land area is roughly 12.31 m ha of which presently 7.85 m ha are under cultivation (BBS, 1996). During the last three decades per capita arable land declined from 0.17 ha in 1960 to 0.07 ha in 1991 and presently reduced to less than 0.06 ha. The cropping intensity in the country is 180 percent. Multiple cropped areas occupy about 35.8 percent, 51.4 percent and 12.8 percent of the net cropped area. Agriculture contributes about 23.5 percent to the GDP.

During the last three decades, food grain production has increased considerably from about 11 mt in 1970-71 to about 27 mt in 2002-03. Present demand of food is 22.55 mt and production is 28.38 mt. The major driving forces are substantial intensification of cropping, introduction of high yielding varieties (HYVs), and expansion of irrigated area and use of chemical fertilizers.

2. Soil fertility status

In the recent years, intensive crop cultivation using high yield varieties of crop with imbalanced fertilization has led to mining out scarce native soil nutrients to support plant growth and production, the dominant soil ecological processes that severely affected the fertility status and production capacity of the major soils in Bangladesh. Available data indicated that the fertility of most of our soils has deteriorated over the years (Karim *et al*., 1994 and Ali *et al*., 1997), which is responsible for national yield stagnation and in some cases, even declining crop yields (Cassman *et al*., 1997). The use of chemical fertilizers mainly for NPKS has been increasing steadily but they are not applied in balanced proportion. For example, in 1996, 421:71:454:44 million tonnes of NPKS, respectively, were removed in grain and straw while in the same year 507:119:114:13 million tonnes were added in the form of inorganic fertilizers. Considering, the recovery percentage of the added nutrients the gap was about 244:47:400:41 million tonnes of NPKS (Islam *et al*., 1998). Moreover, emerging deficiency of micronutrients like Zn, B, Mn, Mo has been reported in some parts of the country particularly northwestern region. It is now well known that S and Zn deficiencies particularly in wet land rice soils in many parts of the country have been induced by imbalanced fertilization. Deficiencies of Ca and Mg are also prevalent in calcareous soils. On the other hand, organic matter content of most of the Bangladesh soils is very low where the majority fall below the critical level (1.5 percent). The organic matter content of Bangladesh soils in continuously cropped areas from 1967 to 1995 has been depleted by 5 to 36 percent (Ali *et al*., 1997). One natural reason is that organic matter decomposition in soils with tropical climate, like Bangladesh, is high. Moreover, the addition of organic materials to soil through FYM, compost and organic residues has been reduced considerably because a major portion of these organic residues (cow dung & crop residue) is used up as fuel by the rural people. The major reasons for the depletion of soil fertility in Bangladesh are listed below:

a. The increased intensity of cropping, specially changes in crop sequence with HYV, makes current management practices, including fertilizer use less effective;

b. More fertilizers are being used on lands with poorer soils or uncertain irrigation facilities;

c. There is an imbalance in the supply of N, P and K with application of latter two nutrients often being too low;

d. Deficiencies of secondary and micronutrients are prevalent; and

e. Gradual decrease in soil organic matter and an increase in soil degradation (erosion, acidification, salinization, alkalization pollution, compaction etc.).

3. Soil nutrient mining

Soil fertility and environment are closely interlinked: Depletion of soil fertility means degradation of the environment and likewise, its improvement also leads to a better environment. The depletion of nutrients (fertility erosion) is widespread on the earth as well as in Bangladesh. The major forms and causes of nutrient depletion include excessive crop nutrient uptake and removal, erosion, leaching, gaseous loss, irreversible fixation in the soil and immobilization in the trunks and branches of tree crops.

Table 1. Soil nutrient mining status in Bangladesh (1998-99)

Location	Dominant cropping pattern	Total yield (t/ha/yr)	Nutrient mining (kg/ha/yr)
Palima, Tangail	Mustard-Boro-T. Aman	13.0	-190
Polashbari, Gaibandha	Mustard-Boro-T. Aman	10.2	-270
Narhatta, Bogra	Mustard-Boro-T. Aman	9.5	-280
Palima, Tangail	Wheat-Jute-T. Aman	7.0	-240
Paba, Rajshahi	Potao-Jute-T. Aman	34.5	-350
Thakurgaon	Sugarcane intercropping	60.0	-80
Joypurhat	Sugarcane intercropping	107.0	-60
Rajshahi	Sugarcane intercropping	90.0	-62
Bogra	Boro-GM-T. Aman	11.0	-180
Bogra	Wheat-GM-T. Aman	7.5	-170

Source: DANIDA/SFFP.

4. Need for balanced fertilization in Bangladesh agriculture

Imbalanced fertilizer use is both costly in terms of nutrient loss from soil mining, decline in food supply and loss of soil fertility and land productivity and the consequent decline in food production.

Bangladesh adopted a strategy for balanced fertilization to promote soil building to support sustainable land use system and ensure stable supply of food grains from existing agricultural lands.

Bangladesh is gradually moving away from the traditional and rather static agriculture dependent on native soil fertility to a dynamic judicious fertilizer dependent agriculture. In a judicious fertilizer-dependent agriculture, balanced fertilization strategy has to be a cornerstone of all activities. Balanced fertilization is aimed at:

- Increasing crop yields;
- Increasing crop quality;
- Increasing farm income;
- Correction of inherent soil nutrient deficiencies;
- Improving soil fertility;
- Avoiding damage to the environment; and
- Restoring soil fertility and productivity of land that has been degraded by wrong and exploitative activities in the past.

5. Fertilizer use in Bangladesh agriculture

Total requirement of fertilizers like Urea, TSP, SSP, MP, Gypsum and mixed fertilizer for crop production are 28.0, 5.0, 1.25, 1.5 and 3.0 lakh metric tonnes per year respectively. Among them 60 percent of Urea and 100 percent of mixed fertilizer is produced in the country (personal communication with Deputy Director, Directorate of Agricultural Extension). Annual consumption of chemical fertilizer is increasing at constant rate. Figure 1 depicted nitrogen, phosphorous and potassium consumption in the country from 1980-81 to 1996-97 and Figure 2 explains trends of chemical fertilizer consumption by two rice and wheat crops.

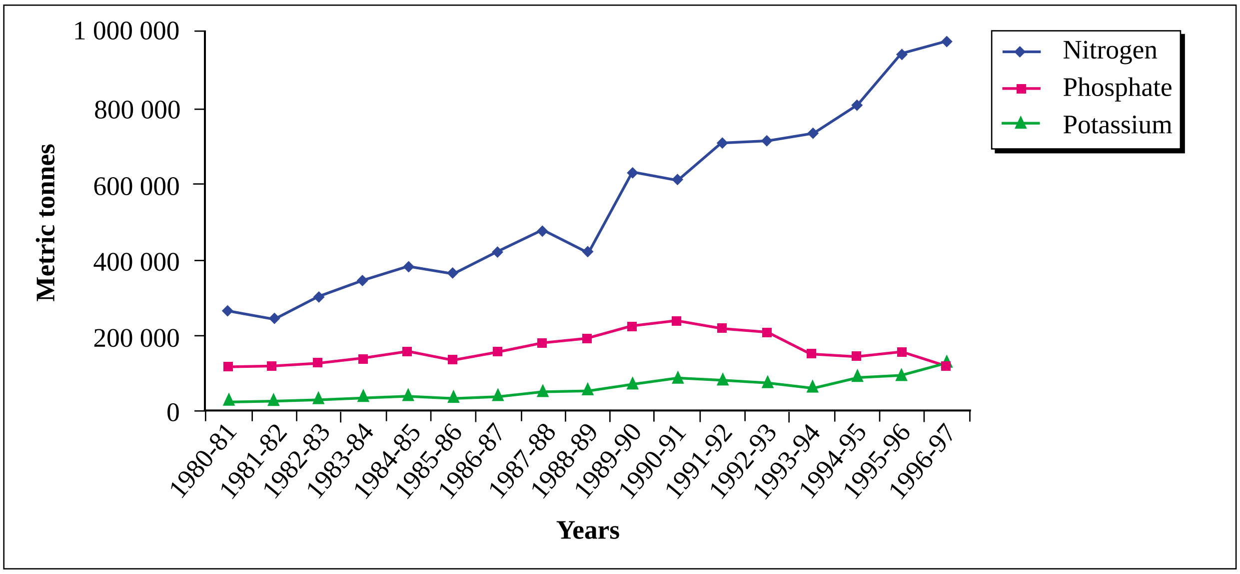

Figure 1. Bangladesh annual consumption of fertilizer nutrient, 1980-81 to 1996-97

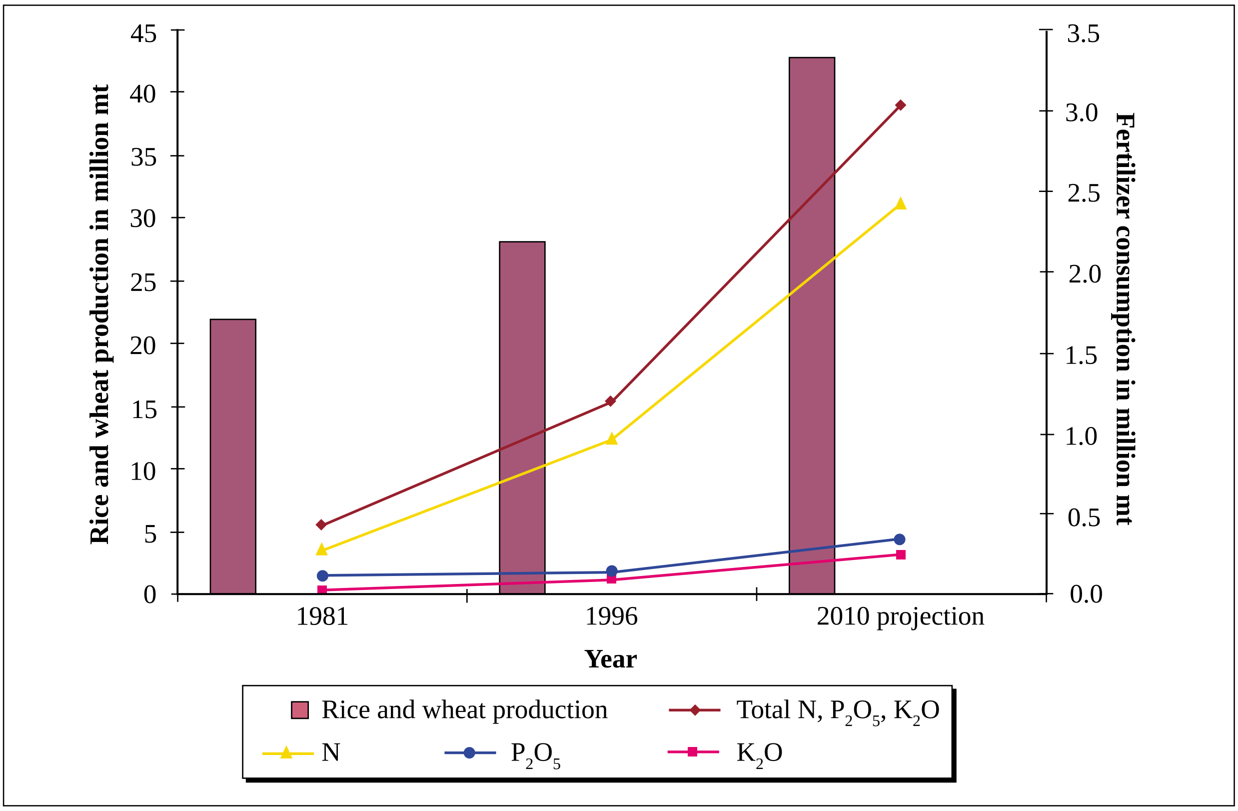

Figure 2. Projection of fertilizer consumption and rice and wheat production in 2010

6. Projection of wheat and rice production and chemical fertilizer use

Considering 1980 as baseline, wheat and rice production were projected to 2010 both in terms of yield and corresponding NPK use. The scenarios are illustrated in the Tables 2 and 3.

Table 2. Projection of wheat and rice production and NPK use up to 2010

Crop	Wheat and rice production (million mt)				
	1981[1]	**1996[2]**	**Diff. btw. 1981-1996**	**2010 Projection[3]**	**1996-2010**
Rice	20.9	26.7	5.8	40.8	14.1
Wheat	1.0	1.4	0.4	2.0	0.6
Total	21.9	28.1	6.2	42.8	14.7
Fertilizer	**Fertilizer consumption (million mt)**				
	1981[4]	**1996[5]**	**Diff. btw. 1981-1996**	**2010 Projection**	**1996-2010**
N	0.28	0.96	0.68	2.43[7]	1.47
P_2O_5	0.12	0.14	0.02	0.35[7]	0.21
K_2O	0.03	0.10	0.07	0.25[7]	0.15
Total	0.43	1.20	0.77	3.03[6]	1.83

[1] 1981 average production calculated form FAOSTAT values for the years 1980, 81, 82.
[2] 1996 average production calculated form FAOSTAT values for the years 1985, 96, 97.
[3] Projected production (source: Agriculture Towards 2010 (W89CS) ESD database, FAO).
[4] 1981 average consumption calculated form FAOSTAT values for the years 1980, 81, 82.
[5] 1996 average consumption calculated form FAOSTAT values for 1995 and FDI-II and ATDP/IFDC value for 1996-97.
[6] Calculation of projected total N, P_2O_5, K_2O fertilizer consumption for the year 2010.

$Ftot_{2010}$ = •Ftot B1-96/•$Ftot_{81\text{-}96}$ •$Ftot_{81\text{-}96}$ x $_{96\text{-}2010}$ + $Ftot_{96}$

[7] Calculation of individual N, P_2O_5, K_2O, projected consumption for the year 2010.

N, P_2O_5, K_2O = N, P_2O_5, K_2O,/$Ftot_{96}$ x $Ftot_{2010}$

Table 3. Trend of different fertilizers used during the period of 1980 to 2003

Year	Urea	TSP	SSP	DAP	MOP	Gypsum	Zinc	AS	Others
1980-81	5.6	2.2	–	0.4	0.5	–	*	–	0.1
1981-82	5.2	2.1	–	0.5	0.5	–	*	–	*
1982-83	6.3	2.1	–	0.7	0.5	*	*	–	*
1983-84	7.1	2.6	–	0.9	0.6	*	*	–	*
1984-85	8.3	3.2	–	*	0.7	*	*	–	*
1985-86	7.9	3.0	–	*	0.6	*	*	–	*
1986-87	9.2	3.4	–	*	0.7	*	*	–	*
1987-88	10.3	3.9	–	–	0.9	*	*	*	–
1988-89	11.4	4.2	–	–	0.9	0.6	*	*	173
1989-90	13.7	4.8	*	–	1.2	0.7	*	*	18
1990-91	133.0	5.1	0.1	–	1.5	1.0	*	*	211
1991-92	15.3	4.6	0.4	–	1.4	1.2	*	*	–
1992-93	155.0	4.1	1.2	0.02	1.3	1.1	*	*	–
1993-94	15.8	2.3	1.7	0.30	1.0	0.9	*	*	97
1994-95	17.5	1.2	5.3	0.02	1.5	0.8	–	*	–
1995-96	20.4	1.1	6.0	–	1.6	1.0	*	*	–

Table 3. *(continued)*

Year	Urea	TSP	SSP	DAP	MOP	Gypsum	Zinc	AS	Others
1996-97	21.2	0.7	5.3	–	2.2	0.9	*	0.1	–
1997-98	18.7	0.6	4.7	0.07	1.9	1.1	*	0.9	–
1998-99	19.0	1.7	3.6	0.4	2.1	1.3	*	0.1	–
1999-00	20.0	2.4	2.1	1.0	2.3	1.7	*	0.3	–
2000-01	21.1	4.0	1.4	0.9	1.2	1.0	*	0.1	–
2001-02	22.5	3.4	1.2	0.9	2.5	0.6	–	–	–
2002-03	22.4	3.3	1.3	1.2	2.8	0.4	–	–	–

Note: Figures in lakh (100 thousand) metric tonne.

7. Plant nutrient balance system

The continuous recycling of nutrients in to and out of the soil is known as the nutrient balance, which involves complex biological and chemical interactions. Figure 3 constructed by Smaling, 1993, provided the illustration of the basic simplified nutrient input – nutrient output balance system.

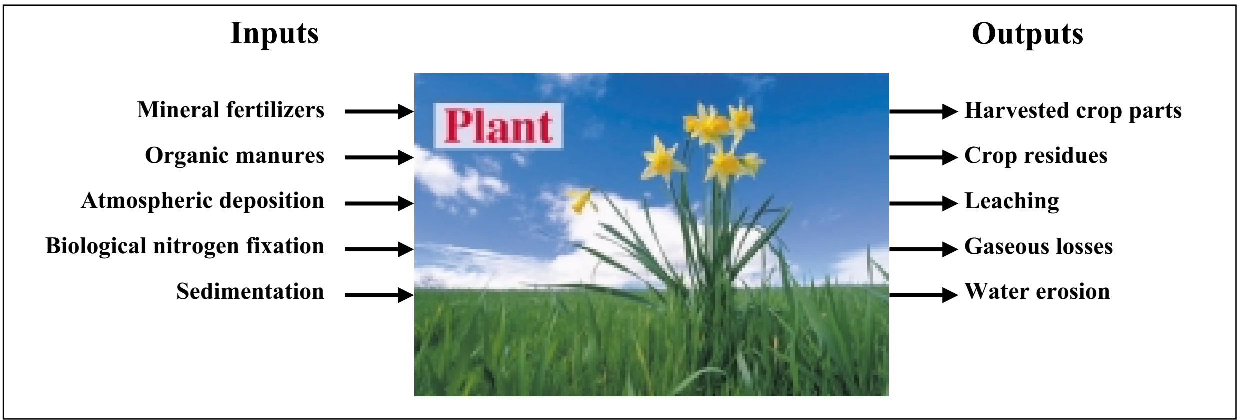

Figure 3. The plant nutrient balance system

The nutrient balance system has two parts: inputs that add plant nutrients to the soil and outputs that export them from the soil largely in the form of agricultural products. Important input sources include inorganic fertilizers; organic fertilizers such as manure, plant residues, and cover crops; nitrogen generated by leguminous plants; and atmospheric nitrogen deposition. Nutrients are exported from the field through harvested crops and crop residues, as well as through leaching, atmospheric volatilization, and erosion. The difference between the volume of inputs and outputs constitutes the nutrient balance. Positive nutrient balance in the soils (occurring when nutrient additions to the soil are greater than the nutrients removed from the soil) could indicate that farming systems are inefficient and in the extreme, that they may be polluting the environment. Negative balance could well indicate that soils are being mined and that farming systems are unsustainable over the long-term. In case of negative nutrient balance, nutrients have to be replenished to sustain agricultural outputs and to maintain soil fertility for future.

However, targeting high yield with a high cropping intensity is the most logical way to raise the total production from the country's limited resources. Since the nutrient turnover in soil plant system is considerably high in intensive farming, neither the chemical fertilizers nor the organic and biological sources alone can achieve production sustainability. Even with balanced use of chemical fertilizers high yield level could not be maintained over the years because of deterioration in soil physical and biological environments due to low organic matter content in soils. In this context and as a further response to economic recession, and also to conserve and improve soil fertility the concept of Integrated Nutrient Management (INM) system has been adopted.

8. Concept of integrated nutrient management

The Integrated Nutrient Management (INM) is the maintenance 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 cropping system and farming situation in its ecological, social and economic possibilities (Roy, 1986).

The basic concept underlying the principles of INM is to integrate all sources of plant nutrients and also all improved crop production technologies into a productive agricultural system (Roy, 1986). In other words, integrated nutrient management aimed to maintain the soil fertility and plant nutrient supply to an optimum level for sustaining the desired crop productivity through optimization of the benefits from all possible sources of plant nutrients in an integrated manner. Therefore, it is a holistic approach, where we first know what exactly is required by the plant for an optimum level of production, in what different forms these nutrients should be applied to soil and at what different timings is the best possible method, and how best these forms should be integrated to obtain the highest productive efficiency on the economically acceptable limits in an environment friendly manner (Chundawat, 2001). One characteristic of the INM is that the fertilizer recommendation should take into account the cropping system as a whole rather than individual crop in the system. This aspect is particularly important in case of phosphorous where the percentage utilization by the crop to which it is applied is rather low and where there is residual effect to benefit the following crop. Similarly, the nitrogen contribution of legume crops in the cropping system will have to be considered. Besides, some crops show selective uptake of some specific elements. Moreover, nutrients supplied from other sources should be accounted for making up the gap between the recommended and actual levels of fertilizer application.

8.1 Components and technology

The main aim of the INM approach is to tap all the major sources of plant nutrients as illustrated in Figure 3 in a judicious way and to ensure their efficient use (Roy, 1986).

8.2 Goal of INM

Sustainable agricultural production incorporates the idea that natural resources should be used to generate increased output and incomes, especially for low income groups without depleting the natural resource base. INM’s goal is to integrate the use of all natural and man-made sources of plant nutrients, so that crop productivity increases in an efficient and environmentally benign manner, without sacrificing soil productivity of future generations (Gruhn *et al.*, 2000). INM relies on a number of factors, including appropriate nutrient application and conservation and the transfer of knowledge about INM practices to farmers through extension personnel.

8.3 Benefits of INM

Sufficient and balanced application of organic and inorganic fertilizers is a major component of INM. However, the following research findings (Tables 4 through Table 8 and Figure 4) on INM technology in different soils and crops, cropping system/patterns of Bangladesh clearly revealed the benefits of INM in respect of yield sustainability and improvement of soil fertility.

Table 4. Grain yield of wheat and T. Aman obtained in integrated nutrient management at Dinajpur, 1994-97

Treatment	Wheat grain yield (t/ha)					T. Aman grain yield (t/ha)				Total grain yield (kg/ha)
	1994-95	1995-96	1996-97	1997-98	Ave.	1995	1996	1997	Ave.	
Control	0.93d	0.83	0.52d	0.20c	0.62	3.79c	3.24c	2.84e	3.29	3.91
100% NPKSZn	3.67a	3.30	3.61a	3.81a	3.60	4.88a	4.64a	4.18ab	4.57	8.16
75% NPKSZn	2.60b	2.67	2.04c	2.99b	2.58	4.11bc	4.08b	3.58cd	3.92	6.50
GM + 50% NPKSZn	2.90b	2.88	2.93c	3.08b	2.95	4.06bc	4.03c	3.73c	3.94	6.89
GM + 75% NPKSZn	2.58b	3.21	3.31b	3.88a	3.25	4.52abc	4.40a	4.03b	4.32	7.56
FYM + 50% NPKSZn	2.60b	2.80	2.87c	3.04b	2.83	4.04bc	3.70b	3.50d	3.75	6.57
FYM + 75% NPKSZn	3.80a	3.21	3.74a	4.22a	3.74	4.76ab	4.65a	4.21a	4.54	8.28

Note: Figures followed by some letters do not differ significantly at 5 percent level.

Source: BARI Annual Report.

Table 5. Effects of combined use of fertilizers and manure/crop residues on the grain yield of T. Aman rice

Treatments	Grain yield (t/ha)							
	BAU farm				BRRI farm			
	1998	1999	2000	Mean	1998	1999	2000	Mean
T_1: Control	2.93g	2.66f	2.45f	2.68	2.78g	2.67g	2.62g	2.69
T_2: 50% NPKS	3.85f	3.89e	6.51e	3.75	3.56f	3.80f	3.69f	3.68
T_3: 70% NPKS	4.30def	4.38cde	3.94d	4.21	4.30de	4.32def	4.05def	4.22
T_4: 100% NPKS	5.05abc	5.06ab	4.85bc	4.99	5.14ab	5.05abc	5.43abc	5.10
T_5: 50% NPKS + RS	4.09ef	4.11de	4.03d	4.07	3.94ef	4.11ef	3.95ef	3.85
T_6: 70% NPKS + RS	4.37def	4.43d	4.22d	4.34	4.49cd	4.64b-e	4.23de	4.45
T_7: 50% NPKS + DH	4.81bcd	4.95b	4.86bc	4.87	5.18a	4.87a-d	5.13c	5.06
T_8: 70% NPKS + DH	5.17ab	5.17ab	5.22abc	5.19	5.22a	5.29ab	5.53ab	5.35
T_9: 50% NPKS + MBR	5.10ab	5.12ab	4.99bc	5.07	5.20a	5.05abc	5.23be	5.16
T_{10}: 70% NPKS + MBR	5.41a	5.23a	5.31ab	5.32	5.42a	5.33ab	5.59ab	5.45
T_{11}: 50% NPKS + CD	4.08ef	4.32cde	4.28d	4.23	4.10e	4.46cde	4.00def	4.49
T_{12}: 70% NPKS + CD	4.55cde	4.66bc	4.82c	4.68	4.74bc	4.73a-e	4.34d	4.60
T_{13}: 50% NPKS + PM	5.16ab	5.12ab	5.13abc	5.14	5.35a	5.02abc	5.54ab	5.30
T_{14}: 70% NPKS + PM	5.47a	5.29a	5.47a	5.41	5.49a	5.34a	5.68a	5.50
CV (%)	6.40	6.30	5.50	–	5.10	7.80		–
Level of significance	0.01	0.01	0.01	–	0.01	0.01		–

Note: In column, figures followed by some letters do not differ significantly at 5 percent level by DMRT.

RS = Rice straw, DH = Dhaincha (Sesbania), MBR = Mungbean residue, CD = Cow dung and PM = Poultry manure

Source: Bangladesh Agricultural University, Mymensingh.

Table 6. Effect of rhizobial inoculum and chemical fertilizers on the yield and major yield contributing characters of cowpea at Joydebpur for 2002-2003

Treatments	Nodule number/ 10 plants	Dry weight of nodule/ 10 plants (mg)	Root weight/ 10 plants (g)	Shoot weight/ 10 plants (g)	Plant height (cm)	1 000 seed weight (g)	Stover yield (t/ha)	Seed yield (t/ha)	Yield increase over control (%)
NPKS	42d	223c	4.24c	29.1a	27.2a	113.1	1.76a	1.03b	28.75
PKS + Inoculum	132a	582a	4.85a	28.4a	27.6a	114.5	1.68a	1.13a	41.25
PKS	80c	456b	4.5b	22.2b	27.5a	112.1	1.69a	1.00b	25.00
Inoculum	99b	567a	3.5d	24.43b	27.4a	112.0	1.22b	1.01b	26.25
Control	29e	206c	2.62e	18.5d	27.1a	108.3	1.10b	0.80c	–
CV (%)	6.06	3.67	3.44	6.04	6.92	7.39	9.48	6.18	

Note: Means followed by a common letter are not significantly different at the 5 percent level by DMRT.

Source: Soil Science Division, BARI.

Table 7. Yield and yield attributes of tomato as affected by organic manure and chemical fertilizer

Tr. No.	Treatment combination			Plant height (cm)	Fruits/ plant (no.)	Fruit weight/ plant (kg)	Yield (t/ha)	% increase over control
	Chemical fertilizer	PM	CD					
	kg/ha	t/ha						
T_1	100% RD	2.5	0	58.8	38.7a	2.79a	75.00a	276
T_2	100% RD of T_1	0	2.5	54.8	35.0abc	2.44bc	66.10bc	232
T_3	100% RD of T_1	0	0	55.9	36.0abc	2.38c	64.80bc	225
T_4	50% RD of T_1	0	0	54.2	30.0bcd	2.27c	48.13d	141
T_5	50% RD of T_1	5	0	55.9	36.0abc	2.58bc	68.14ab	242
T_6	50% RD of T_1	10	0	57.0	36.7ab	2.70ab	70.81ab	255
T_7	50% RD of T_1	0	10	54.6	32.3a-d	2.34c	60.27c	202
T_8	25% RD of T_1	10	0	53.9	28.3cd	2.29c	52.12d	162
T_9	25% RD of T_1	0	10	51.8	26.0de	1.80d	45.49de	128
T_{10}	0	10	0	50.7	25.7de	1.65d	40.69e	104
T_{11}	0	0	10	49.9	19.7ef	1.21e	28.77f	44
T_{12}	Nativenutrient	0	0	48.4	14.7f	0.85f	19.93g	–
	CV (%)			6.7	13.8	7.5	7.3	

Note: Means followed by common letter(s) do not differ significantly at 5 percent level by DMRT.

RD = Recommended dose of chemical fertilizer = $N_{150}P_{45}K_{80}S_{25}Zn_2B_1$ kg/ha

Source: Soil Science Division, BARI.

Table 8. Yield and yield attributes of hybrid maize as influenced by lime and boron during the rabi season of 2002-2003 at ARS, Burirhat, Rangpur

Treatment combination	Plant height (cm)	Cob/plant (no.)	Cob size		Grain/cob (no.)	Grain wt/cob (g)	1 000 grain wt (g)	Grain yield (t/ha)
			Length (cm)	Breadth (cm)				
T_1 = AL* + B_0	198.3cd	1.24c	20.50d	7.54b	462.0c	302.7c	356.0c	6.19f
T_2 = Dolo + B_0	200.7cd	1.26c	21.22c	7.54b	466.0bc	306.7c	356.0c	6.50e
T_3 = AL* + $B_{1.5}$	202.3bc	1.27c	21.27c	7.7ab	471.30b	324.0b	368.7b	7.07d
T_4 = Dolo + $B_{1.5}$	204.3bc	1.26c	21.87b	7.90a	476.6b	326.0b	380.0b	7.53c
T_5 = AL* + $B_{3.0}$	205.0b	1.33b	22.13ab	7.99a	545.02ab	360.0a	413.0ab	7.70b
T_6 = Dolo + $B_{3.0}$	212.0a	1.40a	23.27a	8.00a	570.0a	367.3a	4.34.0a	8.23a
T_7 = L_0B_0	195.7d	1.20d	20.30d	7.31c	450.0d	290.7d	346.7d	5.27g
LSD (0.05)	5.93	0.60	0.34	0.30	6.50	31.32	49.43	0.23
CV %	4.35	7.07	5.36	6.52	4.08	14.30	19.39	8.90

* AL = Agricultural lime.

Blanket dose: $N_{300}P_{50}K_{125}S_{20}Zn_4$ kg/ha & cow dung 5 t/ha

Source: Soil Science Division, BARI.

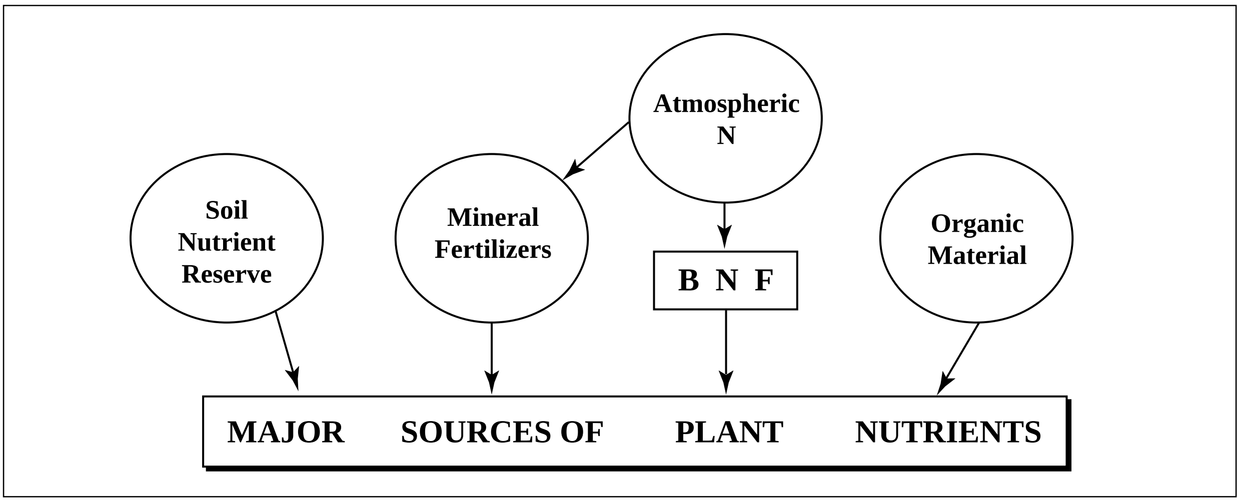

Figure 4. Major sources of plant nutrients

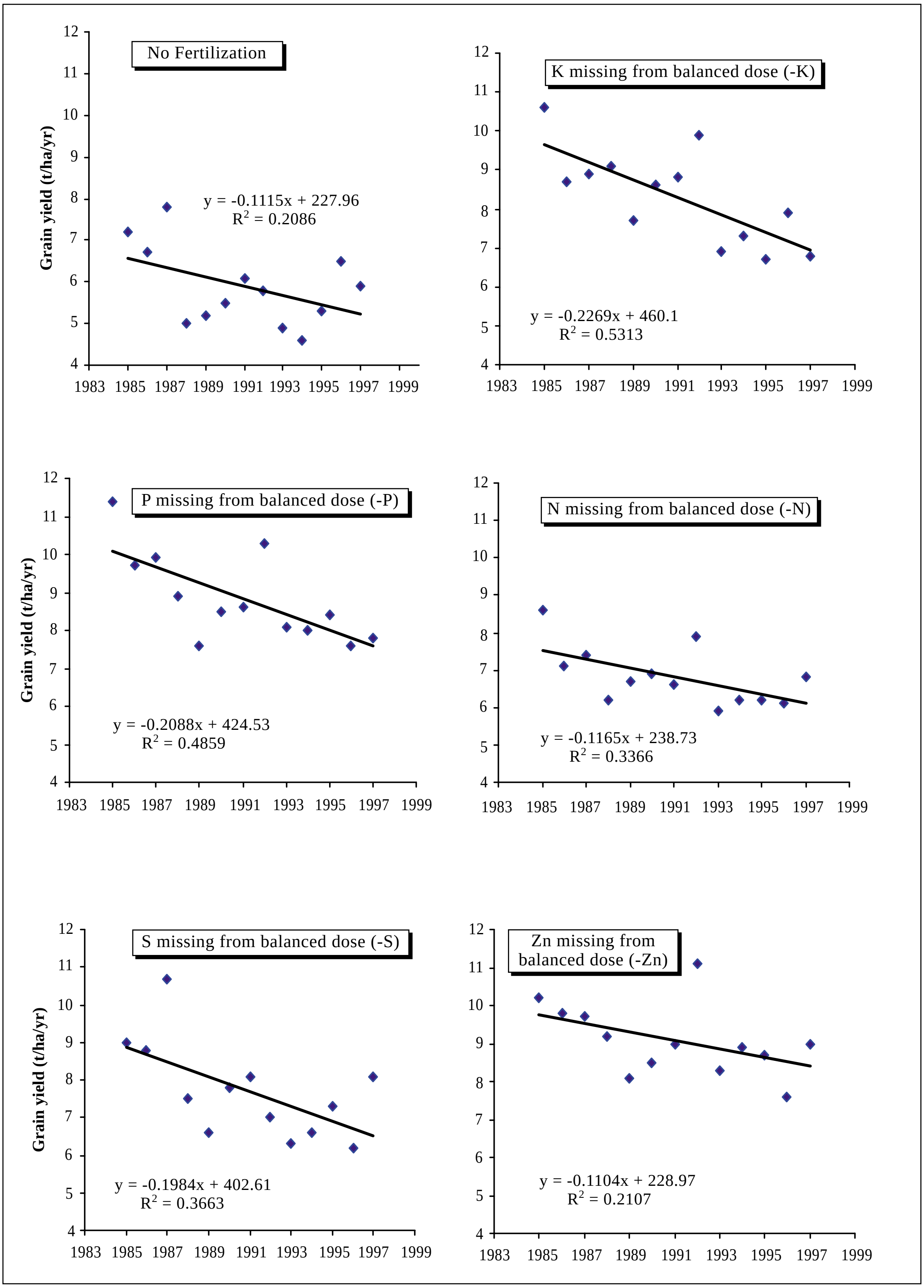

Figure 5. Long-term trends of MV rice yield under incomplete fertilization at BRRI, Gazipur during 1984-1998

8.4 Constraints

The major constrains for proper adoption and utilization of INM technology at farmer's level are listed below:

i) Farmers often have inadequate knowledge and funds, which compelled them to mis-purchase and mis-application of fertilizers. Most of the farmers are aware of fertilizers but do not use it in balanced proportion;

ii) The linkage and interactions among researchers, extension services and NGO personnel are weak;

iii) Degradation of lands due to intensive cropping/over exploitation by the enormous pressure of the ever increasing population;

iv) Risks of water deficit in drought prone period are considered the most important deterrent to fertilizer use; and

v) During monsoon water erosion is a serious threat on soil fertility and productivity.

9. Conclusions

1. With the increasing cropping intensity, the use of chemical fertilizer is also increasing in Bangladesh but due to imbalanced use, the fertility of the soils has been depleted.
2. Research findings showed very encouraging effects of INM technology on the higher yield of many crops and cropping sequences of the country.
3. The benefits of INM technology have been demonstrated and disseminated to the farmers through extension personnel.
4. More motivations and subsidies are required for the adoption of INM technology by the farmers.
5. Agricultural policy measures should be strengthened so that farmers get proper support, encouragement and guidance to switch from conventional agriculture towards technology oriented agriculture.

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South Asian Country

Paper Number 2

Integrated nutrient management *vis-à-vis* crop production/productivity, nutrient balance, farmer livelihood and environment: India*

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Summary

India with a geographical area spreading over 329 million hectares is endowed with a complex diversity of climate, soils, flora and fauna offering both a blessing and a challenge for agricultural development. The population of India with a growth rate of about 2.3 percent has crossed one billion at the beginning of the century. The quality and richness of the country resource endowments is constantly threatened by the huge population and increasing population density and corresponding demand for arable lands and ensuring food security. The 'green revolution', which launched intensive use of high-yielding varieties of crops coupled with other inputs like chemical fertilizers and irrigation water, was both a success in boosting food supply and at the same a challenge in terms of combating the threat of imbalance fertilization the primary cause of soil degradation and decline in soil fertility. The real challenge is the keep the pace of production under condition of decreasing per capita arable without losing land productivity. As benchmark for this great challenge, researchers have estimated that the food output of 200 million tonnes and fertilizer consumption of 17 million tonnes would result in nutrient removal of 25 to 27 million tonnes leaving a nutrient gap of about 10 million tonnes. The country's researchers and policy-makers have considered several soil and plant nutrient management options to sustain soil fertility in their continuing effort to close the food and population gaps, which primarily include the Integrated Nutrient Management, the balanced use of chemical based fertilizers and sourcing and processing all possible use of organic manures, biofertilizers, as well as the Integrated Farming System which improved both cropping systems and livelihood opportunities of small farmers.

1. Food security and livelihood in India

Food security is the most important factor that determines the survival of human kind. Without food security, a nation cannot expect better life for its people. Famines in India are "a nightmare of the past". The green revolution witnessed in late 1960s has contributed immensely over the years to cereal production in India and hence a substantial increase in the net per capita availability of food grains was registered (Table 1). This has led to a nationwide sense of complacency that, in a way, slowed down the growth rate in agricultural production during 1990s, while the population continued to grow at a high rate. The net result was a decline in the per capita food grain availability in the terminal decade of 20th Century. Even with present level of production, there is enough food in the country to meet energy and protein requirements of the current population, if the food were

* This country report has not been formally edited and the designations and terminology used are those of the author.

Table 1. Per capita net availability of food grains in India (g/day)

Year	Cereals	Pulses	Total food grains
1951	334.2	60.7	394.9
1961	399.7	69.0	468.7
1971	417.6	51.2	468.8
1981	417.3	37.5	454.8
1991	468.5	41.6	510.1
2001	385.1	29.1	414.1

Source: FAI (2003).

distributed equitably according to needs. But as we see, surplus production and widespread hunger coexist at the national level. At present, India alone accounts for one fourth of all world hunger. It is particularly ironic that there are 200 million food-insecure people in a country that currently bas buffer stocks of food grains in excess of 60 million metric tonnes.

Inadequate or lack of purchasing power among the poor is the main cause of food insecurity in rural India. As reported by Rajendra Prasad (2003), the per capita consumption of most food items in rural India is far below the recommended dietary allowances (Table 2). Though the per capita intake of cereals in all regions, and sugar and milk consumption in North and Western regions is closer to or above the standard requirements, the consumption of all other food items throughout the country is woefully lower than their respective dietary requirements as per ICMR (Indian Council of Medical Research) norms. A general low intake of pulses, vegetables, fruits, fats and oils, eggs, meat and fish is responsible for widespread occurrence of protein energy malnutrition (PEM) and chronic energy deficiency (CED). It was reported that 23 to 70 percent of the rural population in different parts of the country is suffering from protein energy malnutrition, while the chronic energy deficiency affected 17 to 54 percent of people (Table 3). Prevalence of poverty and low and fluctuating income levels also limit the access to diversified diet and thus adversely affect balanced diet. The vegetable products account for a lion share in the intake of all dietary constituents. A comparison of share of vegetable products and animal products in meeting total dietary energy, protein and fat in India, USA and the World as a whole makes this point clear. In India, vegetable products provide 93 percent dietary energy, 84 percent protein and 73 percent fat, while animal products supply the remaining small portion, i.e., 7 percent, 16 percent and 27 percent of energy, protein and fat, respectively. On the contrary, in a developed country like USA, the animal products account for 30 percent, 64 percent and 511 percent share in meeting dietary energy, protein and fat supply, respectively. Child malnutrition rates in India are still very high. According to the UNDP, 53 percent of children under five in India were under-weight during the period 1990-97, the highest rate from any of the 174 developing countries listed.

Table 2. Per capita food consumption in rural India (g/day)

Region	Food items									
	Cereals	Sugar	Pulses	Vege-tables	Fruits	F&Oils	Milk	Eggs	Meat	Fish
Northern	424.9	39.7	29.8	62.4	20.7	14.6	308.3	1.0	2.7	0.3
Eastern-Central	483.8	13.4	20.5	57.8	18.5	9.6	52.0	2.8	3.1	9.6
Western	416.0	32.3	21.5	61.2	17.7	13.5	179.8	1.2	2.5	1.5
South	402.1	18.9	21.7	57.9	33.3	9.4	76.9	5.6	6.3	14.8
ICMR norm	420.0	30.0	40.0	125.0	50.0	22.0	150.0	45.0	25.0	25.0

Source: Adapted from Rajendra Prasad (2003).

Table 3. Extent of PEM and CED in rural India

Region	Percent of population with	
	Protein energy malnutrition (PEM)	Chronic energy deficiency (CED)
Northern	34.9-36.9	23.0-44.0
Eastern and Central	23.5-58.2	17.1-57.3
Western	30.2-39.8	36.2-53.1
South	31.4-70.3	33.2-53.8

Source: Adapted from Rajendra Prasad (2003).

2. Threats to future food security and livelihood in India

2.1 Growing population

In India, unabated growth in population has been and will continue to be the single most factors that have the potential to negate all the progress made in agricultural production. India's population grew at an annual growth rate of around 2 percent in 1970s, 1980s and 1990s to reach 1 027 million in 2001 and is estimated to increase further to 1 262 and 1 542 million by the year 2011 and 2021, respectively (Sekhon, 1997). Growing population means mounting more pressure on natural resources to meet increased food demand. According to a conservative estimate (Kumar, 1998), the food grain demand in India for the years 2010 and 2020 is projected to be 246 and 294 mt, respectively (Table 4). This means that India's food grain production has to increase from 212 mt (highest production ever achieved in 2001-02) to 246 mt in 2010 and then to 294 mt in 2020. It is by all means a daunting task and the ability to accomplish this task determines the future food security of the country.

Table 4. Current production and future demands of food grains in India

Food item	Current (2001-02) production (mt)	Estimated demand (mt)	
		2010	2020
Rice	93.1	3.6	122.1
Wheat	71.8	85.8	102.8
Total cereals	198.8	224.4	265.8
Pulses	13.2	21.4	27.8
Total food grains	212.0	245.8	293.6

2.2 Declining land to man ratio and size of farm holdings

With continued rise in population, the arable land to man ratio has decreased from 0.5 ha (1951) to 0.14 ha at present and is expected to decline further to 0.08 ha by year 2020. The average number of land holdings has also increased simultaneously from 77 million (1976-77) to over 115 million at present due to population growth and the law of inheritance of land property. The average size of operational farm holding is only 1.57 ha. Further, about 78 percent of the 115 million farm holders in the country come under small and marginal category with the size of farm being less than 2 ha. The small size and scattered nature of the holdings will adversely affect the farm efficiency and will result in high cost of production. This in turn will result in low productivity and thus reduced agricultural sustainability and food security.

2.3 Decreasing total factor productivity

The total factor productivity (TFP) is used as an important measure to evaluate the performance of a production system and sustainability of its growth pattern. As stated earlier, adoption of green revolution technology led to a phenomenal growth in agricultural production during 1970s and 1980s. But of late, there are signs of fatigue in the agricultural growth process. In spite of continued growth of inputs, there has been no matching growth in agricultural production during 1990s, indicating a decrease in TEP. The declining trends of annual growth rate of productivity in respect of all major crops (Table 5) are also suggestive of decreasing TFP in Indian agriculture. In fact, all the crops except wheat registered a negative annual growth rate in their productivity during the recent past (2000-01 to 2002-03). If this alarming trend is allowed to continue, it will spell doom on the country's future food security prospects. Reasons for decreasing the total factor productivity are: (1) High nutrient turn over in soil-plant system coupled with low and imbalanced fertilizer use, (2) Emerging deficiencies of micro and secondary nutrients (S, Zn, B, Fe, Mn, etc.), (3) Soil degradation due to acidification, aluminum toxicity, soil salinization and alkalization, soil erosion, (4) Wide nutrient gap between nutrient demand and supply, and (5) Consequent deterioration in soil physical, biological and chemical quality and low fertilizer use efficiency.

Table 5. Productivity growth rate of important crops in India

Crop	Annual growth rate in productivity (%)		
	1980-81 to 1989-90	1990-91 to 1999-2000	2000-01 to 2002-03
Rice	3.19	1.27	-0.72
Wheat	3.10	2.11	0.73
Pulses	1.61	0.96	-1.84
Total food grains	2.74	1.52	-0.69
Oilseeds	2.43	1.25	-3.83
Non-food grains	2.31	1.04	-1.02
All principal crops	2.56	1.31	-0.87

Source: Chhonkar and Dwivedi (2004).

3. Reasons for declining total factor productivity

3.1 Wide nutrient gap between nutrient demand and supply

The growth in fertilizer consumption slowed down during 1990's and there is stagnation in consumption during the last 4-5 years. After achieving a record consumption level of 18.1 mt of NPK in 1999-2000, the total NPK consumption is hovering around 16-17 mt during the last 3 years (2001-04). At the present level of crop production, there exists a negative balance of 10 mt between nutrient (NPK) demand by crops and supply of nutrient through application of fertilizer annually (Figure 1). The stagnant situation in fertilizer consumption and higher negative nutrient balance are posing a threat to soil quality and sustainable agriculture. It is now imperative to review the reasons for the stagnant trend in fertilizer consumption and take remedial action to alter this trend. The stagnant trend in fertilizer consumption despite slow increase in maximum retail price of fertilizers reveals that besides pricing, there are various other reasons which affect the fertilizer consumption. Weather cannot be solely blamed for the stagnant situation as the performance of southwest monsoon had been normal in the last few years (except 2000-03). The total NPK consumption did not exceed 17 mt during the year-2003-04, in spite of having good southwest monsoon rainfall. Deteriorating

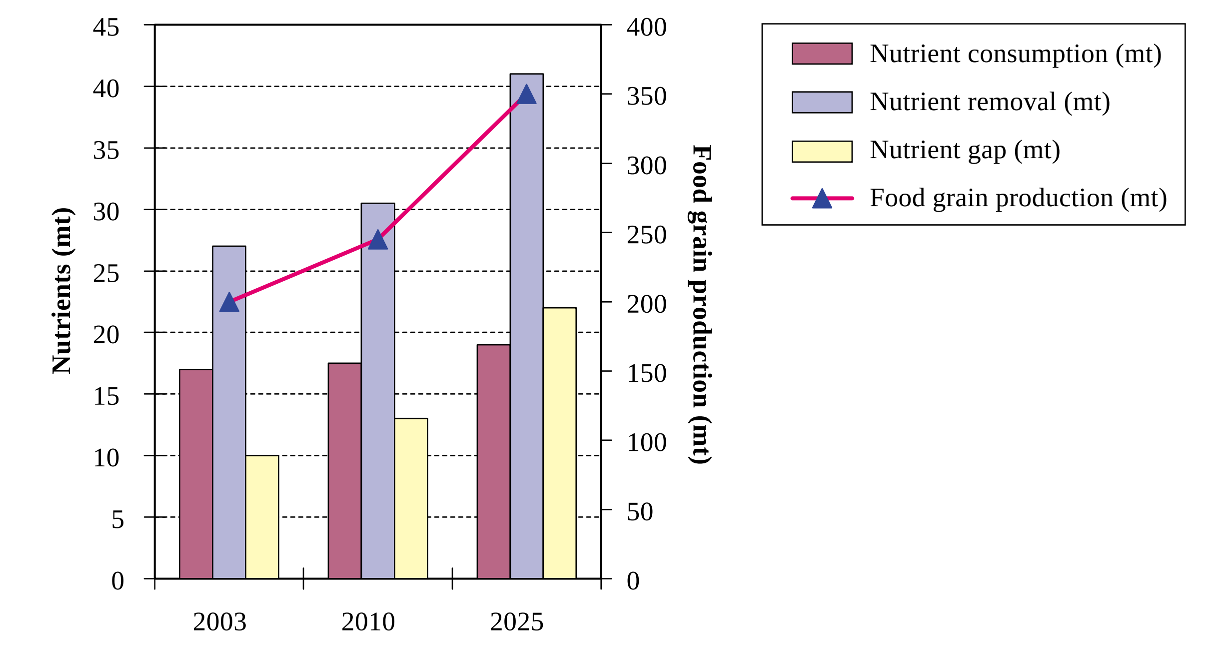

Figure 1. Projected food grain production in relation to nutrient (N-P_2O_5-K_2O) consumption, removal and gap

soil quality and the emerging deficiencies in secondary and micronutrients aside from major nutrients appear to be one of the major factors in the stagnation of fertilizer consumption. A cereal production of 5-10 t/ha/year in rice-wheat rotation, which is the backbone of India's food security removes 380-760 kg N-P_2O_5-K_2O per hectare per year. Farmers generally apply 50 percent to 80 percent of this amount. Thus there is a gradual depletion of the inherent soil fertility.

3.2 Soil nutrient balances under intensive cropping systems

There are hardly any farm-level exercises which have been or are being conducted to monitor nutrient balances in intensively cropped areas. It is generally accepted that soils are being mined and that their nutrient capitals being continuously depleted throughout intensively cultivated areas. No quantitative or semi-quantitative estimates, however, are available on nutrient recycling or balances based on various input-output components at the farm level. This is an area where some insights from a few well-defined benchmark farms (not research stations) will be extremely valuable in developing sustainable systems, not only for site-specific adoption, but also for adoption to similar environments.

The fate of soil nutrient capital and balance in the two most important cropping systems of Uttar Pradesh is illustrated below (Table 6). These computations are primarily illustrative and based on several assumptions, due to the present inadequate database. The initial soil nutrient capital is taken to reflect the soil's low status in nitrogen, medium in phosphorus, and high in potassium for the plow layer. Fertilizer inputs for the sugarcane-wheat system are typical of the practice. The analysis shows that after one cycle of the sugarcane-wheat system, the initial soil nutrient capital decreased by 23 percent in the case of N, increased by 1.2 percent in the case of P but decreased by 104 percent in the case of K. The improvement in P status was attributed to its application to both the main crops and input of FYM and press mud, that less was removed from the crop than was added and the ability of P (unlike N) to accumulate in the soil. The large depletion in K was due to its very weak position in the fertilizer use pattern and crop removal exceeding the K input.

Table 6. Nutrient balance after a sugarcane-wheat system in western Uttar Pradesh (productivity 120 mt cane/ha/2 crops + 3 tonnes wheat grain/ha)

Item	N	P_2O_5	K_2O
Initial available soil nutrient capital (kilograms per hectare)[a]	280	40	336
For sugarcane plant crop			
Fertilizer input (kg/ha)	125	58	10
10 t/ha FYM (0.75-0.175-0.55) of N-P_2O_5-K_2O	75	18	55
1 t/ha press mud (0.026-1.70-0.24% available N-P_2O_5-K_2O)	1	17	2
Green manure (not practiced)	0	0	0
Crop residues (not recycled)	0	0	0
Total nutrient capital	481	133	403
Nutrient uptake by 60 t/ha sugarcane crop (kg/ha)	135	30	144
Losses from soil (25% of fertilizer N)	31	0	0
Nutrient balance after cane harvest (kg/ha)	315	103	215
For sugarcane ratoon crop			
Starting soil nutrient capital	315	103	215
Fertilizer input (kg/ha)	62	29	5
3 t/ha cane residues recycled (0.4-0.18-1.28)	12	5	38
FYM not used	0	0	0
Total nutrient capital	389	137	258
Nutrient uptake by 60 t/ha ratoon crop (kg/ha)	135	30	188
Losses from soil (25% of fertilizer N)	16	0	0
Nutrient balance after ratoon	238	107	70
For wheat crop			
Starting soil nutrient capital (kg/ha)	238	107	70
Fertilizer input	100	50	10
FYM not used	0	0	0
Crop residues burnt	0	0	38
Total nutrient capital	338	157	118
Nutrient uptake by 4 t/ha wheat crop (kg/ha)	96	36	132
Losses from soil (25% of fertilizer N)	25	0	0
Nutrient balance after wheat (kg/ha)	217	121	-14
Change in initial soil capital	-63	81	-350
Percentage change	-23	102	-104
Summary			
Initial soil nutrient capital	280	40	336
Capital after sugarcane plant crop	315	103	215
Capital after sugarcane ratoon			
Capital after wheat	217	121	-14
Capital after the system	217	121	-14
Change after 2 years (one crop cycle) in percent	-63(-23%)	81(102%)	-350 (-104%)

Source: Tandon (1995), based on PDCSR data, personal communication.

Corresponds to low, medium, and high fertility status for N, P, and K respectively.

The apparent K balance of long-term fertilizer experiment under maize-wheat-cowpea during 27 years of cropping showed that mining of soil K occurred even under NPK and NPK + FYM treatments, i.e. application of 15 t FYM/ha along with recommended rates of NPK (Swarup, 2002). This shows that the selection of suitable components of INM should vary with cropping systems and nutrient requirement. Integration of crop residues, along with farmyard manure and fertilizers, may arrest the mining of K from soils where the production systems have higher K demand.

3.3 High nutrient turnover in soil-plant system coupled with low and imbalanced fertilizer use

Fertilizer consumption in India is grossly imbalanced since the beginning. It is tilted more towards N followed by P. Further the decontrol of the phosphatic and potassic fertilizers resulted in more than doubling the prices of phosphatic and potassic fertilizers. Thus, the already unbalanced consumption ratio of 6:2.4:1 ($N:P_2O_5:K_2O$) in 1990-91 has widened to 7:2.7:1 in 2000-01 as against favourable ratio of 4:2:1 implying there from that farmers started adding more nitrogen and proportionately less phosphatic and potassic fertilizers. Even today, the situation is grim as far as fertilizer application by farmers is concerned. In many areas the imbalanced fertilization is the root cause of poor crop yields and poor soil fertility status. Accordingly, agro-ecological regions 4, 9, 14, 15 and 18 and cropping systems like rice-wheat, maize-wheat, rice-pulse, potato-wheat and sugarcane demands immediate attention to correct the imbalances in nutrient consumptions to prevent further deterioration of soil quality and to break the yield barriers. There is wide variation in the consumption ratios of fertilizers from region to region but in the absence of information on the extent of cultivated area and details of cropping patterns in each agro-ecological region, it is difficult to estimate the crop removal of each region (Table 7).

Table 7. Critical areas of imbalances in fertilizer consumption

Sl. No.	Agro-ecological region	N	P_2O_5	K_2O	N: P_2O_5	Crops/ cropping system	N	P_2O_5	K_2O	N: P_2O_5
4	N_8D_2	34.0	9.6	1	3.6	Rice-wheat	205.0	47.0	1	4.35
9	N_8C_3	23.5	4.7	1	5.0	Maize-wheat	34.0	4.9	1	3.61
14	O_8C_4	17.3	3.4	1	5.1	Rice-pulse	7.4	2.1	1	3.47
15	$A_{15}C_4$	14.5	2.5	1	5.7	Potato-wheat	14.5	2.5	1	5.73
18	D_2A_5	11.4	2.9	1	3.9	Sugarcane	21.1	4.2	1	5.00

Source: Swarup and Ganeshamurthy, 1998.

3.4 Emerging deficiencies of secondary and micronutrient in soils

Intensive cropping systems are heavy feeders and are bound to heavily extract nutrients from the soil. Hence, nutrient deficiencies are inevitable unless steps are taken to restore fertility levels. Deficiencies of essential elements in Indian soils and crops started emerging during the 1950s after the initiation of the government of Independent India, a five-year plan to give a fillip to food production through intensification. As food production increased with time, the number of elements becoming deficient in soils and crops also increased (Figure 2). Unless corrective measures are taken immediately, the list of essential elements becoming deficient is bound to increase further. A classical example of the effect of imbalanced fertilizer use is the fertility decline in an intensive cropping for over 25 years that has been reported by Swarup and Ganeshamurthy (1998). When only N was applied the P and K status in soils at all the centers have gone down. When N & P were

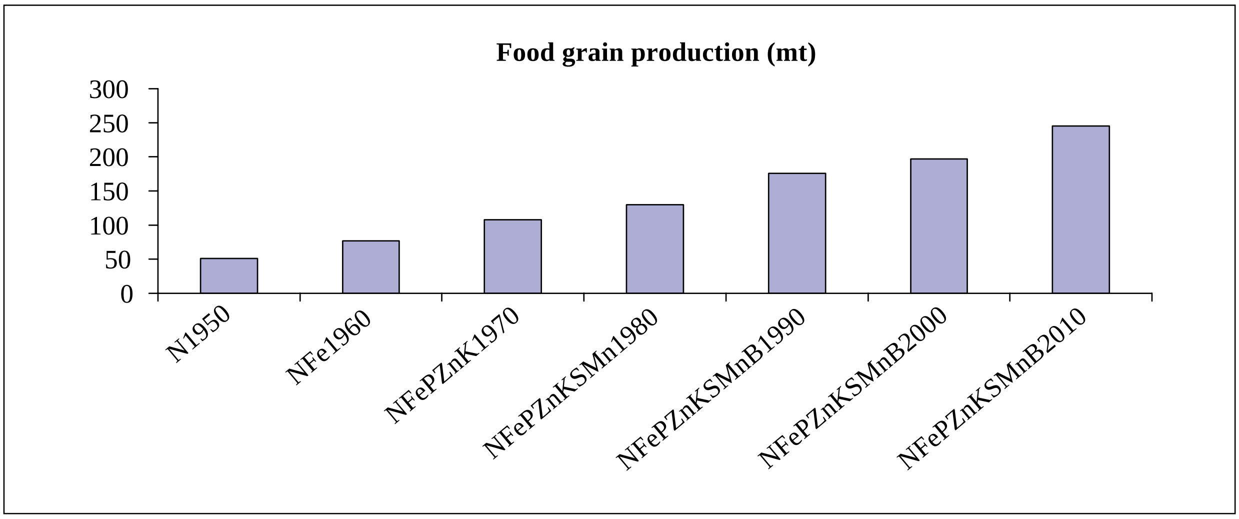

Figure 2. Food grain production and emerging nutrient deficiencies in soils of the country due to intensive cropping (modified from source: Swarup and Ganeshamurthy, 1998)

applied the soil K status declined more conspicuously in alluvial soils (Ludhiana), Terai soils (Pantnagar) and laterite soils (Bhubaneshwar). All secondary and micronutrients generally declined in all the soils.

Although not universal, deficiency of S has cropped up as serious obstacle in the sustainability of yields in cropping systems particularly if a sulphur responsive crop like rice, oil seed or pulse crop is involved. The extent of S problems depends more on input of S through irrigation and atmosphere, the information from which is completely lacking. The results of long-term experiments (Table 8) show that response was very little in certain crops like wheat and jute and very conspicuous in certain other crops like rice and soybean.

Table 8. Mean grain yield response (kg/ha) of rice and wheat at Pantnagar

Nutrient or FYM	Mean response over 5 years (1987-92)		Mean response over 20 years (1972-92)	
	Rice	Wheat	Rice	Wheat
N	1 864	2 372	1 512	2 140
P	124	213	-16	47
K	211	109	430	71
S	183	184	261	150
Zn	520	543	285	307
FYM	587	645	745	623

Source: Swarup and Ganeshamurthy, 1998.

Micronutrient deficiencies in soils are also emerging as yield limiting factors. Analysis of 1.5 lakh soil samples from different regions of the country indicated that about 47 percent of soils were deficient in available Zn, 20 percent of samples were deficient in available B, 18 percent of samples were deficient in Mo, 12 percent of samples were deficient in available Fe and 5 percent of soil samples were found deficient in available Cu. Among the micronutrients, zinc deficiency is widely encountered followed by B, Mo and Fe, in that order. Field scale deficiency of Zn in crops is being increasingly reported. But suggestions that B and Mo as yield limiting factors are not convincing as trials that include these elements rarely generate conclusive evidence to support this hypothesis. Field scale Mo deficiencies and Mn as a factor of yield decline is not common. However, exception to this is in the rice-wheat system on sandy soils and reclaimed sodic soil. Continuous cropping of rice-wheat on these soils led to deficiency of Mn in wheat crop following leaching of reduced Mn from surface soils under rice culture. The productivity of wheat could be restored by soil and foliar applications of Mn (Swarup and Ganeshamurthy, 1998).

3.5 Soil degradation

It has been stated that of the total 328.73 m ha geographical area, nearly 188 m ha of land in the country is potentially exposed to various degradation processes (Sehgal and Abrol, 1994). The land area subjected to degradation by way of soil displacement through erosion by water and wind is estimated at 148.9 and 13.5 m ha, respectively (nearly half of the area). About 13.8 m ha is under chemical deterioration due to loss of nutrients and organic matter, salinization and sodification. Soil acidification also rendered about 49 m ha of land degraded.

4. Integrated nutrient management strategies for sustainable food security and livelihood

Adequate plant nutrient supply holds the key to improving the food grain production and sustaining livelihood. Nutrient management practices have been developed, but in most of the cases farmers are not applying fertilizers at recommended rates. They feel fertilizers are very costly and not affordable and due there is a risk particularly under dry land conditions. Therefore, INM plays an important role which involves integrated use of organic manures, crop residues, green manures, biofertilizers etc. with inorganic fertilizers to supplement part of plant nutrients required by various cropping systems and thereby fulfilling the nutrient gap.

The basic concept underlying the principle of integrated nutrient management is to maintain or adjust plant nutrient supply to achieve a given level of crop production by optimizing the benefits from all possible sources of plant nutrients. The basic objectives of IPNS are to reduce the inorganic fertilizer requirement, to restore organic matter in soil, to enhance nutrient use efficiency and to maintain soil quality in terms of physical, chemical and biological properties. Bulky organic manures may not be able to supply adequate amount of nutrients, nevertheless their role becomes important in meeting the above objectives. Long-term studies being carried out under all Indian Coordinated Research Project have indicated that it is possible to substitute a part of fertilizer N needs of kharif crop by FYM without any adverse effect on the total productivity of the system in major cropping systems such as rice-rice, rice-wheat, maize-wheat, sorghum-wheat, pearl millet-wheat, maize-wheat and rice-maize. Sustainable yield index (SYI) of maize-wheat cropping system after 27 years at Ranchi was the highest with integrated use of 100 percent NPK and FYM (Table 9). Organic manures alone cannot supply sufficient P for optimum crop growth because of limited availability and low P concentration. The organic manures are known to decrease P adsorption/fixation and enhance P availability in P-fixing soils. Organic anions formed during the decomposition of organic inputs can compete with P for the same sorption sites and thereby increase P availability in soil and improve utilization by crops. Reddy *et al.* (1999) observed higher apparent P recovery by soybean-wheat system on Vertisol with a combination of fertilizer P and manure. The INM strategies developed for different cropping systems all over the country are compiled and presented in the Table 10.

Table 9. Effect of INM on sustainable yield index (SYI) in maize-wheat system after 27 years at Ranchi

Treatment	Grain yield (t/ha) (average of 27 years)		SYI	
	Maize	Wheat	Maize	Wheat
100% NPK	0.80	1.70	0.07	0.14
100% NP	0.55	1.20	–	–
100% N	0.11	0.12	–	–
100% NPK + FYM	2.80	2.50	0.30	0.23
No Fertilizer	0.50	0.76	0.06	0.09

Source: Swarup, 2002.

Table 10. IPNS strategies for major cropping systems

Cropping system	IPNS strategy
Rice-wheat	Green manuring of rice with sun hemp equivalent to 90 kg fertilizer N along with 40 kg N/ha produces yield equivalent to 120 kg N/ha. In an acid Alfisol soil, incorporation of lantana camera 10-15 days before transplanting of rice helps to increase the N use efficiency. Apply 75% NPK + 25% NPK through green manure or FYM at 6 t/ha to rice and 75% NPK to wheat. Inoculation of BGA @ 10 kg/ha provides about 20-30 kg N/ha.
Rice-rice	Use of organic sources, such as FYM, compost, green manure, azolla etc. meet 25-50% of N needs in *kharif* rice and can help curtailing NPK fertilizers by 25-50%. Apply 75% NPK + 25% NPK through green manure or FYM at 6 t/ha to *kharif* rice and 75% NPK to *rabi* rice. A successful inoculation of blue green algae @ 10 kg/ha provides about 20-30 kg N/ha.
Rice-potato-groundnut	Use 75% NPK with 10 t FYM/ha in rice and potato.
Sugarcane based cropping systems	Combined use of 10 t FYM/ha and recommended NPK increases the cane productivity by 8-12 t/ha over chemical fertilizer alone.
Maize based cropping systems	Apply 50% recommended NPK as fertilizer and 50% of N as FYM in maize and 100% of recommended NPK as fertilizer in wheat.
Soybean-wheat	To get 2 t soybean and 3.5 t wheat, apply 8 t FYM/ha to soybean and 60 kg N + 11 kg P/ha to wheat or apply 4 t FYM + 10 kg N + 11 kg P/ha to soybean and 90 kg N + 22 kg P/ha to wheat.
Pulses	Integrated use of FYM at 2.5 t/ha and 50% recommended NPK fertilizers plus rhizobium inoculation helps in saving of 50% chemical fertilizers.
Sorghum based cropping system	Substitute 60 kg N through FYM or green *leuceana leaucocephala* loppings to get higher yields and FUE.
Cotton	50% of recommended NPK can be replaced by 5 t FYM/ha.
Oilseeds (Mustard, Sunflower etc.)	Substitute 25-50% of chemical fertilizer through 10 t FYM/ha to get higher yield and FUE.

Source: Subba Rao and Sammi Reddy, 2005.

4.1 Recycling of crop residues and green manuring

Management of crop residues is either through of the following 3 methods; removal, burning or incorporation into soil. Burning is a minor practice in India. Sidhu and Beri (1989) reported that in situ recycling of crop residues in rice-wheat rotation reduced grain yield of rice and wheat. Therefore, most of the farmers recycle the crop residues not by choice but due to combine harvesting, burn the residue causing loss of precious organic matter, plant nutrients and environmental pollution. Experiments conducted in Punjab have shown that co-incorporation of green manure and crop residues of wheat and rice helped alleviate the adverse effects of unburned crop residues on crop yields (Table 11).

Table 11. Effects of incorporation of green manure (G.M.) and crop residue on grain yield of rice (t/ha)

Treatment	1988	1989	1990	1991	1992	1993
Control (No N)	4.0	4.6	3.7	4.3	4.1	3.4
150 kg N/ha	6.3	6.6	6.2	6.5	5.7	5.6
180 kg N/ha	6.6	6.9	5.8	6.7	NT	5.3
G.M.	6.6	6.5	6.2	6.5	5.8	5.5
G.M. + wheat straw	6.9	6.9	6.4	6.8	5.6	5.5
G.M. + rice straw	6.9	6.9	6.7	7.0	5.9	5.3
l.s.d. (P = 0.05)	0.53	0.59	0.46	0.45	0.32	0.37

G.M. = Green manure.

4.2 Role of biofertilizers in INM under intensive systems

Several studies clearly indicate that among the different types of biofertilizers available at present, Rhizobium is relatively more effective and widely used. Considering an average N fixation rate of 25 kg N/ha per 500 g application of Rhizobium, it is expected that 1 tonne of Rhizobium inoculants will be equivalent to 50 tonnes of nitrogen. On the other hand, Azotobacter, which is used in non-legume crops has given inconclusive results. Similarly, Blue Green Algae (BGA) and Azolla have been reported to be effective only in certain traditional rice growing areas in the country. Meanwhile if BGA applied at 10 kg/ha fixes 20 kg N/ha, then 1 tonne of BGA has an equivalent fertilizer value of 2 tonnes of nitrogen. The beneficial effect of the organisms like Azospirillum and Azotobacter in suppression of soil-borne pathogenic diseases of crops is yet to be established on a pilot scale. Another important role of biofertilizers is liberation of growth substances, which promote germination and plant growth. Against the total anticipated biofertilizers demand of 1 million tonne in the country, the current supply position is very low (<10 000 tonnes). There are several constraints to effectively utilize and popularize the use of biofertilizers. Some of these constraints are:

- Unlike mineral fertilizers, use of the biofertilizers is crop and location specific. A strain found ideal at one location may be ineffective at another location due to competition of native soil microbes, poor aeration, high temperature, soil moisture, acidity, salinity and alkalinity, presence of toxic elements etc;
- Low shelf life of the microorganisms;
- Unlike mineral fertilizers, biofertilizers need careful handling and storage;
- Lack of suitable carrier material, for restoration and longevity in actual field conditions.

In order to overcome the above-cited constraints and make biofertilizers an effective supplementary source of mineral fertilizers, these aspects need to be critically attended.

5. Constraints in use of organics complementary with mineral fertilizers

Convenience and advantages in use of fertilizers

Though fertilizers are costly inputs in agriculture, they are ‘concentrated’ source of plant nutrients which can be formulated or tailored before or just prior to field application as per needs of the crops and can be applied with minimum transport and labour and at right time. Fertilizer use is high in irrigated crops, commercial crops and in peri-urban areas where awareness is high. The farmers are aware of the need for high nutrient use in high production areas under irrigated condition.

5.1 Selective use of fertilizers and manures

Fertilizer use is high in rice, wheat, sugarcane and cotton. Organic manures wherever available are invariably used in some vegetable crops like potato, onion, chillies, spices like ginger and turmic, in cereals like rice, in commercial crops like sugarcane, cotton and fruit crop banana. Green manuring is very prominent in rice and sugarcane and farmyard manure is commonly applied in arid and semi-arid dry land areas where costly fertilizers are discouraged due to the risk associated with their use and also due to the need for water for irrigation/soil moisture for better utilization of the applied nutrients. Farmers are also aware of the need for organics in dry land agriculture where some sort of stability to production is ensured because of its possible role in soil structure improvement and moisture storage and supply. The farmers in India apply good amount of organic manure (FYM, compost, goat, poultry and pig manure) at some periodicity to regenerate the soil fertility after three to five years of cropping.

5.2 Agro-ecological differences

Organic manure use is high in arid and semi-arid zones where rainfall/irrigation water or soil moisture is a limitation.

5.3 Peri-urban/rural differences

Developed market encourages farmers to use fertilizers and produce more under intensive system of cropping. Even small farmers use more fertilizers inputs, however in peri-urban areas, there is also possibility for use of agro-industrial or urban municipal wastes along with fertilizers to augment soil fertility. Farmers’ in remote areas with poor infrastructure and without access to market but are aware of the benefits of fertilizer use locally available organic sources.

5.4 Single multiple enterprises

Farmers who have less number of cattle may have to depend solely or mainly on fertilizers whereas farmers who practice several occupations like cash and field crops, dairy or livestock, poultry, fisheries enterprise etc., have opportunities to use/recycle the wastes, manures preferentially and profitably without depending on costly purchased inputs.

5.5 Land tenancy

The farmers who take land on tenure basis try to harvest high yields using mineral fertilizers and irrigation to ensure rapid returns to cover the cost of renting the land and may ignore the use of organic manures especially in cereal crop production.

5.6 Lack of organic materials

Unavailability of organic materials especially animal manure and crop residues is a primary constraint in many areas.

5.7 Competitive use of organic resources

A very important example of competitive use is the use of cow dung as fuel because of the shortage of fuel wood. Similarly, crop straws or stalks like that of castor, red gram, cotton are used as fuel. Crop residues are also very valuable animal feed. Sometimes poultry manure/droppings are mixed with other additives and used as fish or cattle feed.

5.8 High cost of organic manures

Cost of organic manures especially animal manures is high in peri-urban areas where these manures are preferentially used in ornamental gardens, lawns and home gardens in raising vegetable crops.

5.9 Transport

Because organic manures are bulky, it is not convenient to transport and to apply them in all crops in all seasons. So it is applied conveniently in sufficiently good amount in remunerative crops at 4-5 years interval especially in *kharif* crops.

5.10 Pests, diseases and weeds

Some believe that the organic manures may carry pests, pathogens and weed seeds and propagate them in the current or following crops.

6. Farming systems approach

Besides the above stated constraints, to make INM a reality, micro-watershed based agricultural diversification through farming systems approach, consisting of crop and animal husbandry, horticulture, bee keeping, pisci culture, etc. are needed to be adopted. In general terms, the goal of farming systems approach is to increase and stabilize farm production and farm income. Having diverse enterprises creates opportunities for recycling, so that pollution is minimized because a waste in one enterprise becomes an input for another. The risk minimization, employment generation and sustained/increased household income are the benefits associated with multi-enterprise farming systems. Appropriate and situation-specific farm diversification models need to be developed and diffused. Efforts are underway in different locations to develop farm diversification models involving judicious enterprise mix that may provide attractive income besides meeting household demands from a given piece of farmland. One such model put forth by Behera and Mahapatra (1999) suggests an optimum integration of farm enterprises for a small land holding of 1.25 ha for Bhubaneshwar conditions. In this particular model, land was allocated for different enterprises in proportion to their significance in household needs and demand in local market. It was shown that with the adoption of this diversification model, a net income of Rs.58 360/year was derived from 1.25 ha farm land (Table 12). This kind of model is worth emulating in parts of the country as well in our search for comprehensive food and nutritional security.

Table 12. A farm enterprise diversification model for 1.25 ha farmland at Bhubaneshwar and its economics

Components	Employment generation (man days)	Total expenditure (Rs.)	Net return (Rs.)	Return/Rupee invested (Rs.)
Field crops	98.2	3 315	5 638	2.70
Multistoried cropping	87.0	3 831	9 089	3.37
Pomology	18.4	900	1 466	2.63
Olericulture	96.4	3 812	8 302	3.18
Floriculture	4.0	125	100	1.80
Pisciculture	31.0	3 722	16 603	5.46
Poultry	23.0	9 240	981	1.10
Duckery	23.0	5 387	713	1.13
Mushroom cultivation	180.0	18 184	12 856	1.70
Apiary	1.0	170	1 180	7.94
Biogas	11.0	600	1 431	3.38
Total	573.0	49 286	58 360	2.18

Source: Behera and Mahapatra (1999).

7. Current status of INM

Keeping the importance of organic resources in view, a lot of research has been done on integrated nutrient management during last two decades in natural resource management (NRM) institutions and state agricultural universities. This research has led to:

- Development of INM practices for major crops;
- Understanding the enhanced role of organic manures in increasing input use efficiency due to their favourable effect on physical, chemical and biological condition of the soil;
- Establishing the beneficial role of integrated use of organic manures in improving nutrient cycling in different production systems in various types of soils;
- Beneficial role of INM in improving soil chemical, physical and biological quality for sustainable crop production; and
- The work on INM has been compiled and published in the form of books/bulletins by several institutions.

8. Research gaps in INM

The research gaps include:

- Mismatching of INM practices developed at research stations with the farmers' resources and their practices;
- INM recommendations for different crops are not based on soil testing and nutrient release behaviour of the manures;
- Nutrient balance/flow analysis vis-à-vis soil fertility management practices with special reference to INM at farm level needs to be worked out;

- Nutrient release characteristics of farm residues in relation to their quality to develop decision support systems;
- Biofertilizers were not included as component of INM in many cases; and
- Integrated Farming Systems (IFS) approach needs to be encouraged for sustaining livelihood in rural areas particularly for small and marginal farmers.

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South Asian Country

Paper Number 3

Plant nutrient management for improving crop productivity in Nepal*

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Summary

Nepal's economy largely depends on its agriculture sector. Priority strategies, both technical and legislative, have been put in place to achieve sustainable agricultural productivity. Several research studies involving application of modern agriculture technologies have been conducted to address the problem of low crop production, soil fertility, nutrient imbalance and the like. In the legislative aspect, the Nepal had long formulated its Agriculture Perspective Plan (APP) to accelerate agriculture economic growth. However, APP put emphasis on boosting up the agriculture production through use of chemical fertilizers and irrigation in high production potential areas. Researchers have noted the emerging deficiencies of micronutrients especially zinc, boron and molybdenum and are increasing in extent in intensively cropped areas in different ecological belts of the country. Zinc has become a yield limiting in the major rice producing areas of the country. There is likewise a growing concern of the long-term impacts of fertilizer inadequacy and mismanagement in the rapid deterioration of soil health. The country's researchers have conducted a wide range of soil nutrient conserving activities that included management of acid soils, the adoption of sloping agricultural technologies, the use of biofertilizers. The Twenty Years NARC vision (2021) is another strategic master plan for action that was developed few years back to guide research and development activities in the country. It involves the conduct of efficacy testing transferrability of results of researches from the research stations to outreach sites where farmers will participate in testing the technology.

1. Introduction

Agriculture remains Nepal's principal economy activity employing around 65.62 percent of the population (23.3 million). The agriculture sector alone contributes 38.81 percent to the national GDP. The current food production is not sufficient to meet the food requirement of the growing population which is at a rate of 2.25 percent indicating serious food insecurity (MOAC, 2005). Therefore, agriculture is a priority sector and there is a strong need to appraise the potentiality. At the same time subsistence farming has to be changed to commercial agriculture to uplift the economic status of poor people. Unavailability of appropriate technology, rain water erosion in the hills and mountains and nutrient mining, and increasing cropping intensities without judicious fertilization application have been the major technical problems. Small land holding, subsistence farming and poverty are social constraints. The potential arable land is already under cultivation and there is not much scope to increase. The alternative option would be to cultivate the forest land and the marginal land which are already at the state of degradation.

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* This country report has not been formally edited and the designations and terminology used are those of the author.

The productivity of major cereal crops except maize and millet and horticultural crops are far below compared to the neighbouring countries (Kaini, 2004). For the last 15 to 20 years, the productivity per unit area is not attaining to the expectation. Few cereal crops show insignificant improvement that could be because of introduction of new crop varieties and increased in arable land (Figure 1a). This decrease or stagnant crop production is mainly due to land degradation (Karki and Dacayo, 1990, Shah and Shreier, 1991). A wide yield gap exists between the farmers' field and research stations and attainable yield (Figure 1b). Inadequate plant nutrient supply and poor quality of seeds could be one of the major factors governing food production.

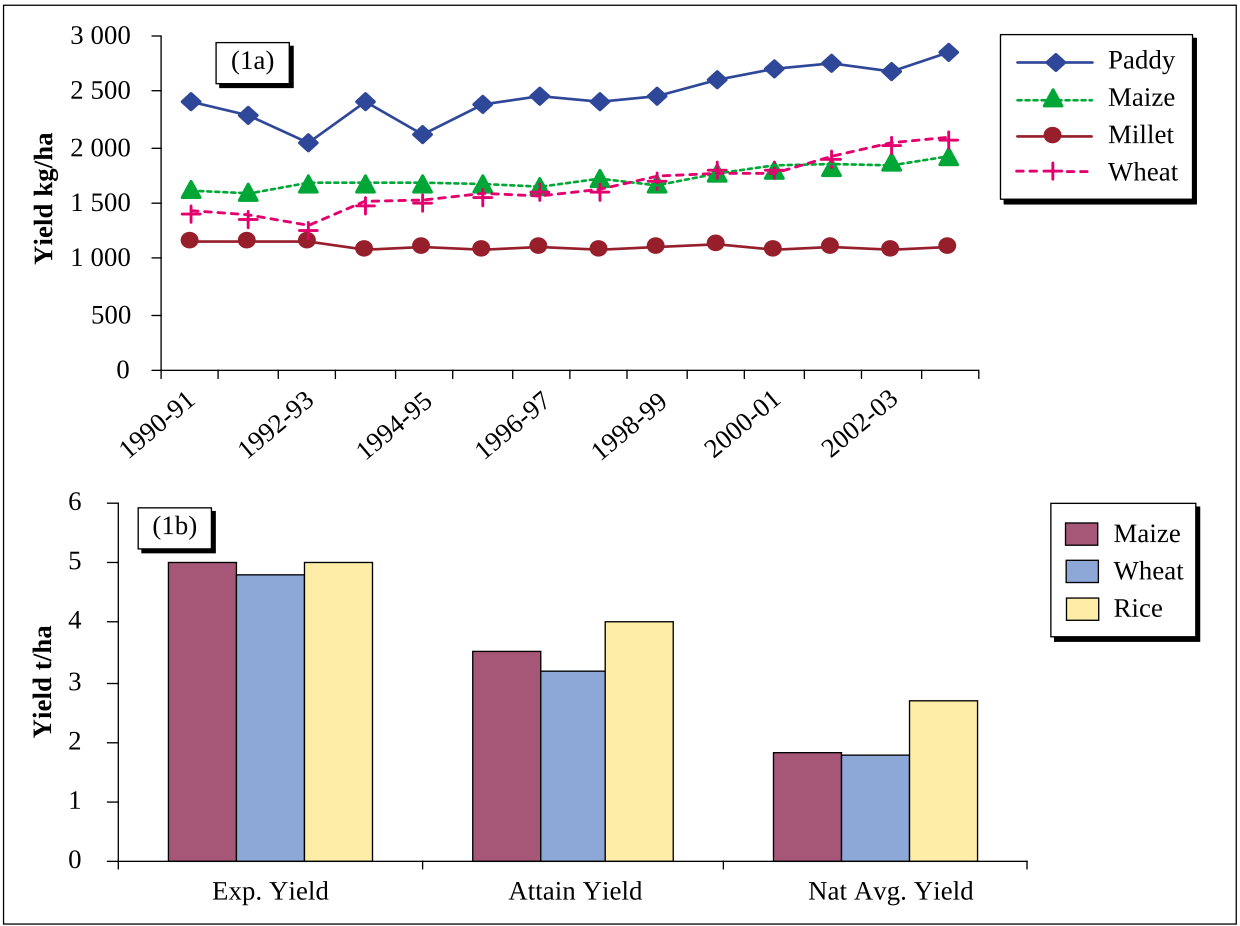

Figure 1 (a and b). The productivity of the major crops and the existing yield gap

The agriculture policy of the government in 2061 also emphasizes priority for improving production and productivity of agriculture. In addition the annual growth rate for the 10^{th} five years plan has been set at 4.1 percent. For the last 9^{th} five years plan the achievement was only 3.3 percent. The sluggish economic growth in the country has been realized as a result of poor performance in agriculture sector.

The APP has also envisioned high consumption of fertilizers in the high production potential areas for better food security. A number of long-term and medium terms field experiments indicated use of both organic and inorganic sources of plant nutrients for sustaining the productivity for a range of cropping patterns (Sherchan, *et al.*, 1999; Regmi, 1998; Tripathi, 1998). Therefore, soil fertility is one of the priorities to boost the productivity of crops and soils. This paper attempts to review the past research activities carried out in Nepal and highlight the useful findings and to analyse the bottlenecks in research and development aspect and raise few pertinent issues relevant to the Nepalese situation.

2. Source of plant nutrients

The various sources of plant nutrients in the Nepalese farming system have been identified (Carson, 1992). Among them chemical fertilizer is becoming gradually a major source (Figure 2). Since the import data indicates an increasing trend. However, earlier to the introduction of mineral fertilizer into Nepal in 1952, crop production mainly depended on farmyard manure (Pandey and Joshy, 2000). Since fertilizer demand increased and the government agency, Agriculture Input Corporation (AIC) the sole authority in fertilizer import could not meet the demand, the HMG of Nepal deregularised fertilizer import policy in 1996/1997. The total N, P, and K consumption is around 35 kg/ha. The statistics show around 75 percent of the total imported fertilizer is consumed in Terai (accessible area) and only was 25 percent in the hills and mountains. There has been constant complains on the quality and supply of fertilizers in the market after the deregulation of fertilizers policy.

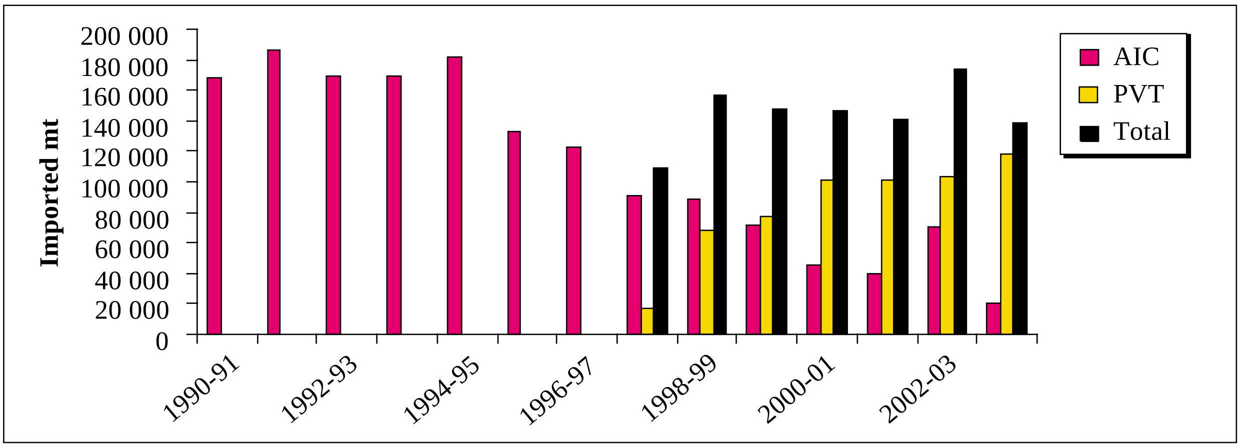

Figure 2. Chemical fertilizer imported into the country

The HMG Nepal has appointed fertilizer inspectors in various districts, however, due to lack of analysis facilities, quality control is not easy. Monitoring to control the quality of fertilizers has been in progress. The supply of chemical fertilizers on time is still not guarantee that restricts use on right time and the majority of farmers cannot afford the costly fertilizers. Frequent change of fertilizers types loose confidence amongst poor farmers.

Cropping pattern, land drainage (soil moisture), access to resources cash, market opportunities, fertilizers types and crops species determine the nutrient management in the Terai, hills and mountains area. The irrigable areas is around 32 percent of the total arable land and the majority of areas are rainfed. The bottleneck with the use of farmyard manure and compost are labour availability, access to forest resources that restrict adequate supply of the composting materials. The farming system both in the hilly and flat land (Terai) is complex, diverse and predominantly resource poor. Pound *et al.* (1990) attempted to show the linkages between the forest, livestock and crop production (Figure 3) and soil management is influenced by these components. Therefore, the agriculture productions and productivity are largely determined by the soil management for improving as well as maintaining the productivity of soils and crop for long-term without an adverse effect on soil environment as well.

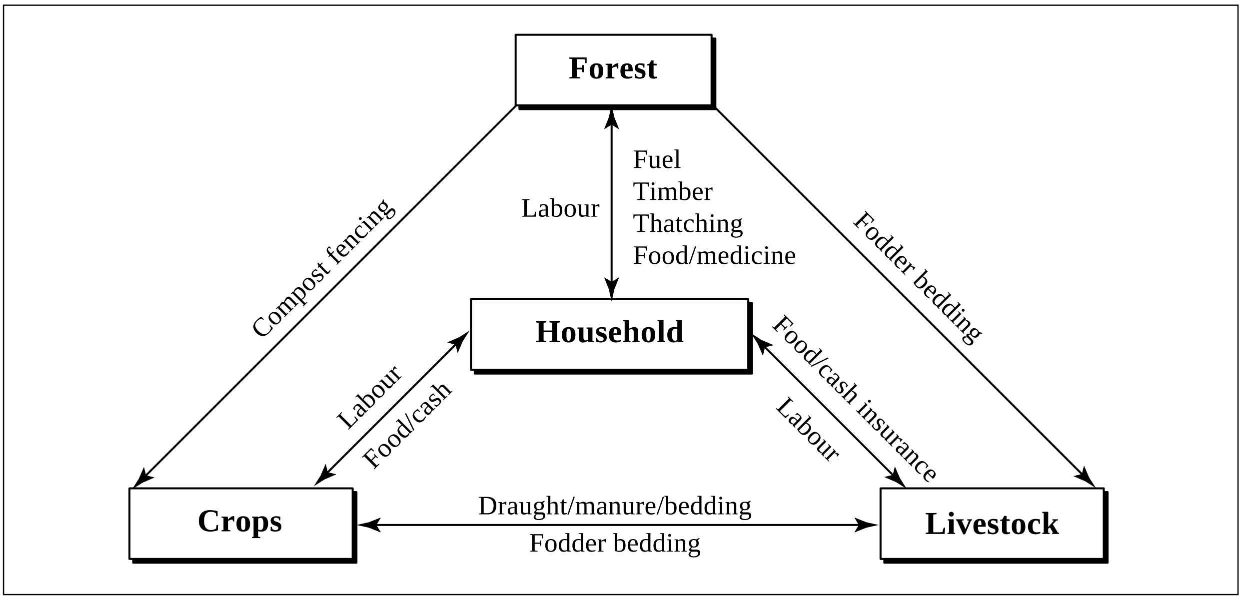

Figure 3. The Nepalese farming system (Pound *et al.*, 1995)

3. Nutrient flow and balance in the Nepalese farming system

Plant nutrients are coming to the soil system from various sources (Figure 4). Forest and livestock are the major sources of nutrients that have been influenced greatly by current changing circumstances. External sources of plant nutrient particularly the chemical fertilizers depends on imports from outside, purchasing capacity of farmers and availability on right time. A limited study conducted to estimate the nutrient balance showed mixed results. Ghani and Brown (1997) reported that the balance of plant nutrients N, P, K and S were estimated after the harvest of the early rice, the main season rice, the maize and the wheat. The early rice showed negative balance of K and S. At two sites N was negative but P was found to be positive balance in all the tested sites. After the maize harvest the N balance was found to be positive around 60 percent of the tested sites. But P, K and S were largely negative. After the wheat harvest N, P, K and S were found strongly in negative balance. This is very surprise to note that despite adequate K in the Nepalese soils the balance is negative. However, Karki (2004) reported that reserve soil K in intensive farming areas is declining. Regmi *et al.* (2002) reported that application 40 kg/ha potash under rice-rice and wheat rotation cannot maintain K balance in soils. Pandey *et al.* (1998) reported results of a three years experiment on rice and wheat rotation in a low land rainfed condition that three major nutrients N, P and K found in negative balance after rice harvest. Application of 50 kg/ha nitrogen, 30 kg/ha phosphorus and 30 kg/ha potash were also found negative in balance. The result also indicated that farmyard manure at a rate of 10 t/ha is not enough to maintain nutrient balance under rice and wheat rotation system. Pilbeam *et al.* (1998) estimated nitrogen balance in positive referring to the nutrient management system of the middle mountain region. Bhattarai *et al.* (2000) reported negative balance of the vegetables cultivation in the majority of study sites except at few locations. They have emphasized use of bacterial fertilizers for maintaining productivity and soil health. However, there is lack of proper study to quantify by the nutrients contribution from various sources and losses through the system.

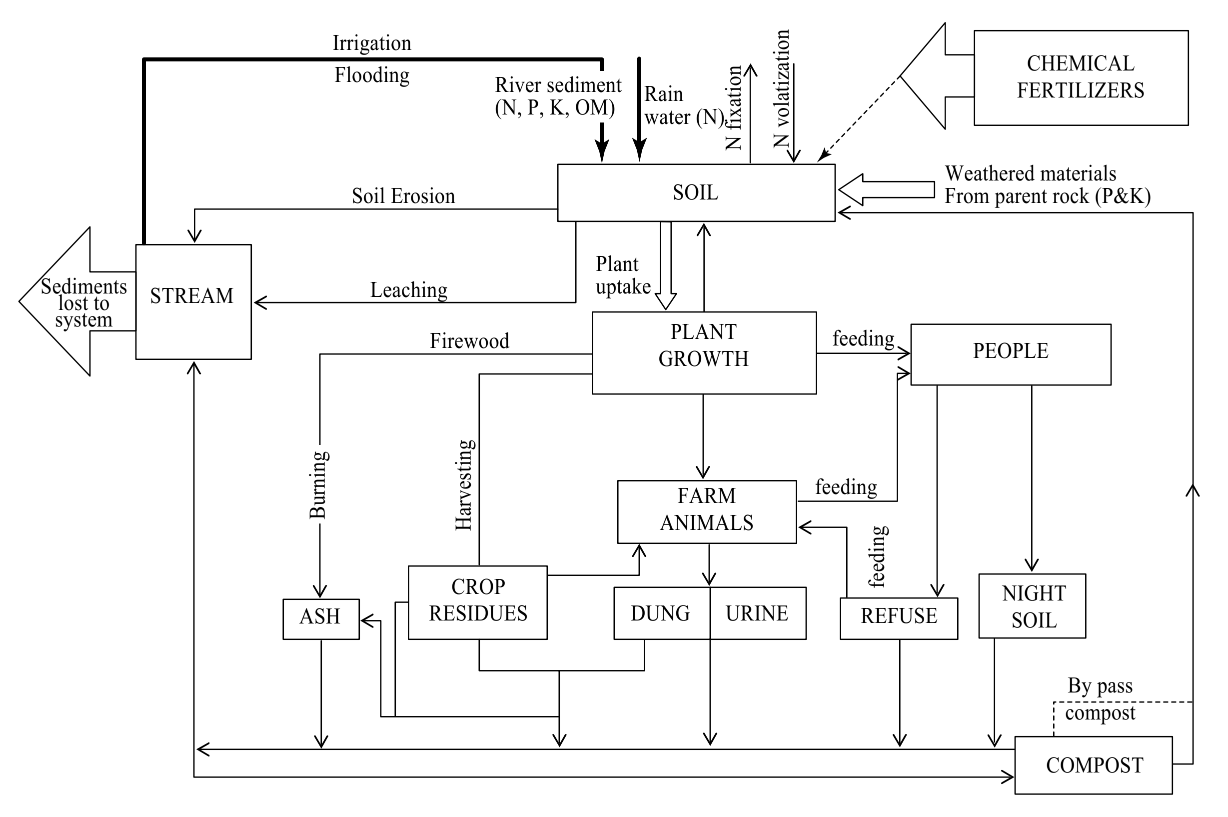

Figure 4. Nutrient flow components in the Nepalese farming system

4. Soil and nutrient losses from the hill slopes

Rain water erosion is a serious land degradation process in the hilly and slopy land that comprises around 86 percent of the total geographical area of the country. The experimental results have been reviewed by Gardner *et al.* (1995) that indicates a bit of confusion about whether the soil loss from top soils is really a serious environmental degradation or not. Recently Shrestha *et al.* (2005) published that 32 t/ha of soil is lost every year from hill terraces which are rather serious the inconsistent results obtained from the various locations would be because of the method employed to record losses. However, it has been well identified that more than 50 percent of soil loss occurred during the early monsoon period. Gardner *et al.* (2000) found out that a nutrient loss through leachate is more serious problem than in the sediments. Nitrate-N losses are high during the transition period between the pre monsoon and main monsoon. K losses also found high in leachate in the early monsoon. Sherchan and Gurung (1992) reported decline of maize productivity over the years because of top soil erosion (Figure 5).

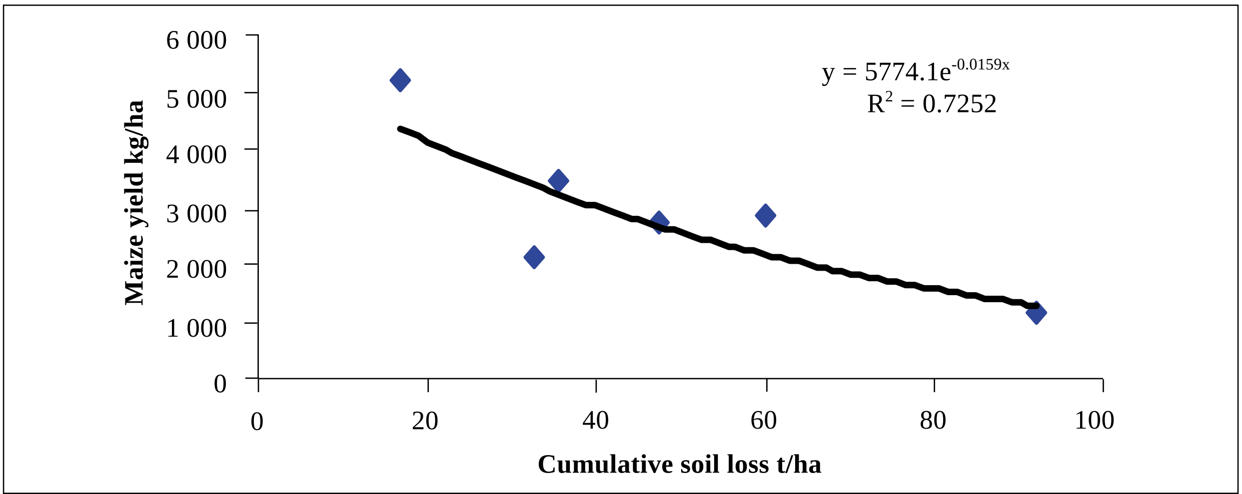

Figure 5. Relationship between cumulative soil loss and the maize productivity

5. Acid soils improvement

Amelioration of acid soils has been recommended by agriculturists since soils nearly 49 percent of the geographic area are acidic in reaction. Acidic condition hinders the availability of many essential nutrients to crops. Karki and Dacayo (1990) recommended 6-9 t/ha of lime on various soils whereas Sherchan (1998) reported that 2 to 4 t/ha lime requirement. However, considering remoteness and lack of logistics support especially in the hills there is a need to find out alternative ways. In this connection Tripathi (2001) initiated to select local and exotic germplasm of maize, wheat, upland rice, soybean and black gram suitable to acidic environment. Tripathi (2000) further recommended applying lime in combination with compost or organic manure. He also recommended 2 t/ha applied for maize and wheat that would increase up to 35 percent yield over non limed plot. So this is one of the areas in nutrient management need to be studied systematically.

6. Bacterial fertilizers, BNF and organic manure

Significant achievements have been obtained in BNF research and its associated fields to improve the productivity of legume crops in Nepal (Bhattarai and Maskey 1987). The productivity of the major summer and winter legumes crops such as soybean and lentil have been increased through using effective inoculums in the farmers' fields (Figure 6). The effective Rhizobium strains for soybean, black gram, cowpea, lentil, chickpea, peanut, mungbean clover, desmodium, stylosanthees,

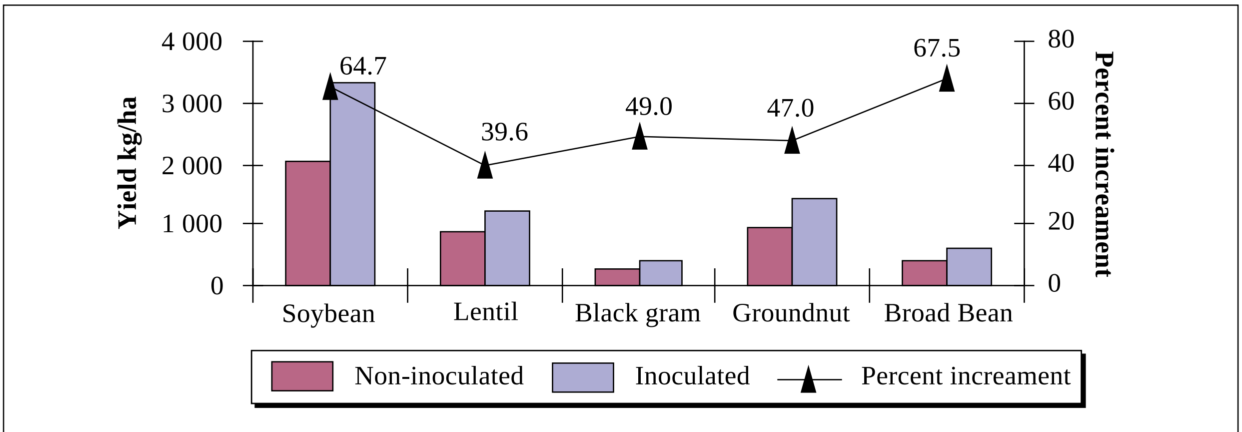

Figure 6: Effect of the Rhizobium inoculum on the yield of leguminous crops

astragtalus, ipil-ipil, medicago and vetch are being maintained at Soil Science Division, NARC. Technologies for the preparation and application procedures have been well standardized. Rhizobium culture for different leguminous crops is on high demand. Since government agencies have not been able to meet the demand private sectors are encouraged to do this job. Field research conducted on various cropping patterns indicated that integrated use of organic and inorganic sources of plant nutrients is the most sustainable nutrient management. The crop productivity has been found quite encouraging (Figure 7 and 8a and 8b).

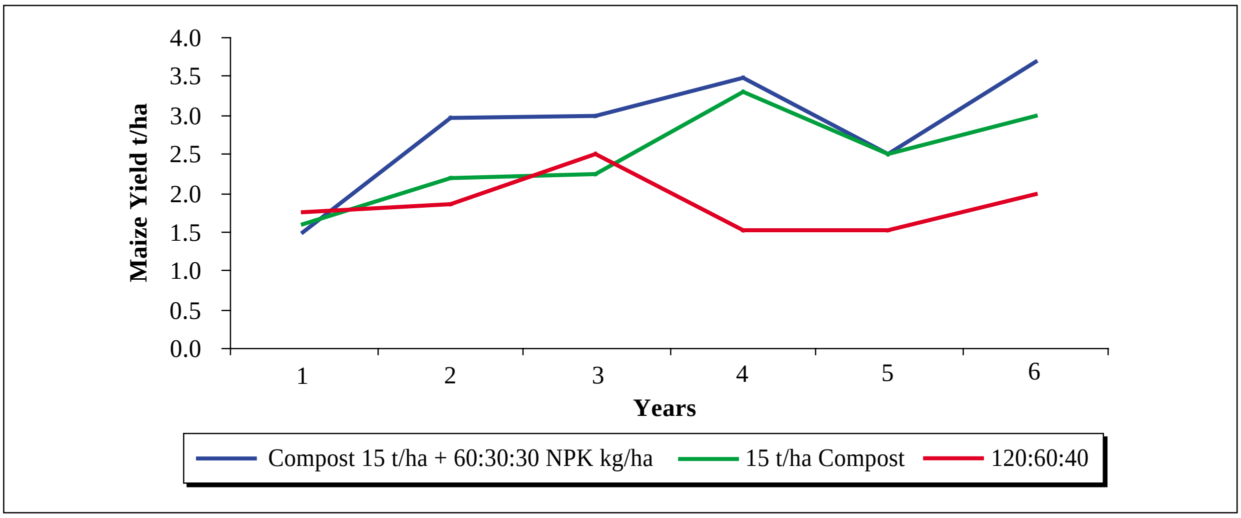

Figure 7. Effect of organic and inorganic manure on the productivity of maize under maize relayed millet systems

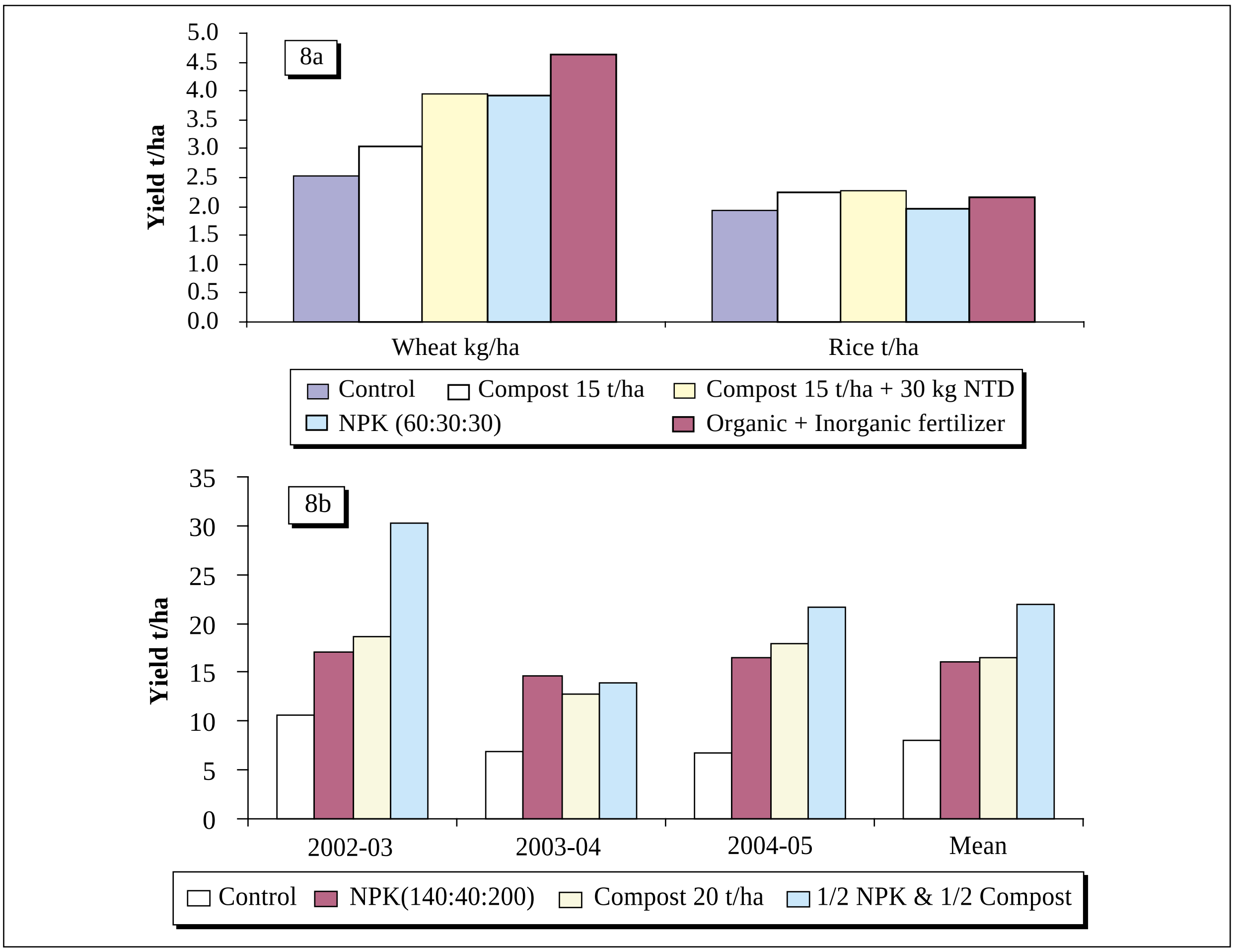

Figure 8a and 8b. Effect of inorganic and organic manure on rice, wheat and potato

7. Emerging micronutrients problems in soils

Deficiency of micronutrients especially zinc, boron and molybdenum is increasing at different ecological belts at varying intensity (Karki *et al.*, 2004). Zinc is a problem in the Terai belt on rice crop. Farmers are now applying zinc sulphate at a rate of 25 kg/ha without proper extension advice. In the hills where vegetables are being grown during off season and normal season, boron and molybdenum are deficient. There is lack of proper recommendation to farmers as well. The Agro-vets are supplying different kinds of products and their content and efficiency is not known in such circumstance farmers might have to bear financial loss. Some farmers apply these materials to every crop in succession; it may pose toxicity in the long run.

8. Livestock raising and its role in soil fertility management

Livestock provides draft power and manure to agriculture, income, nutritional and other byproducts. An estimation in 2002/2003 shows that the population of animal species such as cattle, buffalo, goats and sheep were nearly 7 million, 3.9 million, 6.9 million and 0.82 million respectively (MoAC, 2003/04). These figures indicate an increasing trend of livestock population. Sherchand and Pariyar (2002) reported that 60 percent of livestock's feeds come from low quality crop residues and 40 percent from the forest. The estimated feed balance also indicates 34.7 percent feed deficit on TDN basis (Sherchand and Pariyar, 2002). The indigenous system of livestock raising and access to the forest resources have been broken down due to pressure on the land. In higher altitude areas during winter folks of sheep and goat are brought down to the valleys and in situ manuring is done by leaving the animals overnight in the cultivable field. Composting forest litters with animal excreta is another advantage related to livestock production. Table 1 shows the stock density over the carrying capacity. Except in the alpine meadows the rest of range lands are over the stock density than its carrying capacity. The poultry industry is coming up as attractive entrepreneur in the road access areas but at the same time farmers have found new sources of plant nutrients and particularly poultry manures are used for maize and potato crops.

Table 1. Stock density by rangeland type (Pariyar, 1993)

Rangeland	Carrying capacity (LU/Ha)	Stock density (LU/Ha)	Stock density over the carrying capacity
Middle hills	0.31	4.08	13.2
Steep grassland	0.01	0.19	19.0
Open grassland	0.54	7.07	13.1
Alpine meadows	1.42	0.64	0.5

9. Zero/minimum tillage resource conserving technology (RCT) in rice-wheat system

Under the technical and financial support from rice wheat consortium, resources conservation technologies (RCT) such as zero, minimum till and permanent bed planting technologies have been tested and validated. The aim is to utilize the moisture, cost saving and timely seeding wheat for higher productivity. Seeding wheat by Chinese hand tractor saves nearly 50 percent cost compared to the traditional system in the Kathmandu valley. This technology is getting popularity both in the hills and Terai, however, in the hills there is lees potential area to expand much due to narrow steep terraces whilst in the Terai the scope is greater. But the research gap on how best plant nutrients efficiency could be improved is not known clearly. Currently the productivity is at par with the farmer's method of seeding (Annual report, 2003/04).

10. Role of biogas in improving soil fertility and environment

Methane gas production from animal dung was started in 1973 since then it was popularized extensively in the country. In a study conducted by Karki (2004) reported that there are more than 120,000 biogas plants in the country. Biogas has numerous advantages that improves the environmental condition by reducing the emission of carbon dioxide and preserves forest resources by reducing the total firewood requirement by 49 percent and 51 percent during summer and winter respectively. Farmers perceived that after the installation of biogas, the production farmyard manure and compost have been reduced. But if the quality of manure is considered then the biogas slurry contain high nutrients. The application of biogas slurry increased maize, rice, wheat and cabbage by 30 percent, 23 percent, 16 percent and 25 percent over control respectively (Karki 2004). Installation of biogas by using animal dung as main source of feeding the biogas plant has improved environment but the effluent use in agriculture has not been successful. It is mainly due to the effluent being in liquid form and Nepalese farmers have scattered land holding being difficult to transport. Improvement over the quality of compost and nutrient losses during handling needs to be studied.

11. Sloping Agricultural Land Technology (SALT): A potential technology to improve productivity

The SALT technology has been tested in the hills of Nepal and found potential to reduce run off and soil loss and also provide fodder and biomass for various purposes. Farmers have grown fodder trees and other plant species on the edge of terraces for fodder fuel and timber. Farmers do have immense knowledge on the effect on soil properties from the fodder trees. They perceived that the hedge row plant reduces the total land area available for crops. A participatory research on SALT technologies carried out by the soil science division reveals that fruit trees with small stature would fit into their system and can fetch some cash earnings. There is a need to blend farmers' local knowledge and the SALT together. Currently, the promotional activities have been constrained by unavailability of seedlings and saplings and open grazing systems (Maskey, 2001). During pre-monsoon period soil is exposed and identification of suitable cover crops to conserve soils and nutrients loss is recommended. In addition, study on nutrient flow in watershed base on the biophysical feature and hydrological behaviour needs to be taken up. Agri-silvipastoral approach is a successful approach under the leached hold forestry programme (Pariyar, 2002). Various types of fodder species and nitrogen fixing legumes and trees can be established and the fodder and other need of the rural household can be met. The government policy also encourages for the utilization of the degraded or marginal land for fodder, fuel and other purposes particularly for targeted group of people with very low income and they are landless. Some of the initiative developed in Nepal is the community forest which is run by the communities under the supervision or advice of the respective district forest offices.

12. Appropriate technical/policy solutions

The 10th five years plan of the government policy is to alleviate the poverty and improve the living standard of the Nepalese people. The recent national policies of HMG/Nepal 2061 in agriculture are:

1. Increased agriculture production and productivity
2. Making agriculture sector competitive in regional and world market by developing basis for commercial agriculture system
3. Conservation, production and use of natural resources, environment and bio-diversity.

Before the inception of the current government policy, Agriculture Perspective Plan was in placed exclusively looking to accelerate the agriculture economic growth. The strategies envisaged in the APP are as follows:

1. Major dominant food crops rice, maize, wheat and potato
2. High values crops apple, off season vegetables, vegetables seeds, sericulture and apiculture
3. Dairy production, animal nutrition high value fodder crops
4. Develop soil fertility and shallow tube well farming system
5. Develop strong outreach systems
6. Develop scientific information system
7. Develop close association with other organization in agriculture research

APP has emphasized to boosts up the agriculture production through use of chemical fertilizers and irrigation in high production potential areas. This would raise environmental effect on soil health. The Twenty years NARC vision (2021) is another strategies document that was developed few years back to guide research and development activities in the country. The strategies are:

1. Demand-driven and appropriate technology developed for priority client groups and fed into uptake networks.
2. Demand-driven agricultural policy, trade, marketing and socio-economic research conducted and fed into uptake networks.
3. Coordination and networking to maximise the impact of agricultural research enhanced.
4. NARC ability to achieve its objectives improved.
5. Mandated direct services delivered appropriately.

These all policy papers or documents address the poverty reduction with better agriculture growth, sustainability of the systems and environments for future and improve the capability to compete in the world market. These all changing scenarios have an implication in current agriculture farming and future sustainability of the system. Therefore, an integrated nutrient management which uses all sources of plant nutrients (mineral fertilizers, compost, bacterial fertilizers) could be scientifically applied. Sustainable plant nutrients management leads to improve productivity thereby improve the livelihood of the people and better environment since it takes into consideration the factors that may have negative effect. Some of the appropriate solution and issues need to be addressed and they are discussed in brief below:

A. Identification of research domain

There is a need to identify the domain for research and development. The flat land or the Terai is basket for food production in Nepal although 66 percent of the populations live in Middle Mountain region and food deficit is the major problem. Therefore, two domain that is Terai and hills and two sub-domain irrigated and non-irrigated. Irrigated area as high production potential domain and the high cropping intensity as well as consumption of mineral fertilizer is high. In non-irrigated area with low cropping intensity including fertilizer consumption is low. In simpler terms the *Khet* land (irrigated level terrace in the hills) where rice-based cropping pattern is the major one and another is *Bari* land (upland) where maize based is the major cropping pattern.

Therefore, the strategy should be to use balance application of chemical fertilizers along with making best use of organic resources. Green manuring practices should be promoted since its positive effect on crop production has already been proven in warmer air temperature regime and irrigated domain. Both exotic green manuring plant species such as *Sabena* and the indigenous non leguminous species as *Adhatoda vassica* (3.8 percent N), *Artmesia vulgaris* (2.5 percent N) have been tried, however, adoption is weak that might be because of labour, mechanization and other social factors. In the hills due to remoteness the use of chemical fertilizer is restricted very much but in the areas where nutrients deficient have been investigated, the right type of chemical fertilizers can play a greater role. However, still the compost and farmyard manure would be the major sources for plant nutrients, therefore, the quality production and proper management of compost or farmyard manure would be priority in the hills. APP has also emphasized on organic matter management in the hills (APP, 1995).

B. Chemical fertilizer import policy

Government lifted the single door system of importing chemical fertilizers expecting a free and healthy competition in the market. The government has put subsidy in transportation of the fertilizers and provided improved seeds for twenty six very remote districts to support the food security. International donors fund import of chemical fertilizers was also established to commensurate the demand and ensure the continuous supply. Till now there are limited choices for farmers. The highest demand nearly more than 50 percent is Urea followed by Diammonium Phosphate (DAP), Mutate of Potash (MoP) and few others. Mixed or multiple nutrients containing fertilizers would give much more benefit compared with straight fertilizers provided the market price is affordable to farmers. Therefore, we should think whether the market price on certain chemical fertilizer such as ammonium sulphate or Urea can be increased and at the same time the market price can be relaxed for mixed or complete fertilizers type.

C. Formulation of fertilizers recommendation

Joshi and Deo (1975) developed a comprehensive recommendation on economic use of fertilizers for various crops in 1975. Since then, no further systematic work has been tried in Nepal. We can expect quite different response level due to change in cropping pattern, increasing intensity and change in soil fertility status. The current recommendation should tie up with the farmer's knowledge and should be most practical from farmer's perspective. Site specific fertilizer recommendation has been made to the important crops but farmers deviate and use their own rate of fertilizer (Joshi, 1997). This indicates that farmers do have their own economic judgment which we overlooked. Dissemination of information on chemical fertilizers handling would be an area for promotion on the use of fertilizers.

D. Improve biological processes in soil system

Evidences indicate that research is needed to improve the quality and quantity of compost as well as its efficient management. Poor quality of compost and its poor management and decreasing production are some of the well known hurdles. In the Terai, animal dungs are largely used for fuel purposes but gradually there has been increasing use for biogas or methane gas production. This has been a positive change for better environment. But farmers are complaining of less production of organic manure because of this new practice. The researchable areas identified are animal shed management for collection; reduction of the losses from rainwater and sun, and faster decomposition and use of all available biomass to improve their quality. It has also been stressed in the 10th five-year plan of the government to conserve and utilize the natural resources and environment for the production and utilization of the organic fertilizers. However, we should have strategies for farm level production and commercialization in an accessible areas.

An integrated nutrient model developed quite some time ago as shown below Figure 9 was a successful programme but it has not been popularized or has not been well adopted by large number of farmers. There should be a follow up study to see the impact on soil fertility management and to look on how best we can promote to wider areas.

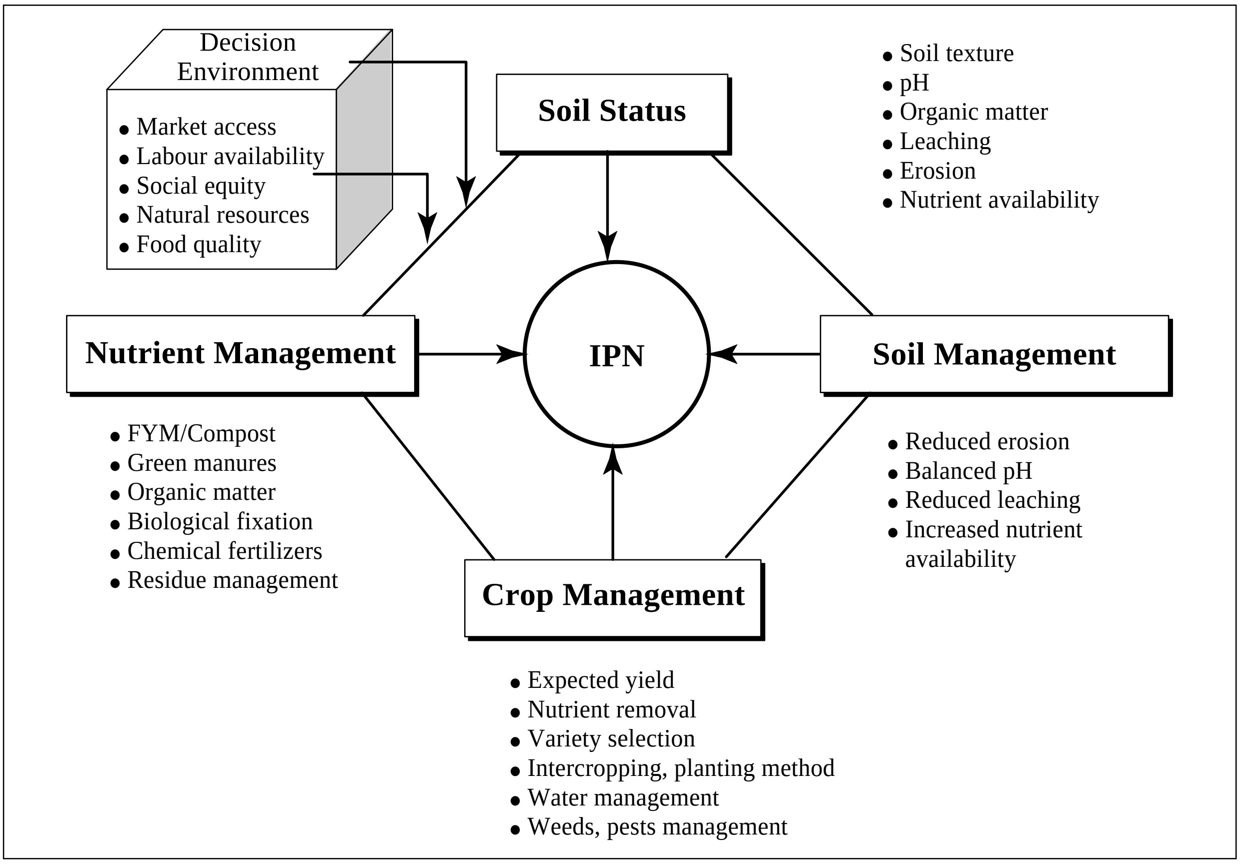

Figure 9. Integrated plant nutrient components in the Nepalese farming system

E. Soil moisture management and conservations/cover crops

Around 68 percent of the total cultivated land is rainfed. The efficiency of applied nutrient would be greater if the optimum moisture is available that eventually improve the crop productivity. The mulching practices, water harvesting and utilize them as life saving in the form of irrigation would be an option. Since during monsoon more than 80 percent of the total rainfall occurs but the excess water could be reserved for dry season use. Identification of suitable species which could be used as cover crops for early monsoon period would be a solution to mitigate the soil and nutrients losses. Maskey *et al.*, (2000) also recommended research and development activities on cover crops since biomass availability could be a major issue in near future.

F. Inclusion of legumes in crop rotation

Both in the hills and Terai regions of Nepal, legumes are one of the important sources of protein and covers around 316 010 ha area with total production of 265 360 mt (MoAC, 2004). However, N-fixing capacity of these legume crops varieties is low. So the priority work should be to develop high productive varieties and improve the N-fixing capacity by developing appropriate strains. Currently, Soil Science Division has identified effective strains of most legume crops. The current export is 12.2 million USD. Therefore, pulses could be very attractive exportable commodity.

G. The role of women in soil fertility management

It is well emphasized the importance of women roles in soil fertility management practices (Turton *et al.*, 1995) since their overall contribution in agriculture is very high. Study reveals that compost preparation and application in the field is solely the work of women in Nepal. However, we have not captured their knowledge and experiences to improve the plant nutrients management.

H. Organic product and commercialization

Organic farming is one of the policies of the government under the competitive and commercialized agriculture. In Nepal, commercialization in agriculture is yet to be promoted. The recent activities show encouraging move. With the increasing living standard of the people there would be more demand for quality products in the market and also for export. However, guidelines are not available for the production of organic produce.

I. Nutrient management through in watershed concept

The biophysical features of a watershed in Nepal are quite unique and do not match with each other. The hydrological behaviour depends upon the condition of a watershed as well. Crops and soil management between the upper and lower catchments are also determined by the moisture regime and temperature regime. The flow of nutrients cycle between the upper and lower catchments has a strong relationship in soil fertility management. The rain water erosion occurs in the upper catchments and gets deposition in the down valleys. This is the area where our attention is required.

13. Dissemination of technologies and capacity building

A. Research planning process

It has been felt that the spread and adoption of technologies is rather slow or weak. This could be due to poor planning processes and setting of priorities. NARC recognizes that the first step would be to strengthen the planning process. There are a series of discussion forums such as regional technical working group, planning and coordination meeting, review meetings to address these issues. Different stakeholders such as Government, Non-governmental Organization, private sectors and innovative and progressive farmers participated in the meetings. Based on the problems identified by the working groups, projects are submitted to NARC (once a year) for research funding. Similarly for development activities proposals are developed and submitted to the Department of Agriculture, Ministry of Agriculture and Cooperative for approval of fund. Projects are implemented in the following years after the concerned authorities approved the proposals.

B. Testing and validation of technologies

In the field of crops research, participatory research methodologies have been well standardized and being followed whilst it has been experienced difficult to follow the same approach in case of soil related activities. However, some of the successful approach experienced by the Sustainable Soil Management Programme (SSMP) project can be expanded to other areas of Nepal. Group approach is reported as most appropriate method of diffusing technologies with limited financial, technical and managerial supports (SSMP, 2003). Diffusion of sustainable soil management (SSM) practices from leader-farmer to group-farmer is considered to a low cost and demand driven extension approach. The leader-farmers can be developed as a resources person. They can also provide their expertise to other non-project areas. They have also found that farmers-led experiments are effective to diffuse

SSM technologies due to the involvement of the farmers. Initially, integrated pest management (IPM) project started the farmer's field school (FFS) approach in pest management. The same method was also applied in SSM activities especially on compost and farmyard manure production and management. This was found quite effective. A system approach is followed in case of integrated nutrient management aspect. Bhattarai *et al.,* (2000) experience on the farmer's field school (FFS) approach is quite successful to demonstrate and validate the integrated nutrient management systems in diverse agri-ecological and social environment condition. It has been found that farmers have developed their skills and adopted the technologies comparatively in short period of time.

C. Technology testing and validation through NARC outreach sites

The technology developed on research farm will be further verified in out reach sites where farmers will participate in testing the technology. All research stations and regional centres under the NARC umbrella have three to four outreach sites depending upon the area coverage for testing and validating the technologies. Field trials will be put in the farmers fields in close cooperation with the farmers. At various critical stages of crops, visits will be made by the group of farmers. Interaction and discussion will be held to evaluate the technology. Neighbouring farmers will frequently visit the experimental sites and interact with concerned technical staffs and the farmers actually testing the technology. Observational visits of all the stakeholders such as extension workers, agricultural planners members of NGOs, private sectors including farmers will be organized when the crop is about to be harvested. Detailed discussion on the pros and cons of the technology to be disseminated will be discussed and further verification will be done if needed. Socio-economic aspect of the technology will also be discussed. Then scaling up will be carried out. After the visit, posters and pamphlets will be prepared including media broadcasting.

D. Capacity building

Training is a strong means to improve the capability of the researcher, extension agent, NGOs partners and the clients or the ultimate end users. Various forms of training modules are being organized. Among them, training conducted in the field itself is the most effective. Female farmers have problem to attend the training since they can not stay overnight outside because of cultural problem. It is also experienced that long duration training is not effective. Identification of innovative farmer to implement activities through him/her is also found effective approach.

14. Conclusions

The poor socio-economic condition is directly related to degradation of natural resources mainly land, soil and forest that also eventually determine the sustainability of the system. These resources are gradually at danger state in Nepal due to population pressure. The difficult terrain condition prevails smooth running of lives, however, we may have to exploit the potentiality. Since the range of agro-ecological environments is within a very short distance, agriculture provides a plenty of opportunities to diversify. We feel that there is no dearth of policies to guide or lead either it is a research or development activities, however, the main bottlenecks would be the implementation phase that often lack in terms of cash/kinds and human resources. Soil fertility management is no doubt a priority area. Based on our experiences and looking at the farming systems, the integrated nutrient management approach to improve the productivity of crops and maintain a sound environment would be a sustainable approach. There are few areas where research is lacking such as the contribution to plant nutrient from the various sources and need to quantify and measure the deficit. However, dissemination and quicker adoption of soil fertility based technologies should be the priority issues. For that we may have to improve the capability of personnel's involved in research and development.

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South Asian Country

Paper Number 4

Plant nutrition management for better farmer livelihood, food security and environment*

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Summary

Pakistan's economy largely depends on agriculture, employing 42 percent of the total workforce. Agriculture serves as a major supplier of raw materials to the industry as well as market for the industrial products. It also contributes substantially to Pakistan's export earning. However, skewed distribution of landholdings not only adversely affected the access of the rural poor to basic production resources, but also cropping intensity and consequently farm productivity. In terms of fertilizer use, the nitrogen (N) consumption in Pakistan has increased more rapidly, than phosphate (P_2O_5) and potash (K_2O) fertilizers during last 40 years, which promoted nutrient imbalance and soil quality deterioration. Despite a very large production base, the country is not able to meet its entire fertilizer requirement, thus the need for importation. Among other strategies, the efficient, balanced and optimum use of chemical fertilizers along with organic and biosources will play a vital role to achieve crop production targets for food security and improving livelihood of small farmers.

1. Introduction

Agriculture is the dominant sector of the economy and accounts for 23 percent to the Gross Domestic Product (GDP) of the country. It employs 42 percent of the total workforce. Agriculture serves as a major supplier of raw materials to the industry as well as market for the industrial products. It also contributes substantially to Pakistan's export earning. Almost 67.5 percent of country's population are living in rural areas and are directly or indirectly linked with agriculture for their livelihood. Agriculture sector has grown at an average rate of 4.5 percent per annum during the decade of the 1990s (GOP, Eco. Survey, 2005). However, in the first two years of the new millennium (2000-2002). Pakistan witnessed crippling drought which seriously affected agriculture lands and productivity. As a result, the overall agricultural growth turned negative for these two years but recovered gradually during the next two years (2002-2004) and witnessed a modest recovery.

A strong performance of agriculture has been one of the hallmarks of the fiscal year (FY) 2004-05, with growth reaching as high as 7.5 percent on account of unprecedented increase in cotton production (14.6 million bales) and a near bumper wheat crop of the size 21.1 million tonnes. Major

* This country report has not been formally edited and the designations and terminology used are those of the author.

crops account for 37.1 percent of agricultural value added, minor crops 12 percent and livestock 46.8 percent.

Greater reliance is placed in achieving higher per unit production within a water constrained environment. Another dimension to the whole scenario of agriculture performance is the climatic change that to a great extent will determine the type, magnitude and productivity of Pakistan's agriculture. The economics and technical feasibility of high input-output agriculture will come to test when all these emerging trends are taken into account simultaneously. Besides availability of water, the other factors hampering growth of sector are low productivity, inefficient use of water, degradation of land resources, ineffective transfer of technology and inefficient and unbalanced use of fertilizers.

The current population of the country is about 153 million, increasing at 1.87 percent per annum. At this trend total population will reach 167 million by year 2011 and 194 million by 2020 (NIPS, 2005). Thus the main objectives of agriculture in the medium term development framework (MTDF, 2005-2010) is to achieve self-reliance in agriculture commodities, ensure food security and maintain average annual growth rate of 5.2 percent per annum. Among other strategies, the efficient, balanced and optimum use of chemical fertilizers along with organic and biosources will play a vital role to achieve crop production targets for food security and improving livelihood of small farmers.

2. Small farmers' livelihood in Pakistan

Despite all developmental efforts, Pakistan is facing many difficult challenges. One third of the population still lives below the poverty line. The literacy rate is about 54 percent, access to quality education is limited, income and regional inequalities are widespread, skill shortages are taking a toll in the economy's productivity including agriculture. Based on the last Pakistan Integrated Household Economic Survey (PIHES) 2000-2001, the official poverty line is estimated at Rs.748 consumption expenditure per month per capita. Poverty estimates based on official poverty line suggest that the poor accounted for 32.1 percent of Pakistan's population in 2000-2001. Poverty estimates show a higher incidence of poverty in Pakistan's rural areas. In 2000-2001, rural and urban poverty is estimated at 38.99 percent and 22.67 percent, respectively. The Government of Pakistan has set a target for reducing the poverty up to 21 percent by 2009-2010 and 13 percent by the end of 2015. (Pakistan Millennium Development Goals 2005, Government of Pakistan).

Among all poor communities in Pakistan, the farmers and particularly small farmers are at worst in their livelihood. They are deprived of most of the basic facilities. The reasons for miserability of small farmers are having less land holding and consequently low income, in spite of getting the higher productivity.

The most serious inequities at present exist in the rural areas mainly because of the pattern of land ownership. Despite three land reforms (in 1959, 1972 and 1977), the land distribution in Pakistan is much skewed. The skewed distribution of landholdings has not only adversely affected the access of the rural poor to basic production resources, but also cropping intensity and consequently farm productivity. Farms less than 5 hectare in size account for about 85.7 percent of farmers' owned only 43.4 percent of the total farm area. On the other hand, large farmers of more than 10 hectare comprised only 5.5 percent of all farmers account for 37.5 percent of the total farm area (Table 1).

This basic inequity in land holdings is clearly reflected in the differences in their respective economic and social positions as in the case in other economic sectors. The larger landowners have more access to water, credit, fertilizer and other resources.

Table 1. Land distribution by farm size

Size of Farm in hectare	% of total No. of Farms	% of total Farm Area	% of Farm Area cultivated
<2	57.6	15.5	93
2-<5	28.1	27.9	89
Sub-total	**85.7**	**43.4**	
5-<10	8.8	19.1	83
Sub-total	**8.8**	**19.1**	
10-<20	3.9	16.3	78
20-<60	1.4	13.0	67
>60	0.2	8.2	52
Sub-total	**5.5**	**37.5**	
Total	**100**	**100**	

Source: Pakistan Agriculture Census 2000.

In contrast to this situation, when input use, particularly fertilizers and aggregate productivity at national level is viewed with respect to farm size, an inverse relationship is quite evident. Fertilizer use adoption by farm size is higher in small farmers in comparison to large farmers. It was found that small farms' aggregate productivity in term of gross output value per cultivated hectare was higher (Fertilizer Use Survey at Farm Level in Pakistan, NFDC – March 2000).

Despite high use of inputs and better productivity the small farmers have little surplus to market and farm income not sufficient to sustain livelihood. There is need to diversify and tap other sources of income other than crop sector such as livestock, etc. Most of the small farmers are unable to use the facility of concessional credit because of cumbersome procedures for transacting a bank loan. Even within the small farmer category there is a case for improving the condition of the poorest of the poor.

3. Soil fertility status

The cultivated soils are calcareous and alkaline with pH 7.0 to 8.5. The data generated by public and private sector research organizations in the country reflect the general agreement about the deficiency of nitrogen (N) in all the soils. In case of phosphorus (P) more than 90 percent soils have inadequate soil phosphorus or can be called deficient. In case of potassium, the picture is not as clear as in case of N and P. The reports state the deficiency of potassium (K) exist up to 40 percent in soils, but crop responses to K are erratic and potash use is negligible. Among micronutrients, field-scale deficiencies of economic significance prevail in case of Zn, B, and Fe. The organic matter content of the majority of cultivated lands averages around 0.5 percent. About 84 percent soil samples analysed have shown that organic matter content is very low (Ahmed and Rashid, 2003).

4. Fertility supply

4.1 Domestic production

There are 14 fertilizer plants in the country. Of these, 8 are Urea plants, 2 of single superphosphate (SSP) and one each of Calcium Ammonium Nitrate (CAN), Nitrophos (NP), Diammonium Phosphate (DAP) and NPK. The present fertilizer production capacity and actual production is given in Table 2. Urea plants have performed well, producing 110.6 percent of capacity during 2004-05.

Table 2. Existing fertilizer capacity and actual production ('000 tonnes)

Products	Plate capacity	Production		% capacity utilization of plants 2004-05
		2003-04	2004-05	
Urea	4 170	4 435	4 611	110.6
Calcium Ammonium Nitrate (CAN)	450	350	330	73.7
Diammonium Phosphate (DAP)	450	268	408	90.7
Nitrophos (NP)	305	363	339	111.1
Single superphosphate (SSP)	180	168	164	91.1
NPK's (various grades)	100	89	139	139.0
Total	**5 655**	**5 673**	**5 991**	**105.9**

4.2 Imports

Despite a very large production base, the country is not able to meet its entire fertilizer requirement. Annual import of fertilizer products is around 1 352 thousand tonnes (Table 2). All fertilizer was imported by private sector except Urea. Imports in 2004-2005 are higher by 10.9 percent due to additional import of Urea.

Table 3. Fertilizer imports ('000 tonnes)

Products	2003-04	2004-05	% change over 2003-04
Urea	–	307	–
DAP/MAP	1 125	912	-18.9
SOP/MOP	11	29	163.6
NP + AS	31	51	64.5
TSP	52	53	1.9
Total	**1 219**	**1 352**	**10.9**

5. Fertilizer consumption

The nitrogen (N) consumption in Pakistan has increased more rapidly, than phosphate (P_2O_5) and potash (K_2O) fertilizers during last 40 years (Figure 1). This fast increase in nitrogen can be attributed to a variety of economic and technical factors. Urea which is the main source of nitrogen was cheaper, locally available and provides rapid crop response. Comparatively, phosphate and potash fertilizers were imported and expensive. This promoted imbalance use.

It is also important to look at the fertilizer products, through which the nutrients are supplied (Table 4). Total consumption (here the off take is used as an indicator for consumption) has increased rapidly over a relatively short period from 3.4 million tonnes in 1985/1986 to more than 7.0 million tonnes in 2004/05. Urea is the most important nitrogenous fertilizer (46 percent N) with a fast growing trend, reaching 5.1 million tonnes (product) consumption in 2004/2005 followed by DAP.

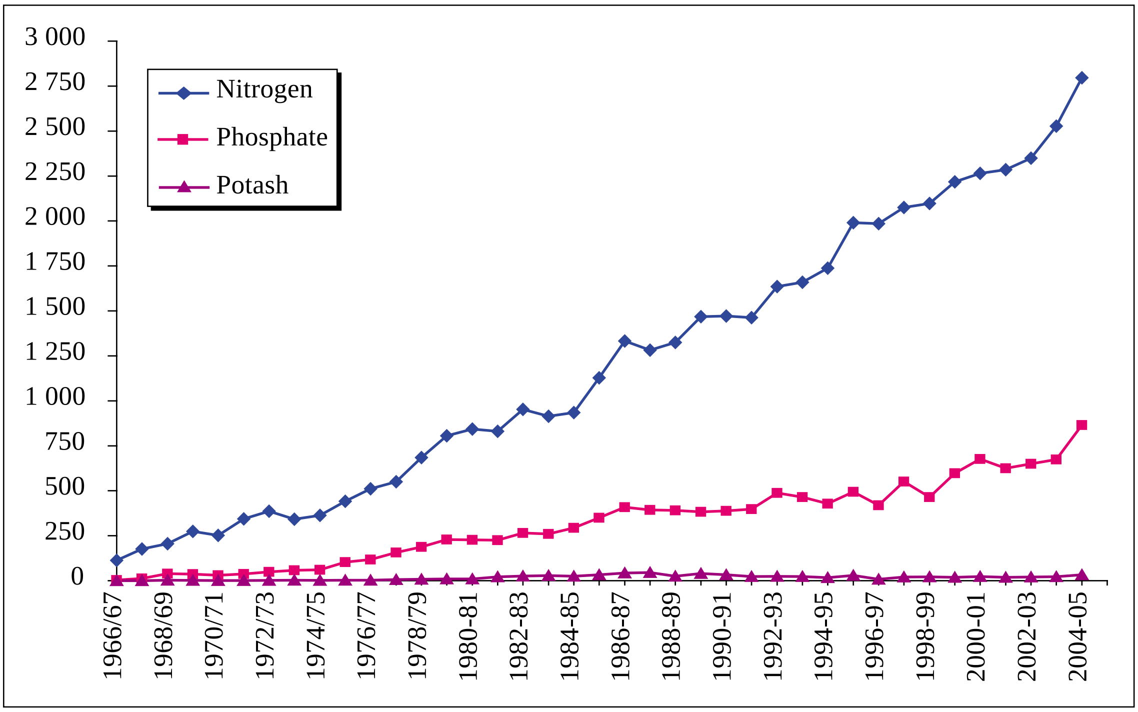


Figure 1. Total fertilizer nutrient consumption in Pakistan

Table 4. Fertilizer off take (equals consumption) by products in '000 tonnes

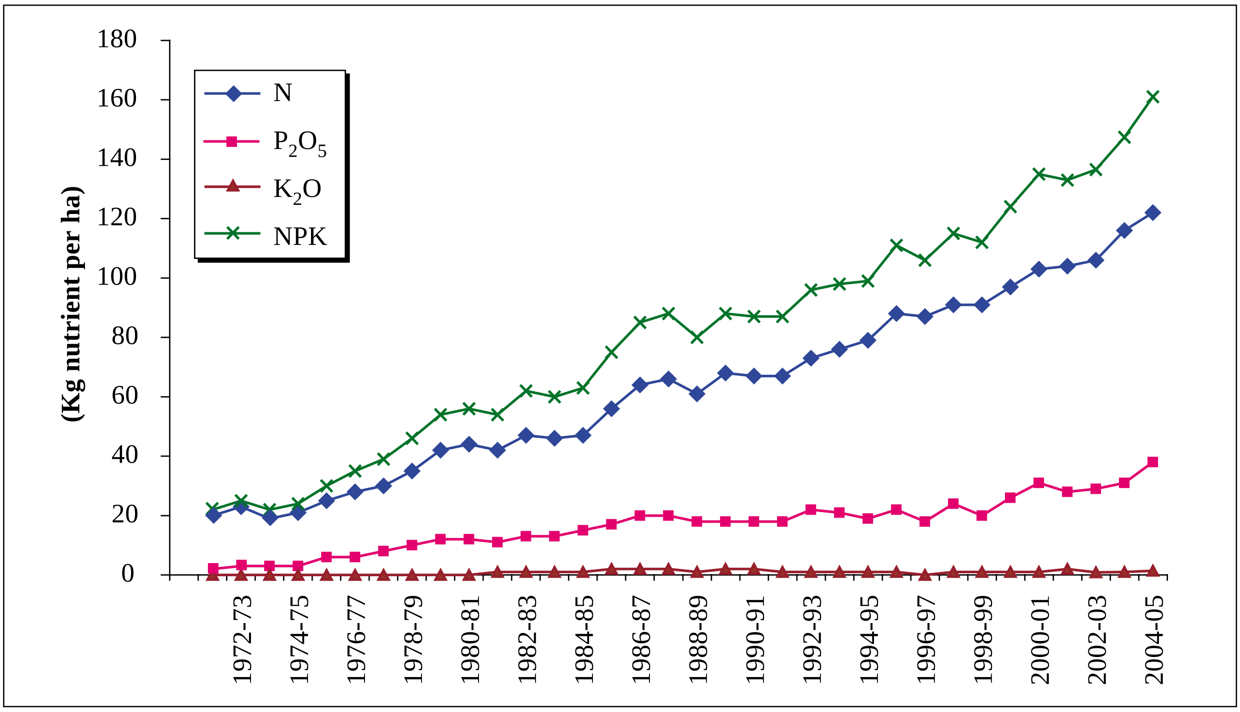
	1984-85	**1994-95**	**2004-05**
UREA	1 429	3 152	5 120
CAN	72	304	330
AS	106	84	1
SSP	375	207	161
DAP	366	673	1 377
NP	35	301	354
TSP	44	22	91
SOP + MOP	44	27	25
NPKs	14	14	129
Total	**2 485**	**4 783**	**7 589**

Source: NFDC, 2005.

5.1 Consumption per hectare of cropped area

The application of plant nutrients per hectare of cropped land gives an indication of the intensification of agricultural production. Increase in arable land has been very marginal due to the natural limitations and conditions. Increase in agricultural production had to be achieved through higher yields per hectare. One of the underlying factors was steady increase from a level of about 20 kg/ha in early 1970's to 161 kg/ha in 2004-2005. The increase in total application can be attributed largely to nitrogen, and to a lesser degree of phosphates (Figure 2).

The development in fertilizer consumption can be seen as a success. But what has been of concern is the fact that only the consumption of N has increased, leaving the use of other nutrients at a very low level. Since crops take the necessary nutrients mainly from soil resources, a depletion of these



Source: NFDC, 2004/05.

Figure 2. Application rate in kg per ha nutrients

reserves could be termed as soil mining. In the long run, a decrease in soil fertility with additional negative effects on the environment is to be expected. Table 5 indicates the extent of stagnation in imbalance which has stayed over the past years. Balanced crop nutrition requires the proper supply of N, P and K plus other nutrients such as sulphur and micronutrients (Zn, B, Fe), as determined by soil analysis.

The fertilizer consumption has grown at compound rate of 4.2 percent per annum, whereas growth in major crops was less than 2 percent. The N:P_2O_5 ratio did not change during the past 20 years. The application of potash was negligible.

Table 5. Fertilizer use and crop yields

Year	Fertilizer use (kg/ha)	N:P ratio	Crop Yields kg/ha			
			Wheat	Rice	Cotton	Sugarcane
1985/86	75	3.2	1 881	1 567	515	35 700
1990/91	87	3.8	1 841	1 546	615	40 700
1995/96	111	4.0	2 018	1 835	601	47 000
2000/01	134	3.3	2 325	2 021	624	45 400
2004/05	161	3.2	2 540	1 995	769	48 000
Growth %	**4.2**		**1.59**	**1.28**	**2.13**	**1.57**

Source: NFDC, 2004/05.

5.2 Impacts of balanced fertilizer use

Balanced fertilizer use is a key for efficiency and crop productivity. The comparison of yield for major crops obtained from current farmer's practices of fertilizer use and with balanced mix is given in Table 6.

Table 6. Crop yield comparison with current farmers' practices of fertilizer use vs obtained with balanced recommended level (kg/ha)

Sr. No.	Crop	Yield farmer's practices Av. of 3 years	Yield obtained with balanced fertilizer level		% Yield obtained
			Trials	Yield	
1	Wheat Irrigated	2 536	99	4 043	60
2	Wheat Rainfed	1 027	24	2 631	39
3	Rice IRRI	2 625	11	4 946	53
4	Rice (fine)	1 611	25	3 837	42
5	Cotton	1 773	25	2 400	74
6	Sugarcane	48 366	5	101 125	48
7	Maize	1 876	12	4 656	40

Source: Joint trials of FAO/NFDC/IMPHOS/Provinces.

Thus, the present yield obtained by farmers is about 40-70 percent of that which can be obtained with recommended rates and balance use. It is, therefore, important to correct the balance.

6. Fertilizer demand

The quantum of fertilizer growth will depend upon water availability, and any increase in area and commodity prices received by farmers. In the next five years Urea imports may reach 1.4 million tonnes if no new capacity is added and DAP imports will be 1.6 million tonnes (Table 7). The proposal for BMR in the existing Urea plants and new investment is under consideration subject to availability of gas. However, it appears Urea and DAP imports will continue in the next 3-4 years.

Table 7. Future demand forecast ('000 tonnes)

Year	Urea			DAP/MAP		
	Supply/ production	Demand	Deficit or imports	Supply/ production	Demand	Deficit or imports
2004-05 (Actual)	4 797	5 120	-323	760	1 485	-725
2005-06	4 600	5 299	-699	450	1 589	-1 139
2006-07	4 600	5 485	-885	450	1 700	-1 250
2007-08	4 600	5 649	-1 049	450	1 819	-1 369
2008-09	4 600	5 819	-1 219	450	1 947	-1 497
2009-10	4 600	5 993	-1 393	450	2 083	-1 633
Growth %		3.2			7.0	

Note: Supply contains domestic production + inventory of last year.

i) Urea production capacity is 4 170 thousand tonnes but producing about 4 600 thousand tonnes annually due to around the year availability of gas.

ii) BMRE of FFBL 264 thousand tonnes expected in 2007.

iii) New Plant of Fatima and BMRE of Pak Arab is expected in 2009.

iv) Engro has also plan for new plant.

7. Soil nutrient balance and flow analysis

A nutrient balance sheet gives the net changes in the crop environment over a given period: a season, a year, or longer. It is constructed by placing together all the additions to the crop environment and all the removals from that environment in the period studied. A comparison of additions and removals gives the nutrients balance. If the balance is positive it indicates that the crops produced, together with other removals are not depleting the soil. However, an excessive positive balance may represent over-fertilization, a waste of nutrients.

Negative balance means that the nutrients provided from all sources are not sufficient to support crop (and other) nutrient removal and therefore usually represent a drain on the soil. Repeated negative balances lead to real soil depletion to the point where crop yields decline. In such situation, restoration of soil fertility is indeed difficult.

Crops remove quantities of all nutrients, including the secondary and micronutrients, but additions often do not supply the whole range. In Pakistan, the two principal fertilizers Urea and DAP do not provide appreciable quantities of any nutrients other than N and P_2O_5. Farmyard Manure (FYM) contributes all nutrients to some extent. The green manure and biological sources only introduces N from external sources (air); all else comes from the soil. The balance sheet works out on these assumption: (FAO, 1996).

Additions to soil	**Removals from soil**
Fertilizers	Crop nutrient content exported
FYM	Volatilization
BNF by legumes	Denitrification
Nutrient in irrigation water	Leaching
Rain and thunderstorms	Fixation of Phosphate
Air	Water erosion
Dust	
Flood waters	
Flood silt	

The present report considers fertilizer application to be reflected in off take data. FYM data are estimates based on limited livestock surveys, estimated FYM proportion (25 percent) recovered for manure (and not fuel or lost), dung and urine production. BNF has been calculated from measured N fixation by pulses, and the figure doubled to account for berseem clover, for which no N fixation data were found.

Irrigation water is an important aspect of crop nutrition in Pakistan, as it is actually a dilute solution of cations and anions. The K contribution in normal irrigation is substantial, overestimates of K supply, particularly when groundwater is major source.

Crop production figures were used to calculate nutrient removals in Pakistan. This is because all crop residues are normally used for animal feed, fuel, house roofing and other purposes. The set of conventional uptake efficiency percentages used in the calculations are set out below (FAO, 1998):

Normal (lower or "B")			**Higher (upper or "A")**		
N	P_2O_5	K_2O	N	P_2O_5	K_2O
40	20	65	60	30	85

Based on these assumptions at national level there is negative balance of about 18 kg N, 25 kg P_2O_5 and 50 kg K_2O per ha. However, if data are further disaggregated there is positive balance of N in cotton zone. However, trend shows that depleting of soil is continuing despite improvement in fertilizer use.

8. Integrated Plant Nutrient Management (IPNM) concept

The basic concept underlying the principle of Integrated Plant Nutrient Management (IPNM) is the maintenance and possibly increase of soil fertility for sustaining increased crop productivity through optimizing of all possible sources, organic and inorganic, of plant nutrients required for crop growth and quality in an integrated manner appropriate to each cropping systems and farming situation within its ecological social and economic possibilities (FAO, 1995; Tandon and Roy, 2004).

Integrated Plant Nutrition System is a conceptual approach and is imbedded on a philosophy of social, economical, environmental and technological considerations, while Integrated Plant Nutrient Management (IPNM) is actually the technical and managerial aspects of achieving the objectives of IPNS under farm situation. Soil fertility improvement following the IPNS approaches will:

- Raise soil productivity and food production, and will ensure food security at local level;
- Enhance resilience of the land to erosion and degradation;
- Enhance soil and agrobiodiversity;
- Enhance soil capacity to sequestrate carbon and mitigate the effect of climate change; and
- Ensure prosperity and healthy environment for the future generation. (Roy, 2000)

9. Components and technology

Agricultural research contributes towards component and technologies governing principle of crop production and of plant nutrition. Field research fills gaps and generates knowledge which is translated into extension messages and disseminated to farmers. The main components of integrated plant nutrient management are (i) soil (ii) balance and efficient use of mineral fertilizers (iii) organic fertilizer sources (iv) green manures (v) biofertilizers, and (vi) industrial waste and city garbage. These are briefly discussed in the follow up sections with their relevance to Pakistan conditions.

9.1 Soil resources

Soil supplies all the known essential plant nutrients. However, due to crop intensification and cultivation of soils over the years there is continuous mining of the essential plant nutrients from the soil. Most of the soils in Pakistan have poor status of available plant nutrients and can not supply optimum level for crop productivity. Soil fertility is depleting due to mining of essential plant nutrients. However, through good tilth and physical condition of soil, the nutrient availability can be improved.

9.2 Chemical fertilizers

Balance and adequate use of chemical fertilizers is very important component of technology. It has been discussed in detail in Section 5.0.

9.3 Farmyard Manure (FYM)

FYM consists of materials collected from animal droppings, beddings, and domestic sweep. The value of animal manures has been recognized since ancient times. Based on number of animals, the

Table 8. Livestock population, production of manure, and nutrient potential of manure in Pakistan

Animal	No. of animals (million heads)	Droppings (million tonnes per year)	Urine	Manure moisture (av. %)	Total dry matter (million tonnes per year)	Total N per year ('000 t)	Total P_2O_5 per year ('000 t)	Total K_2O per year ('000 t)
Cattle	23.77	208.3	103.6	79	43.7	1 159	477	1 242
Buffalo	26.15	267.0	134.2	79	56.1	1 492	611	1 600
Goat	59.15	33.1	21.5	65	11.6	595	204	512
Sheep	24.46	17.7	9.3	65	6.2	252	80	217
Poultry	357.18	8.1	0.0	54	3.7	120	68	31
Others	4.84	21.0	6.0	60	8.4	143	47	149
Total	**495.55**	**555.2**	**274.6**		**129.7**	**3 761**	**1 213**	**3 049**

Sources: (i) Livestock Census, 1996. (Figures modified/estimated for 2005). (ii) Hussain. 1996.

estimated contribution is shown in Table 8. However, it may be stated that about 50 percent of animal dropping is not collected. Of the collected about 50 percent is used as fuel. Thus, nutrients recycled to crops are about 1/4th of the total droppings.

9.4 Green manures

Green manuring with N-fixing leguminous crops improves soil fertility (Buresh *et al*., 1993) and enhances availability of other nutrients (Hundal *et al*., 1988; Nagarajah *et al*; 1989). The prominent cropping systems in Pakistan are:

i) Rice-wheat

ii) Cotton-wheat

iii) Mixed cropping (sugarcane-maize-wheat-cotton)

iv) Oilseed-pulses-wheat

The three cropping systems i) rice-wheat, ii) cotton-wheat and iii) mixed cropping are very exhaustive. The cropping intensity is over 150 percent. The use of only nitrogenous and phosphatic fertilizers is causing potash, sulphur and micronutrient deficiencies restricting the yield potential. The sandwiching of green manuring crops in these tight cropping patterns is considered not only an excellent source of nitrogen, but the intervention improves physical condition of soil and availability of other nutrients. The studies have shown that the contribution of green manure legumes was quite high at low level of nitrogen application through fertilizers and dropped with increase in rates (RRI, 1998; Mian *et al*., 1988 and Bhatti *et al*., 1985). The studies of pre-rice green manuring of three years showed a significant impact on yield of next wheat crop and reducing its N requirements. The studies further concluded that green manure production technology along with zero tillage (Conservation Agronomy) can benefit the exhaustive rice-wheat cropping system through N fertilizer saving and increase in grain yields (Mann, 2000, Zia *et al*., undated). Major green manure crops are dhaincha/jantar (*Sesbania aculeatea*) and guar (*Cyamopsis tetragonolaba*). However, trials on sun hemp (*Crotalaria juncea*) and tropical jantar (*Sesbania rostrata*) have also been conducted. The nitrogen contribution from all these sources have been quantified from 70 to 100 kg/ha (Hussain, 1996). In wheat-cotton system, there is generally no time for green manure except to try relay cropping. The farmers are also not prepared to sacrifice main crop.

9.5 Crop residues

A huge quantity of crop residues such as wheat straw, cotton sticks, sugarcane trash/tops and rice husk, etc., are available. But due to some economic compulsions such as need for animal fodder and fuel, the crop residues are partially recycled in the soil, or burned to clear field for next crop otherwise these may contribute in improving organic matter in the soil and thus keep it productive. Kallar grass is recognized as a salt tolerant grass capable of producing a good amount of biomass on degraded soils in summer.

9.6 Filter cake and stillage

Pakistan sugar industry is producing about 1 million tonnes of filter cake every year, which is a rich source of organic matter, micro and macronutrients. Some sugar mills have molasses-based distillery plants, which produce stillage that contains nutrients especially potassium. The major portion of filter cake is sold to the brick baking industry and stillage is drained out thus causing loss of plant nutrients and environmental pollution. If all these materials are recycled by composting back to soil, it will provide essential plant nutrients for crop growth.

9.7 Sewage sludge, city garbage, industrial wastewater etc.

Sewage sludge, city garbage, industrial wastewater and effluents are also good source of plant nutrients. However, these materials require proper treatment to remove the toxic heavy metals before application to crops. It is estimated that the urban areas of Pakistan generate about 55 thousand tonnes of solid waste daily or about 20 million tonnes per annum (GOPa, 2005). However, this solid waste is not being properly managed and recycled for different useful purposes including pre-treatment and composting for crop nutrition. Sewage water is partially used for raising vegetables near the urban areas without any pre-treatment. If adequate treatment of above waste materials is managed before their application, they will not only supplement the chemical fertilizers but the chance of environmental pollution will also be minimized.

9.8 Biofertilizers

A broad term used for products (carrier or liquid based) containing living or dormant microorganisms like bacteria, fungi, actinomycetes, algae alone or in combination which on application help in fixing atmospheric nitrogen or solubilise/mobilize soil nutrients in addition to secretion of growth promoting substances for enhancing crop growth. ‘Bio’ means living and ‘fertilizer’ means a product which provide nutrients in usable form. Biofertilizers are also known as bio-inoculants or microbial cultures. Biofertilizers can be broadly classified into four categories.

- Nitrogen fixing biofertilizers: (Thizobium, Azotobacter, Azospirillum, Acetobacter BGA, Azolla)
- Phosphorus solubilising/mobilising biofertilizers (PSB or PSM): (P-solubilising e.g. Bacillus Pseudomonas, Aspergillus etc. P-mobiliser e.g. VA-mycorrhiza).
- Composting accelerators (i) Cellulolytic (Trichoderma), (ii) Lignolytic (Humicola). Plant growth promoting rhizobacteria: (Species of Pseudomonas).

The Pakistan Agriculture Research Council (PARC), National Institute of Biotechnology and Genetic Engineering (NIBGE) and Provincial Agricultural Research Institutes are carrying out work on biological fertilization. All these institutions are isolating strains of rhizospheric bacteria, which have potential for mobilizing atmospheric N, both on legumes and non-legumes. In greenhouse, field and laboratory studies, effective microorganisms, in combination with NPK, green manure and FYM, have been shown to give yield responses of 18.3 percent in rice and 39 percent in wheat. Significant responses have also been reported in maize, peas and potatoes. NARC in collaboration with Engro Chemical Pakistan Limited (ECPL) commercialized rhizobium specific for chickpea in the name of Biozot. One packet of 500 gms was sold at Rs.50 to farmers. The project continued for three years (1996 to 1998) covering an area of one thousand acre each year. On the average, yield improvement of 25-40 percent was recorded (personal communication with Biological Section). However, it could not sustain.

At NIBGE, isolates were tested for their ability to produce indole acetic acid (IAA) in the rhizosphere and it was found that certain *Pseudomonas* spp. were most active. IAA, like 2:4D, can produce nodule-like excrescence on wheat roots and has been shown to mobilize atmospheric N thereby. Thus the prospects of providing partial N nutrition of wheat by inoculation of soil with isolates of *Pseudomonas* appear promising (Malik, *et al*., 1993). NIBGE based on its facilities including different capacity fermenters has already marketed its bio-fertilizer for rice under the name biopower. This product has been used over 10 000 acres of rice growing areas, and response of farmers has been excellent (Malik, K.A., 1997). Rashid *et al*., 1998 at Ayub Agricultural Research Institute reported that diazotroph bacterial inoculum increased wheat yield from 0 to 35 percent with low to high nitrogen application.

NIBGE has also been carrying out experimentation with *Azolla* for rice nutrition. An earlier problem, that *Azolla* would not survive the summer temperatures of Pakistan, has been overcome and there are now several heat-tolerant strains available. *Azolla* has been combined with N fertilizer and rice rhizospheric diazotrophic bacteria in field trials, from which it was found that an *Azolla* cover with 30 kg/ha N gave maximum rice yield, although biological nitrogen fixation (BNF) assisted in providing N to the rice plants.

At PARC, another important biological fertilization study is being conducted on microorganisms, which solubilize soil P. It has been found that strains of *Aspergillus niger* and *Penicillium* spp. have some solubilizing properties, not only in soil but also of P from rock phosphate.

At University of Agriculture, Faisalabad, Effective Microorganisms (EM) technology is being advocated, where claim has been made that this co-existing culture of five major types of beneficial microorganism has the potential to increase nutrient availability in the soil and thus crop productivity. However, many scientists have expressed their reservations about the product due to bio-safety concerns and lack of scientific evidence.

10. Limitations in the adoption of IPNM

10.1 Package of technology

Technology has not been developed to suit different farms and farming systems. There is need of commitment at research extension and national level for bottom up participatory approach and leadership. More allocation of resources is required to develop state of art technology.

10.2 Low availability of FYM

Amount of FYM available for use in the field is low and insufficient for meeting the requirements of crops. Farmers lack proper knowledge about the preparation of FYM and composting. Most used as fuel. Alternate sources of energy are to be made available to farmers.

10.3 Limitations in use of green manuring

- Small size of holdings;
- High demand for fodder;
- Lack of proper knowledge about green manuring and legumes; and
- Lack of organized research

10.4 Limitation in use of crop residues

- The price of straw and stalks is very high and the farmers are not willing to leave crop residues on the soil surface or incorporate into the soil as they fetch a good income from straw and stalks;
- Farmers dry crop residues and feed their cattle during winter when there is a shortage of fodder;
- Farmers use crop residues as fuel energy source as they do not have access to other sources of energy;
- Crop residues are used as a construction material in mud houses or cattle sheds.

10.5 Limitation in use of biofertilizers

- Application techniques and efficiency of strain
- Packing the product in marketable form
- Shelf life
- Specified minimum population of concerned microbes
- Good quality

11. Conclusion

Integrated Plant Nutrient Management (IPNM) through balanced use of mineral fertilizers, combined with organics and biosources may usher into new era for sustainable crop production to achieve food security, improving livelihood of small farmers and poverty reduction. The combined use of all these sources can lead to new green revolution. However, the national research institutions, universities, agriculture extension, private sector and government at policy level, all have to play their relevant role for technology development, its transfer and adoption at farm level in different ecological regions. The future approach will be to shift from increased use of fertilizer towards optimizing integrated management of all sources to address issues of low productivity, efficiency, soil nutrient depletion and environmental concerns. Government of Pakistan in Medium Term Development Framework (MTDF/2005-10) has emphasized the importance of IPNM in fertilizer use and crop production strategies. It will get due attention at policy level.

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South Asian Country

Paper Number 5

Improvement of plant nutrient management for better farmer livelihood, food security and environment in Sri Lanka*

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Summary

Sri Lanka is an agricultural country with diverse agro-climate and land resources. Agricultural soils are laterites which are generally acidic, low in organic matter and would require sound phosphorous management. Aside from low per capita land availability, soil fertility generally limits crop production and would require considerable attention and support. However, fertilizers necessary for improving yields of food crops are imported. The total quantity of fertilizer imported in 2002 was 568 072 mt. About 59 percent of this importation is Urea and the rest are divided into other fertilizers such as sulphate of ammonia, triplesuperphosphate and muriate of potash. Nutrient use imbalance and the general decline in soil fertility in Sri Langka is primarily policy-induced. The national government adopted a subsidy scheme for Urea, which inadvertently resulted in increased Urea consumption and the evident reduction in the use of P and K fertilizers. To alleviate to situation, the national government has taken steps to locally produce phosphate fertilizers using local rock phosphate (eppawala rock phosphate). In addition, recently, to help farmers in adopting the rational use of Urea and general balance use of available organic and inorganic fertilizers the Ministry of Agriculture and the Department of Agriculture developed a national policy for the promotion of Integrated Plant Nutrition System (IPNS) and its adoption by the farmers in Sri Lanka.

1. Introduction

Sri Lanka is an island which is situated in the Indian Ocean and lies between latitude 5°55' and 9°50'N and longitude 79°42' and 81°53'E. The total land area of the island is 65 610 sq km. Population is estimated to be 20 million with an annual growth rate of 1.2 percent. The contribution to the gross domestic product (GDP) by agriculture is estimated to be 18.6 percent and employment in the agriculture sector is 37.7 percent. Contribution to the GDP in the agriculture sector by rice is 13.8 percent and other food crops 33.8 percent. Sri Lanka is divided into three major zones on the basis of annual rainfall viz. wet (>2 000 mm), intermediate (1 000-2 000 mm) and dry (<1 000 mm) zones. The wet and intermediate zones are further categorized into low, mid and up-country regions based on elevation. The low country is situated at elevation between 0 and 300 m above mean sea level (MSL), while midcountry is considered as the area between 300 m and 900 m elevation. The up-country region is the area above 900 m elevation. Sri Lanka is generally described in terms of its terrain as comprising of a central highland mass surrounded by undulating to flat plans. It can be observed that about one third of the country is made up of hilly, mountainous or steep terrain.

* This country report has not been formally edited and the designations and terminology used are those of the author.

Three major agro-climatic regions, wet, intermediate and dry zone, are further sub divided into 24 agro-ecological regions. According to the modern scheme of climatic zonation the wet zone of Sri Lanka falls within the humid tropics and the dry zone within the seasonally dry tropics. A small section in the northwest and southeast of the island falls within the semi-arid tropics. Four basic types of rainfall, namely, monsoon, convectional, cyclonic and orographic, are identified in the country (Panabokke, 1996). There are two main cropping seasons namely "maha" (northeast monsoon) – wet season from September to February and "yala" (southwest monsoon) – dry season from March to August. Due to availability of water, the "maha" is considered as the major cropping season.

The main annual rainfall in Sri Lanka various from 2 500 to over 5 000 mm in the southwest of the island, while in the northwest and southeast an annual rainfall is less than 1 250 mm. Rainfall over most parts of the country follows a bimodal, seasonal pattern for the year. The minimum and maximum air temperature various from 10 to 20^oC in the Up-country Wet Zone (UCWZ) from 25 to 32^oC in Low Country Dry Zone (LCDZ). The regional differences in temperature are mainly due to attitude with the temperature falling about 1^oC for every 150 m rise in elevation.

2. Soils

The major soil types in Sri Lanka are Lateritic soils, the Red Earths, and the Alluviums. They cover 90 percent of Sri Lanka. The rest consisting saline soils and peat, are limited occurrence. Thirteen great soil groups have been identified in Sri Lanka namely Rhodustalfs, Tropaqualfs, Haplustalf, Haplustox, Tropaquents, Natraqualfs, Ustipsamments, Quartzipsammets, Pellusterts, Eutropepts, Rhodudults, Tropudults and Tropohemists (Panabokke, 1996).

3. Food production

3.1 Rice

Rice has been cultivated in Sri Lanka for well over 2 000 years. Sri Lanka has 0.734 million ha of rice lands (AgStat, 2004) of which 0.46 million ha (55 percent) are in the Low Country Dry Zone (LCDZ), 0.13 million ha (20 percent) in the low country intermediate zone (LCIZ), 9.14 million ha (25 percent) in the low country wet zone (LCWZ) and about 4.5 thousand ha are situated in up-country and midcountry areas. Rice cultivation accounts for a little more than 40 percent of the cultivated area. Presently, Sri Lanka produces 3.1 million tonnes of rough rice and national average yield of 3.8 t/ha^{-1}(CBSL, 2004). Domestic annual rice requirement in the year 2000 was 3.11 million tonnes and it is estimated to be 3.46 million tonnes in the year 2010 (Abeysiriwardena and Sandanayake, 2000). Rice is grown in diverse soil and environmental conditions in throughout the country. Rice is grown in almost all the grate soil groups and soil series found in Sri Lanka.

3.2 Vegetables

Approximately 60 000 ha of land is used for vegetable cultivation in Sri Lanka. (Maraikar *et al.*, 1996). Vegetable crops grown in Sri Lanka could be divided into two major groups, the local vegetables and the low country vegetables. Popular low country vegetables are okra (*Abelmoschus esculentus)*, eggplant (*Solanum melongena)*, luffa (*Luffa acutangula)*, snake gourds (*Trichosanthes cucumetina),* bitter gourds (*Momodica charantia),* cucumber (*Cucumis sativus)*, pumpkin (*Cucurbita maxima)*, and leafy vegetables, while, the exotic or up-country vegetables are bean (*Phaseolus vulgaris),* carrot (*Daucus carota)*, beetroot (*Beta vulgaris)*, cabbage (*Brassica olerccea)*, leek (*Allium ampeloprasum*), and radish (*Raphanus sativus)*. Low country vegetables are grown throughout the country with the exception of hill country areas, while up-country or exotic vegetables are mainly grown in the Up-country Wet Zone (UCWZ) and UCIZ. In general, vegetable cultivation is intensive and highly commercialized when compared to rice and other field crops (OFC) in Sri Lanka.

3.3 Root and tuber crops

Important root and tuber crops are potato (*Solanum tuberosium*), sweet potato (*Ipomaaea batatas*) and cassava (*Manioc esculentus*). In general, potato is mainly grown in the UCIZ and UCWZ. Sweet potato, cassava and other root and tuber crops are grown in many parts of the country with the exception of the UCWZ. The extent of root and tuber crops grown in Sri Lanka is over 50 000 ha (AgStat, 2004).

3.4 Other Field Crops (OFC)

OFC, which include annuals of coarse grains, grain legumes, condiments and oil crops are grown in the dry zone. In general, the majority of OFC is cultivated under rainfed conditions. The extent of OFC grown in Sri Lanka is over 115 000 ha (AgStat, 2004).

4. Current status of fertilizer use

Significant use of high analysis chemical fertilizers for food crops in Sri Lanka started in early 1950, but widespread use of chemical fertilizer for food crops commenced in the year 1960. In order to promote balanced use of plant nutrients, fertilizer mixtures containing N, P and K nutrients had been recommended during early stages. However, the Department of Agriculture (DOA) changed its policy in 1990 by recommending straight fertilizers instead of fertilizer mixtures for food crops grown in Sri Lanka. This policy decision was taken in order to provide an opportunity for farmers to make necessary adjustments in fertilizer application for optimum yield. However, the use of fertilizer mixtures containing N, P and K is more popular than straight fertilizers. This may be due to convenience in fertilizer use and lack of available straight fertilizers in the local market. The cost of fertilizer has increased tremendously over the last few decades and is still increasing. This situation has created financial difficulties particularly for small farmers. Fertilizer consumption by different crop sectors is presented in Table 1.

Table 1. Fertilizer consumption by crop sectors (mt)

Crop	1998	1999	2000	2001	2002
Paddy	251 880	321 032	262 362	284 488	356 174
Tea	182 339	164 139	200 254	182 033	185 059
Rubber	15 684	9 936	13 801	9 129	6 924
Coconut	37 667	39 161	33 942	29 531	38 452
OFC	44 182	42 617	40 467	34 320	42 035
EAC*	11 317	9 637	8 704	8 711	8 321
Tobacco	3 768	3 666	3 204	2 525	2 577
Others	14 515	26 147	29 797	28 770	30 675
Total	**561 352**	**616 335**	**529 531**	**579 507**	**670 217**

* EAC – refers to spices and beverage crops.

Source: NFS, 2002.

5. Types of plant nutrient used

5.1 Nitrogen fertilizers

At present, Urea is the most dominant form of nitrogen fertilizer used in Sri Lanka. It accounts almost 59 percent of the total fertilizers used in the country (NFS, 2002). In 1990, the DOA changed its policy of recommending sulphate of ammonia and switched to Urea fertilizers. Annually, almost 350 000 mt of Urea are imported and used either as a straight fertilizer or in mixed form. The introduction of heavy subsidy scheme for Urea by the government caused the tremendous increase in the demand for the said nitrogen fertilizer.

Sulphate of ammonia is considerably the second major nitrogen fertilizer used. However, sulphate of ammonia is only presently used for selected crops, and for the preparation of fertilizer mixtures found in the market. Annual imports of different fertilizers and their percentage share are given in Table 2.

Table 2. Annual fertilizer imports and their percentage share (mt)

Fertilizer	2001		2002	
	Quantity	Share	Quantity	Share
Sulphate of ammonia	71 214	16.04	75 136	13.24
Urea	258 785	58.27	337 906	59.48
Imported rock phosphate	12 250	2.76	11 778	2.07
Triplesuperphosphate	14 557	3.28	40 495	7.13
Muriate of potash	74 737	16.83	95 156	16.75
NPK-5:15:15	6 600	1.49	–	–
Kieserite	4 411	0.93	5 402	0.95
Sul-Po-Mag	800	0.18	200	0.04
Commercial epsom salt	405	0.00	538	0.09
Zinc sulphate	305	0.07	599	0.11
Sulphate of potash	195	0.04	214	0.04
Diammonium phosphate	154	0.03	648	0.11
Total	**444 112**	**100.00**	**568 072**	**100.00**

Source: NFS, 2002.

5.2 Potassium fertilizers

Muriate of Potash (MOP) could be the second most dominant fertilizer used in the country. The annual importation is estimated to be at the level of over 95 000 mt. As a whole, paddy field sector uses almost 36 percent of imported MOP, while oher field crops use about 8 percent and vegetable and other crops use about 37 percent. (NFS, 2002). Another minor source of potash, Sulphate of Potash (SOP) is used in limited scale for chloride sensitive crops.

5.3 Phosphorus fertilizers

Triplesuperphosphate (TSP) is the most dominant phosphorus fertilizer used for short-duration crops such as rice, vegetables and other crops. Almost 41 000 tonnes of TSP are imported into the country annually, 80 percent of which are utilized for paddy cultivation. The balance is used mainly for vegetables, OFC and fruit crops, except in wet zone areas of Sri Lanka. Phosphorus is the most limiting plant nutrient in Sri Lankan soils. Notably, application of TSP has shown beneficial effects for crop growth and for subsequent high yields (Wijewardena, 1994). Local rock phosphate named eppawala rock phosphate is mainly being used for fruit crops grown in the wet zone of Sri Lanka. However, a number of research studies conducted in relation to eppawala rock phosphate revealed that it cannot match the P-supplying ability of TSP for annual crops, and its direct application as a source of P fertilizer for food crops will not be beneficial (Wijewardena, and Amarasiri, 1990; Wijewardena, 1998).

5.4 Compound fertilizers

The most popular compound fertilizers used in Sri Lanka are granular NPK with trace elements. One of the most important compound fertilizers used was NPK of the formulation 5:15:15 supplied under the Japanese Food Production Grant for paddy cultivation particularly in the wet zone of the country. This formulation of compound fertilizer was very popular among paddy farmers especially in the Low Country Wet Zone (LCWZ) where annual rainfall is over 2 500 mm. Various types of compound fertilizers with different formulations are also available in the local market despite the absence of large imports of NPK compound fertilizer.

5.5 Magnesium fertilizers

Most popular magnesium fertilizer is dolomite which is available locally as calcium magnesium limestone. Dolomite is often used as a soil ameliorant for acid soils. It is mainly used for potato, vegetables and other horticultural crops. However, kieserite is also imported in limited quantities mainly for horticultural crops. Similarly, epsom salt is used to correct widespread magnesium deficiencies in fruits, vegetables and OFC.

5.6 Zinc sulphate

The Department of Agriculture in 2001 recommended application of zinc sulphate for rice grown in dry and intermediate zones. In addition, zinc deficiency is a common problem in fruit cultivation particularly of citrus. As a result, almost 600 mt of zinc sulphate was imported in 2002 to Sri Lanka.

5.7 Special fertilizers

Special fertilizers used in Sri Lanka are NPK formulations with trace elements, micronutrient, mixtures for hydrophonics, fertigation mixtures and fertilizer with growth promoting substances (Table 3). These fertilizers are used for vegetables, floriculture crops and other horticultural crops. Most of these fertilizers are comparatively high value fertilizers imported in small quantities.

Table 3. Imports of special fertilizer in the year 2002

Fertilizer	Liquid (liters)	Quantity granules (mt)	Powder (mt)
NPK	2 296	179.5	21.0
NPK + TE	8 910	636.5	7.9
TE	6 001	47.1	18.9
Fertigation mixture	–	–	11.5
Hydro phonic mixture	–	–	12.0

TE = Trace Element

Source: NFS, 2002.

5.8 Liquid fertilizers

There are more than hundreds of types of liquid fertilizer that are available in the market. They are either organic fertilizers or fertilizers containing both organic and chemical fertilizer. Even though the DOA has not recommended liquid fertilizers, some farmers are using them for crops such as vegetables, onion, potatoes, floricultural crops, etc. By application of foliar fertilizers, farmers expect to obtain attractive product, which can fetch high prices in the market rather than get their yield increased.

6. Trends in plant nutrient use

Some economic factors play an important role in determining the quantity of chemical fertilizers used by farmers vis-à-vis yield response to added fertilizer, farm gate price of produce, price of fertilizer, etc. Prior to 1966, use of low analysis fertilizer was a common feature for rice. Rock phosphate or bone meal and sulphate of ammonia were the sources of phosphorus and nitrogen, respectively. However, during the period of 1967 to 1978 Urea became the major source of nitrogen. Similarly, TSP replaced rock phosphate. The period from 1979 to 1989 indicates a high rate of growth in fertilizer use for paddy. Introduction of high fertilizer responsive varieties and the enhanced area under irrigation are some factors that contributed to this growth. A setback in 1996 was observed due to the price shock after the removal of fertilizer subsidy. It took almost 3-4 years to recover from this setback. Use of sulphate of ammonia was recommenced during the period 1990-1994 due to transport restrictions on Urea to north and to the east because of security reasons. However, in 1990 the DOA changed its policy of recommending fertilizer mixtures for food crops and switched to straight fertilizers due to increased flexibility in terms of adjusting amounts of nutrients to suit the crop and soil. Still, a large number of fertilizer mixtures continue to be marketed in Sri Lanka. Most farmers prefer the mixtures, probably because they are less cumbersome to use, although they can be more costly than straight fertilizers per unit of nutrient. In general, for the past several years, the use Urea fertilizer maintained an increasing trend.

6.1 Rice

Paddy consumes the largest part of chemical fertilizers. It accounts for approximately 50 percent of the overall use of chemicals fertilizers in Sri Lanka (Table 1). The main fertilizers used for paddy cultivation are Urea, TSP and MOP. Though many farmers in dry and intermediate zones use recommended level of chemical fertilizers, farmers in wet zone use chemical fertilizers less than the recommended level. These facts indicate that overall fertilizer use is below the recommended level. This may be due to using less or no basal fertilizer for paddy cultivation by the farmers growing paddy in marginal lands and in cultivation under rainfed conditions. The cost of cultivation of paddy in Sri Lanka is increasing from season to season. As a result, use of balanced NPK for rice has been decreased. In addition to NPK fertilizers, the DOA has recommended once-a-year application of zinc sulphate at the rate of 5 kg $ZnSO_4$/ha for rice cultivation. Popularization of straight fertilizer and promotion of Integrated Plant Nutrition System (IPNS) in paddy cultivation have been conducted by the DOA in recent past. It has been observed that there is a slow, but a steady growth in straight fertilizer use for paddy during the last few years. However, paddy fertilizer mixture such as 'V' mixture (5:15:15) and TDM (30:0:20) were also in wide use by rice farmers. Paddy production depends on several factors and imbalances in fertilizer usage need to be investigated for future improvements, as there had been a set back in the NPK ratios in the fertilizer application of paddy. In this regard, production increase programme conducted by the DOA namely "Yaya" demonstrations programme, had contributed positively to enhance higher productivity in paddy cultivation.

6.2 Vegetables

Vegetables have become an important component in almost every cropping system. Of the reasons for widespread cultivation of vegetables, the most important is that net returns from vegetable production are higher than returns from rice and most other field crops. Unlike the general pattern of low fertilizer used in paddy and OFC farmers, most vegetable farmers use high quantities of chemical as well as organic fertilizers. The level of fertilizer applied by the farmers to the vegetables crops is almost two to three times the quantity recommended by the DOA (Wijewardena, 2001). This may be due to favourable crop price relationship for vegetable crops. As a result, net returns from vegetable cultivation are much higher than in rice and OFC, making chemical fertilizer a relatively inexpensive input. Various types of liquid fertilizers are also used regularly as foliar fertilizers.

6.3 Other field crops

Since OFC are mainly grown under rainfed conditions, areas under these crops may vary season to season. The area under OFC covered approximately 76 000 ha in rainy season – Maha (northeast monsoon) followed by 30 000 ha in dry season – Yala (southwest monsoon). In general, fertilizer use for OFC crops could be considered as little or no fertilizer application at all. It indicates that OFC crops mainly depend on soil nutrients rather than on fertilizers. However, for cash crops such as onion and chili, high rates of fertilizers are used. Overuse of chemical fertilizers for onion has been reported in some areas, such as in Kalpitiya.

6.4 Fruit crops

Nutrient management can be considered as one of the most neglected aspects for the majority of fruit crops grown in Sri Lanka. In addition, nutrient management recommendations for the majority of fruits are not based on proper research conducted in the country. Hence, due attention should be given to nutrient management practices in relation to fruit crops. Except few commercial growers, most small-scale farmers rarely use chemical fertilizers for many fruit crops. In general, fertilizer prices currently prevailing in Sri Lanka are not affordable to marginal fruit growers. Even most commercial growers use various types of fertilizer mixtures available in the market such as coconut, paddy and vegetable fertilizer mixtures. However, after establishment of the Horticultural Crop Research and Development Institute in Sri Lanka, research studies have been initiated to solve such problems in the fruit crop sector.

7. Future trends

Price factor of fertilizer is major constraint in promoting chemical fertilizers in Sri Lanka, particularly for food crops such as rice and OFC. As a result, production and use of local fertilizers is a strong future possibility. In view of high price of triple superphosphate there is a necessity for utilization of local eppawala rock phosphate (ERP) for food crops. In this regard, steps have been taken to produce single superphosphate (SSP) locally using ERP.

8. Types of fertilizer produced locally

Sri Lanka depends on imports of chemical fertilizer to meet the requirement. In the year 2002, almost 92 percent of the total supply of chemical fertilizer, except for eppawala rock phosphate (ERP) and Dolomite, was made available through imports. Rock phosphate deposit at eppawala was discovered in 1971. Its tonnage has been estimated as 40-60 million mt of apatite rock. There are two forms of rock phosphate fertilizers being produced in Sri Lanka, namely ERP and high grade eppawala rock phosphate (HERP). HERP, could be considered as an improvement, which is processed by crushing pure apatite only. At present, annual production of ERP is 41 000 mt (Table 4), while HERP is almost 6 000 mt (Lanka Phosphate Ltd., 2005 Unpubl.). Though Sri Lanka imported high citric acid soluble rock phosphate, a few years ago after introduction of HERP, substitution of imported rock phosphate (IRP) with HERP was done. As a result, rock phosphate fertilizers are not presently being imported to the country. With the increased demand for plantation crops and also with enhanced promotional efforts, the local supply of ERP had reached the highest level achieved so far. Eppawala rock phosphate is used for perennial crops, such as tea, rubber, coconut, fruit crops etc.

Table 4. Annual production and issues of local rock phosphate (mt)

Operation	2000	2001	2002	2003
Production	35 085	35 769	37 664	41 351
Issues	35 805	35 441	38 412	40 170

Experiments have been conducted during the past three decades to find out the suitability of ERP for annual crops (Nagarajah *et al.*,1979; Wijewardena and Amarasiri, 1990; Wijewardena, 1998). Removal of phosphate by annual crops like potato and vegetables are high as they generate a high biomass within a short period of time. In addition, the shallow root system found in these plants requires soluble types of P fertilizers. As a result, direct application of rock phosphate sources are not suitable for annual crops due to their low solubility in soil solution. However, partial acidulated rock Phosphate (Wijewardena and Yapa, 1998), mixtures TSP and rock phosphate combinations, combined application of rock phosphate and organic manure showed beneficial effects for all annual crops including rice, potato and vegetables. The Lanka Phosphate Limited (LPL) has produced limited quantity of single superphosphate (SSP) from ERP, which contain more soluble P than ERP. At present, experiments are in progress to study the suitability of SSP as a source of P for annual crops such as rice, vegetable and OFC.

Dolomite is mined and crushed by private firms in the Central Province of Sri Lanka. The estimated use of dolomite as a fertilizer or soil ameliorant has arisen to about 20 000 mt. It is regularly used as a liming material for tea, fruit crops, vegetables and potatoes.

9. Cost of fertilizer products

Urea is subsidized in Sri Lanka. However, the local price of all other fertilizers including TSP, MOP and sulphate of ammonia was determined by the open market forces. The competition among the number of wholesalers also assisted in keeping the open market price competitive. The demand for Urea, owing to its subsidized price, was maintained at a reasonably high level. The price of other fertilizers increased in the local market due to increase of oil prices in the world market. In general, however, price of Urea in Sri Lanka continues to be increased. The retail price of major fertilizer in selected ESCAP countries during the year 2002 indicated that comparative price of fertilizer appear to be high in Sri Lanka (NFS, 2002). Retail prices of fertilizers are presented in the Table 5. This table indicates that among commonly used fertilizers in Sri Lanka, TSP is the most expensive in the local market followed by MOP and Urea.

Table 5. Average retail prices of important fertilizers (US$/mt)

Fertilizer	6th July 2000	12th Feb. 2001	18th July 2001	15th July 2002	10th Oct. 2002
Urea	70	70	70	70	110
Sulphate of ammonia	106	106	136	136	156
Triplesuperphosphate	192	192	172	210	210
Muriate of potash	165	165	186	199	199
Local rock phosphate	41	41	45	36	56

Source: NFS, 2002.

10. Fertilizer subsidies

The subsidy scheme for fertilizer was initiated more than a decade ago. However, since 1997, only Urea was subsidized in Sri Lanka. At present, subsidy for Urea is approximately US$230 per mt. As a result, an increasing trend in use of nitrogen fertilizer was observed. In addition, a gradual and substantial reduction in use of P and K fertilizer is evident. This implies a deterioration of NPK ratios in recent years. The international market price of Urea also increased during the year 2004. Application of the US dollar against the local currency, removal of national security levy on fertilizer and introduction of value added tax (10 percent) contributed to increase in Rupee expenditure on Urea. In keeping with the fluctuation in the international market price of Urea, reasonable import prices and the corresponding rates were fixed for implementation of the subsidy. At present, there is a substantial increase in the quantity imported under the subsidy scheme due to enhanced demand for fertilizer. However, fertilizer subsidy is a very strong political issue in Sri Lanka.

Recently elected government in Sri Lanka has decided to revise the subsidy scheme and implement a fixed subsidy for all three fertilizers such as Urea, TSP and MOP. Under this proposal, a 50 kg bag of any fertilizer will be US$3.5. This new scheme will be implemented with effect from 5 December 2005. According to this new scheme, subsidy will be given only for straight fertilizers. Estimated cost for proposed subsidy will be US$0.12 billion per year. However, the new proposal is targeted to small farmers in the country.

11. Depletion of soil organic matter

Soils in Sri Lanka are low in organic matter (Panabokke and Nagarajah, 1964; Wijewardena, 1995; Wickramasinghe and Wijewardena, 2003). Long-term experiments conducted over eight (8) seasons with rice (J.D.H. Wijewardena, 2001 Unpubl.), potato and vegetables (Wijewardena, 1993; Wijewardena and Yapa, 1999) showed that there was no increase of organic matter in soil by application of organic manure 4 and 10 t/ha per crop, respectively. Research shows that the majority of soils in main rice growing areas are low in organic matter (Table 6). As a result, many soils found in Sri Lanka are low in CEC. Cation exchange capacity levels in majority soils are lower than 10 cmo1/kg (Panabokke, 1966). Under such conditions, retention of plant nutrients is low. In general, organic manures are useful in conserving soil fertility. As a result, seasonal application of available organic manure sources showed beneficial effects of crop growth as well as overall soil fertility (Wijewardena 1993; 2000). Hence, a policy decision was taken by the Ministry of Agriculture and the Department of Agriculture in 1999 to promote IPNS technology among farmers in Sri Lanka. This technology showed economical benefits as well as soil fertility improvement in relation to various food crops grown in Sri Lanka (Wijewardena and Yapa 1999; Dissanayake, 2000).

National average yields of paddy and several other food crops have been stagnating over the last decade (Wickramasinghe and Wijewardena, 2003) requiring a new approach on how to increase at

Table 6. Soil organic matter content (percent) in major rice growing districts

District	1964*	1984**	2000***	
	Organic matter content (%)		Organic matter content (%)	
			<1%	1-3%
			No. of sites	
Ampara	0.69-1.72	1.4	45	25
Anuradhapura	0.86-2.58	1.4	3	87
Polonnaruwa	0.86-2.58	1.9	20	75
Kurunegala	0.68-1.72	1.9	89	9
Hambantota	0.72-3.87	2.5	34	49
Badulla	2.59-6.45	2.0	26	40

* Panabokke, 1964; ** Rezania, 1984; *** Soil Testing Programme of the DOA, 2000.

(Adopted from: Wickramasinghe and Wijewardena, 2003)

the national yield levels. Reasons for such problem may be due to declining of organic matter content, imbalance of major plant nutrients, and inadequacy of various micronutrients in most of the cultivated lands in Sri Lanka. As a result, these factors have adversely affected the overall soil fertility in cultivated lands in Sri Lanka. Soil organic matter content is one of the key parameters which influence the soil fertility and productivity. However, it should be noted that increase of organic matter in soils is a difficult task due to prevailing high temperature in many parts of the country. In this regard, the seasonal applications of organic materials are necessary. Rice straw, animal manure, green manure, city wastes, crop wastes, etc. could be used as sources of organic manure to maintain the organic matter content in soil. There was an indication that in all the zones, except in the low country wet zone (LCWZ), highest rice production occurs on soils with an organic matter content of around 2 percent. However, at the LCWZ, soils with an organic matter content of 4-6 percent gave better crop response (Dissanayake *et al., 1*993). In addition, high content of organic matter was recorded in wet season (Maha) than in dry season (Rezania *et al.*, 1992). However, a slight increase in soil organic matter content was evident with more intensive cropping of potato and vegetable cultivation in the up-country areas of Sri Lanka where low temperatures are prevailing due to high elevation.

12. Decline of plant nutrients

Agricultural lands diminish in crop production potential or suitability for crop production through various types of land degradation in Sri Lanka (Nayakekorale, 1998). Being an agricultural country, Sri Lanka has to place much attention on soil degradation problem in consideration of the low per capita land availability at present. The directly available land for human use was estimated at 0.15 ha/person (Madduma Bandara, 2000). Soil fertility decline in Sri Lanka is mainly due to depletion of soil organic matter as well as loss of plant nutrients etc. Soil analytical studies conducted in various parts of the country revealed that low plant nutrient content is a major threat to crop production in Sri Lanka (Wijewardena, 1995; Nayakekorale and Prasantha, 1996). The depletion of soil nutrient due to leaching and run off could be considered as major course of fertility decline. Thus, many agricultural farming systems are becoming non-profitable to farmers.

Rice growing soils in Sri Lanka have very low content of P in available form (Tables 7 and 8). In general, P-fixing capacity of majority of soils is also high. Phosphorus deficiency in rice soils of the midcountry has been previously reported by Panabokke and Nagarajah (1964) and Maraikar *et al.*, (1983). Similarly, low available P in rice soils of the LCWZ (Wijewardena, *et al.*, 1998) has been

Table 7. Uncultivated and cultivated soil characteristics in the up-country

Characteristic	Uncultivated soil	Cultivated soil
pH (1:2.5; Soil: H_2O)	4.0-5.5	4.5-6.0
OM (%)	1-2	2-4
Total N (%)	0.1-0.15	0.2-0.3
Olsen P (mg/kg)	2-10	20-400
Exchangeable K (meq/100 g soil)	0.1-0.2	0.2-0.5

Source: Wijewardena, 1995.

Table 8. Range of available P in rice, vegetable and fruit growing soils of the LCWZ

Rice*		Vegetables**		Fruits***	
Soil P (mg/kg)	No of sites (%)	Soil P (mg/kg)	No of sites (%)	Soil P (mg/kg)	No of sites (%)
<5	33	<10	43	<5	41
5-10	36	10-20	30	5-10	28
10-20	26	20-30	3	10-20	17
>20	5	>30	24	>20	14

Source: * Wijewardena *et al.*, 1998; ** Wijewardena *et al.*, 1999a; *** Wijewardena *et al.*, 1999b.

reported. Critical level of available soil P in the soils of the LCDZ and LCIZ is about 3-5 mg/kg, while it is around 10-15 mg/kg in soils of midcountry wet zone (MCWZ) and MCWZ, to achieve a yield response to added P. Rice farmers apply low quantities of P due to high cost of TPS in Sri Lanka. Soil analysis conducted in different areas show that 63-80 percent soils are low available P (Olsen P) except in some soils which grow potato and vegetables in rotation with rice (Wijewardena,1999) in the up-country intermediate zone (UCIZ).

Similarly, low available P in upland soils is also common in Sri Lanka: in soils of the UCWZ (Kumaragamage *et al.*, 1999), UCIZ (Wijewardena, 1995; Wijewardena, 1996), and UCWZ (Wijewardena *et al.*, 1999). High P-fixing capacity in up-country vegetable growing soils has been reported by Withana and Kumaragamage (1993). A study conducted with 70 soil samples by Wijewardena *et al.* (1999) reported that majority of soils collected from vegetable growing soils in the LCWZ had available P below 20 mg/kg (73 percent sites), which is considered as the low content of P according to the criteria set by the DOA in 1995. Similarly, Kumaragamage *et al.* (1999) also reported the low P availability in soils of the LCWZ.

However, build up of P could be seen in many intensive vegetable growing soils in Sri Lanka. This condition is caused by indiscriminate use of organic and chemical fertilizers. Build up of phosphorus in some potato and exotic vegetable growing soils in the up-country area particularly in UCWZ and UCIZ has been reported (Jeewananthan *et al*., 1995; Wijewardena, *et al.*, 1996; Wijewardena, 1999). Similarly, occurrence of high available P due to use of high rates of deep litter as well as chemical fertilizers was observed in leafy vegetable growing soils in the LCWZ. Soil analysis revealed that available P (Olsen's) in these soils is as high as 2 500 mg/kg (J.D.H. Wijewardena, 2004 Unpubl.).

Field crops in Sri Lanka are traditionally cultivated in the dry and semi dry areas. Field crops on rainfed uplands receive inadequate fertilizer phosphorus and as a result, soils are relatively low in available P. However, crops such as chilli and onion on irrigated uplands receive excessive fertilizer P, thus, soils become generally high in available P.

In Sri Lanka, most fruit crops are grown in home gardens under rainfed conditions. As a result, use of fertilizer for fruit crops is limited. Hence, fruit growing soils in Sri Lanka are low in phosphorus (Wijewardena *et al.*, 1996; J.D.H. Wijewardena, 2003 Unpubl.).

All rice growing soils have different K supplying capacity. According to Panabokke and Nagarajah (1964), K status in rice growing soil was in a range of 39-59 mg/kg. The exchangeable K content of rice growing soils in the LCWZ ranges between 27-94 mg/kg. In addition, coarse textured soils found in the LCDZ also contain the lower exchangeable K content at 47 mg/kg. In some cases, K in these soils has been reported to be as low as 12-24 mg/kg (Weerasinghe, 1991). Almost 50 percent of the rice growing soils in the LCWZ have exchangeable K content of less than 58 mg/kg, which is considered as the critical soil K level for mineral or alluvial soils (Rezania, 1992). It has been also observed that there is a declining trend in these soils when rice is grown continuously. According to Wijewardena, *et al.*, (1998), 48 percent of soils in the LCWZ contain exchangeable K below 78 mg/kg of soil, while remaining soils contain more than 78 mg/kg of exchangeable K.

In the UCIZ, a total of 150 soil samples collected in 57 fields revealed exchangeable K values exceeding 300 mg/kg in soils fertilized for potato and vegetable crops for few decades (Wijewardena, 1999). Since P is also high in these soils, the DOA has recommended only N for rice grown in this region. Similarly, high K contents in rice-vegetable cropping systems were also reported in the MCIZ (Joseph *et al.*, 1988).

A study conducted by Wijewardena *et al.*, (1999) reported low exchangeable K even in vegetable and tuber crops growing soils in the LCWZ. They showed that based on soil K standards introduced by the DOA (1997), 83 percent sites had a low soil K. Hence, application of K fertilizers is necessary to improve soil fertility in the LCWZ vegetable and tuber crops growing soils to obtain high crop yields in the LCWZ. Similarly, low exchangeable K in soils of the LCWZ was also reported by Kumaragamage *et al*., (1999). Soils found in LCDZ and LCIZ are containing reasonable amount of exchangeable K. However it should be noted that K in LCDZ are higher than in LCIZ (Wijewardena, 2002).

Soils found in Kalpitiya peninsula were used to cultivate vegetable, chili etc. Though soils are poor in soil fertility, chemical fertilizers are used extensively for crops grown in this region. As a result, build up of some plant nutrient could be seen in these soils. However, exchangeable K content in these soils is low. This could be expected due to the sandy nature of soils found in this area.

Investigations conducted (Joseph *et al*., 1988) in midcountry area revealed that accumulation of K could be seen in cultivated soils. Farmers use high rates of both organic and chemical fertilizers for vegetables and chemical fertilizers for vegetable crops grown in this region.

In both UCWZ and UCIZ, vegetable and tuber crops cultivation is intensive and highly commercialized. In the UCWZ, vegetables are cultivated throughout the year in rotation with potato. In the UCIZ, vegetables are grown under upland rainfed, irrigated and lowland rice-based cropping systems. Due to the hilly nature and high rainfall in this region, soils are rather poor in plant nutrient contents. As a result, inherent soil fertility in Ultisoils (Kumaragamage *et al.*, 1999) is very low. However, Ultisoils in the up-country contain reasonable quantity of K in exchangeable form (Wijewardena 1995a). In addition, most farmers in the up-country utilize inorganic fertilizer mixtures in combination with large amount of organic manures with particular emphasis on the use of poultry litter and cattle manure. Wijewardena (1995) compared the characteristic of uncultivated and cultivated soils in the up-country of Sri Lanka (Table 7). A total of 290 soil samples analysed by Wijewardena *et al*., (1996) reported that 44 percent of soil samples had K up to 160 mg/kg, 50 percent of soil samples had K between 160-400 mg/kg and only 6 percent soil samples had K more than 400 mg/kg. A sampling programme conducted after rice crop included 68 fields for a total of 161 soil samples taken at depths of 0-15 and 15-30 cm respectively in the rice based cropping system in the UCIZ showed the available K in excess of exchangeable K of 156 mg/kg in 71 percent of the fields and relatively high K content even in the subsoil of 15-30 cm depth (Wijewardena, 1999).

13. Micronutrients

Rice growing soils particularly in dry and intermediate zones are deficient in Zn and Cu (Bandara and Silva, 2000a; 2000b). In addition, poorly drained rice growing soils of midcountry wet zone of Sri Lanka are also deficient in zinc (Nagarajah, *et al.*, 1983). Significant response to Zn addition was observed in dry and intermediate zones. Zinc application improved the grain yield of rice from 10-15 percent (Bandara and Silva, 2001). Hence, Zn was recommended by the DOA for rice cultivation at the rate of 2.5 kg Zn/ha as $ZnSO_4$. $7H_2O$. Study conducted by Deb *et al*. (1993) reported that majority of rice growing soils are also deficient in micronutrients such as Zn, Mn, Cu. Similarly, they reported toxicity levels of Fe in paddy soils in the LCWZ. In general, 30 000 ha of cultivated rice lands in the LCWZ considered as having a potentially iron toxic condition (Bandara and Gunathilaka, 1997). This problem may be associated with excess soluble iron, low pH, low soil fertility, poor drainage etc. (Ponnamperuma, 1958). Some chemical characteristics of iron toxic rice growing soils are shown in Table 9. Application of balance chemical fertilizers, particularly K fertilizer in combination with organic manures, is a very important soil management practice. Application of liming materials such as dolomite, lime and deep litter has shown effective measures of minimizing iron toxicity in rice cultivation (J.D.H. Wijewardena, 2004 Unpubl.).

Table 9. Some chemical properties of rice growing soils in the LCWZ

Property	Range	Average	SD
pH (1:2.5; Soil: H_2O)	4.2-5.1	4.5	0.24
EC (dS/m)	0.019-0.042	0.028	0.0067
OM (%)	2.8-7.9	4.9	1.3
Exchangeable K (mg/kg)	15.5-65.7	31.2	12.4
Olsen P (mg/kg)	4.8-18.3	9.7	3.54
NH_4OAc Exchangeable Fe (mg/kg)	377-923	626	130

Source: J.D.H. Wijewardena, S.P. Gunaratna and S. Weerasinghe, 2004 Unpubl.

Studies on micronutrients are rather limited in Sri Lanka. However, an investigation conducted by Wijewardena and Kannangara (2003) reported that majority of vegetable growing soils of LCWZ contain adequate amounts of Zn (>0.6 mg/kg), Mn (3.5 mg/kg) and Fe (2.5 mg), but soils were deficient in Cu (<0.2 mg/kg).

In addition, citrus growing soils in the Uva region are deficient in available Zn, Fe and Cu contents (Wijewardena, 2004). As a result, application of Zn, Fe and Cu fertilizers and organic manures could be considered as important crop and soil fertility management practices to obtain high yields of citrus growing soils in Sri Lanka. Zinc and boron deficiency in citrus and papaya, respectively, is a widespread occurrence in fruit crops grown in Sri Lanka. A soil analytical programme conducted with 120 soil samples collected from major citrus growing region of Sri Lanka revealed that citrus growing soils are deficient in micronutrients such as Zn, Cu, Fe, and Mn. (Wijewardena, 2004). Similarly, fruit growing soils in the LCWZ are deficient in Cu (Wijewardena *et al.*, 2001).

14. Organic fertilizer use in Sri Lanka

Since ancient times, manuring has been considered as one of the most important techniques to increase and maintain soil fertility. Soil organic matter plays an important role in soil fertility. Rice straw could be considered as a very valuable organic fertilizer material for rice grown in Sri Lanka. Since, many rice soils in Sri Lanka are low in soil fertility it should be noted that straw can be successfully used to improve the long-term soil fertility in many parts of the country. However, a large number of farmers burn the straw at the threshing site especially when there is no alternative way of disposal. Majority of Sri Lankan farmers are fully unaware of the value of rice straw as a fertilizer material and a large quantity of rice straw is wasted. Despite the recommendation from DOA, there is still low acceptance by farmers to apply rice straw as a source of organic manure. Some of the reasons for this are the following: cost and inconvenience of transporting the bulky material to the field, unavailability of simple and inexpensive methods to apply straw to the fields in the manner which does not hinder land preparation without causing adverse effects on the rice crop.

In general, rice straw is a valuable source of carbon, potassium, silicon, etc. It is also a convenient source of organic manure in Sri Lanka, aside from being considerably the cheapest. Rice straw thereby could be considered as a very important organic fertilizer material for rice grown in Sri Lanka (Dissanayake 2000). Long-term field experiments conducted at the LCWZ revealed that straw application in combination with NPK can increase the yield of rice as well as over all soil fertility (J.D.H. Wijewardena, 2000 Unpubl.). Hence, rice straw should be applied in combination with recommended chemical fertilizers. In order to get maximum benefits, the straw must be incorporated into the soil by 2-3 weeks before the land preparation or 3-4 weeks before planting of rice.

On the other hand, the use of animal wastes for rice cultivation is very limited. Unlike for cash crops, the costs of transportation of animal manure are too high to permit their application in rice cultivation. These considerations suggest that organic manure should be generated in the field itself or in its near vicinity if the practice is to be accepted by farmers. In addition, sources of animal manure are expensive due to high demand by vegetable and potato growers in the country. As a result, rice farmers are not in a position to purchase organic fertilizers such as deep litter, cattle manure, goat dung.

Alternatively, green manures have been added to rice fields for many years. Field experiments have shown that chemical fertilizer can be reduced by addition of green manure. However, use of green manure in rice cultivation is not widespread primarily due to limited availability of suitable plant materials. Often it is applied to nursery area or to parts boarding the high lands. Experiments with *Gliricidia maculata* and *Tithonia diversifolia* showed that 9 t/ha of these green manure in combination with 59 kg/ha NPK fertilizer gave rice yields more than the recommended NPK levels (Nagarajah, 1999). In addition, 4 seasons long-term experiment with *Tithonia diversifolia*, showed that the amount of NPK fertilizer added to rice can be substantially reduced. Studies on the use of *Sesbania sesban* and *S. rostrata* as *in situ* green manures for lowland rice showed that both species can supply up to 50 percent of the recommended N fertilizer.

It is a common practice to apply organic sources, such as cattle manure and poultry manure, when growing vegetable and potato throughout the country. The up-country is considered as the region where main potato and vegetable growing area of the country. Potato and vegetable cultivation in the up-country is intensive and highly commercialized. A unique feature observed in the up-country of Sri Lanka in potato and vegetable cultivation is the use of animal manure such as cattle and poultry manure. Poultry manure, which has to be transported over a long distance, approximately 200-250 km from west and Northwestern part of the country, is commonly used as a fertilizer at the rate of 10-15 t/ha per crop (Wijewardena 1993; Wijewardena, 1995). Cattle manure is used as a fertilizer at the rate of 20-30 t/ha per crop (Maraikar *et al.*, 1996). In the up-country, it could be considered more as farmyard manure rather than pure cattle manure because it contains large quantities of grass, straw and leftovers of bedding materials. However, farmers in the up-country prefer to use farmyard manure than pure cattle manure. Cultivation of potato and vegetables has never included the application of cattle or poultry manure.

In vegetable cultivation, sunken beds are prepared and filed with cattle manure and covered with layer of soil. Then, farmers apply chemical fertilizer mixtures, mixed with soil and irrigated 1-2 days before planting. In the case of potato, cattle manure or poultry manure is spread along the furrows and are covered with a layer of soil. Here, too, chemical fertilizer mixtures are applied and irrigated 1-2 days before planting potato tubers.

It is very important to note that farmers in the up-country apply poultry manure 3-4 days prior to planting vegetable and crops and irrigate for 2-3 days if rains are not experienced within this period. By this practice, farmers avoid the harmful effects of poultry manure on their crops at the initial stage. In addition, farmers apply chemical fertilizer mixtures containing N, P and K or straight fertilizers 1-2 days prior to planting and mix with previously applied poultry manure. After irrigating for 1 or 2 days, poultry manure is mixed with chemical fertilizers before planting the crop. During the growing season, farmers top-dress their crops with NPK mixtures or TDM or Urea.

15. Use of foliar fertilizers

Potato and vegetable growers, particularly in the up-country, apply different kinds of foliar fertilizers during the growing period at 6-7 days intervals at a high rate of 12 l/year/ha (Rezania *et al.*, 1989). In general, foliar fertilizer is applied to vegetable crops grown in this region even just before harvesting. By these applications, farmers expect to obtain attractive vegetables, which can fetch high prices in the market rather than get their yield increased.

16. Use of liming materials

Application of liming materials such as dolomite and burnt lime is also a common practice for potato and vegetable growers particularly in the up-country areas. Despite the recommendation of DOA to apply such materials at 2 t/ha/year if soil pH is below 5, farmers still apply almost 650 kg/ha (Wijewardena, 2001).

17. Nutrient balance

Rice is a biannual crop and it removes considerable amounts of nutrients especially potassium and silica, which are found in straw and in grain. The total removal depends on the yield. Nutrient removed by rice crop indicates a negative balance of P and K even with the application of DOA recommended levels (Table 10).

Rice crop removes more P and K than quantities applied as chemical fertilizers. However, this situation could be improved by application of organic manures recommended by the DOA (Wickramasinghe and Wijewardena, 2003). It indicates that nutrient removed needs integrated use of organic and chemical fertilizers to compensate for the nutrient loss (Dissanayake, 2001).

Table 10. Nutrient balance in different rice growing environments of Sri Lanka

Area / Nutrient	Total removal (kg/ha)	Amount recommended (kg/ha)	Balance (kg/ha)
LCDZ			
N	100	100	0
P	18	13	-5
K	106	28	-78
Up-country or Midcountry			
N	100	60	-40
P	18	13	-5
K	106	28	-78
LCWZ			
N	100	55	-45
P	18	13	-5
K	106	53	-78

In straw: N = 0.74 percent; P = 0.1 percent; K = 1.81 percent

In grain: N = 1.26 percent; P = 0.26 percent; K = 0.32 percent

18. Farm budgets in different cropping systems

The increasing total cost of production and declining profit have become significant issues particularly in rice and OFC. In high potential areas, nominal cost of production has doubled from US$0.04/kg in 1987/88 maha season to US$0.08/kg in 1998/99 maha season (Jayawardena, 2003). This analysis indicates that the real cost production per kg of paddy has become more prominent in low potential areas, attributing to decreased productivity. Similar trend could be seen in many OFC crops other than chili and onion. However, it is interesting to note that vegetables have become an important component in almost every cropping system. Of the several season for widespread cultivation of vegetables, the most important is that net returns from vegetable production are higher than returns from rice and most other field crops (Table 11).

Table 11. Comparison of net returns from cultivation of different crops per hectare (US$)

Crop	Cost of cultivation	Value of product	Net return
Rice	45.7	75	29.3
Potato	424.3	825	400.7
Tomato	123.3	188	56.7
Bitter gourd	123.6	160	36.4
Bean	144.8	280	135.2
Green gram	213.5	230	16.5

19. Soil test-based fertilizer recommendations

The soil test-based fertilizer recommendation programme introduced by the DOA has contributed, to some extent, to prevent build up of P and K in the cultivated fields as well as to minimize groundwater pollution (Tables 12 and 13). Under this programme, any farmer can get his soil

Table 12. Application rate of TSP for potato and vegetable crops based on soil test results

Soil P level (mg/kg)	Application rate of the recommended level	Potato	Cabbage	Tomato	Brinjal
<20	Full	270	270	270	325
20-30	Half	200	135	135	165
>30	Starter dose	70	70	60	85

Table13. Application rate of MOP for potato and vegetable crops based on soil test results (kg/ha)

Soil K level (mg/kg)	Application rate of the recommended level	Potato	Cabbage	Tomato	Brinjal
<160	Full	250	150	130	170
160-400	Half	130	90	90	110
>400	No application	–	–	–	–

sample tested and obtain a site specific P and K fertilizer recommendation for rice, vegetables, tuber crops and OFC for a nominal fee of approximately US$3 (DOA, 1997). This programme helped farmers in the up-country to make substantial savings in the money spent to purchase fertilizers (Maraikar *et al.*, 1996).

20. Pollution of water resources due to agricultural production

Almost one-third of land in Sri Lanka is cropped. Intensive agriculture associated with increase fertilizer and pesticide use has resulted in serious groundwater pollution in some areas of the island. Eastern, northern and some parts of northwestern parts have predominately permeable soils with shallow water tables, which are more susceptible to leaching with high application rates, making the groundwater potentially hazardous. Groundwater and surface water of central highlands too are becoming polluted with high application of nitrogenous fertilizers from both inorganic and organic sources. The use of fertilizers and pesticides in Sri Lanka is expanding rapidly as in other developing countries, particularly with the introduction of new high yielding crop varieties.

Nagarajah *et al. (*1983) reported that due to intensive cultivation of annual crops in Jaffna peninsula, the nitrate-nitrogen levels exceeds WHO recommended levels. The studies conducted in the Kalpitiya peninsula indicate that leaching of chemical fertilizer from intensively cultivated lands seems to elevate the concentration of nitrates in groundwater (Kuruppuarachchi, 1995). He reported that most irrigation wells had nitrate-N concentrations in excess of the WHO guideline of 11.3 mg N/l and often in excess of 22.6 mg N/l. Further, he reported that build up of nitrate is quite dramatic and has been estimated at 1-2 mg N/l per annum.

In the up-country, potato and vegetables have been cultivated for several decades. The rates of fertilizer applied by farmers are much higher than the quantity recommended by the DOA. The levels of chemical fertilizer applied by farmers to potato and vegetable crop are almost double or triple the quantity recommended by the DOA (Wijewardena, 1996; Wijewardena, 2001). In addition, use of high rates of animal manure is also common in the up-country. Quantities added range from 10 to 15 t/ha of poultry manure and from 20 to 30 t/ha of cattle manure (Wijewardena, 1993;

Wijewardena, 1995). Due to the hilly nature and high rainfall in the area, rain could easily wash out applied fertilizer. Wijewardena *et al.* (1995) and Wijewardena *et al.* (1999) monitored drinking water quality of wells in the UCIZ and UCWZ. NO_3-N values reported in these areas were lower than values reported in Jaffna and Kalpitiya areas.

21. Integrated plant nutrition system

During the past decade, average yields of food crops including rice have been stagnant or declining. One of the reasons for this yield decline or stagnation is the unbalanced use of fertilizer. This trend in many cropping systems will result in soil mining leading to decline in soil fertility. In order to improve soil fertility, it is important to follow environmentally-friendly plant nutrition management practices under what has been termed the Integrated Plant Nutrition System (IPNS). This concept advocates the balanced use of fertilizer for crop production. Also, when adding fertilizer to a crop, it would be necessary to assess and take into account the contribution of different sources such as soil, water, organic manure, rain etc. to the nutrient pool.

Studies conducted in relation to plant nutrition management had shown that in many cropping systems the integrated nutrient supply and management through judicious use of organic and chemical fertilizers would lead to sustainable crop production (Tables 14 and 15), as well as overall soil improvement. Hence, the use of this technology is advantageous as it helps to improve fertilizer use efficiency, improvement of long-term soil fertility as well as increase the benefit-cost ratio (Wijewardena and Yapa, 1999; Dissanayake, 2000).

Table 14. Rice yield and VCR with different fertilizer management practices

Treatment	Yield (t/ha)	VCR
Mean yield without chemical fertilizer	3.0	2.68
Mean yield with chemical fertilize	4.5	2.638
Mean yield with chemical fertilize + Rice straw	6.0	5.02
Mean yield with chemical fertilize + Rice straw + Cow dung + Green manure	9.8	8.22

Source: Dissanayake, 2000.

Table 15. Effect of organic and chemical fertilizers on crop yield (Data is shown from the last three seasons of an eight-season study)

Treatment	Yield (t/ha)		
	Cabbage	Tomato	Bush bean
No fertilizer	6.4	2.2	5.1
NPK	33.0	7.2	10.7
Poultry manure	62.1	18.4	11.1
Poultry manure + NPK	81.8	24.6	15.8

NPK = Rates recommended by the DOA for each crop; Poultry manure = 10 t/ha.

In general, IPNS is a long-term approach to effective maintains soil and crop productivity. However, farmers expect immediate and quick economic benefits with IPNS practices. This hinders and restricts adoption of IPNS at the farm level. Thus, creating an awareness of the benefits of IPNS among farmers by introducing various methods of technology transfer would indeed help to solve this problem. In addition, bulky organic manures and its application make IPNS labour intensive. In this respect, Local and Government Organizations should encourage farmers by providing suitable facilities to utilize such materials particularly in rice cultivation, as well as large-scale demonstration, extension services conveying practical training and educational programme to farmers.

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Southeast Asian Country

Paper Number 6

Soil fertility management and conservation under agriculture productivity improvement project in Cambodia*

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Summary

The Royal Government of Cambodia after years of conflict has started in earnest, the basic programmes and works on the improvement of agricultural and soil productivity. In general, most soils released for use in various agriculture and food production programmes are acidic, low in organic matter and very poor in soil fertility. One of the recent efforts are dedicated to the promotion and adoption of sustainable land management (SLM) in response to the country's commitment to the United Convention to Combat Desertification, including land degradation and drought. The banner programme is the Agriculture Productivity Improvement Programme (APIP) which provided human and financial resources for the nationwide implementation of the Soil Fertility Management and Conservation (SFMC). Networks of on-farm techno-demos were established in over 14 provinces to showcase different farming systems to improve soil fertility and also to improve farmer's technology on plant nutrient management and improvement. Massive soil and plant tissue samples for soil fertility analysis and fertilizer use calibration were conducted and this now forms the critical benchmark and data base for future soil fertility programme and formulations for the Royal Government of Cambodia.

1. Introduction

Food and fiber production systems in the Royal Government of Cambodia now and into the future needs to meet three major requirements: (1) to provide adequate supply of safe, nutritious, and sufficient food for the world's growing population, (2) to significantly reduce rural poverty through augmentation of household income derived from activities, and (3) to curb further degradation of natural resources, particularly land resources. These challenges have to be resolved in anticipation of unpredictable changes in global climate- a key factor in natural and agro-ecosystem productivity. Other major factors that will influence how agriculture meets the challenge of food security include globalization of markets and trade, increasing market orientation for agriculture, emerging technologies and increasing public concern about the impacts of unsustainable natural resource management.

It is imperative, therefore, to share lessons learned and focus on the strategic management and implementation of the Sustainable Land Management (SLM) in pursuance of the objectives of United Nation Convention to Combat Desertification (UNCCD).

* This country report has not been formally edited and the designations and terminology used are those of the author.

SLM initiatives through the Soil Fertility Management and Conservation (SFMC) in the country are being undertaken through:

- High quality research and development activities in different agro-ecosystem target areas to demonstrate, extend and raise awareness of SFMC technologies;
- Capacity building activities to strengthen the capability of partners to demonstrate and extend relevant SLM technologies to their farmer clients; and
- Effective coordination and information support to strengthen and improve the existing collaborative with regions having similar problems.

2. Activities and achievements

While poor external participation, institutional limitations and national funding uncertainties have acted to impede progress, and that limited human and institutional skills have undermined the value of very good 'Science' in the SLM programme. For instance, the Agricultural Productivity Improvement Programme (*APIP)* for *SFMC* has achieved its objectives within the design timetable as follows:

- Field activities of SLM core site saw the establishment, operation and maintenance of 3 run off and soil loss monitoring sites. Data collection, collation and assessment completed.

From these works, rainfall patterns at each site with recorded annual rainfalls showed the following summarized data trends:

- Typically >2 500 mm rainfall level for all sites;
- 71 percent of rain occurs in falls of <10 mm/day, 24 percent in falls of 10-50 mm/day and 4 percent in falls of >50 mm/day; and
- Similarly, low rainfall intensities (<10 mm/hr) were observed in 81 percent of rain events, and higher, more erosive intensities (>20 mm/hr) were observed in 9 percent of instances reflecting catastrophic events such as various effective cyclones were recorded.
- The recorded/collected information and data suggests that run off is initiated at rainfalls in the excess of 5-10 mm/day i.e. only in about 29-38 percent of all rainfall events. Run off under 'normal' rainfall was typically <5 percent of total rainfall suggesting these soils is stable with low erosivity, respectively.

The recently collected soil loss data suggests that contour-based farm treatments can be grouped into four broad categories, *viz*. (1) Farmers Practice (FP), (2) FP + vetiver, (3) FP + short to medium-term cash crops, and (4) FP + agroforestry hedges. The actual annual soil losses per site vary relative to FP (= 0 percent or no change). Obviously, the on-farm demonstrations using the above 4 categories have one common message that reconfirmed hedgerows planted across the slopes can effectively control soil erosion. Figure 1 describes the following trends in relative annual soil loss:

1. Vetiver grass strips reduced soil losses to 30-50 percent of FP in the 2 years after planting, and to >90 percent after that;
2. Short to medium-term cash crop barriers reduced soil losses initially to 50 percent of FP, and to >90 percent after 3 years (very similar trend to vetiver grass); while,
3. Agroforestry hedges maintained soil losses at around 50 percent of FP during this time.

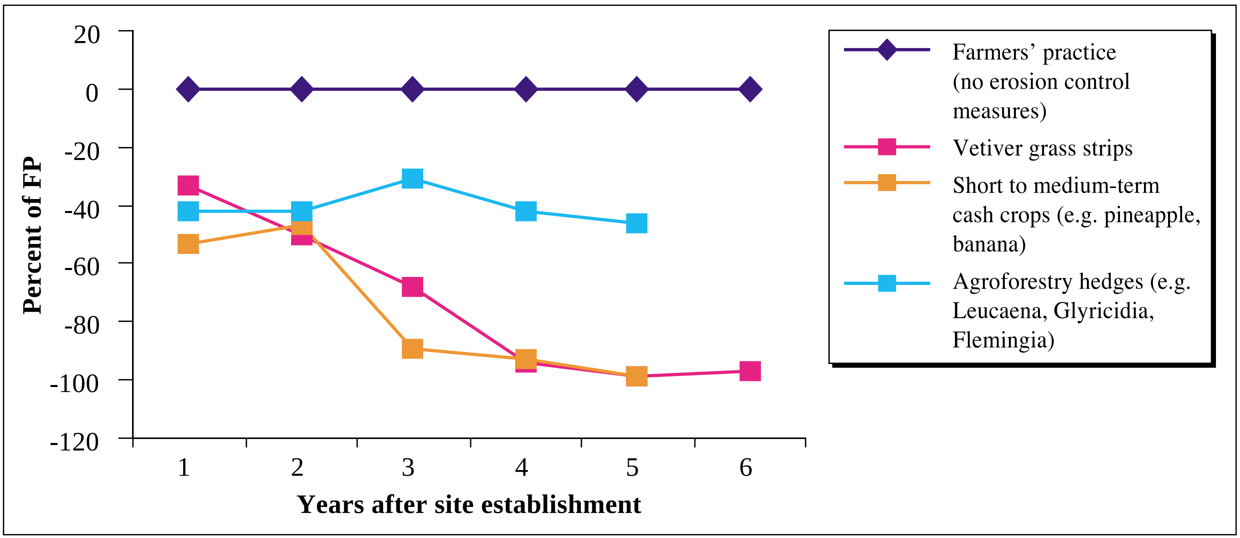

Figure 1. Trends in relative annual soil loss for treatment groupings on *APIP-SFMC* sites

The network of SFMC on-farm techno-demos

The network of on-farm techno-demos covered and ensured the implementation of thousands on-farm demonstration and survey activities over 14 provinces. In addition to the technical data on-farm production, due consideration was given to the three impact areas such as environmental impact, social impact and economic impact.

The quantified measurements of local impacts of the techno-demos in various sites resulted in the further development of farming system models for semi-commercial producers which considered soil fertility and erosion control, giving due consideration to the productivity of the hedges/barriers, especially as it affects needs and access of poor and vulnerable to basic production-improving services.

Cooperators showed through their country programmes that they could apply SFMC knowledge learned during training. Coordination and technical backstopping visits supported on-the-job training in areas relating to implementation, day-to-day management and demonstration of techniques and collection, collation, analysis and reporting gathered data. Regular activities associated with field trial management are being institutionalised and activities included as line items in Ministry budgets.

Timely technical assistance, training and capacity building activities and workshops on SFMC provided:

- Technical assistance, training and capacity building activities involving 503 provincial technical staff, extension worker and private sectors participants (16 percent females).
- Effective links with other 6 national programmes, and the 14 PDAs network coordinator attended. Cooperative links with regional and bilateral activities developed during Phase 1 were strengthened to promote longer-term sustainability of national and regional activities. Successful regional staff exchanges added value to regional training workshops and coordination and technical backstopping visits by allowing network members to share experiences and extend 'lessons learned' to their peers. These experiences further rewarded both trainees and trainers through skill recognition, communication and personal networking.

Effective administration, management and information distribution systems allowed:

- Leadership;
- Effective distribution of information on SFMC/SLM several Agri-Notes, balanced approach to the network management function, and country programme 5 annual technical reports, and workshop reports.

A total of 3 440 soil samples were collected in the farmers field and field stations and were analysed to provide soil chemical properties and soil fertility relational data base and benchmarks. This massive and systematic soil sampling programme aimed to: (i) determine and/or confirm soil types, (ii) compare the soil and soil properties of the field station with those used by the farmers in the adjoining farms, and (iii) prepare an inventory of soil types, soil chemical properties and fertilizer management practices for these field areas. Inventory activities were undertaken in conjunction with other agronomic and infrastructure databases being developed for each field sites.

Table 1. Soil sampling and analysis by provinces

No.	Provinces/Location	Number of Collected Soil Samples
1	Kampong Cham, Rubber farms	300
2	Kratie, SFMC field trial's sites	660
3	Kampong Thom, SFMC field sites	600
4	Battambang, SFMC field sites	300
5	Svay Rieng, AQIP sites	420
6	Prey Veng, AQIP sites	380
7	Kandal, AQIP field sites	490
8	Takeo, AQIP field sites	35
	Total	**3 440**

The Soil and Plant Analysis Laboratory's mission is to provide a quality national soil, fertilizer and plant nutrient analysis service to encourage sustainable land management and improve food security in Cambodia. Its purpose is to serve Government, national research institutions, NGOs, agribusinesses and farmers as a semi-autonomous agency under DAALI. The laboratory, likewise, participated in the regional soil and plant sample exchange programme.

3. Lessons learned

SFMC is an institutional capacity building programme of technical staff and extension workers and other stakeholders learning to work together under the leadership of DAALI under the National Action Programme (NAP). The processes of human and institutional capacity building and the actual knowledge and experiences gained in the hands-on implementation in the various stations and farmer's field provided important lessons learned and unlearned:

- To address SLM issues, and its function. For its operation, external funding is required, from one or more donors. Further, the network needs scientific and organizational guidance, especially for the poor resources;
- The ability and willingness for further achieving SFMC/SLM needs time for development and guidance supporting a longer-term intervention;

- Integration into national and regional programmes and communication of experiences within and between national and regional organizations and activities with value added of minimising risks associated with project isolation.
- Individual objective has to be consistent with the NAP's objectives to encourage longer-term sustainability;

4. Problems and constraints

1. SFMC staff limited skills and knowledge on management, planning, monitoring and reporting;
2. Not enough resources for TA to supervise and provide on the job training;
3. Some specific natural and administrative constraints are recognized: (i) interruption of field activities by yearly flood occurrences (ii) Slow release of funds, (iii) Delays in arrival and subsequent release of procured items, (iv) A lack of clear procedural guidance.

5. SWOT analysis

From field observations and analysis of data collected in the soil fertility and land management area, the following strengths, weaknesses, opportunities and threats (SWOT) were recognized:

- **Strengths:** Laboratory and provincial personnel are collaborating with other agencies. The Soil and Plant Analysis Laboratory is applying QA/QC procedures to further progress soil fertility and land management activities. Counterparts and provincial cooperators are undertaking technical M&E visits to inspect field trial sites for experimental rigor. Counterparts have recognized their own limitations in many technical areas and see the need for further technical training. Strong collegiate networks exist among counterparts. There is an awakening recognition of the value of applying a holistic approach to working in a professional environment.
- **Weaknesses:** Land Management Office (LMO) and laboratory insufficient attention to: (1) trial design, (2) field and technical M&E activities. Not enough quality management support to field operatives and farmers efforts to improve data management, analysis and reporting skills should also be continued.
- **Opportunities:** Counterparts should continue networking and collaborative land management activities. Great potential exists for technical and laboratory staff to plan and undertake collaborative activities with CARDI, DAE, provincial NGOs and extension staff. This is especially so when linking field operations and specialized analytical functions in areas of plant nutrition, soil fertility and land management. However, institutional reform and ongoing technical 'mentoring' (i.e. as technical guidance) will be required for this to happen smoothly. Also the sustainable management of land and resources is likely to become an increasingly important political issue in Cambodia. LMO should continue to develop:
    1. Expert knowledge in soil fertility management in order to become a storehouse of related knowledge on land management and an adviser to government, NGOs, other agencies, agribusinesses and farmers.
    2. Simple, transparent administrative and financial management systems and practices to further streamline information flows in collaborative activities.

Institutional and legislative processes to develop national land management policies that link sustainable production and food security to appropriate land use strategies and practices.

Southeast Asian Country

Paper Number 7

Soil organic matter and soil fertility in the long-term experiment of Lao People's Democratic Republic*

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Summary

The Soil Survey and Land Classification Center (SSLCC) of Lao PDR conducted a long-term research on soil conservation and fertility management to address their major problem of soil erosion and attendant soil fertility loss. Experimentations have been carried out in two locations in the northern and central regions: Luangprabang and Vientiane provinces. The various land use and farming systems technologies were assessed and included: Agroforestry (teak + upland rice, peanut); Strip cropping (soybean, upland rice, peanut); Alley cropping mixed with Agroforestry (vetiver, flemingia + mango, banana as hedgerow); Hillside ditch (upland rice, peanut + mango on the dike). These technologies were compared to the farmer's practice (mono-cropping of upland rice), whose current farming practices were found to have caused serious soil erosion, the major reason of soil fertility decline among resource poor farmers. The results showed that, over time, the continuous use of appropriate agroforestry and soil management technologies and practices can improve and maintain soil fertility for the enhancement of crop yield and increase income.

1. Introduction

The Lao PDR has a land area of 23.7 million ha, about one million ha of which are under agriculture. There are 18.7 million ha of hills and mountains. Hills account for 50 percent and mountains 30 percent, with slopes over 8 percent. Most of the hills and mountains are in the northern and central eastern part of the country where shifting cultivation is the major farming system. Luangprabang is the province with the highest area of shifting cultivation in the country.

The topography greatly influences the climate. Areas in the mountains usually receive high amount of rainfall than flat land area. The annual rainfall varies in amount and intensity from one area to another which invariably caused various forms of soil degradation depending on the nature and steepness of slopes and current farming practices.

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In 1973 only 12.7 million ha or 54 percent of total area remained under forest cover and was further reduced in 1989 to 11.2 million ha, or 47 percent of total area of the country. Barren land/mountains, and grassland now cover 10.2 million ha where about 5 million ha are under bush fallow due to continuous slash-and-burn practices.

Current farming practice is unsustainable due to reduced fallow periods resulting from population increases. The government instituted a national policy to stop slash-and-burn cultivation as a way to protect the country's forest resources. However, this policy, which failed to consider management of population growth, unnecessarily resulted in the controlled reduction of access and availability of lands to growing upland communities and individual upland farming families. As a result, fallow periods have rapidly decreased, thereby causing a serious decline in soil fertility, nutrient depletion, soil compaction, weed problems, and consequent soil degradation.

This paper presents the result of the two long-term soil fertility on-farm research sites in Luangprabang (northern part) and Vientiane (central part) from 1994 to 2001.

2. Objectives of the long-term research

a. To monitor the improvement and/or degradation of soil resources under different technologies applied

b. To assess the economical returns of different soil management practices

3. Materials and methods

3.1 Location and site characteristics

Luangprabang's site

The site is located at longitude 102.10ºE and latitude 19.44ºN, within elevation of about 400 m above sea level in Houaykhot village, Xiengngeun district, Luangprabang province. The topography is classified as low hilly land with slope ranging from 25-35 percent.

The climate is classified as wet and dry tropical climate which is characterized by two distinctive seasons: the rainy season covers the months of April to October and the dry season, November to March. The annual rainfall of the area ranges from 1 100 mm to 1 400 mm. Monthly average rainfall distribution at the site from 1994 to 2001 is shown in Table 1.

The soil is classified as Typic Haplustaft, clay loam, isohyperthermic developed on shales. Soil profile description of the experimental site is show in Table 2.

Vientiane site

The site is located at longitude: 102.20ºE and latitude: 18.17ºN at Hineherb village, Hineherb district, Vientiane province. The topography is a low hill with slope ranging from 20-35 percent, the elevation is about 250 m above sea level, the climate is classified as wet and dry monsoon tropical, with annual rainfall of about 1 400-2 000 mm. The rainy season starts from May to September and the dry season start from October to April. Monthly average rainfall distribution at the site from 1995 to 2000 is shown in Table 3.

The soil is classified as typic haplustult clayloam isohyperthermic, developed on sandstone and siltstone. Soil profile description of the experimental site is shown in Table 4.

Table 1. Monthly average rainfall, from 1994 to 2000 at Luangprabang site

Year	Month												Total
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Aug.	Nov.	Dec.	
1994	0	3.6	107.8	25.4	150.0	143.6	213.8	262.4	105.6	262.4	19.8	76.5	1 134
1995	0	0	3.8	50.0	200.5	117.4	205.4	326.3	108.8	326.3	80.3	0	1 252
1996	0	20	39.8	150.3	146.7	109.8	195.6	201.5	164.3	201.5	65.2	0	1 268
1997	0	0	29.6	115.6	122.8	132.6	211.5	249.3	108.7	249.3	8.0	0	1 015
1998	33.4	4.6	29.7	158.3	162.0	107.8	117.8	289.2	61.8	289.2	42.8	13.0	1 064
1999	2.5	0	32.7	114.3	267.8	268.2	112.8	137.0	173.5	137.0	33.2	34.3	1 260
2000	0	0	18.7	178.0	259.6	117.5	334.6	138.9	137.6	138.9	30.0	0	1 303
2001	0	33.1	70.8	118.5	141.3	340.1	236.3	165.6	110.6				

Table 2. Soil profile descriptions of Luangprabang site

Depth (cm)	Profile description
A 0-12	Dark brown, (7.5 yr 4/2 moist) clay loam, moderate coarse sub angular blocky structure, firm, sticky and plastic, many tubular pore, many medium to fine roots, abrupt wavy boundary, pH 6.
Bt1 12-45	Dark brown (7.5 yr 4/2 moist) heavy clay, sticky and very plastic, many fine roots, few fine weatherable material, clear smooth boundary.
Bt2/C	Brown (7.5 yr 5/4 moist) heavy clay, moderate medium sub angular blocky structure, very firm, sticky and very plastic, very few fine roots, about 5 percent of weatherable shale fragments.

Table 3. Monthly average rainfall, from 1995 to 2000 at Vientian site

Year	Month												Total
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Aug.	Nov.	Dec.	
1995	2.3	3.2	12.5	92.5	160.9	368.8	579.0	596.4	269.0	6.3	3.1	0	2 094
1996	2.3	14.1	42.2	112.4	193.2	219.1	259.8	399.4	214.6	85.8	0	0	1 542
1997	1.9	0	2.1	63.6	186.4	217.4	577.9	318.1	208.6	67.4	0	0	1 643
1998	0	0	0	16.0	156.3	347.5	359.8	470.4	167.6	65.1	1.2	0	1 583
1999	0	0	17.1	59.8	361.7	218.9	236.3	340.5	266.7	5.2	4.80	0	1 511
2000	0	13.1	12.5	120.8	270.6	326.0	255.1	371.5	308.8	69.5	4.10	0	1 752
2001	0	0	78.7	18.6	320.8	144.2	254.8	392.6	287.9				

Table 4. Soil profile description of Vientiane site

Depth (cm)	Profile description
Ap 0-20	Strongly brown (7.5 yr/4.6 moist) clay loam, moderate medium angular blocky structure, hard when dry, firm when moist, slightly sticky when wet, moderate medium tubular pores, many medium tubular roots, abrupt wavy boundary pH = 4.9
Btcs 20-40	Yellowish red (5 yr 4/6 moist) light clay, moderate medium subangular blocky structure, slightly firm and sticky when wet, many medium interstitial roots and moderate medium interstitial pores, few fine concretion, abrupt wavy boundary pH = 4.8
Bts1 40-69	Reddish brown (5 yr 4/4 moist) heavy clay, moderate fine subangular blocky structure, slightly hard firm, very sticky, many fine roots, few very fine interstitial pores gradually wavy boundary pH = 4.9
Btcs2 60-120	Dark red (2.5 yr 3/6 moist) heavy clay, moderate fine subangular blocky structure, slightly hard, firm, very sticky, few very fine interstitial pores, with 40 percent of concretions pH = 5.4

3.2 Experimental design

The experiment was carried out using a randomized complete block design with 3 replications. Individual plot is 10 x 24 m at Luangprabang site and 10 x 20 m at Vientiane site. The validated treatments were as follows:

Luangprabang site

- T1 Agroforestry (teak, and rice)
- T2 Strip cropping (rice and soybean)
- T3 Alley cropping using vetiver and mango trees as hedgerow
- T4 Hill side ditches with mango trees on the bund
- T5 Farmer's practice

Vientiane site

- T1 Farmer's practice (random planting)
- T2 Alley cropping using flemingia congesta as hedgerow
- T3 Alley cropping using flemingia congesta + banana as hedgerow
- T4 Agroforestry (rice and teak)

At Vientiane site, in 1998, 1999 and 2000, 100 kg of Diammonium Phosphate (18N, 46P) with 1 500 kg of powered lime were applied for peanut in T2 and T3. There is no fertilizer use in Luangprabang site.

4. Results and discussion

4.1 Soil loss

An average total annual soil loss from different treatments at Luangprabang site from 1994 to 2001 and Vientiane site from 1995 to 2001 are shown in Tables 5 and 6.

The highest soil loss occurred in farmer practice (T5) with amount of soil loss of 6.07 t/ha. Alley cropping (T3) is most effective in reducing soil loss (0.86 t/ha), followed by the hillside ditches (1.89 t/ha).

The Agroforesty and strip cropping treatment can reduce soil loss equivalent, at 2.88 and 3.05 t/ha, respectively.

Table 5. Total soil loss (t/ha) from 1994-2001 at Luangprabang site

Treatment	1994	1995	1996	1997	1998	1999	2000	2001	Average
Agroforestry	3.47	6.55	4.67	2.77	2.38	1.17	0.98	1.09	2.88
Strip cropping	2.07	4.71	3.55	3.45	3.20	2.52	2.59	2.35	3.05
Alley cropping	3.56	1.76	0.45	0.14	0.27	0.21	0.32	0.24	0.86
Hillside ditches	2.66	2.41	0.56	0.19	0.15	0.32	0.52	0.35	0.89
Farmer's practice	4.88	9.21	5.23	3.90	9.63	8.62	3.69	3.47	6.07

Table 6. Total soil loss (t/ha) from 1995-2001 at Vientiane site

Treatment	1995	1996	1997	1998	1999	2000	2001	Average
Farmer’s practice	47.57	24.77	16.44	26.53	29.68	15.59	13.75	24.90
Alley cropping	42.56	2.86	0.62	0.16	0.74	0.68	0.56	6.88
Alley + Agro	43.03	2.93	0.76	0.92	1.25	1.13	1.23	7.32
Agroforestry	46.95	23.76	13.99	7.89	8.79	5.72	4.96	16.00

At Vientiane site, among validated technologies, alley cropping using flemingia congesta hedgerow (T2) and alley cropping using flemingia congesta with banana hedgerow were the most effective in reducing soil loss, the amount of soil loss of these treatments were 6.88 and 7.32 t/ha respectively.

The farmer’s practice treatment had the largest soil loss (24.90 t/ha), followed by the Agroforestry treatment which produced the amount of soil loss of 16.00 t/ha.

4.2 Run off

An average total annual run off from different treatments at Luangprabang site and Vientiane site are shown in Tables 7 and 8.

Table 7. Total run off (m^3/ha) from 1994-2001 at Luangprabang site

Treatment	1994	1995	1996	1997	1998	1999	2000	2001	Average
Agroforestry	1 108	1 822	1 533	2 267	1 869	1 054	976	865	1 436
Strip cropping	730	1 146	1 063	1 553	1 078	1 137	1 186	1 216	1 138
Alley cropping	1 269	765	744	862	893	769	703	634	829
Hillside ditches	608	629	773	839	679	713	698	528	683
Farmer’s practice	1 457	2 119	1 589	2 560	2 795	2 869	2 976	2 728	2 386

Table 8. Total run off (m^3/ha) from 1995-2001 at Vientiane site

Treatment	1995	1996	1997	1998	1999	2000	2001	Average
Farmer’s practice	3 308	2 532	3 010	3 365	3 569	3 459	2 937	3 168
Alley cropping	3 161	1 439	1 547	1 127	960	1 086	976	1 470
Alley + Agro	3 026	1 497	1 599	1 226	1 098	1 137	1 035	1 516
Agroforestry	3 209	2 404	3 046	2 573	2 183	2 294	2 169	2 554

At Luangprabang site, the lowest run off was found in the hillside ditches treatment (683 m^3/ha), the alley cropping treatment can also effectively reduced run off (829 m^3/ha). The strip cropping and Agroforestry treatment could reduce run off similarly, the amount of run off from these treatments were 1 138 m^3/ha and 1 436 m^3/ha respectively. The farmers practice produced the highest run off (2 386 m^3/ha).

At Vientiane site, alley cropping using flemingia congesta hedgerow and alley cropping using flemingia congesta with banana as hedgerow gave the lowest run off 1 470 and 1 516 m^3/ha respectively. The farmers’ practice produced the highest run off (3 168 m^3/ha), fallowed by the Agroforestry treatment which produced run off (2 554 m^3/ha).

4.3 Soil fertility change over time

Soil pH

Soil reaction pH from different treatments at Luangprabang and Vientiane site is illustrated in Tables 9 and 10.

Table 9. Soil pH from 1994-2000 at Luangprabang site

Treatment	1994	1995	1996	1997	1998	1999	2000	2001
Agroforestry	5.6	6.0	5.8	5.8	5.7	5.5	5.6	5.5
Strip cropping	6.2	6.1	6.2	6.2	6.0	5.8	5.9	5.8
Alley cropping	5.8	5.8	5.9	6.0	6.1	6.0	5.9	5.7
Hillside ditches	6.0	5.9	5.8	5.8	5.9	5.7	5.6	5.6
Farmer's practice	6.2	5.9	6.0	5.9	5.7	5.5	5.4	5.5

Table 10. Soil pH from 1995-2000 at Vientiane site

Treatment	1995	1996	1997	1998	1999	2000	2001
Farmer's practice	5.0	4.9	4.8	4.5	4.6	4.5	4.5
Alley cropping	4.9	5.0	5.0	5.4	5.7	5.8	5.7
Alley + Agroforest	4.9	4.8	4.8	4.7	5.3	5.6	5.6
Agroforestry	4.9	4.9	5.0	4.8	4.7	4.6	4.6

At Luangprabang site, soil pH from the farmer's practice decreased from 6.2 in 1995 to 5.5 in 2001. While, the hillside ditch treatment from 6.0 to 5.6 in 2001 and the strip cropping from 6.2 in 1995 to 5.8 in 2001 . However there is slightly change in soil pH from the alley cropping and Agroforestry.

At Vientiane site, soil pH from alley cropping using flemingia congesta as hedgerow and alley cropping using flemingia congesta with banana as hedgerow increased from 4.9 in 1995 to 5.7 in 2001 and from 4.9 in 1995 to 5.6 in 2001, respectively. This was due to the application of powered lime at the rate of 1 500 kg/ha. While soil pH from the farmer's practice and Agroforestry decreased from 5.0 in 1995 to 4.5 in 2001 and from 4.9 in 1995 to 4.6 in 2001, respectively.

4.4 Soil organic matter (OM)

Soil organic matter (OM) from different treatments at Luangprabang and Vientiane site is shown in Tables 11 and 12.

At Luangprabang site, soil organic matter content from all treatments tends to decrease from year to year. When comparing all treatments, the farmer's practice decreased the most amount of organic matter content followed by Agroforestry and hillside ditch treatments. In the farmers' practice treatment, soil organic matter decreased from 3.71 percent in 1994 to 1.78 percent in 2001. This was due to the removing crop residues from the plot coupled with top soil loss through water erosion. On the other hand, alley cropping and strip cropping showed the least decline in soil organic matter content. This was due to more crop residues that were returned back to the soil.

Similar results were found at Vientiane site with farmers' practice showing highest decrease in soil organic matter. Alley cropping using flemingia congesta as hedgerow yielded a least decline in soil organic matter content, due to the application of fertilizer and lime enhancing more biomass production by crop.

Table 11. Soil organic matter (percent OM) from 1994-2001 at Luangprabang site

Treatment	1994	1995	1996	1997	1998	1999	2000	2001
Agroforestry	2.65	2.58	2.49	2.29	1.89	1.75	1.73	1.85
Strip cropping	2.30	2.25	2.65	2.98	2.52	2.14	1.98	2.18
Alley cropping	3.00	3.09	2.95	2.92	2.78	2.46	2.19	2.30
Hillside ditches	3.18	3.00	3.00	3.12	2.85	2.35	2.18	2.20
Farmer's practice	3.71	3.68	3.35	2.86	2.58	2.23	1.75	1.78

Table 12. Soil organic matter (percent OM) from 1995-2001 at Vientiane site

Treatment	1995	1996	1997	1998	1999	2000	2001
Farmer's practice	2.25	2.62	2.50	2.30	2.15	1.53	1.50
Alley cropping	2.52	2.50	2.48	2.22	2.23	2.13	2.10
Alley + Agro	2.30	2.30	2.38	2.16	1.94	1.97	1.98
Agroforestry	2.37	2.30	2.30	2.12	1.89	2.09	2.06

4.5 Soil phosphorus available

Soil phosphorus available (P_2O_5) from different treatments at Luangprabang and Vientiane site is shown in Tables 13 and 14.

Table 13. Soil phosphorus available (P_2O_5 ppm) from 1994-2001 at Luangprabang site

Treatment	1994	1995	1996	1997	1998	1999	2000	2001
Agroforestry	6.7	7.5	6.5	6.8	6.2	5.9	5.3	5.3
Strip cropping	4.0	4.5	4.1	4.3	3.8	3.6	3.2	3.3
Alley cropping	4.6	4.8	4.2	4.3	2.9	2.8	2.6	2.9
Hillside ditches	6.7	5.2	5.2	6.1	5.9	4.6	4.3	4.5
Farmer's practice	5.2	5.4	5.3	5.2	5.3	4.9	4.8	4.4

Table 14. Soil phosphorus available (P ppm) from 1995-2001 at Vientiane site

Treatment	1995	1996	1997	1998	1999	2000	2001
Farmer's practice	5.7	5.2	5.0	4.3	3.9	2.7	2.7
Alley cropping	3.0	3.2	3.3	5.1	8.3	12.3	12.5
Alley + Agro	3.7	4.0	6.1	9.5	11.3	13.8	14.9
Agroforestry	3.0	2.9	2.7	2.5	1.3	1.3	1.7

At Luangprabang site, phosphorus available from all treatments decreased over time this was may due to uptake by annual crops every year and coupled with no input of phosphorus fertilizer.

At Vientiane site, there was obvious evident that phosphorus available under alley cropping using flemingia congesta as hedgerow and alley cropping using flemingia congesta with banana as hedgerow, phosphorus available increased from 3.0 ppm in 1995 to 12.35 ppm in 2001 and from 3.7 ppm to 14.9 ppm in 2001. This was due to the application of diammonium phosphate (18N, 46P) at the rate of 100 kg/ha/year.

Phosphorus available under farmers practice decreased over time from 3.0 ppm in 1995 to 2.7 ppm in 2001, followed by the Agroforestry that decreased from 3.0 ppm in 1995 to 1.7 ppm in 2000.

4.6 Soil potassium available

Soil potassium available (K) from different treatments at Luangprabang and Vientiane site is show in Tables 15 and 16.

Table 15. Soil potassium available (K_2O mg/100 g) from 1994-2000 at Luangprabang site

Treatment	1994	1995	1996	1997	1998	1999	2000	2001
Agroforestry	19.3	18.6	16.3	15.4	12.1	12.5	10.9	11.2
Strip cropping	25.6	24.5	25.7	26.3	23.0	21.5	22.4	21.3
Alley cropping	18.8	19.2	18.0	18.0	16.7	13.5	12.0	13.2
Hillside ditches	31.2	28.5	28.0	30.8	27.6	25.4	20.8	19.3
Farmer’s practice	29.0	30.5	29.7	28.5	20.9	15.6	13.2	13.4

Table 16. Soil potassium available (K_2O mg/100 g) from 1995-2000 at Vientiane site

Treatment	1995	1996	1997	1998	1999	2000	2001
Farmer’s practice	29.2	30.0	29.7	25.6	23.4	24.0	18.5
Alley cropping	24.0	24.5	24.9	21.6	20.8	21.5	15.7
Alley + Agro	25.5	27.5	27.3	24.5	23.8	22.8	16.8
Agroforestry	20.0	20.7	20.7	19.5	18.7	18.6	15.4

At Luangprabang site potassium available from all treatments declined over time. Potassium available under farmer practice decreased from 29.0 mg/100 g in 1994 to 13.4 mg/100 g in 2001, Under Agroforestry treatment, potassium declined from 19.3 mg/100 g in 1994 to 11.2 mg/100 g in 2001, hillside ditches from 31.2 mg/100 g in 1994 to 19.3 mg/100 g in 2001; alley cropping from 18.8 mg/100 g in 1994 to 13.2 mg/100 g in 2001 and strip cropping from 25.6 mg/100 g in 1994 to 21.3 mg/100 g in 2001. This was due to uptake by annual crops every year and coupled with no input of potassium fertilizer. Similar feature was found at Vientiane site.

4.7 Crop yield

4.7.1 Rice yield

Average upland rice yield from different treatments at Luangprabang and Vientiane site is shown in Tables 17 and 18.

Table 17. Rice yield (kg/ha) from 1994-1997 at Luangprabang site

Treatment	1994	1995	1996	1997	2001	Average
Agroforestry	1 102	1 570	778	failure	no crop	862
Strip cropping	317	491	517	116	failure	360
Alley cropping	745	1 078	716	failure	failure	634
Hillside ditches	397	930	807	failure	failure	533
Farmer’s practice	816	1 100	856	failure	failure	693

Table 18. Rice yield (kg/ha) from 1995-1997 at Vientiane site

Treatment	1995	1996	1997	2001	Average
Farmer's practice	1 270	941	563	575	837
Alley cropping	1 160	972	538	1 031	925
Alley + Agro	1 150	820	478	967	853
Agroforestry	1 420	1 160	528	no crop	1 036

At Luangprabang site, the Agroforestry treatment gave highest yield 862 kg/ha. This due to crop densities is well regularly arranged, when compare with the farmer practice, followed by the farmer practice which produced rice yield of 634 kg/ha.

The alley cropping and hillside ditches gave the lowest yield (634 kg/ha and 533 kg/ha respectively). The lower yields of these treatments were because part of the area on these plots was used for vegetative hedgerow and ditches.

Similar feature, was found at the Vientiane site, the highest rice yield was found under Agroforesty with the yield of 1 036 kg/ha, followed by the farmer practice, alley cropping using flemingia as hedgerow, which produced yield of 924 kg/ha and 890 kg/ha respectively.

Alley cropping using flemingia congesta with banana produced less rice yield than the other treatments with yield of 816 kg/ha, this was due to the effect of shading and nutrient competition from banana.

At both sites, upland rice yield seemed to decline from year to year, this was due to the mono cropping of upland rice, and without legume crop rotation.

4.7.2 Peanut yield

Average peanut yield from different treatments at Luangprabang and Vientiane site is shown in Tables 19 and 20.

Table 19. Peanut yield (kg/ha) from 1998-2000 at Luangprabang site

Treatment	1998	1999	2000	Average
Agroforestry	–	–	–	–
Strip cropping	764	958	676	799
Alley cropping	436	550	432	472
Hillside ditches	463	500	369	444
Farmer's practice	652	894	498	681

Table 20. Peanut yield (kg/ha) from 1998-2000 at Vientiane site

Treatment	1998	1999	2000	Average
Farmer's practice	468	689	429	528
Alley cropping	867	1 059	732	886
Alley + Agro	526	763	360	549
Agroforestry	–	–	–	–

At Luangprabang site, the strip cropping produced highest yield (799 kg/ha), this was due to having regular crop density, followed by the farmer practice which produced yield of 681 kg/ha. The lowest yield were under alley cropping and hillside ditches treatments with yield of 472 kg/ha and 444 kg/ha respectively. This was due to the effect of shading canopy of mango threes.

At Vientiane site, the alley cropping using flemingia congesta as hedgerow gave the highest yield (868 kg/ha), this was due to the application of Diammonium Phosphate at the rate of 100 kg/ha and powered lime at the rate of 1 500 kg/ha. It was observed that under alley cropping using flemingia congesta with banana as hedgerow even fertilizer and lime used as the same rate of alley cropping using flemingia as hedgerow, the yield was still low. This was due to the effect of shading canopy and the competition of nutrient element from banana.

4.7.3 Banana yield

Average banana yield from alley cropping treatment using flemingia congesta with banana as hedgerow at Vientiane site is shown in Table 21.

Table 21. Banana yield (kg/ha) from 1996-2000 at Vientiane site

Treatment	1995	1996	1997	1998	1999	2000	Average
Farmer's practice	–	–	–	–	–	–	–
Alley cropping	–	–	–	–	–	–	–
Alley + Agro	–	3 800	5 600	2 240	720	112	2 494
Agroforestry	–	–	–	–	–	–	–

At Vientiane site, banana yield under alley cropping using flemingia congesta with banana as hedgerow was higher in the first two years with yields of 3 800 kg/ha in 1995 and 5 600 kg/ha in 1996, then declined from year to year. It was noticed that banana can not maintain yield for long period of time.

4.7.4 Mango yield

Average mango yield from alley cropping and hillside ditches treatments at Luangprabang site is shown in Table 22.

At Luangprabang site, after three years old of mango trees, since 1998 the yield of mango under hillside ditches increased from year to year with yield of 215 kg/ha in 1998, 636 kg/ha in 1999 and 920 kg/ha in 2000. Similar feature was found under alley cropping treatment.

Table 22. Mango yield (kg/ha) from 1994-2000 at Luangprabang site

Treatment	1994	1995	1996	1997	1998	1999	2000	2001	Average
Agroforestry	–	–	–	–	–	–	–	–	–
Strip cropping	–	–	–	–	–	–	–	–	–
Alley cropping	–	–	–	–	197	517	890	1 519	780
Hillside ditches	–	–	–	–	215	636	920	2 072	960
Farmer's practice	–	–	–	–	–	–	–		–

4.7.5 *Biomass yield*

Total biomass (rice straw and peanut residues) of different treatments at Luangprabang and Vientiane site are shown in Tables 23 and 24.

Table 23. Total crop residues (t/ha) from 1994-2000 at Luangprabang site

Treatment	1994	1995	1996	1997	1998	1999	2000	Total
Agroforestry	5.53	7.85	3.75					17.13
Strip cropping	3.48	4.53	3.97	1.74	4.25	5.16	3.55	26.68
Alley cropping	3.80	5.44	3.79	–	2.40	2.93	2.30	20.65
Hillside ditches	2.12	4.10	4.62	–	2.60	2.78	2.00	18.22
Farmer's practice								

Table 24. Total crop residues (t/ha) from 1995-2000 at Vientiane site

Treatment	1995	1996	1997	1998	1999	2000	Total
Farmer's practice							
Alley cropping	5.67	4.81	2.68	3.84	4.69	3.24	24.93
Alley + Agro	5.25	4.01	2.54	2.29	3.49	1.59	19.16
Agroforestry	6.74	5.71	2.62				15.07

At Luangprabang site the highest biomass was recorded in the strip cropping which produced biomass of 26.68 t/ha, including, soy been residues, and rice straw, followed by the alley cropping and hillside ditches treatment which produced biomass of 20.65 t/ha and 18.22/ha respectively. While, for the farmer practice treatment crop residues were removed out from the plot.

At Vientiane site, the highest biomass was found under alley cropping using flemingia as hedgerow which gave the biomass of 24.93 t/ha. This was due to the application of fertilizer with lime enhancing biomass production of crops. Followed by the alley cropping treatment using flemingia congesta with banana as hedgerow gave biomass of 19.16 kg/ha. The least biomass was found under Agroforestry treatment, because, after three years old of teak, any crop could not be planted under teak canopy. For the farmer practice crop residues were removed out from the plot.

4.7.6 *Net return*

Net return (US$/ha) from different treatments at Luangprabang and Vientiane site is shown in Tables 25 and 26.

Table 25. Net return (US$/ha) from 1994-2000 at Luangprabang site

Treatment	1994	1995	1996	1997	1998	1999	2000	Average
Agroforestry	-211.39	24.03	-56.17	-157.22	–	–	–	-100.19
Strip cropping	62.67	104.19	48.85	6.87	73.26	136.91	47.17	68.56
Alley cropping	-554.54	-33.67	-75.45	-157.09	76.46	232.30	331.66	-180.33
Hillside ditches	-605.30	-58.40	-51.90	-148.04	91.24	265.87	330.05	-176.68
Farmer's practice	-108.28	-42.09	-52.00	-154.51	37.59	115.63	-9.20	-30.41

Table 26. Net return (US$/ha) from 1995-2000 at Vientiane site

Treatment	1995	1996	1997	1998	1999	2000	Average
Farmer's practice	-133.23	-140.67	-187.02	-12.99	54.58	-38.03	-65.34
Alley cropping	-216.27	-116.05	-174.05	4.85	153.90	53.61	-42.00
Alley + Agro	-308.23	95.22	156.86	38.56	110.94	-47.56	45.79
Agroforestry	-259.09	-93.56	-185.26	–	–	–	-179.30

At Luangprabang site, highest negative net return was found under hillside ditches and alley cropping treatments in the first year of operation. This was due to the high cost of plating material (mango seedlings) coupled with the cost of establishing measure of soil erosion control (ditches and vetiver hedgerow). However, high net return could be received in the succeeding later year with additional income derived from mango trees. Strip cropping gave positive net return for all years due to income from soybean and peanut rather than upland rice. Farmer practice gave negative income in the first four years due to lower price of upland rice. A positive net income could be received when legume crop (peanut) replaced to rice. Agroforestry gave negative net return in the first year of operation (1995) due to the high cost of planting materials (teak seedlings) and in the later year due to crop could not be inter cropped under teak canopy.

At Vientiane site, negative net return occurred for all treatment in the first year of operation. Positive net return could be received in the second, third, fourth and fifth year, however the highest net income occurred in the thirst year (156.86 US$/ha), for the alley cropping using flemingia hedgerow with banana, when high income derived from banana. After that net return decreased from year to year, due to the declining of banana yield. Followed by the alley cropping using flemingia congesta as hedgerow, which could receive positive net return from 1998 to 2000 when upland rice replaced by peanut. Farmer practice gave negative net return for the most of the year due to low crop yield.

5. Conclusions

After seven years of long-term research (1994-2000) on sloping land for sustainable agriculture in Lao PDR, a number of conclusions can be made.

a. Among soil and crop management technologies being validated in Lao PDR, alley cropping using vetiver and flemingia congesta as hedgerow and hillside ditches were very effective in reducing run off and soil loss. The farmer's practice of planting crop without soil conservation measures caused high run off and soil loss.

b. Soil fertility changed after seven years of cropping, the decreasing soil organic matter under farmer's practice was evident after several cropping, the alley cropping and strip cropping shown the least decrease in soil organic matter content. The application of fertilizer and lime for alley cropping treatment resulted in increasing level of phosphorus content and soil pH.

c. Crop yield (annual crop) could be maintained in the first two years, after that declined from year to year.

d. Alley copping using vetiver with mango trees as hedgerow and hillside ditch planting mango trees on the bunds gave high net income in later year (sixth and seven year) after trees produced fruits.

e. Alley cropping using flemingia congesta with banana as hedgerow gave high net income in second, third and fourth year and declined in later year.

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Southeast Asian Country

Paper Number 8

Improving plant nutrient management for better farmer-livelihood, food security and environment*

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Summary

Cereal crops such as paddy rice and maize are very important in Myanmar not only for local consumption but likewise for export. The country, being dominated by degraded soils and resource poor farming communities, is basically depend on indigenous nutrient of the soil and natural fertilizer for crop production. Most soils used for crop production were recorded to suffer from the deficiency of major (N and P) and micronutrients (zinc) and other secondary plant nutrients. Typical crop is paddy rice whose area covers about 62 percent of the net grown area. In 1992, soil samples were collected from different states and division of the country. Comprehensive analysis of their chemical contents done in Agricultural Research of Finland indicated nutrient imbalance and soil infertility. Hence, Land Use Division and Extension Division of Ministry of Agriculture cooperated in carrying-out the movement of Integrated Nutrient Management. In this regard, organic matter production sites are all over the country and are continuously encouraged by the government. On the other hand, the farmers are practicing compost making in various ways, such as pit, heap and efficient storage technique. The government has also been providing support for field testing of the efficacy of biofertilizers in collaboration with international institution.

1. Introduction

No one can survive without plant and soil meeting the essential needs of life being. Moreover, plants would need the soil to supply their nutrients for sustained growth and productivity. Allowing unsustainable extraction of native soil nutrients for plant growth and production will result to degradation of the soil and its environment. If the situation remained uncontrolled, the recovery of the loss of soil productivity may be difficult, if not irreversible, since it takes hundreds of years of natural parent material decomposition processes to develop a new productive soil.

Union of Myanmar is geographically situated on western side of Indochina peninsular, between 9º32' to 28º31' North Latitude and 92º to 101º East longitude. It share 5 858 km of international borders with China, India, Bangladesh, Thailand and Laos.

Total land area of Myanmar is 676 577 sq km, stretching for 2 276 km along the sea coast. The western, northern and eastern parts of the country are hilly regions with altitudes varying from 915 to 2 134 metres. It is the longest country on the main land of Southeast Asia.

* This country report has not been formally edited and the designations and terminology used are those of the author.

Myanmar has tropical and subtropical climates with three seasons, rainy season (mid May to mid October), the dry cold season (mid October to mid February), and the hot season (mid February to mid May).

The average annual rainfall varied from 728 mm to 5 825 mm according to the different regions topography. The coastal and hilly regions received 1 045 to 5 825 mm and the central, dry zone, has 728 mm to 849 mm. The temperature differs according to season and region. Seasonal temperature variation lies from about 30º to 34º Celsius in hot season and 10º to 15º Celsius in cold season for dry zone area, central Myanmar. In contrast, in the hilly region such as Chin Hill and Shan Plateau has a maximum temperature of 29º Celsius and minimum of as low as 7º Celsius.

The total population is recently estimated at 55.14 million (2004-2005) with 2.02 percent growth rate. The population is concentrated in southern part of Myanmar especially in delta area. Around 75-80 percent of the total population at present is residing in rural areas and engaging with Agriculture, Livestock and fishery activities of which 43 percent of the rural population is land less farm labour. The country is blessed with rich water resources and favourable climate that make rice as the national crop and indicator of success in agricultural production.

Economically, Myanmar largely based on agriculture sector, the backbone of its economy contributed 44 percent of GDP (2002-03), 34 percent of total export earning (2001-02) and employ 61.4 percent (2002-03) of the labour force.

Geographically and topographically, Myanmar consists of the series of river valleys running from north to south as slope direction divided from each other by mountain ranges and plateau. The country is surrounded by a mountain barrier on the west north and east with a plateau at the eastern part. Four major rivers are Ayeyarwaddy, Chindwin, Thanlwin, Sittaung and Ayeyarwaddy forms a large delta that is food bowl of the country and strategic location to the major port of “City Yangon”.

Considering the topography, landform, climate, natural vegetation and agriculture, Myanmar is divided into *nine* natural regions such as:

- Yakhine coastal strip (Western)
- Taninthayee coastal strip (Southern)
- Western mountain region
- Northern hilly region
- Central Myanmar (Dry Zone)
- Ayeyarwaddy delta
- Bago Yoma (Central mountain ranges)
- Sittaung river valley and
- Shan plateau (Eastern)

Myanmar constitutes with 135 national races living in 7 States and 7 Divisions. As Myanmar is Agriculture country, land and soil fertility related to the plant nutrient management and soil conservation is undoubted play vital roles. Especially, in crop growing areas, plant nutrient management is an important national programme not only for improving food security but also for the environmental protection and management. In Myanmar, the Ministry of Agriculture and Irrigation has laid down the following three main objectives:

- Surplus in paddy
- Sufficiency in edible oils
- Increased production and export of pulses and industrial crops

2. Status of cultivable land area and soil type

Myanmar is rich with the natural resources such as favourable land, water sources etc. Total land area covers 67.69 million hectares, with arable lands limited to only 17.38 million hectares, or 26 percent of the total land area in Myanmar. The actual land utilization in Myanmar is shown in Table 1.

The country has altogether 24 different soil types classified by soil analysis of Land Use Division and related with adaptable crops as shown in Table 2.

Table 1. Land utilization of Myanmar (2003-2004)

Type of land	Area (million ha)	Percent
Agriculture Land (A + B)	**17.38**	**25.67**
(A) Net Sown	**10.30**	**15.22**
Le	5.79	8.55
Ya	2.97	4.40
Kanin/Kyun	0.51	0.75
Orchard	0.78	1.15
Other	0.25	0.37
(B) Cultivable Land	**7.08**	**10.45**
Fallow	0.51	0.75
Cultivable waste	6.57	9.70
(C) Reserved Forest	**15.29**	**22.58**
(D) Other Forest	**18.16**	**26.84**
(E) Other land	**16.86**	**24.91**
Total	**67.69**	**100.00**

Table 2. Soil types of Myanmar

Sr. No.	Soil type	Area (mil. ha)	%	Suitable crops
1	Fluvisol	0.74	1.1	Pulses, Chilies, Onion, Vegetable, Groundnut, Paddy, Jute, Maize, Sesame
2	Gleysol	3.07	4.5	Paddy, Pulses, Sesame, Maize, Sugarcane, Vegetable. Groundnut, Cotton, Jute, Tobacco
3	Gley-Gleysol	0.56	0.8	Paddy, Jute
4	Gleysol-Calcaric	0.06	0.1	Paddy, Chilies, Pulses, Sorghum, Maize, Cotton
5	Ferralsol (plinthic)	0.59	0.9	Mango, Durian, Rubber, Coconut, Cassava, Pineapple, Banana, Oil palm
6	Ferralsol (rhodic)	9.97	14.7	Forest, Rubber, Pine-apple, Horticulture, Mango, Tea, Coffee
7	Ferralsol (xanthic)	8.36	12.4	Forest, Rubber, Pine-apple, Horticulture, Mango, Tea, Coffee
8	Gleysol (humic)	0.20	0.3	Mangrove Forest
9	Arenosol	0.24	0.4	Forest
10	Solonchak (thionic fluvisol)	0.04	0.1	Mangrove Forest
11	Gleysol (solonchak)	2.24	3.3	Paddy, Vegetable, Jute, Sugarcane, Pulses
12	Cambisol (d)	1.09	1.6	Upland crop, Horticulture, Maize, sesamum
13	Nitosol (cambisol)	0.53	0.8	Horticulture, Sesame, Groundnut

Table 2. *(continued)*

Sr. No.	Soil type	Area (mil. ha)	%	Suitable crops
14	Catena of luvisol	1.78	2.6	Paddy, Chilies, Groundnut, Sesame, Cotton, Pulses, Sugarcane, Fodder, Sunflower, Sorghum, Vegetable
15	Vertisol	0.48	0.7	Paddy, Groundnut, Sesame, Pulses, Sunflower, Sugarcane, Chilies, Sorghum, Fodder
16	Acrisol	4.13	6.1	Upland rice, Coffee, Tea, Vegetables, Groundnut, Sesame, Maize, Pulses, Niger
17	Cambisol (h)	6.29	9.3	Forest
18	Cambisol (c)	1.37	2.0	Forest
19	Cambisol (orthic)	2.46	3.6	Forest
20	Cambisol (orthic)	2.19	3.2	Forest
21	Cambisol (gelic)	2.60	3.8	Natural reserved
22	Andosol	0.05	0.1	Forest
23	Lithosol (turfy primitive)	0.24	0.4	Forest
24	Lithosol (primitive crushed stone)	0.29	0.4	Forest
25	Not suitable for crop	18.12	26.8	–
	Total	**67.69**	**100**	

3. Status of crop area and crop production

The diverse agro-ecological conditions prevailing in the country have allowed Myanmar to grow over 60 different crops species of economic importance. Due to the population growth rate and market demand in Myanmar, government emphasize the extension of cultivable land and cropping intensity to increase crop yield per acre. Unfortunately, however, the national government did not provide equal and adequate attention to the judicious management of soil and environmental resources for sustainable plant growth and production. Yearly status of crop sown area and crop production is shown in Table 3.

4. Past and present situation of plant nutrient status

After 1948, mountains ranges with low population growth rate but with plenty of cultivable lands have used the shifting cultivation method. The central dry zone areas with optimal population growth rate used only one crop growing system and delta areas with large population growth rate used continuous rice growing system year after year.

These strategies resulted to soil erosion and degradation as well as increase the plant nutrient deficiency. However, at that time, land utilization and population growth rate are harmonious, hence the farmers could still use the fallow system.

In 1976, the government encouraged the implementation of production programmes that combined the use of high yielding varieties and increased application of chemical fertilizers. The immediate impact of the programme is the accelerated attainment of high rice yield per acre. However, in long-term, the high yields were not sustained because of incomplete provision of supply including appropriate amounts and combination of chemical fertilizers. This is explained by the fact that high yielding plant varieties take up large amount of nutrient from the soil and the inability to replenish

Table 3. Yearly status of crop area and production in Myanmar

Sr. No.	Crop Name	Sown area ha ’000			Production mt ’000		
		1988-89	2004-05	Increased (%)	1988-89	2004-05	Increased (%)
1	Paddy	4 778	7 008	147	2.91	3.60	124
2	Wheat	135	103	76	1.07	1.34	125
3	Maize	138	307	223	1.60	2.67	167
4	Sorghum	177	230	129	0.72	0.79	109
5	Black gram	92	747	813	0.79	1.05	133
6	Green gram	50	787	1 586	0.51	0.91	180
7	Butter bean	34	55	163	1.12	1.06	95
8	Sultapya	35	63	181	0.66	1.03	154
9	Soybean	34	138	402	0.80	1.10	137
10	Chickpea	138	196	142	0.75	1.10	146
11	Pigeon pea	138	553	400	0.78	0.95	122
12	Garden pea	50	787	1 586	0.58	0.96	167
13	Groundnut	548	672	122	0.85	1.36	160
14	Sesame	1 212	1 513	125	0.22	0.38	170
15	Sunflower	212	533	252	0.73	0.69	95
16	Cotton	179	315	176	0.37	0.65	174
17	Jute	49	27	55	1.09	1.02	94
18	Rubber	78	199	256	0.37	0.57	155
19	Sugarcane	50	146	293	50.16	49.42	99
20	Coffee	14	14	103	0.47	0.55	118
21	Potato	14	34	133	8.76	13.04	149
22	Virginia tobacco	2	4	218	5.09	7.06	139

the lost nutrients causes severe nutrient depletion and the corresponding decline in crop production. This situation holds true for perennial crops. A case in point is the practice of low and unbalanced fertilizer use in a continuous cropping in the Upper Delta region and large uptake and export of plant nutrients resulted in a negative soil fertility budget and subsequent loss of soil fertility, decline in crop yields and deterioration of environmental quality.

5. Soil and plant nutrient relationship

Soils are an integral part of the ecological system which serves as natural resource base to support the production of our basic food and fiber needs. Soils are the fundamental medium for plant growth and basically act as the storehouse for the water and nutrients essentials for plant growth. In most instances, the natural supply of nutrient form the soil remained inadequate to meet the needs of the plant and which therefore threatened the overall supply of food and fiber needs of the country.

The improper cropping systems and cropping patterns which is centered on the increase in the crop density per unit area and mono-cropping to compensate for less arable lands caused the increasing depletion of soil fertility. The inability to formulate balanced fertilizer formula has wide and far reaching impacts on soil fertility characterized by serious nutrient deficiency and the increasing problems on micronutrient deficiencies as in the increasing incidence of serious zinc deficiency in a continuous irrigated rice growing in the country.

In Myanmar, cereal crop such as paddy and maize are very important not only for local consumption but for export. Pulses, oilseed crop, and major group in rice based cropping system accreting to the nature of crop, soil and weather relationship. Other crops needed to be improved to attain food security and raw materials for industry.

Rice requires a high N input and moderate to high soil fertility. Intensive rice cropping with 2-3 crop/year and larger yields results in a risk of depleting the soils reserves of phosphorus and potassium. The amount of nutrients, particularly P and K, are forever lost by the soil and will need to be considered in fertilizer formulation. Those however, stored in the rice straw that contained large amount of K and roots can be recovered as nutrient source depending on whether these are recycled or plowed back to field or removed from the field for use as animal feed, fuel, or other uses.

The optimal ratio of fertilizer N: P: K to be applied is site/soil specific as it depends on the yield target and the supply of each nutrient from soil indigenous sources. Optimal N, P and K uptake at harvest of modern rice varieties:

Plant part	N	P	K
	Kg uptake/grain yield		
Grain	9	1.8	2
Straw	6	0.8	13
G + S	15	2.6	15

A. Plant nutrient in crop in growing soil

In 1992, soil samples were collected from different states and division of the country. These samples were comprehensively analysed for their chemical contents in Agricultural Research of Finland. The results of the analysis showed that:

- 30 percent of all soil samples have lower pH 5.5 and these are acidic soil. Most of the soils in Myanmar are suitable for crop growing.
- Organic matter content is low and most of the paddy lands are deficient in phosphate nutrients and 70 percent of which are very low condition. Bago division, Yangon, Ayeyarwaddy (Delta), Mandalay, Sagaing, Magwe division and Mon and Yakhaing States have very low phosphorus status. In 50 percent of soils, potassium also low and very low condition and the rest 40 percent is moderate.
- Zn deficiency occurred in Mandalay, Bago west and Ayeyarwaddy (Zn content low and very low condition).
- S and Boron deficiency break down is 70-80 percent of the total growing soil. Especially, in oil palm growing area, Boron deficiency is very serious.

B. Nutrient loss

The nutrient loss and increasing soil infertility in Myanmar are attributed to the following situations:

- Soil erosion by water
- Acidic soil problem in high rainfall areas such as mountainous regions. In this condition, P is fixed and unavailable for plant use and the Al, Mn and Fe could have reached toxic levels for some plants.

- Soil degradation and depletion of soil fertility by wind erosion in dry zone area. (In these regions, not only less rainfall but parent material, groundwater table result in salinity problem and nutritional imbalance.)
- Traditional farming such as shift cultivation, lack of proper agronomic practices, forest burning and more crop production in low fertility land without fertilizer induces the soil fertility depletion and even increased the risks to the natural environment.
- Poverty and soil fertility reduction: Most of the farmers in Myanmar are resource poor and basically depend on the indigenous nutrient of the soil and natural fertilizer for crop production. They simply can not afford to buy fertilizers especially under current increases in the cost of fertilizer such as Urea, TSP, MOP.

C. Nutrient deficiency

As the typical crop is paddy, its growing areas cover about 62 percent of the net grown area where major nutrient N, P deficiencies and minor nutrient Zn, S deficiencies are greater.

N deficiency

Nitrogen deficiencies occurs in all of the major rice growing regions area (Ayeyarwaddy, Bago, Mandalay Division and Dry Zone areas) caused by low fertilizer use efficiency (Losses from volatilization, denitrification, in correct timing and placement, leaching or run off and temporarily immobilized by soil microbes.) and very low organic matter content, poor indigenous N supply and alkaline and calcareous soils. In Myanmar, farmers utilize Urea fertilizer as sources of N. N affects all parameter of plant growth that contributes to yield. N reaction related to the demand for other nutrients such as P, K and S.

P deficiency

P deficiency rarely occurs in rice growing regions except acid soil, acid sulphate soil saline and sodic soil, peat in dry zone soil area and in coastal regions. Thus, deficiencies cannot affect economic yield target. Low indigenous soil P, supplying insufficient application of mineral P fertilizer, high P fixation capacity in soil or erosion losses and crop establishment in direct seeded rice growing areas where plant density is high and root system are shallow occurs P deficiencies. The farmers used to apply chemical fertilizer such as only Urea and do not apply P and K fertilizer in long-term, imbalance nutrient occurred and damaged the natural balance of soil and environment.

Zn deficiency

Zn deficiencies largely occur in major rice growing areas especially in irrigated areas. Zinc deficiency generally occur in intensively cropped soils, triple rice crop systems, calcareous, sodic, saline neutral, old acid sulphate soil, peat and sandy soil, highly weathered area. The deficiency is widely spread in rice growing areas of delta, dry zone and coastal area.

S deficiency

It occurs in dry zone area, many rural areas and irrigated rice-grown areas. In these areas, depletion of soil S is evident because of intensive cropping, use of S free fertilizer, small quantities of SO_4^{2-} in irrigation waters and forest burning. Sandy soils are also prone to S deficiency.

Fe deficiency

Fe toxicity affects wide range of the rice growing areas, due to flood occurrence in long time, low pH, acid condition and poor root oxidation and large Fe^{+2} concentration. Common feature of Fe toxicity sites are poor drainage and low soil CEC in lowland rice growing areas and highland peat soils.

6. Activities of integrated nutrient management in Myanmar

Land Use Division and Extension Division of MOAI cooperated in carrying-out the movement of Integrated Nutrient Management. The activities include the following:

- Dissemination to the farmers on the proper use of scientific and modern agrotechnique such us more utilization of chemical fertilizer and organic manure and provision of chemical fertilizer.
- Laying down the planning of long-term and short-term for soil fertility, prevention of soil degradation and environmental deterioration.
- Implementation of Research and demonstration in soil problem areas.
- Implementation of the soil and nutrient management project and soil conservation methods.

7. Production and utilization of chemical fertilizer and organic manure

Plants obtain their nutrients from two main sources of fertilizer application and indigenous nutrients in soil. These sources are necessary to be applied in balance ration to the soil. Chemical fertilizer is undoubtedly one of the agricultural inputs to increase the high yield when used in proper time, proper nutrient balance and combination and in adequate amount as needed by specific farm site and plant varieties.

In Myanmar, chemical fertilizer application for paddy crop started in 1956-1957. However, proper application was adopted in 1978 as part of the package of the IR 8, the first high yielding variety that supports the Green Revolution campaign. After 1978, farmers widely used chemical fertilizer because of the proven good response to the applied chemical fertilizer by high yielding rice varieties. Government encouraged the farmers to use the chemical fertilizer by subsidizing the prices and by constructing three (3) Urea Processing Plants with the planned production of about 300 thousands tonnes per years.

Table 4 shows that the highest utilization of chemical fertilizer reached the level of about 415 thousand tonnes in 1985 and 1986. This trend was attributed to the implementation of the Special High Yield (SHY) Programme adopted by each township in Myanmar. However, after 1986, utilization of chemical fertilizer descended because inability to sustain the support for SHY programme. In 1991-1992 with the adoption of summer rice programme, the fertilizer utilization resumed the positive growth. However, due to the high fertilizer prize, fertilizer utilization once again declined after 1995-1996.

Table 4. Utilization of chemical fertilizer in Myanmar

Year	Rice sown area '000 ha	Fertilizer use in rice cultivation mt ('000)					Table equivalent nutrient mt ('000)			
		Urea	TSP	Potash	Others	Total	N_2	P_2O_5	K_2O	Total
1985-86	4 907	288	103	24	–	415	132	47	14	193
1991-92	–	137	22	2	–	161	63	10	1	64
1996-97	5 880	163	50	23	27	263	79	27	16	122
1997-98	5 789	94	19	1	3	117	43	8	1	52
1998-99	5 761	124	9	3	–	136	57	4	2	63
1999-2000	6 391	156	33	8	–	197	72	15	5	92
2003-04		157	98	10	–	205	72	45	6	123

Source: MAS planning division (1999-2000).

8. Domestic production of fertilizer

Myanmar established 3 state own factories, which can produce capacity of 425 000 tonnes of Urea per annum, was constrained by lack of utilities and cost of power generation, which limit the factories to operate at an annual average of only 46 percent of its capacity. Table 5 shows yearly domestic production of Urea.

Table 5. Domestic production of Urea in Myanmar

No.	Location	Year established	Capacity thousand tonne/annum	Capacity utilization (%) 1993-94
1	Sale (Magwe Division)	Plant A 1970 Plant B 1984	70 85	65
2	Kyunchaung (Magwe Division)	1970	70	57
3	Kyawzwa (Magwe Division)	1985	200	59
	Total		**425**	**46**

Notes: Capacity initialization is based on 330 days.

Source: Agro-chemical News in brief, vol. XVII, No. 3. 1994.

9. Fertilizer import

Since 1990, the government of Myanmar has initialized trade liberalization policies. Owing to this policy, the government and private sector imported various fertilizers in 2003-2004 shown in Table 6.

10. Fertilizer distribution

After 1990, with initiation of trade liberalization policies, the private sector participated and competed with government agencies (e.g. Myanmar Agriculture Service, MAS) in the fertilizer procurement and distribution. For distribution of fertilizer, MAS was holding its role because of its storage facilities and agricultural extension staffs who could reach the grass root level of farmers. Moreover, sometimes MAS's fixed prices were cheaper than that of private sectors.

Table 6. Fertilizer import (2003-04, metric tonne)

Sr. No.	Type of fertilizer	Border trade	Normal trade	Total
1	Urea	109 506	47 979	157 485
2	T-Super	78 255	19 500	97 755
3	Potash	205	10 000	10 205
4	Compound	25 372	7 516	32 888
5	Ammonium Nitrate	4 159	–	4 159
6	Ammonium Sulphate	435	13	448
7	Foliar Spray	–	138	138
8	Others	–	440	440

At present, the private fertilizer trade grows significantly in Myanmar. The local traders mainly import Urea fertilizer from Qatar, Iran and Indonesia and phosphates fertilizers from the neighbouring counties like People's Republic of China and Thailand. Private entrepreneurs put up in the local market and import fertilizers through borders trade as well as normal trade. In Myanmar, states and division authorities, the member of State Peace and Development Council (SPDC) are also responsible to increase the agriculture production. Some of the regional commanders got fertilizers from local entrepreneurs and distribute to farmers in term of after harvest payment with help of MAS extension staffs.

11. Soil nutrient budget and nutrient uptake

The results of the study of the Phosphate Potash Institute (PPI) in 1993 showed the soil nutrient budget and nutrient uptake in Table 7 and the result on the Yearly Nutrient Input and Output study are shown in Table 8. The study for the fertilizer requirements for Urea, T-Super, and potash are shown in Table 9.

Table 7. Soil nutrient budget and nutrient uptake in Myanmar

Crop	Sown acre (million)	Yield tonne (million)	Nutrient uptake (tonne, '000)				
			N	P_2O_5	K_2O	MgO	CaO
Edible Crop (1)	16.1	18.2	451	140	618	79	87
Fruit	0.7	3.2	30	11	36	5	8
Vegetable	0.2	3.5	13	2	10	2	7
Case Crop (2)	–	–	–	–	–	–	–
Perennial Crop (3)	0.5	0.2	3	1	7	1	1
Total	**17.5**	**25.1**	**497**	**154**	**671**	**87**	**103**

Remark: (1) Paddy, Maize, Soybean, Groundnut, Cassava and Sweet potato; (2) Sugarcane, Tobacco, Coco, Tea, Coffee; (3) Coconut, Oil palm.

Source: PPI Singapore, 1995, FAO, 1994, IFAW-Fertuse.

Table 8. Yearly input & output data of soil nutrient in Myanmar

Parameter	Nutrient input & output, tonne ('000)				
	N	P_2O_5	K_2O	MgO	CaO
Input					
Natural fertilizer	107	54	143	57	25
Chemical fertilizer	49	14	5	5	15
Output					
Plant Nutrient Uptake	497 (-341)	154 (-86)	671 (-523)	87 (-25)	104 (-64)
Nutrient Requirement					
Kg/ha	48	12	73	4	9
lb/acre	43	11	65	4	8

Table 9. Yearly fertilizer requirement of Myanmar

Measurement	Unit	Urea	Triplesuper-phosphate	Potash
National	tonne ('000)	741	191	871
Per acre	lb/acre	43	11	65

12. Organic fertilizer utilization

The rise in fertilizer prices in Myanmar affected the poor farmers in Myanmar, who have no options left but to depend on the use of any available organic and natural fertilizers. Because of its affordability to most resource poor farmers, the expanded uses of FYM become more important in maintaining crop yields and in sustaining good soil quality and soil fertility. Moreover, Myanmar has tried to introduce the decomposition technology. The raw materials for compost making were not enough because of the increasing multi-user demands and uses of crop residues and weeds.

As a part of the campaign to boost organic matter utilization, Myanmar embarked the enhancing of the green maturing technique and organic fertilizer production. Notable efforts are done on the Sesbania Rostata, one of the many species found to be promising green manure crop by the researchers in Myanmar. According to research findings, at the seed rate of 22 kg/ha. Sesbania plants gives additional equivalent N inputs of 42.5 kg/ha when plowed in at the age of two months after sowing. The researchers likewise recognized a number of practical constraints that prevent widespread acceptance of the sesbania-base green manure technology. This includes area shortage for seed production, moisture availability, and short duration between crop sequences, need for new improved cropping pattern and draught power scarcity and many others that affects farmer labour use and availability. Whatever the case may be, with the persistent yearlong educational programmes, the farmers have started adopting the technology and likewise have improved further their awareness that the use of green manure improves soil structure, its fertility and crop yields.

Currently, organic matter production sites are all over the country and are continuously encouraged by the government. The private sectors and local government are doing their share in the advocacy and promotion organic farming as shown by production of organic fertilizers from wastes of urban and agro-based industry sectors.

13. Biofertilizer utilization

Various kinds of biofertilizer were utilized for many years ago. There are rhizobium, blue green algae, azolla and micorhyza. Rhizobium, is gaining wider and popular acceptance because farmers can see, understand the value on crop production and can easily adopt the technology by themselves. This is not the case of blue green algae and azolla which is laborious and required some specific knowledge.

In the lowland areas of Myanmar, after rice pulses are grown as second crops. Most of the second crops in this system are leguminous and there is a larger scope of the use of biological fertilizer for rhizobium as increasing yields of legumes with minimum fertilizer addition. Considerable research efforts were done since 1978 for the selection of effective rhizobium strains for groundnut, chickpea, mung bean, green gram. Myanmar Agriculture Service has produced annually rhizobium in the range of 100 mt of biofertilizer. In general, the use of $^1/_2$ kg of rhizobium could bring an increase of crop yield. This yield level is also attained by the application of 30 kg N (or 67 kg Urea per hectare).

On the other hand, E.M. (effective microorganism) has been introduced since 1993 by collaborative project with International Nature Farming Research Center (INFRC) of Japan. E.M. is very beneficial for crop production because of its better crop yield, better protection of pests and disease, improvement in soil moisture, structure and texture, rapid decomposition of biomass. Accordingly, the utilization of E.M. is gradually, increased yearly. Fast decomposition techniques are introduced by using E.M. The farmers are practicing compost making in various ways, such as, pit, heap and efficient storage technique. The efficacy of biofertilizer is field tested in many techno-demonstration areas funded by government.

14. Research and demonstration in soil problem areas

Land Use Division under MAS is responsible to do the research and demonstration plots in soil problem areas as routine work. It consists of 12 regional offices; they are located in different division and states. For acidic problem, liming experiments and demonstration plots have been done in delta regional office, Pathein. Likewise, Gypsum experiment are in alkaline problem areas of central Myanmar, Sloping Agriculture Land Technique demonstration plots on hilly, mountain ranges and wind break plantation and soil conservation demonstration plots in dry zone and eroded region have been continuously carries out and these acridities are directly or in directly related to the soil fertility and plant nutrient availability.

15. Recommendation for future planning of improving plant nutrient management for better livelihood of farmers, food security and environment

a. Establish and strengthen human resource development by the conduct of short-term and long-term international and in-country training

b. Strengthen capacity of NARES partners within county and abroad.

c. Develop and provide knowledge and technologies for different farming communities.

d. Strengthen support to national and local policy-making process.

e. Provide an international platform for dissemination of technologies.

f. Undertake local projects and international projects in cooperation with FAO of United Nations and other advanced technology countries.

16. Conclusion

For better livelihood of farmers, Myanmar laid down long-term and short-term planning for improving the soil and land management including plant nutrient. In addition, the government has been enthusiastically participating in sustainable environmental management. Therefore, Myanmar would fully support and cooperate with international activities on plant nutrient management, poverty alleviation, environmental management and integrated food and livelihoods security of the people.