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MESSAGE FROM IPI

The ability of food production systems to feed the world's growing population is an increasing cause for concern and there is an urgent need for more effort to develop new and innovative ways of achieving food security.

Stagnant productivity and declining farm incomes in many parts of South Asia have made the issue of crop sustainability more and more relevant. Unbalanced crop nutrition often results in a decline in crop productivity; sub-optimal realization of genetic potential under high-yielding cropping systems; and negative environmental consequences. Hence, it is the right time to review the progress of research carried out in this field and to develop updated strategies for sustaining crop productivity.

On an average, the rice-growing area of Bangladesh is declining at a rate of about one per cent per year, mostly as a result of industrialization. The two most recent major flood and cyclone events in 2007 have also severely impacted on the rice supply in the country. Moreover, the current crisis in fertilizer availability only aggravates an already difficult situation.

Nutrient management has therefore become a key priority for increasing grain production in the country, along with the need to optimize use of limited fertilizers, and to improve soil fertility in intensively cultivated areas. It is likely that food insecurity will continue to prevail in the near future and there should be a concerted nationwide effort in Bangladesh to increase grain production.

The International Potash Institute (IPI), based in Switzerland, conducts research and extension activities aimed to improve balanced nutrition of crops, with emphasis on fertilization with potassium. To meet these goals, IPI sponsors research projects; organizes seminars, symposia and workshops; conducts research and demonstration experiments; and publishes scientific literature in different languages. IPI coordinators in various regions liaise with researchers, extension officers, government officials, farmers and their advisors.

IPI has a long association with various stakeholders in Bangladesh and in recent years has conducted several projects on rice-based cropping systems in collaboration with the Bangladesh Rice Research Institute (BRRI). IPI has successfully organized many farmers' meetings as well as training programs for fertilizer dealers, in cooperation with BRRI and the Bangladesh Fertilizer Association (BFA).

The joint IPI-BFA-BRRI International Workshop on 'Balanced fertilization for increasing and sustaining crop productivity', 30 Mar–1 Apr 2008, in Dhaka, focused on discussing balanced fertilization, particularly in the context of potassium nutrition and its affect on soil fertility, yields, quality and sustainability of agricultural systems. Prominent national and international scientists were invited to deliver presentations, including leading specialists from the International Rice Research Institute (IRRI, Philippines), Netherlands Development Organization (SNV), Potash Research Institute of India (PRII), Tamil Nadu Agricultural University (TNAU), Fertilizer Association of India (FAI), BRRI, Bangladesh Agricultural Research Institute (BARI), Bangladesh Agricultural University and University of Dhaka. Most papers are included in these Proceedings.

We hope that this publication will serve as a valuable source of information for scientists, extension officers, and fertilizer dealers in Bangladesh.

Hillel Magen
Director, International Potash Institute (IPI)

MESSAGE FROM BFA

Balanced Fertilization, which is the main objective of good soil management and holds the key to optimum crop production, supplies nutrients in adequate amounts and suitable proportion for proper growth and development of crop plants for augmenting targeted yields without any detrimental effects on crop yield. Chemical fertilizer was introduced in our country in the year of 1949-1950 with the import of only 2600MT of Ammonium Sulphate. Since then, fertilizer use in the country is steadily and progressively increasing. During this year 2007-2008 the demand of chemical fertilizers has been determined 4.372 million MT. Agriculture is the life force of Bangladesh economy. It plays a vital role in socioeconomic progress and sustainable development through upliftment of rural economy, ensuring food security by attaining autarky in food grain production, alleviation of poverty and so on. Bangladesh as a whole has been food deficit area for a long time. During 2004-05, the combined contribution of all sub-sectors of agriculture (crop, livestock, forestry and fisheries) to GDP was 21.91 percent.

In Bangladesh promotion of balanced fertilization practices generated on different crops and cropping patterns at the various National Agricultural Research System (NARS) institutes like BARI, BRRI, BINA, BJRI, BSRI etc. are transferred through various mechanisms. One of the main mechanism is through the Department of Agricultural Extension (DAE), which directly takes the balanced fertilization practice or technology to the farmers' fields for demonstration. Besides that, BFA directly involved along with other private sectors in agricultural development activities and take this technology to the doorsteps of the farmers.

The Bangladesh Fertilizer Association (BFA), a non-profit, non-political organization having about 7000 members is the largest private business organization in the country since 1994. The vision of the association is to protect, develop, support and promote all measures and steps towards open/free competitive marketing, trade and manufacture of all fertilizers and plant nutrients in Bangladesh and to co-ordinate the efforts of the members of the Association towards this end. BFA is representing in different Government Committees related to policymaking and other agricultural development activities.

Earlier BFA worked with FAO under a project in obtaining the results of research on soil test based nutrient needs & fertilizer use on crops and soils as well as to disseminate such information to farmers, dealers, distributors and merchants to improve fertilizer use efficiency & to improve crop and food production.

BFA has a monthly publication named URBORA in Bengali since 1999, which focuses up to date information and extension message on fertilizer and fertilizer use. BFA also publishes a half yearly international standard scientific journal entitled **Bangladesh Journal of Agriculture and Environment (BJAE)** where many of the papers cover fertilizer related research activities**.**

I think Balanced Fertilization is one of the most important cultivation techniques that ensure optimum supply of nutrients for successful crop production and maintenance of soil health. The supply of nutrients to the soil – plant system comes from various sources, the most important sources being the organic manure and chemical fertilizers.

The jointly arranged IPI-BFA-BRRI International Workshop on **"Balanced Fertilization for Increasing and Sustaining Crop Productivity"** 30 March-01 April 2008 in Dhaka, Bangladesh will help to increasing the knowledge those who are involved in the agricultural activities.

I hope that this publication is a valuable source of information for the all agricultural personnel's and the participants to future action plan for their respective country.

Kafiluddin Ahmed
Chairman, Bangladesh Fertilizer Association (BFA)

MESSAGE FROM BRRI

We are pleased to know that the Bangladesh Fertilizer Association (BFA) is going to publish a special issue of the Bangladesh Journal of Agriculture and Environment on the occasion of the International Workshop jointly organized by BFA-IPI-BRRI on Balanced Fertilization for Increasing and Sustaining Crop Productivity.

During last years, the Bangladesh Rice Research Institute (BRRI) in collaboration with the International Potash Institute (IPI) has been conducting several site-specific trials on different cropping systems. The joint activities also included farmers' meetings, training programmes for fertilizer dealers, workshops, seminars and extension activities which have a positive impact on increased crop productivity of the country.

We appreciate the BFA initiative to publish the documents especially the important findings of the research activities on the relevant areas conducted by different experts at home and abroad.

I hope the special issue of the journal will be helpful to policy makers, agribusiness community and those concerned with the subject.

Dr. Md. Nur-E-Elahi
Director General
Bangladesh Rice Research Institute (BRRI)
Gazipur

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DEVELOPMENT OF AGRICULTURAL POLICIES IN BANGLADESH

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Abstract

This study reviews different papers both published and unpublished articles with the aim to develop guideline for sustainable agriculture so as to help reducing poverty and ensuring food security through increased crop production. A well-coordinated research and extension system is needed for the rapid development of agricultural sector of Bangladesh. The paradigm of agricultural research and extension system needs to be shifted from a supply-driven to a demand-driven approach. Good governance in planning, coordinating, implementing and monitoring the programs with necessary incentives at each level to be ensured. Strengthen the linkages and coordination between research-extension information management systems. Ensure adequate supply and timely delivery of inputs like seeds and fertilizers at the doorstep of the farmers. Mechanization in agriculture is essential for minimizing cost of production. The idea of market integration is obsolete in terms of providing benefits to both producers and consumers at the present situations. On the other hand, market control through increasing supply and delivery system could benefit both the stakeholders equally. Equal emphasis on all agricultural sectoral development i.e., crop, livestock, fisheries and forestry should be given. Massive public and private investment in all sectors will create multiple effects facilitating a more dynamic agriculture in the economy

Introduction

Agriculture is the driving force of the Bangladesh economy. It is the dominant economic activity of the country. Many of us think it as the life-blood of the rural economy of Bangladesh. As the largest private enterprise, agriculture contributes about 21% to the country's GDP. It is the major source of supply of raw materials for the country's agro-based industries. It is also a source of food and nutritional security, employment and income generation as well as reducing rural poverty. However, an official estimate says that this sector is threatened due to declining trend of its productive land by 1% every year and the land quality is deteriorating owning to degradation of soil fertility, soil erosion and soil salinity. In addition, water resources are also shrinking due to uplifting a huge amount of water for crop production and day-to-day use by ever increasing population of Bangladesh. So, in order to produce more food for country's increasing population and raw materials for its agro-based industries, there is need for increasing agricultural growth through higher productivity, including yield, agricultural intensification and diversification and value addition.

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In order to achieve the GDP growth rate of 6-7% per year, agriculture must grow by at least 4% per year. This is presumably possible through an increase in agricultural productivity (i.e., crops, forestry, livestock, poultry and fisheries) based on modern agricultural technology and a supply of chain linking farmers with consumers in the domestic as well as overseas markets.

Moreover, the Millennium Development Goals (MDG) of the Government of Bangladesh emphasizes to reduce poverty to at least 50% of its population living below the poverty level by 2015. To do so, a sound macro-economic policy framework, the Poverty Reduction Strategy Paper (PRSP) entitled *"Unlocking the Potential – National Strategy for Accelerated Poverty Reduction"* highlights the need for higher growth in rural areas, development of agriculture and rural non-farm economic activities as one of the four priority areas to accelerating pro-poor economic growth.

To reduce rural poverty and improve rural livelihoods, it is necessary to recognize and to develop existing agricultural production system into a dynamic and viable commercial sector. The challenges for the Bangladesh agriculture remain confined not only to raising productivity and profitability, reducing instability and increasing resource-use efficiency, and improving equity, but also meeting demands for commercialization and diversification of agriculture.

The existing agricultural production system demands considerable scientific and technological input to be supported by appropriate value addition and market linkages, which requires increase and effective public expenditure in research and extension.

In recent time, new issues and concerns have emerged, which need to be addressed in the development of national agricultural policy. This necessitates the revision and updating of the earlier documents to make it relevant to the present agro-economic context.

Objectives of the National Agricultural Policy

The agriculture policy broadly aims at creating an enabling environment for sustainable growth of agriculture for reducing poverty and ensuring food security through increased crop production and employment opportunity as envisaged in Poverty Reduction Strategy (PRS), SAARC Development Goals (SDGs) and Millennium Development Goals (MDGs).

The objectives of the National Agricultural Policy are to provide a set of guidelines as to:

- Increase productivity and generate income by transferring appropriate technologies;
- Promote competitiveness through commercialization of agriculture;
- Harness and develop emerging and improved technologies through research and training;
- Promote a self-reliant and sustainable agricultural system.

1. Research and development

A well-coordinated research system is needed for the rapid development of agricultural sector of Bangladesh. The paradigm of agricultural research system needs to be shifted from a supply-driven to a demand-driven approach, which requires a series of strategic action as:

♦ Governance of research institutions

The research institutes are working independently. They develop their research program by themselves passed through respective program area meeting. BARC as an apex body of the NARS, calls program review meeting of the concerned disciplines. Each NARS institute presents their research program in the meeting for discussion and improvement based on national priority basis. BARC, an apex body of NARS, in this case is coordinating the research program development stage. However, further attention needs to be given among others on:

- Strengthening of coordination in planning, monitoring and implementation of research program by the NARS Institutes could be done.
- Incentives and built-in reward will be provided to individual researchers or research institutes for innovation, excellence in agricultural research.
- Adequate research contingency support will be provided to scientists and institutionalize project-based activities.
- Government should foster research environment for better return from investment.
- Appropriate infrastructure will be built and existing infrastructure will be maintained for research, training and outreach programs.
- The National Agricultural Research Institutes, i.e. BRRI, BARI, BJRI, etc., need to be strengthened with adequate manpower development programmes (e.g. sufficient scope for higher education and training), job promotion through introducing upgrading the positions at all levels.

♦ Research relevance

- The supply-driven research needs to be changed with demand-driven research.
- The government will emphasize practicing of research planning and prioritization as bottom-up initiatives.
- The government will encourage promotion of participatory approach for conducting research activities.
- Farm management research for identifying optimum size of holding appropriate to support at least the family having a family size equal to the national average (i.e. 5.8 persons holding family with modern amenities).
- Biotechnology research for both rice and non-rice crops needs to be strengthened further targeting the disadvantaged regions like deeply flooded areas, char land, flash flood prone areas, coastal tidal surge and salinity prone areas, and hilly areas.

- **Diversified agriculture**
  - Research focus should be given on diversification of agriculture and on whole farm activities for farmers.
  - Attention will be given to post-production technologies, value addition, agri-business management and trade.
  - Sufficient government support for high priority research on the emerging issues including rainfed agriculture, emphasizing intensification and diversification of agriculture to improve productivity, stability and sustainability of the production system.
  - Government funding for agricultural policy research technology dissemination system should be ensured.
- **Transfer of technology**
  - Research institutions will lay emphasis on technology assessment, refinement and transfer by improving interface with farmers and other stakeholders.
  - Involvement of scientists in outreach extension program to be extended.
- **Equity in the delivery of services**
  - Decentralization of agricultural research management among the NARS institutes should be ensured so that the benefits are shared by the targeted people.
  - Government should ensure the removal of regional imbalance for institutional infrastructure and human resources.
- **Natural resource management**
  - Constant encouragement from government site should be given for generation and promotion of eco-friendly technology and sustainable land and water management for different agro-ecological zones and regions.
  - Thrust will be given on weather and crop forecasting, climate change and disaster management.
  - Conservation and effective use of life support system of soil, water flora, fauna and atmosphere will be addressed.
- **Management information system**
  - All research units will develop a comprehensive relevant database for agricultural research and development planning.
  - Facilitate functional electronic networking for all the stakeholders under the NARS and with other national, regional and international centers of excellence through Agricultural Research Information System.

- **Human resource development**
  - Strengthen the existing human resources to be nationally and globally efficient and competitive.
  - Provide opportunities for advanced training on frontier sciences, technologies and agricultural research management.

- **Forging partnership**
  - NARS institutes will create opportunities for promotion of research action through increased public-private sector collaboration in research activities.

2. Agricultural extension

The recent evidence of flood and cyclone sidr states extension as an emergency service for sustainable growth and development of agriculture in Bangladesh. As a primary role of service delivery system, the Department of Agriculture Extension will assist farmers through appropriate technical and farm management advice and information, new technology, improve farming methods and techniques aimed at increasing production efficiency and farms' income.

3. Seeds and planting materials

Seed is the main production input in the agriculture sector. The availability and quality of which are the means of sustainable agricultural production. The GO, NGOs and some private companies have started producing, importing, storing and marketing of quality seeds of hybrid rice, maize and vegetables at a limited scale. Therefore, national policies for making sustainable supply and maintaining quality seed are needed.

4. Fertilizers

Another critical factor of production is fertilizer input. The expansion of modern agricultural practices together with intensified cultivation has led to an increasing demand for fertilizers. It is, therefore, necessary to ensure timely supply of fertilizers to meet the increasing demand. Imbalanced use of chemical fertilizers is causing land degradation. Excessive mining of plant nutrients resulted in declining of soil fertility on the one hand and reduction in the potential yield on other. It is, therefore, important to adopt pragmatic measure so as to encourage farmers in using balanced fertilizers to maintain soil fertility. To strengthen fertilizer management, the government will pursue following policies:

- Stress should be given by the government on procurement and distribution of fertilizers both at the private and the public sectors.
- Steps will be taken to maintain a fertilizer buffer stock at the regional, district and upazila level.
- Government should facilitate availability of quality fertilizers at farmers' level.

- Production, importation, marketing, distribution and use of any kinds of fertilizer that are harmful or detrimental to plant, soil, flora and fauna will be banned.
- Constant monitoring of supply, storage, price and quality of fertilizers at various levels should be ensured.

5. Minor irrigation

Like seeds and fertilizers, irrigation is considered as another important input for increasing crop production. At present, about 90-95% of the total irrigated land is covered by minor irrigation. The country's total food production is largely dependent on minor irrigation like STW. Owing to shrinkage of water resources, a significant portion of area is not getting water during lean period. Moreover, river linking project of upper riparian country is likely to aggravate the situation. A well-planned irrigation management system is, therefore, essential for gradual increase of cropping intensity as well as yield. As such, national agricultural policy places special emphasis on the judicious use of water resources.

6. Mechanization in agriculture

Mechanization in agriculture is essential for minimizing cost of production. The need for mechanization is increasing fast with the decrease of draft power. Without mechanization it will not be possible to maintain multiple cropping patterns, which need quick land preparation, planting, weeding, harvesting and processing, etc. Significant increase in use of agro-machinery primary in tilling, seeding, weeding and threshing has been achieved. This trend needs to be extended further so that efficiency of production can be achieved with increased production and reduced cost. Mechanization should include post-harvest activities including processing and preserving. The following policies could be undertaken for agricultural mechanization in Bangladesh:

- The government will pioneer research and development of appropriate agricultural machinery and equipment.
- The government will encourage production and manufacturing of agriculture machinery locally.
- Manufacturing workshops and industries engaged in agricultural machinery development activities will be provided with appropriate support.

7. Agricultural marketing

Efficient marketing benefits both producers and consumers. A strong market infrastructure helps increasing efficiency in marketing services. Development of efficient agricultural marketing system will, therefore, help farmers enhancing their bargaining power and enable them to fetch better prices for their produces. Therefore, the government will facilitate smooth flow of agricultural produces from the production point to the consumption point by setting up village market and improving distribution to main markets and the existing marketing institutions will be strengthened both in terms of workforce and infrastructure. Both private and public sectors should be encouraged in improving agricultural products through values addition activities.

8. Women in agriculture

As women represent nearly half of the total population of the country, utilization of their hand into productive way is a must for accelerating and sustainable development of the country. It is obligatory on the part of the government to meaningfully involve them in agriculture-related income-generation activities.

9. Human resource development

A vast proportion of rural workforces in Bangladesh are illiterate, untrained and unskilled. With such reservoir of human resources, frontier production and food security could not be achieved. So, proper policy for developing the skill of this group of people is a must for increasing productivity and achieving food security for future generation.

10. Forestry

Forest in Bangladesh is not so less important in the macro-economic policy aspect. It has been estimated that forest covers around 2.53 million hectares or 17.5% of the country's total land area, of which government khash land constitutes 10.5%. These areas are mainly concentrated in Chittagong hill tracts (Rangamati, Bandarban and Khagrachari) and Sundarban mangrove forestland. Forest coverage is gradually being eroded owing to excessive harvests of timbers and fuel woods. One estimate finds that every year 37.6 thousand hectares of tree coverage is destroyed through illegal felling by timber traders and the encroachment by the people – local as well as internal migrants. It is claimed that tree coverage in forest areas has already reduced to below 10% and causing irrecoverable loss of biodiversity. At least $1/4^{th}$ of the country's land area should be kept reserve for forest for protecting biodiversity as well as environmental degradation. Development projects on social forests including trip plantation, woodlots and farm forestry in both government and private lands need to be encouraged. A forestation project in the name of a coastal green belt in the newly developed islands char lands in the Bay of Bengal with mangrove plants is to be established. There is a wide potential for mangrove plantation in the newly growing char areas in the coast of Bay of Bengal.

11. Fishery

Bangladesh is uniquely rich in water resources. Water/land ratio in Bangladesh is one of the highest in the world. Its shore sea, estuaries, mangroves, rivers, lakes and ponds all offer tremendous opportunities for fish farming. There are about 2.89 million ha of paddy fields that remain under floodwater for some 3 to 5 months in the year providing feeding and breeding grounds for various species of fishes (Haque 1984). Bangladesh fisheries sector contributes about 5.6% to the country's GDP, supplies 63% of animal protein intake, 9% of the total export earning and employs about 10% of the total 130.20 million population (AIS 2001). Therefore, the fisheries sector, which is important in terms of nutrition, income, employment and earning of foreign exchange, should be kept ideally and should not run unplanned.

As the fisheries sector plays an important role in respect of self-employment, poverty alleviation and socio-economic development of the country, therefore, the necessary policy should be taken to save this sector.

Conclusion

The policy provisions as mentioned above are views of the authors and some drawn from the draft report on “National Agricultural Policy”, Ministry of Agriculture, Government of the Peoples’ Republic of Bangladesh, prepared by the host researchers, practitioners and expert members of committee meeting held at BARC in October 2006. It is hoped that, if the NAP is implemented, the millennium development goals, SDGs and PRS will be partly fulfilled.

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OUTLOOK FOR FERTILIZER CONSUMPTION AND FOOD PRODUCTION IN BANGLADESH

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Abstract

Fertilizers support half of the world's grain production. Cultivation of high yielding variety (HYV) and irrigation facilities increased the consumption of fertilizer in Bangladesh from 313 thousand tons in 1970-75 to 3,223 thousand tons in 2000-04. A tendency to use higher amount of all fertilizers was observed in Boro season than the Aman or Kharif season. However, the sudden rise in price at peak season may cause negative impact on fertilizer consumption by the farmers. Still, there remained a gap between the actual use and recommended dose of the major fertilizers. The estimated total fertilizer requirement for rice and other crops will be 3.79 million ton in 2010. Use of organic manure in combination with fertilizer may reduce the requirement of chemical fertilizer.

Introduction

Bangladesh is densely populated and agriculture based country. Agriculture is the main source of livelihood for more than 80% of the country's population. The main purpose of agriculture is to provide food for the increasing population. Fertilizer is considered one of the main inputs for increasing crop yields and farm profit. To understand the role of fertilizer for increasing production Tandon and Narayan (1990) cited the Nobel prize-winning wheat scientist Dr Norman E Borlaug's dialogue as "If the high yielding wheat and rice varieties were the catalyst that ignited the Green Revolution, then chemical fertilizer was the fuel that poured its forward thrust". This is also true for Bangladesh agriculture because the country has virtually no possibility of increasing its cultivable land area. So, the food production of this country can be increased through increasing irrigation facilities together with HYV and greater use of fertilizer. The purpose of this review is to provide factual information about the fertilizer consumption magnitude with emphasis on the role of fertilizer to increase food production to meet the demand of future generation.

Role of fertilizers to cereal production

Fertilizers support half of the world's grain production (Bockman *et al.* 1990). Fig. 1 visualizes the role of soils reserves of nutrients, manures and fertilizers in increasing cereal yields.

Tandon (1992) reported that the contribution of fertilizers to rice production was 40%. Results of long-term experiments conducted in BRRI also showed 36-40% contribution of fertilizer for rice to the total annual production (averaged over Boro and T. Aman crops during the period 1985-86 to 2006-07) (Fig.2). Thus, the increasing fertilizer response with times indicates the degradation of soil fertility.

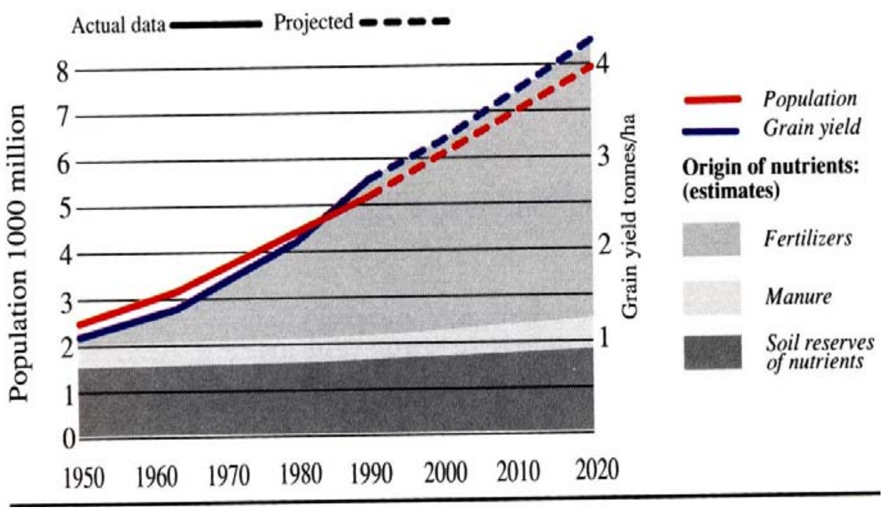


Fig. 1. Global trends in population growth, grain yield and origin of plant nutrients.

Source: Bockman et al.(1990)

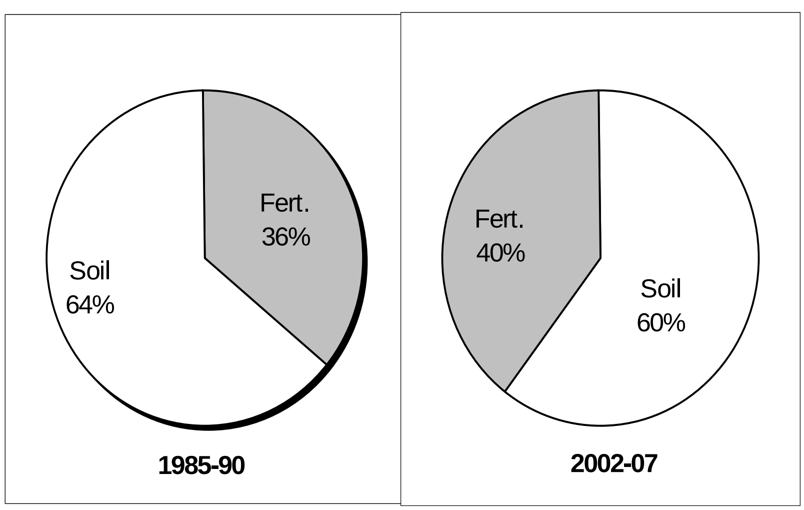


Fig. 2. Percent contribution of soil and fertilizer on rice yield in 1985-90 and 2002-07.

Another long-term experiment of BRRI with and without fertilizers demonstrated that higher yields could be obtained with fertilizers over time in triple-crop rice system (Fig. 3). On unfertilized soil HYV rice gave a markedly lower yield in absolute terms. In 2000, fertilizer application on this unfertilized soil increased the yield similar as continuously fertilized soil (data are not presented). It indicates that fertilizer plays a vital role in increasing crop yield.

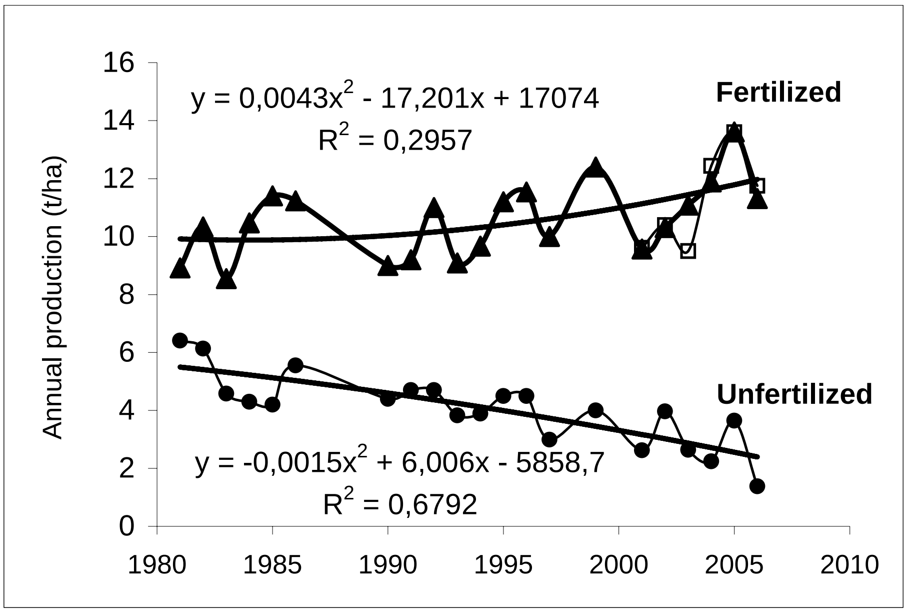


Fig. 3. Changes in the annual production of rice with fertilized and unfertilized soil in perpetually wetland conditions (1980-2006).

Fertilizer use scenario in Bangladesh

In early 1950's, farmers applied organic manures such as cow dung, bone meal to Aus and Aman rice and farmyard manure (FYM), mustard oil cake and fishmeal to mustard and vegetable crops (EPBS 1950). Ahmed (2004) pointed out that the use of inorganic fertilizer started in the country in 1951 with the import of 2,698 tons of ammonium sulphate, phosphates in 1957 and muriate of potash in 1960. Quasem (1978) reported that fertilizer was introduced at the farm level in 1959. Then, in 1965, the Government launched a 'Grow More Food' campaign and provided fertilizers and low lift pump (LLP) at a highly subsidized rate with pesticide as free of cost to popularize these inputs among the farmers and meet the country's food shortage. Thus, fertilizer consumption began to increase rapidly with the introduction of HYV rice (i.e. IR5 & IR8) and LLP use. The irrigated area of rice and other crops were increasing year after year (Fig. 4). In irrigated condition, most of the farmers use HYV rice, which requires high fertilizer dose than local low yield rice varieties. Hossain (1987) reported that the HYV acreage and irrigation have a significant positive influence on fertilizer consumption.

On the other hand, at present, about 220 ha of agricultural land per day go to urbanization and homestead area expansion in rural area (Amader Shomoy 2007). For this reason the net cropped sown area of the country is decreasing but the cropping intensity is increasing over times (Fig. 5). This resulted in increasing demand for nutrients, which was reflected in more nutrient deficiencies exhibited by the crops.

Bangladesh, a sub-tropical country, possesses soils poor in organic matter and obviously deficient in nutrients. Deficiency of soil N and P was found first in 1950's. With the advent of intensive cropping, the deficiencies of some essential elements in rice and other crops emerged chronologically (Fig. 6). The fertility of a soil is not a fixed property. It changes depending on how intensively the land is used, nutrients are added and removed through crops. Fertilizers used in Bangladesh are mainly urea, triple super phosphate (TSP) and muriate of potash (MOP). Around 1980 and 1982, gypsum and zinc sulphate were introduced to correct S and Zn deficiency in soil. In 1993, boron was applied in wheat to minimize grain sterility. Besides, diammonium phosphate (DAP), single super phosphate (SSP) and mixed fertilizers (NPKS) are being used in rice and other cereal crops.

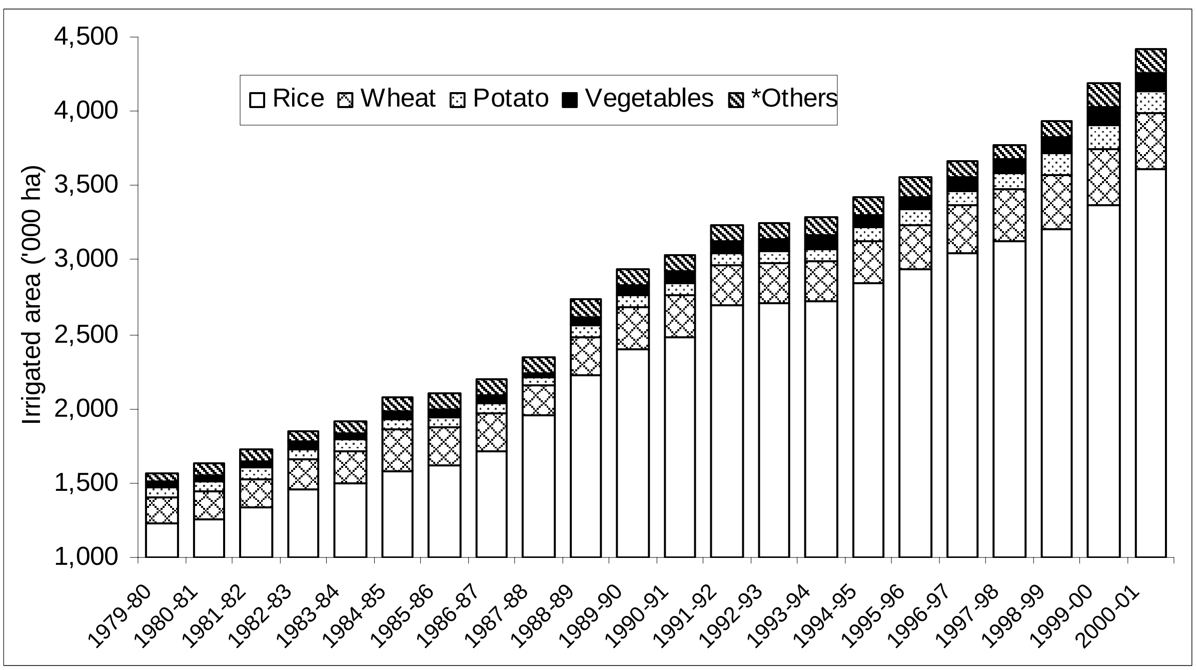


Fig. 4. Irrigated area coverage under different crops (Adapted from BBS 1985-2004).

Among different fertilizers used in Bangladesh, farmers use nine more commonly in crop production. Three fertilizers, namely urea, TSP and MOP ranked top 3 positions and the use of remaining 6 fertilizers vary year to year (Table 1).

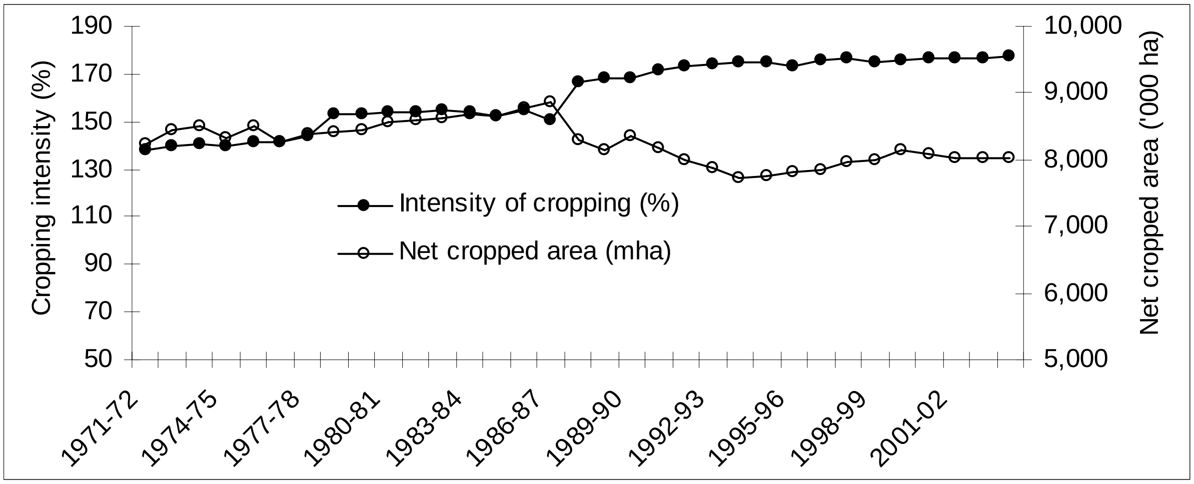


Fig. 5. Net cropped area and cropping intensity over time in Bangladesh, 1971-72 to 2001-02 (Adapted from BBS 2005).

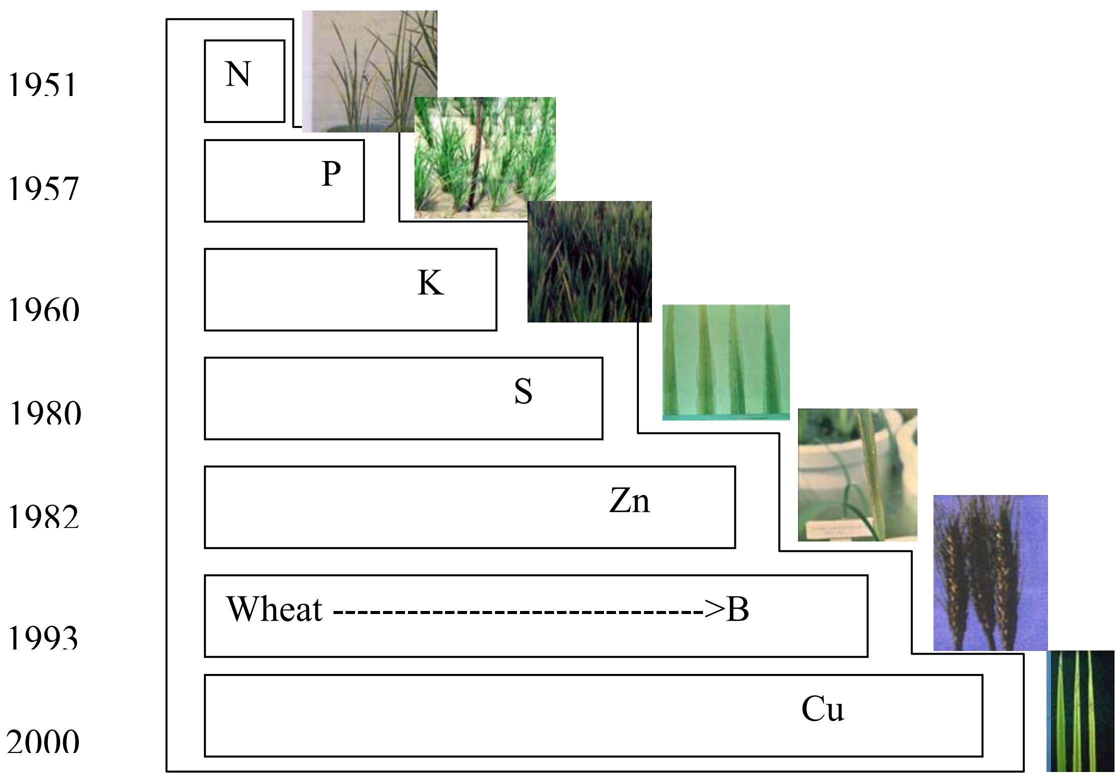


Fig. 6. Chronological emergence sequence of nutrient deficiencies in rice and wheat in Bangladesh.

Use of mixed fertilizer and DAP increased with times while the use of SSP fertilizer decreased. In Bangladesh, there are six urea fertilizer manufacturing factories, one TSP and SSP fertilizer complexes and two DAP fertilizer factories started to production. It appears from Table 2 that the Government of Bangladesh imported large amount of urea and TSP from abroad to meet the demand even though these two fertilizers are produced in our country. The imported amount of fertilizer showed a little increasing trend over times indicating that the growers of Bangladesh use higher amount of fertilizer day by day.

The fertilizer consumption outlook

The introduction of fertilizer responsive HYV seeds in the country in mid 60's, coupled with the governmental favorable policy for fertilizer distribution and price controlling, resulted in a rise in fertilizer consumption from 313 thousand tones in 1970-75 to 3,223 thousand tones in 2000-04 (Fig. 7). Total fertilizer consumption is considered here as national sales of fertilizer for the corresponding years.

Table 1. Ranking of different fertilizer use by farmers in Bangladesh (2001-02 to 2005-06).

Fertilizer	Year				
	2001-02	2002-03	2003-04	2004-05	2005-06
Urea	1	1	1	1	1
TSP	2	2	2	2	2
DAP	5	6	6	5	4
SSP	4	4	4	4	7
MP	3	3	3	3	3
Gypsum	6	5	5	6	6
Zinc	9	9	9	8	9
Mixed fertilizer	8	7	7	7	5
Am. sulphate	7	8	8	9	8

Note: "1" indicates the highest use and "9" indicates the lowest use. Source: Ali and Ali (2006)

Table 2. Fertilizer production and import ('000 t) during 2000-01 to 2005-06

Year	Urea		TSP		SSP
	Production	Import	Production	Import	Production
2000-01	1883	302	68	363	119
2001-02	1545	522	66	341	136
2002-03	2057	286	65	328	135
2003-04	1986	235	67	369	141
2004-05	1878	567	54	451	163
2005-06	1730	770	56	374	135

Source: MOA (2007)

Bruce (1987) reported that the fertilizer consumption per hectare in Bangladesh is considerably lower than in many developed countries, but it is higher than the average level in many of developing countries. Fig. 8 observes that on total crop area basis near about 198 kg nutrients were used for crop production, which was higher than in India, Pakistan, Sri Lanka, Thailand and even Philippines (BARC 2005).

Fig. 9 shows the overall consumption of major fertilizers (as N, P and K) with an exponential growth rate of 7.8 per annum.

Twelve years interval (since1968-69 to 2003-04) growth rate of fertilizer decreased over times in case of all 3 major fertilizer nutrients (Table 3) because of increased fertilizer selling price. It does not mean that the total amount of fertilizer used by farmers in crop production decreases. The growth rate decrease here measures the magnitude of fertilizer quantity use in crop production as compared to previous 12 years' fertilizer consumption.

During 1992-93 to 2003-04, the growth rate of P use was <1% that might be the cause of higher availability of SSP in the market due to its higher production and import than TSP (Table 4). During this time, granular SSP was adulterated which hampered farmers' interest. Farmers' assumption was that SSP containing P similar to TSP. The non-availability of TSP in the market might have caused abrupt lower consumption growth rate.

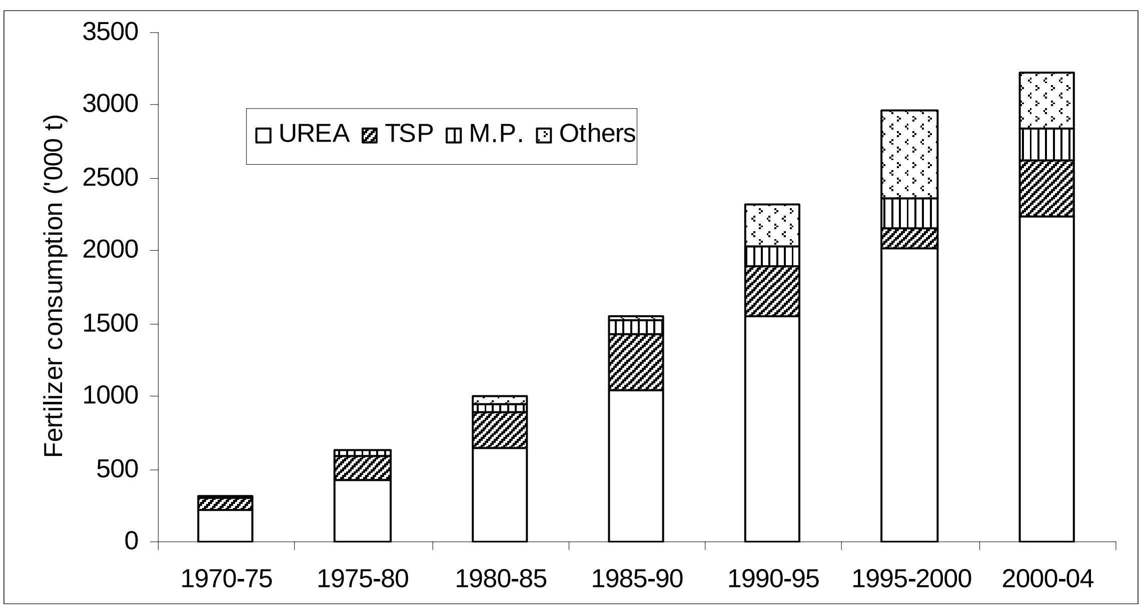


Fig. 7. Total fertilizer consumption trend of Bangladesh during 1970- 2004 (Adapted from BBS 1973, 1985 and 2004).

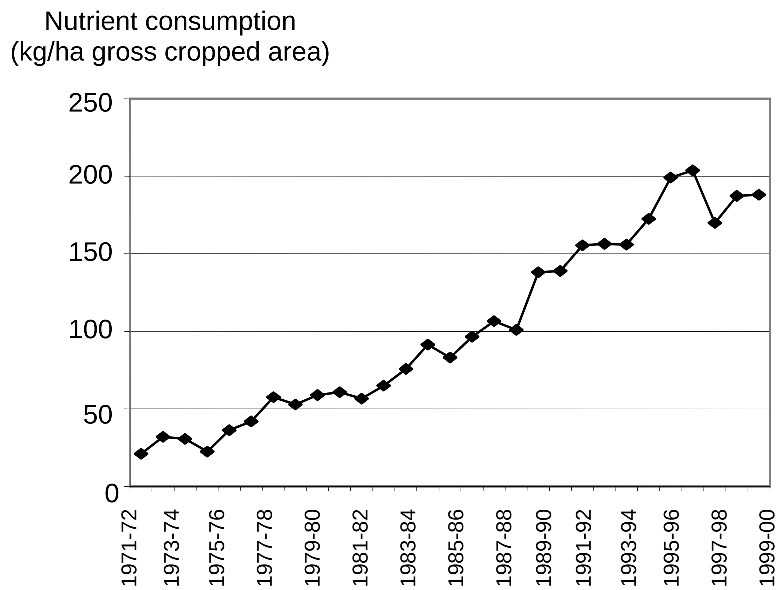


Fig. 8. Consumption rate of major nutrients in crop production during 1971-2000 (Adapted from BBS 1973-74 and 2002).

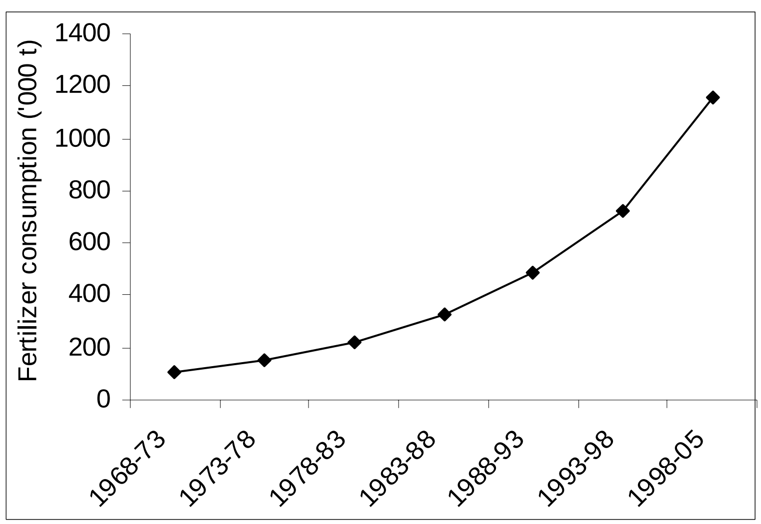


Fig. 9. Growth of NPK fertilizer nutrient consumption over years (Adapted from BBS).

Table 3. Growth rate of major fertilizer nutrients consumption (%) in Bangladesh.

Years	Major nutrients growth rate (%)		
	N	P	K
1968-69 to 1977-1978	10.92	12.21	17.69
1978-79 to 1991-1992	9.16	7.13	10.09
1992-93 to 2003-2004	3.83	0.91	5.89
Mean	7.69	6.44	10.27

Source: EPBS 1968-69: BBS 1985 and 2005

Table 4. Production and import of TSP and SSP abroad ('000 t) during 1994-95 to 1999-2000

Year	Production		Import	
	TSP	SSP	TSP	SSP
1994-95	76.58	-	54.51	558.94
1995-96	27.50	79.11	64.00	502.02
1996-97	-	98.40	-	427.97
1997-98	-	95.58	28.20	246.57
1998-99	60.00	111.30	151.00	262.00
1999-00	64.78	125.80	215.29	43.32

Source: MOA(2007)

The selling price of TSP at higher level is also one of the causes of less use of P fertilizer in crop production (Fig. 10). The selling price of imported K fertilizer also increased over times but not as high as TSP fertilizer. The price of urea increased little over times but remained stable as compared to TSP and MOP fertilizers. Country's urea production may help government keep the selling price to the farmers more or less stable. Khondoker *et al.* (2002) reported that the price and supply situation of urea was satisfactory during late 1990s in the sense that prices were low and there were no reports of shortage of supply. Although the overall growth rate of N & K fertilizer consumption decreased with time as compared to before 1980s, it's yet not as less as P fertilizer consumption growth rate.

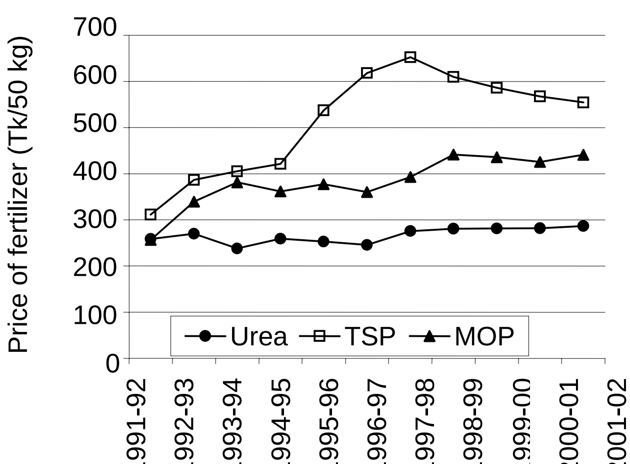


Fig. 10. Changes in the price of major fertilizers from 1991 to 2002 (Adapted from BBS 2004).

However, in Bangladesh we have three marked cropping seasons, i.e. Rabi or Boro season, Kharif I or Aus and Kharif II or T. Aman season. In Rabi or Boro season, winter vegetables and Boro rice are grown and have comparatively higher yield than the other seasonal crops. As the yield is higher, higher amount of fertilizer are used by the farmers. Ishaque (2001) reported that farmer used higher amount of all necessary type fertilizer in Boro season than Kharif I and Kharif II (Table 5).

Table 5. Season-wise fertilizer use in Bangladesh (kg/ha) in 2000.

Name of fertilizer	Rabi	Kharif I Aus	Kharif II T. Aman
Urea	11.5	26.9	73.1
TSP	23.3	3.3	8.9
SSP	20.8	4.6	10.8
DAP	9.3	1.3	3.3
MOP	16.9	3.1	6.2
Gypsum	6.0	2.2	8.4
Zinc	1.0	0.2	0.7
Total	192.3	41.6	111.4

Source: Ishaque(2001)

Sidhu *et al.* (1982) also reported that the average level of fertilizer use was higher during the Boro season (220 kg fertilizer/ha) and lower during the Aus (162 kg/ha) and Aman (142 kg/ha) seasons. They also noted that the higher level of fertilizer use during the Boro season may be attributed to a higher level of irrigation (35% of the cropped area compared with 8% and 6% during Aus and Aman, respectively) and a higher level of use of HYV seeds. A study done by Mustafi and Harun (2000), covering nine regions of Bangladesh, reported that rice growing farmers use higher amount of fertilizer in HYV than local varieties (Table 6). At present, MV rice covers 92% in the Boro season, 31% in Aus and 44% in T. Aman (BRRI 1999). This MV rice cultivation requires high fertilizer for maximum yield.

Table 6. Fertilizer use (kg/ha) in rice cultivation during the period of 1999 and 2000.

Fertilizer	Varieties	Aus		T. Aman		Boro	
		1999	2000	1999	2000	1999	2000
Urea	HYV	154	187	144	168	251	346
	LV	146	157	73	112	-	-
TSP/SSP	HYV	17	35	35	46	62	38
	LV	19	31	03	33	-	-
MOP	HYV	04	29	17	33	28	32
	LV	05	-	02	09	-	-
Gypsum	HYV	05	03	-	08	01	06
	LV	03	-	-	-	-	-

Source: Mostafi and Harun (2002).

Month-wise consumption (6 yrs. average data) also indicated that during the Boro season the overall fertilizer consumption is higher than during other seasons (Table 7).

Table 7. Monthwise consumption of fertilizer during 1980-86 (Average over 6 years).

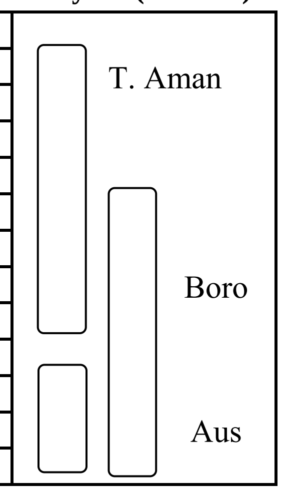
Rice season	Month	Total fertilizer consumption ('000 t)
T. Aman	July	245
	August	348
	September	645
	October	558
	Total	1,796
Boro	November	712
	December	597
	January	559
	February	712
	March	642
	Total	3,222
Aus	April	355
	May	380
	June	479
	Total	1,214
	Grand total	6,232

Source: BADC 1985-86

It means that farmers are fully aware of the necessity of fertilizer for maximum yield. The problem is that at peak season the price of fertilizer goes little up (Table 8) even when the fertilizer distribution systems and selling prices are monitored by governmental agencies.

Table 8. Farm level price of chemical fertilizers (Tk/50 kg bag): fluctuation in a year (2005-06).

Month	Urea	TSP	SSP	MOP
July*	298.5	637.0	452.0	565.0
Aug.	+1	-20	+33	+9
Sept.	0	+72	+9	+25
Oct.	+6	+10	+26	+31
Nov.	+2	+44	+18	+62
Dec.	0	+52	+15	+78
Jan.	-3	+40	-22	+76
Feb.	+4	+33	-2	+60
Mar.	+11	+51	-3	+107
April	+4	+86	-19	+11.7
May	+4	+79	-7	+129
June	+5	+87	-7	+135



* The fertilizer price of July month considered as fixed price **Source: MOA (2007)**

The farm level price fluctuation within a year may create an artificial crisis or sudden rise of fertilizer price that, in turn, may cause less fertilizer use by farmers. The higher price of urea over July (financial starting month) ranged from Tk. +1.00 to +5.00 per 50 kg bag except three month, when the price of it remained always higher. Similarly, the price of MOP fertilizer remains always higher (Tk. +9.00 to +135.00 per 50 kg bag) than starting month of July. In case of TSP, the price of 50 kg bag also remains higher and price variation margin is wide. In contrast, SSP price decreases (Tk. -2 to -22) from January to June indicating farmers' understanding that the nutrient value of TSP and SSP is not the same. It also means that farmers aware of fertilizer quality. With the application of low content SSP under the situation of the higher price of TSP, the farmers may use less amount of P as indicated by the decreasing trend of P:N ratio (Fig. 11).

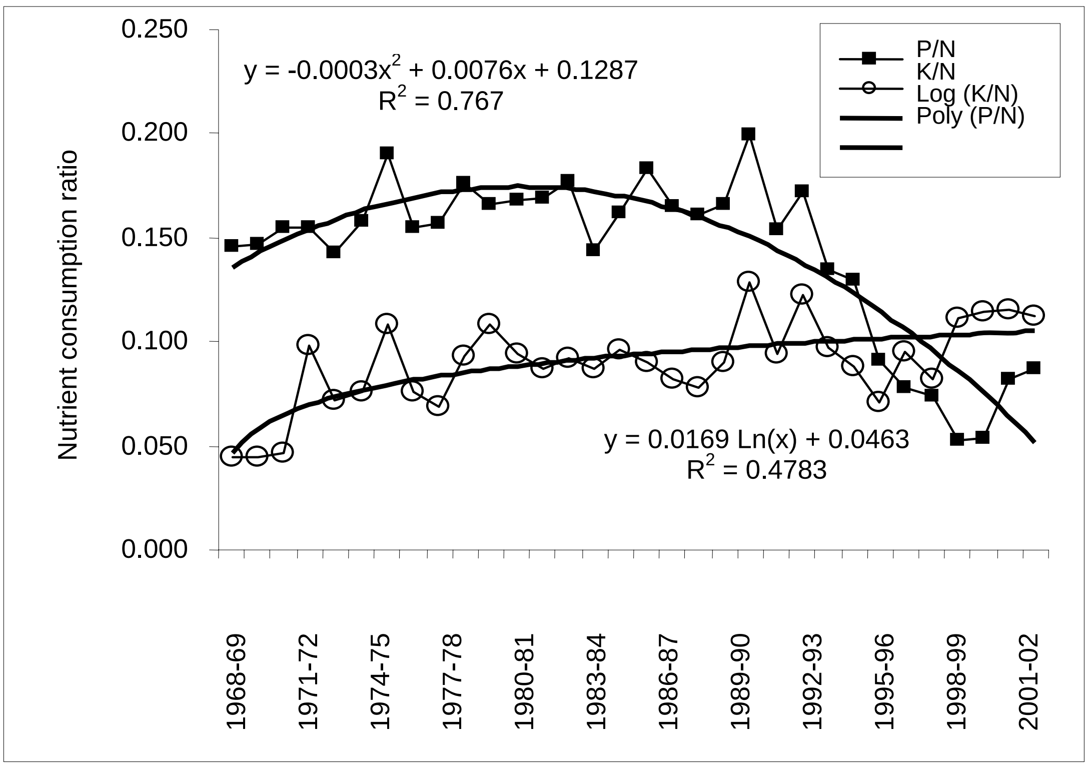


Fig. 11. Nutrient consumption ratio (Adapted from EPBS 1969; BBS 2004-05).

Though MOP fertilizer price was in a little increase, K:N ratio showed upward trend indicating that the farmers still remain positive as regards MOP use in crop production. However, K:N ratio remains at around 0.1. The low ratio indicates that the use of MOP fertilizer by the farmers might be far below as compared to recommended rates. As a result, all the research experiments based on major cropping patterns showed negative balance of K in the soil (Table 9).

Table 9. Estimation of nutrient depletion in major cropping pattern in Bangladesh.

Major cropping pattern	Total yield (t/ha/yr)	Input			Output			Balance		
		N	P	K	N	P	K	N	P	K
		(kg/ha)								
Boro-Fallow-T. Aman	8.0	248	49	118	324	32	234	-76	+17	-116
Boro-T. Aus-T. Aman	11.5	350	60	151	469	57	368	-119	+3	-217
Boro-GM-T. Aman	8.0	285	-	135	324	32	240	-39	+28	-105
Mustard-Boro-T. Aman	9.5	378	73	183	404	95	326	-26	-22	-143
Potato-T. Aus-T. Aman	38.0	386	67	220	430	53	435	-44	+14	-215
Potato-Jute-T. Aman	36.0	380	70	240	385	55	496	-5	+15	-256
Mustard-Jute-T. Aman	7.5	340	75	205	430	79	429	-90	-4	-224
Wheat-T. Aus-T. Aman	10.0	335	65	166	420	64	292	-85	+1	-126
Wheat-Mungbean-T. Aman	8.0	275	64	190	305	52	284	-30	+12	-94
Sugarcane + Potato intercropping	100.0	190	55	150	210	60	320	-20	-5	-170

Source: MOA(2007)

The present level of fertilizer application is considerably below the recommended dose for almost all food grains. Fig. 12 indicates the percent fertilizer use gap between actual and recommended dose for all 3 major fertilizers still existing in rice cultivation at farmer level. Thus, there appears to be a large potential for raising fertilizer consumption through adoption of the recommended fertilizer practices by farmers.

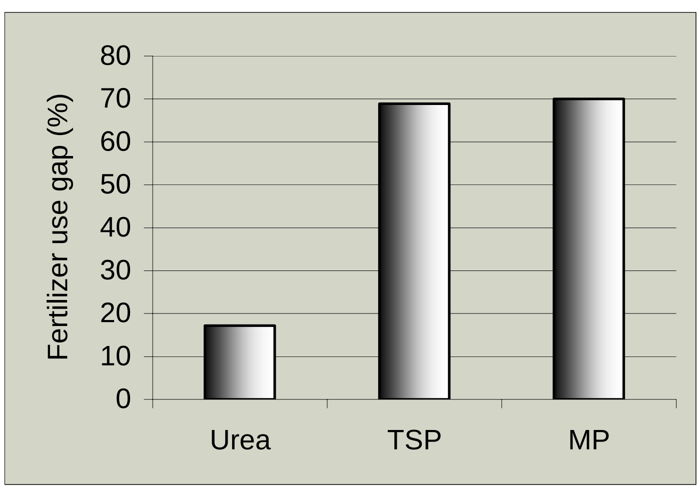


Fig. 12. Percent gap between actual fertilizer use and recommended dose (Adapted from MOA 2007).

Fertilizer marketing system

The pragmatic policies pursued by the Bangladesh Agriculture Development Corporation (BADC) in the field of fertilizer distribution, however, produced an inevitable result and the progress was remarkable from year to years. Considering the importance of fertilizer for stable and expanding agricultural production, various efforts have been made time to time to design an effective fertilizer distribution system in Bangladesh. The present fertilizer distribution system can be presented schematically in Fig. 13.

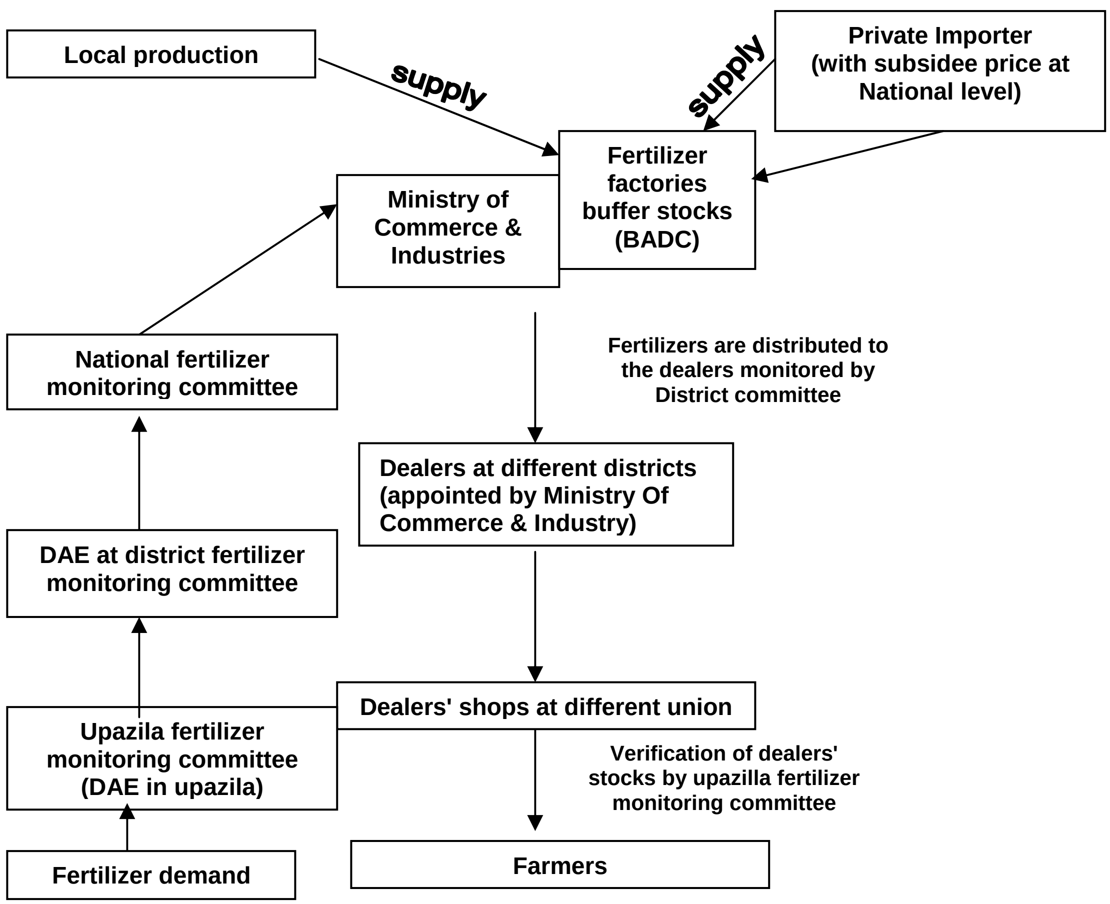


Fig. 13. Fertilizer distribution and sales flowchart in Bangladesh.

Khonadker (2002) evaluated the fertilizer distribution system based on the availability of right amount in right time with fairly stable price of present completely privatization marketing system (CPMS) over old marketing system (OMS). According to his report, almost 88% of farmers were more or less satisfied with the CPMS when compared to early OMS regarding the time availability of fertilizers.

Future requirement of fertilizer for crop production

If the increasing population of Bangladesh will feed itself, food production levels of our country will have to increase drastically. Rice is the only dominant cereal crop and the main staple food for Bangladeshi peoples. Based on total gross cropped area, rice occupies about 73%, wheat 5% and other crops 22% (BBS 2005). Zaman (1987) reported that 75% of total fertilizer would be consumed for rice production and the rest 25% for other crops.

To feed the increased population, an estimated 5.14 million tonnes more rice are needed as compared to the baseline of 2006-07. Gomosta (2004) hypothesized the following options to meet the demand for obtaining increased yield:

- ❖ Replacement of local T. Aman varieties by modern T. Aman varieties in some areas
- ❖ Limited increase in the area of modern Boro varieties
- ❖ Supplementary irrigation needs to be ensured in some drought prone areas during T. Aman season

All the three pointed implications require more assistance in fertilizer use development to get a higher yield from a piece of land. The total estimated requirement for commonly used 5 fertilizers for rice production is about 3.03 million tonnes to 2010. The estimation of individual fertilizer levels is provided in Table 10. If 25% of total fertilizer is consumed by other crops, the cumulative fertilizer requirement will be 3.79 million tonnes to 2010.

Integrated nutrient management/Integrated plant nutrient systems (IPNS) is an effective mechanism to obtain high yield through the combination of mineral fertilizers with organic manures (Table 11). To reduce the total dependency on chemical fertilizer enriched manure like poultry litter at 2 t/ha may satisfy STB dose of P and S, and 50% of N and K fertilizer dose. The integrated plant nutrient systems (IPNS) may be considered as a requirement for target yield of 5-6 t/ha of paddy. Thus, integrated nutrient management is an effective mechanism to obtain high yields as well as to partially reduce the total dependency on mineral fertilizers. Besides this, the use of rice straw or its ash can partially reduce the dependence on imported costly MOP fertilizer for rice production. For this reason, studies must define the right types and quantities of organic fertilizers to be used for each crop and cropping system.

Table 10. Estimated population and rice production demand with fertilizer requirement for rice cultivation action plan up to 2010.

Estimated parameters	2006-07*	2007-08	2008-09	2009-10
Population (million)	141.16	143.25	145.37	147.52
Total rice production (Mt)	29.75	31.17	32.82	34.85
Rice area (Mha)	11.25	11.06	10.89	10.75
Estimated fertilizer requirement (Mt)				
Urea	2.50	1.9	1.9	2.0
TSP	0.45	0.4	0.4	0.4
MOP	0.30	0.2	0.2	0.3
Gypsum	0.15	0.3	0.3	0.3
Zinc sulphate	0.03	0.3	0.3	0.03

* Base year
Source: BARC 2007.

Table11. Effect of poultry liter alone and in combination with mineral fertilizers on rice yield.

Treatments	Boro rice yield (t/ha)	
	2003-04	2006-07
Fertilizer control	2.96	2.53
STB* fertilizer dose	4.53	5.68
Poultry liter @ 2.6 t/ha	4.49	-
STB + Poultry liter @ 2.0 t/ha	-	5.24
STB + Poultry liter @ 2.6 t/ha	6.07	-

STB* = NPKS @ 101-9-64-6 kg/ha

Conclusion

Fertilizer is such a kind of production input whose demand cannot be avoided to obtain maximum yield or sustainable crop production from a piece of land even when other management technologies are evolved by researchers. Achievement of high yield potential through the evolution of new genotypes or bringing of more acreage under irrigation facility are both fertilizer demanded technologies throughout the world. IPNS concept can partially reduce the total dependency on mineral fertilizer for intensively cultivated production system.

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EMERGING ASPECTS OF BALANCED FERTILIZER USE IN INDIA

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Abstract

There has been a remarkable growth in fertilizer consumption in India particularly after the introduction of fertilizer responsive HYVs of paddy and wheat in mid 60s. The per hectare fertilizer consumption increased from 5 kg in 1965-66 to 113.5 kg in 2006-07. Government and industry have made concerted efforts to encourage balanced use of fertilizers by targeting to achieve the ideal NPK ratio of 4:2:1 at national level. The concept of balanced fertilization was severely hit with the government decision of decontrol of phosphatic and potassic fertilizers in August 1992. The NPK consumption distorted to 9.5:3.2:1 in 1992-93. The country is now facing various problems like inadequate & imbalanced fertilizer use, distorted NPK consumption ratio, wide interstate/district variation in fertilizers consumption and nutrient mining leading to multinutrient deficiency. Increasing deficiencies of secondary and micronutrients have started declining the response of applied NPK. This paper presents the various aspects of balanced fertilizer use and suggests the measures which need attention to promote balanced and efficient fertilizer use in India.

Indian agriculture scenario

India is world's seventh largest in geographical area and second largest nation in population. It is basically an agrarian country. The contribution of agriculture to national Gross Domestic Product is 18%. The agriculture sector provides livelihood to nearly two-third of country's population. About 40% of net cultivated area has irrigation facilities. Broadly, the climate is of tropical monsoon type with most of rainfall being received during June to September. Wide variation in climate, rainfall and soil types enables it to grow a variety of crops. About 64% of total gross cropped area (190 million ha) is under food grains, followed by oilseeds (16%), sugar (2.5%), fruits & vegetables (4.9%).

Indian agriculture is characterized by the small size of farm holdings. There are about 120.8 million farm holdings with an average size of 1.32 ha. About 82% of farming holdings are less than 2 hectares covering 39% of cultivated area. The land suffers from varying degree of degradation. Soil fertility depletion due to nutrient mining has emerged as a serious threat to sustainability of agriculture.

Fertilizer in Indian agriculture

Indian farmers have a long history of supplementing soil fertility by using organic manures and green manures. The use of fertilizers is relatively new and is only 100 years old. The growth in fertilizer consumption remained very slow in first 50 years and was confined to plantation crops. After the independence, Indian government realized the need of promoting the use of fertilizers to increase foodgrains production. Various favourable policies were implemented to improve availability and use of fertilizers.

In 1957, Government declared the fertilizer as an essential commodity and enacted fertilizer (Control) order to ensure timely and adequate availability of good quality fertilizers at affordable prices to the farmers. The Sivaraman Committee Report (1966) laid foundation of modern fertilizer policy. It underlines the need of using fertilizer responsive HYVs, balanced fertilizer use, adequate credit support for distribution of fertilizers, and liberalization of fertilizer marketing. The recommendation of Maratha Committee in 1972 gave birth of Retention Price Scheme (RPS), which was intended to encourage the domestic fertilizer production and improve availability of fertilizers.

The favourable fertilizer policies implemented by government had the desired impact. India emerged as the 3rd largest user of fertilizers in world after China and USA. Annual fertilizer consumption reached 21.7 million tonnes during 2006-07. The per hectare fertilizer consumption increased from 5 kg in 1965-66 to 113.5 kg in 2006-07 (Table 1). Unlike in pre-HYVs era, wherein fertilizers use was limited to some commercial crops the use of fertilizer spread to variety of crops in post-HYVs era.

Table 1. Growth in fertilizer (NPK) consumption in India.

Year	Fertilizer consumption		Foodgrain production, million tonnes
	million tonnes	kg/ha	
1950-51	0.07	0.49	50.82
1965-66	0.78	5.05	72.35
1979-80	5.26	30.99	109.70
1989-90	11.57	63.47	171.03
1999-00	18.07	94.90	209.80
2006-07*	21.67	113.4	216.13

* Provisional

The introduction of fertilizer responsive High Yielding Varieties (HYVs) of rice & wheat in mid sixties was a turning point in Indian agriculture. The expansion in HYVs coverage led to rapid growth in fertilizer consumption. Fertilizers played a key role to sharp increase in foodgrains production enabling the country to achieve self sufficiency in foodgrain production. A direct relationship between fertilizer use and foodgrain production particularly up to 2001-02 is evident from Fig. 1.

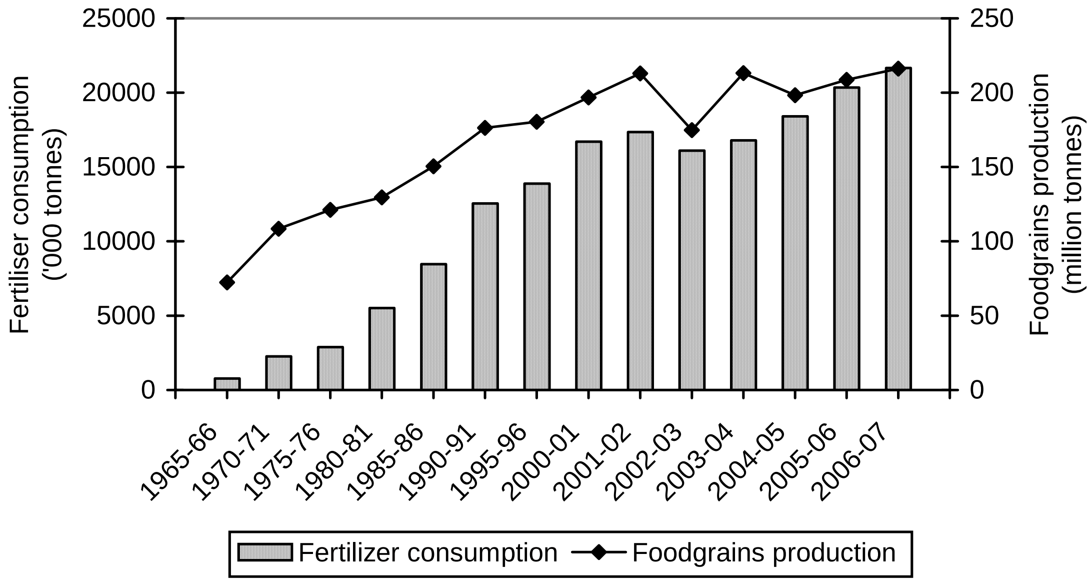

Fig. 1. Fertilizer consumption vis-à-vis food grains production.

Promotion of balanced fertilizer use

Right from the beginning, efforts were made to improve the balanced use of fertilizers. Most of the governmental programmes aimed at increasing fertilizer consumption in a balanced manner using 4:2:1 NPK consumption ratio as guideline. In 1971, Government used the fertilizer legislation (FCO) to promote BFU by making it mandatory for fertilizer dealers to keep 20% of his stocks of fertilizer in form of potassic fertilizers. The mandatory provision was withdrawn after the awareness was created. Indian Council of Agricultural Research (ICAR) and State Agricultural Universities (SAUs) did the commendable job in development of fertilizer best management practices and highlighting the benefits of balanced use of fertilizers on crop yields (Table 2). The results of long term fertilizer experiments have established that the inadequate and imbalanced use of fertilizer adversely affect the soil health and crop productivity.

Besides government, Indian fertilizer industry also initiated number of programmes to educate the farmers on balanced use of fertilizers. Important programmes being undertaken by fertilizer companies including soil testing, fertilizer demonstration farmers meetings, crop seminar, village adoption, dealers training programme, etc.

The efforts of government and industry helped in improving the balanced fertilizer use. The NPK consumption ratio in India reached to 5.9:2.4:1.0 in 1991-92, very close to the ideal ratio of 4:2:1. The sudden decontrol of phosphatic and potassic fertilizer in August 1992 came as serious setback to the balanced fertilization programme. NPK consumption ratio distorted to 9.5: 3.2:1 in 1992-93. Government introduced adhoc concession scheme on P&K fertilizers to repair the damage by improving the NPK ratio.

Table 2. Results of on-farm trials on balanced fertilization and foodgrain yields.

Crop	Trials No.	Nutrients added (kg/ha)			Yield increase (kg/ha)
		N	P_2O_5	K_2O	
Wheat	10,133	120	0	0	890
		120	60	0	590 (over N)
		120	60	60	290 (over NP)
	2,358	25 $ZnSO_4 \cdot 7H_2O$ over NPK			360 (over NPK)
Rice (Kharif)	5,955	120	0	0	1,236
	3,231	120	60	0	636 (over N)
	3,231	120	60	60	366 (over NP)
	4,856	25 $ZnSO_4 \cdot 7H_2O$ over NPK			248 (over NPK)
	958	50 $ZnSO_4 \cdot 7H_2O$ over NPK			375 (over NPK)
Rice (Rabi)	4,179	120	0	0	1,116
	1,979	120	60	0	624 (over N)
	1,979	120	60	60	252 (over NP)
	1,891	25 $ZnSO_4 \cdot 7H_2O$ over NPK			252 (over NPK)
	584	50 $ZnSO_4 \cdot 7H_2O$ over NPK			385 (over NPK)

Source: Tandon(2004)

Since the beginning of 1990s, the Indian fertilizer industry has witnessed sudden policy changes leading to the environment of uncertainty in fertilizer sector. Consequently, the industry is now facing various problems on production, import, pricing subsidy and availability front. The imbalanced and inefficient uses of fertilizers have resulted in deterioration of soil fertility, emergence of multinutrient deficiencies and decline in factor productivity.

Emerging aspects

Although India witnessed significant growth in agricultural production during 1965-2000, the growth in crop production has been at the cost of soil fertility. There has been continuous decline in soil fertility status, especially for the nutrients that were ignored in fertilizer use. Many second generation problems of post green revolution have come up which threaten the sustainability of agriculture. Some of the aspects which are important from balanced plant nutrition point of view are discussed.

Low and imbalanced fertilizer use

Although India is third largest user of fertilizers in the world, the per hectare fertilizer (NPK) consumption is much lower compared to many developing countries and even our neighboring such as Pakistan, Bangladesh, Sri Lanka and China (Table 3). The problem of low fertilizer use is more acute in case of secondary and micronutrients.

Table 3. Fertilizer consumption (kg/ha) in selected countries.

Country	Consumption	Country	Consumption
New Zealand	307	Sri Lanka	135
Korea Republic	407	Bangladesh	198
Netherlands	510	Pakistan	146
U K	305	USA	114
Japan	363	India	108
China	289	World	101

Source: Fertiliser Statistics (2006-07) 2007.

Fertilizer consumption is not only low but imbalanced also. Among the primary nutrients (NPK) the consumption of potassium is minimum but its removal is maximum (Fig. 2). Out of total NPK use of 113.5 kg/ha, the K_2O consumption was 12.2 kg/ha in 2006-07. Moreover, there exists a wide variation in K consumption among states varying from 0.2 kg in Nagaland and Sikkim to 45.9 in Tamil Nadu. There are only 5 states namely Tamil Nadu, West Bengal, Andhra Pradesh, Kerala and Karnataka in which the per hectare K consumption has crossed 20 kg (Table 4).

Although concerted efforts have been made to achieve the ideal NPK ratio of 4:2:1, the success has not been achieved to the desired level. The NPK consumption ratio was 5.9:2.4:1.0 in 2006-07 (Table 5). The distortion in NPK consumption ratio is more pronounced among the zones and states. NPK consumption ratio is very wide in northern zone.

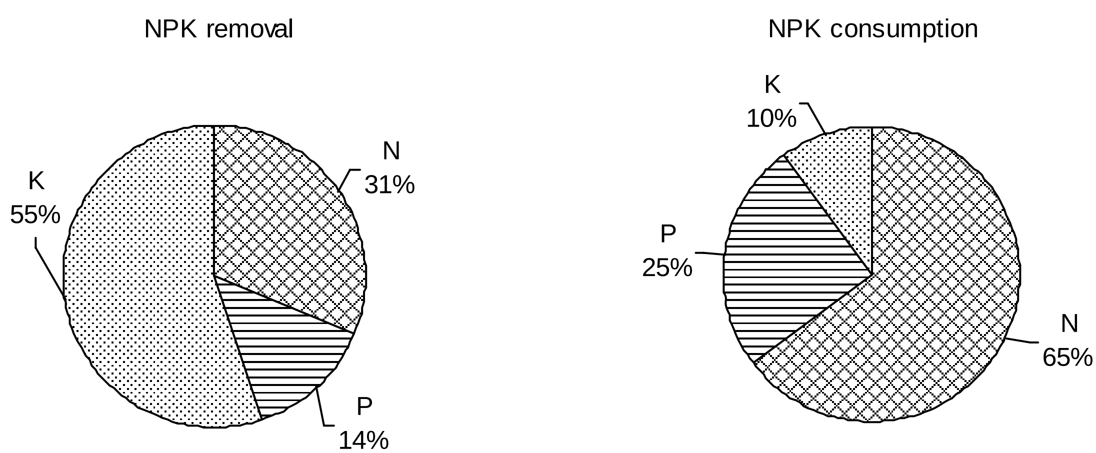

Fig. 2. Potassium addition and removal pattern.

Table 4. Potassium use pattern in some selected states.

State	Potassium consumption (kg/ha)			
	1971-72	1981-82	1991-92	2006-07
West Bengal	3.3	5.0	19.0	32.0
Punjab	2.2	4.9	2.4	4.8
Uttar Pradesh	2.5	3.7	4.0	6.6
Andhra Pradesh	2.1	3.7	9.8	26.5
Karnataka	2.5	7.1	14.1	22.7
Kerala	6.2	10.7	31.1	24.9
Tamil Nadu	8.5	14..0	39.1	45.9
Maharashtra	2.3	5.9	10.1	16.6
Madhya Pradesh	0.3	0.9	2.1	3.2
All India	1.9	3.9	7.6	12.2

Table 5. NPK consumption ratio.

		N	P_2O_5	K_2O
Year	1957-58	16.6	1.7	1.0
	1991-92	5.9	2.4	1.0
	1992-93	9.5	3.2	1.0
	2002-03	6.5	2.5	1.0
	2003-04	6.9	2.6	1.0
	2004-05	5.7	2.2	1.0
	2005-06	5.3	2.2	1.0
	2006-07	5.9	2.4	1.0
Zone	East	4.0	1.5	1.0
	North	20.9	6.2	1.0
	South	3.0	1.5	1.0
	West	6.1	2.9	1.0

Uneven growth in consumption

The growth in fertilizer consumption has not been uniform throughout the country. There exists a wide gap in per hectare fertilizer consumption among states/districts. The per hectare fertilizer consumption varied from less than 5 kg/ha in states of Arunachal Pradesh, Nagaland, Sikkim to more than 200 kg/ha in Punjab during 2006-07. Three states (U P, A P and Maharashtra) accounted for nearly 40% of the total fertilizer consumption. In 78 districts (15%) the per hectare fertilizer consumption has crossed 200 kg whereas in 25% of districts, the fertilizer consumption is still less than 50 kg/ha. In 45% districts in eastern zone, the fertilizer use is less than 50 kg/ha. The two irrigated crops of rice and wheat account for more than 50% of total NPK consumption (Table 6). Four crops, namely rice, wheat, cotton and sugarcane consume almost 2/3 of total fertilizer consumption. The per hectare fertilizer consumption is low in coarse cereals and pulses as they are grown under rainfed conditions.

Table 6. Cropwise share and per hectare fertilizer consumption.

Crop	Gross cropped area (million ha)	Share in fertilizer consumption (%)	Fertilizer consumption (kg/ha)			
			N	P_2O_5	K_2O	Total
Cotton	8.5	6.0	89.5	22.6	4.8	116.8
Groundnut	6.6	2.9	24.4	39.3	12.9	76.6
Jute	0.8	0.2	38.0	11.5	5.0	54.4
Maize	6.6	2.3	41.7	14.7	3.8	60.2
Paddy	44.7	31.8	81.7	24.3	13.1	119.1
Pearl millet	9.8	1.7	21.9	5.5	0.8	28.2
Pigeon pea	3.6	0.8	20.9	13.3	2.0	36.2
Rapeseed & mustard	6.0	3.4	69.1	25	2.9	97.0
Sorghum	9.9	2.9	29.2	14.2	4.1	47.5
Sugar cane	4.3	5.4	124.8	44.0	38.3	207.1
Wheat	25.7	21.0	99.6	30.2	6.9	136.7
Other crops	60.4	21.6	34.5	18.5	7.1	60.1
All crops	187	100	59.2	22.1	8.5	89.8
Irrigated	75.1	68.5	103.2	35.3	14.5	153.1
Rainfed	111.9	31.5	29.7	13.1	4.5	47.3

Source: FAO(2005)

Narrow product mix

Although there is a long list of more than 80 fertilizer products in FCO, 3 products dominate the consumption pattern. Urea accounts for 81% of the total consumption. The share of straight nitrogenous fertilizers namely ammonium sulphate, CAN and ammonium chloride has come down to 1%. DAP accounts for 61% of total P_2O_5 consumption. Single super phosphate (SSP), once the important source of P, now accounts for 8% of total P_2O_5 consumption only. There is shift from low analysis fertilizer like SSP, AS, CAN, ACl to high analysis fertilizers like Urea, DAP and MOP. The shift on high analysis fertilizer has resulted in wide spread deficiency of sulphur in Indian soils.

The use of NP/NPK complexes (other than DAP) has increased significantly in recent years, which has contributed to some extent in improvement in NPK use ratio. The share of NP/NPK complexes in total P_2O_5 consumption increase from 21% in 1991-92 to 31% in 2006-07.

Emerging multinutrient deficiencies

There is no greater threat to sustainable agricultural production system than the alarming rate at which Indian soils are being mined of their plant nutrient reserves. Against an estimated annual depletion of 30 million tonnes of nutrients (NPK) from the soil, the replenishment through fertilizers is only 21.7 million tonnes, leaving a net annual deficit of 8 million tonnes, which keep accumulating year after year depleting the soil fertility. The situation in case of secondary and micronutrients is even worse where additions are very low. Extent of depletion in soil fertility over time in Haryana, intensively cultivate state, is shown in Table 7.

Table 7. Comparison of per cent soil sample deficient in 1996 as compared to 1980 in Haryana.

Nutrients	1980			1996		
	Low	Medium	High	Low	Medium	High
Nitrogen	80	18	2	92	8	<1
Phosphorus	25	40	35	70	25	5
Potassium	0	18	82	5	33	62

Source: Kumar *et al*.(2001)

The continuous mining of nutrients from soils coupled with inadequate and imbalanced fertilizer use has resulted in emergence of multinutrient deficiencies. The deficiencies of at least six nutrients (N, P, K, S, Zn and B) are quite widespread in Indian soils (Table 8). The increasing deficiencies of secondary and micronutrients have started limiting the response to primary nutrients (NPK). The problem of secondary and micronutrients is more acute under high productive intensively cultivated areas. The increase in agricultural productivity under intensive agriculture puts severe drain on soil fertility, especially with respect to potassium, secondary and micronutrients.

Table 8. Extent of nutrient deficiencies in India.

Nutrients	Samples deficient (%)
Nitrogen	89
Phosphorus	80
Potassium	50
Sulphur	40
Zinc	48
Boron	33
Iron	12
Manganese	5

Source: Tewatia(2007)

Weakening fertilizer and foodgrains relationship

The fertilizer consumption in India has increased substantially in last three years. However, the increase in use of fertilizers has not resulted in increasing foodgrain production (Table 9). A constant decline in factor productivity has been noticed in recent year, which is indicator of non-sustainability of agriculture production system. Stagnation in foodgrains production despite significant fertilizer use has affected the farmers' profitability and country's self sufficiency in foodgrain production.

Table 9. Recent trends in fertilizer use and foodgrains production (million tonnes).

Crop	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07
Rice	89.7	85.0	93.3	71.8	88.3	83.1	91.8	92.8
Wheat	76.4	69.7	72.8	65.8	72.1	68.6	69.4	74.9
Cereals	196.4	185.7	199.5	163.6	198.5	185.2	195.2	201.9
Pulses	13.4	11.1	13.4	11.1	14.9	13.1	13.4	14.2
Foodgrains	*209.8*	*196.8*	*212.9*	*174.8*	*213.4*	*198.4*	*208.6*	*216.1*
Fertilizer use	18.1	16.7	17.4	16.1	16.8	18.4	20.3	21.7

Declining fertilizer response

Crop response to fertilizers is low and declining continuously. The average crop response to fertilizer application (kg grain/kg NPK) has declined from 10:1 during 1960s and 70s to 8:1 during 1980s and 7:1 during 1990s. The crop response may be still lower at present. With the decrease in crop response to fertilizers, the profitability of the farmers is going down year after year. Besides other factors, the problem of increasing multinutrient deficiency is largely responsible for declining crop response to fertilizers.

Inadequate soil testing facilities

Soil testing is a basic necessity to determine the quantities of nutrients to be applied and hence ensures soil health through balanced and efficient use of fertilizers. The country has about 651 soil testing laboratory with an analyzing capacity of 6.86 million samples per annum. Given the vast cultivated area and number of farm holdings, the soil testing facilities are grossly inadequate. Moreover, the utilization of existing soil testing facilities at farmer's level is very low putting a question on the reliability of soil testing services.

In most of the states, the exiting fertilizer recommendations are outdated and obsolete. The present fertilizer recommendations are suboptimal and many progressive farmers are using higher doses of fertilizers to get the higher yields.

Increasing imports and subsidy burden

Due to spurt in fertilizer demand coupled with stagnation in domestic production of fertilizers, the country is facing the problem of tight availability of fertilizers. There has been sharp increase in imports of fertilizers to meet the increasing fertilizer demand. The import of urea was nil in 2000-01 and it increased to 4.7 million tonnes in 2006-07. Similarly, DAP imports increased from 0.9 to 2.9 million tonnes during the same period. With the entry of India for a large scale fertilizer import, the prices of fertilizers have sky rocketed in the international market (Table 10).

Table10. Increase in prices of imported Urea, DAP and MOP (FOB US$/tonne).

Year	Urea	DAP	MOP
1993	72-145	119-170	50-125
1995	162-232	140-260	60-120
2001	72-147	133-173	87-131
2003	98-175	147-212	87-129
2004	112-275	200-265	80-160
2005	168-290	220-270	122-195
2006	190-270	250-276	145-195
2007 (Jan-Sept)	240-340	269-475	150-270

The decontrol of P & K fertilizers in August 1992 was done with the sole objective of reducing the fertilizer subsidy burden. However, the objective has not been achieved at all and there has been a continuous increase in fertilizer subsidy since 1992-93 (Table 11). It may be noted that the increase in subsidy is substantial in last 3 years due to sharp increase in consumption, increase in cost of production and sharp increase in prices of imported fertilizers and raw materials.

Table 11. Increase in subsidy on fertilizers from 1992-93 to 2007-08 (Rs. billion).

Year	Subsidy	Adhoc concession	Total
1992-93	57.96	3.40	61.36
1995-96	62.35	5.00	67.35
1998-99	75.97	37.90	113.87
2000-01	94.81	43.19	138.00
2003-04	85.21	33.26	118.47
2004-05	107.37	51.42	158.79
2005-06	118.64	65.96	184.60
2006-07 (RE)	141.04	83.48	224.52*
2007-08 (BE)	141.04	83.47	224.51**

*Plus an additional amount of Rs. 35.00 billion in the third supplementary grant.

**Plus an additional amount of Rs. 140.50 billion in the first supplementary grant.

Unfavourable pricing policy

The changes in fertilizer policy has been very frequent and adhoc particularly after the decontrol of P and K fertilizers in August 1992. The present fertilizer policy does not encourage the balanced, efficient and integrated use of fertilizers. The unfavourable pricing policy is responsible for the distorted NPK ratio, which is skewed in favour of N. There are more than 80 products in FCO. However, fertilizer subsidy is available on a few products only. The current pricing and subsidy schemes do not include secondary and micronutrients. Policy has created intra-product and intra-nutrient distortion in prices leading to imbalanced fertilizer use. Fertilizer subsidy is available on MOP and not on other products like potassium sulphate and 100% water soluble complexes (potassium nitrate, mono-potassium phosphate, potassium magnesium sulphate). There is no encouragement for product innovation as the manufacturers are neither reimbursed nor allowed to recover the extra cost from farmers on value addition. Incorporation of new product in FCO is also a time consuming process

Suggested measures: Some of the measures, which need urgent attention

Ensuring balanced fertilization

The concept of balanced fertilization now goes beyond NPK as the country has entered into an era of multinutrient deficiency. The present fertilizer product pattern, which is dominated by urea, DAP and MOP is not conducive for solving the problem of multinutrient deficiency. The farmer knowledge regarding the right product doses time and method of application is very limited leading to imbalanced and inefficient use of fertilizers. The efforts should be made to ensure that the farmers use the fertilizers in balanced proportion based on soil testing and crop requirements.

Increasing fertilizer use efficiency

The sharp increase in fertilizer prices and tight availability underline the need of using fertilizer in the most productive and profitable manner.

The fertilizer materials that are better than prilled urea should be promoted to get higher fertilizer use efficiency. The application of fertilizer through fertigation should be promoted to increase fertilizers and water use efficiency. There is a considerable potential to improve nitrogen use efficiency by promoting the use of neem coated urea. Products and practices which improve fertilizer use efficiency need special encouragement through a combination of extension services and flexible pricing.

Promoting Integrated Nutrient Management

The nutrients needs of Indian agriculture are increasing continuously and are more varied due to growing multinutrient deficiencies. No single nutrient source, be it fertilizer, organic manures or biofertilizers, is adequate to meet the needs of crops. The complimentary use of chemical fertilizers, organic manures and biofertilizers referred to as integrated nutrient management can play an important role in solving the problem of nutrient mining. Efforts should be made to increase the availability of organic manures, FYM, green manures and biofertilizers. To ensure the quality, the government has brought biofertilizers and organic manures under FCO.

Strengthening soil testing infrastructure

There are 651 soil testing laboratories with annual analyzing capacity of 6.86 million samples. However, considering the requirement the analyzing capacity of soil testing labs is grossly inadequate. Besides, increasing the analyzing capacity, it must be ensured that the existing soil testing facilities are fully utilized. All the soil testing laboratories should have the facilities for analyzing the secondary and micronutrients.

Developing value added/fortified/customized fertilizers

The government has included customized fertilizers in the Fertilizer (Control) Order 1985, as a new category of fertilizers that are area/soil/crop specific. The development of customized fertilizers fortified with secondary and micronutrients would be best option to ensure the balanced and efficient use of fertilizers. Inclusion of new fertilizers in FCO is being liberalized but the registration of new products still take a long time. A system with quick approvals of new fertilizers with proven efficiency and largely applicability should be put in the place.

Appropriate pricing policy

Adoption of an appropriate pricing policy is a prerequisite for ensuring the integrated and balanced use of fertilizers. The current pricing policy provides no incentives to the manufacturers to develop value added/fortified fertilizers. The pricing policy should encourage the use of all plant nutrients in a balanced manner. From the present product based subsidy and pricing mechanism, the need is to progressively move towards a nutrient based subsidy and pricing mechanism. The pricing of value added/fortified/customized fertilizers should be left to the market.

Conclusions

It must be recognized that nutrients needs of Indian agriculture are now bigger and more varied. The compulsion to produce more and more from decreasing per capita land availability will continue to put increasing pressure on the soil resources. India would require 45 million tonnes of nutrients (NP) to produce 300 Mt of food grains to feed its population of 1.4 billion by 2025. Thus the dependence on fertilizers will increase to produce more and more to meet the increasing food demand of ever increasing population. Besides ensuring adequate and timely availability of fertilizers, it must be ensured that farmers use fertilizer in balanced and efficient manners. The adoption of fertilizer best management practices (FBMPs) should be encouraged in view of low fertilizer use efficiency and declining factor productivity. Products and practices which improve fertilizer use efficiency and ensure better returns to farmers should be promoted by the concerned agencies. Extension agencies should ensure that farmers use the fertilizers in accordance with soil and crop requirements and deficiency of any nutrient does not become a limiting factor in achieving optimum yields.

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IMPLEMENTING FIELD-SPECIFIC NUTRIENT MANAGEMENT IN RICE-BASED CROPPING SYSTEMS

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Abstract

The site-specific nutrient management (SSNM) approach, as developed for rice through partnerships of the International Rice Research Institute (IRRI) with national agricultural research systems across Asia, provides scientific principles for optimally supplying rice with essential nutrients. It enables rice farmers to tailor nutrient management to the specific conditions of their fields through the pre-season determination of crop needs for fertilizer N, the within season distribution of fertilizer N to optimally meet crop needs, and the pre-season determination of fertilizer P and K rates to match crop needs and maintain soil fertility. The optimal fertilizer N rate typically ranges between 40 to 60 kg N per ton of increase in grain yield obtained from N fertilization. The leaf color chart (LCC) is a tool for dynamically adjusting the within-season rates and timing of fertilizer N to match the spatial and temporal needs of the crop for N. Fertilizer P and K rates are determined with a range of tools including soil testing, nutrient omission plots, historical fertilizer, and nutrient addition plots. A web site (www.irri.org/irrc/ssnm) features the principles for nutrient management, techniques for implementing SSNM, and publications. Training materials and simple tools targeted to building the capacity and effectiveness of local extension in the public and private sector continue to be developed to facilitate the effective identification and implementation of locally adapted practices at the farm and field level. Simple computer-based decision tools are being developed, which rapidly provide fertilizer guidelines for a specific location based on the response of farmers to about ten easy-to-answer, multiple choice questions.

Introduction

Much of the essential nutrients taken up by rice come from soil and crop residues, but high yields still require the input of supplemental nutrients. Rice farmers often apply fertilizer N at rates and times not well matched to the needs of the crop for supplemental N. For example, the application of fertilizer N by farmers during early vegetative growth soon after transplanting or direct seeding often exceeds the needs of rice for N, whereas the application of N at the critical growth stage of panicle initiation is often insufficient to match crop needs for high yield. Balanced fertilization – particularly with K, S, and Zn – to ensure nutrients other than N are not limiting yield is becoming increasingly important to achieving increased profit for farmers and high efficiency for fertilizer N use.

Site-specific nutrient management (SSNM) as developed in Asia through partnerships of IRRI with national agricultural research systems is a plant-based approach for supplying rice with nutrients as and when needed (IRRI 2008). The SSNM approach provides the principles and guidelines that enable farmers to apply fertilizer to optimally match the needs of their rice crop in a specific field and season. It aims to achieve high rice yield and high efficiency of nutrient use by rice, leading to high cash value of the harvest per unit of fertilizer invested. The SSNM approach was developed across diverse irrigated rice-growing environments in Asia. Researchers developed the concept of SSNM in the mid 1990s. It was then evaluated and refined from 1997 to 2000 on about 200 irrigated rice farms in eight major rice-growing areas across six countries in Asia (Dobermann *et al.* 2004). From 2001 to 2004, the initial SSNM concept was systematically transformed to provide farmers and extension workers with simplified plant-need-based management of N, P, and K. This included use of the leaf color chart (LCC) for N management. Since 2005, increased emphasis has been placed on the dissemination of SSNM through expanded partnerships with research and extension organizations, non-government organizations (NGOs), and the private sector.

Principles of nutrient management for rice

The SSNM approach is based on the direct relationship between crop yield and the need of the crop for a nutrient, as determined from the total amount of the nutrient in the crop at maturity (Witt *et al.* 1999). A yield target provides an estimate of the total nutrient needed by the crop. The portion of this requirement that can be obtained from non-fertilizer sources such as soil, crop residues, organic inputs, atmospheric deposition, and irrigation water is referred to as the indigenous nutrient supply. Because rice grain yield is directly related to the total amount of nutrient taken up by rice, indigenous nutrient supply can be determined from the nutrient-limited yield, which is the grain yield for a crop not fertilized with the nutrient of interest but fertilized with other nutrients to ensure they do not limit yield.

The fertilizer N needed by a rice crop can be estimated from the anticipated crop response to fertilizer N application and the expected efficiency of fertilizer N use by the crop. The crop response is the increase in grain yield due to fertilizer N, which is the difference between a yield target and yield without fertilizer N referred to as the N-limited yield.

The yield target is the rice grain yield attainable by farmers with good crop and nutrient management and average climatic conditions.

Only a fraction of the fertilizer N applied to rice is taken up by the crop. Hence, the total amount of fertilizer N required for each ton of increase in grain yield depends on the efficiency of fertilizer N use by rice, which is defined as the increase in yield per unit of fertilizer N applied. In low-yielding seasons with crop response to fertilizer N typically <2 t/ha, an efficiency of fertilizer N use of 17 to 20 kg grain

Increase/kg N is often achievable with good crop and nutrient management in farmers' fields in tropical Asia. This corresponds to a fertilizer N need of about 50 to 60 kg N for a one ton increase in grain yield (Table 1). In high-yielding seasons with very favorable climatic conditions and a crop response to fertilizer N of up to 3 to 4 t/ha – such as in Boro – an efficiency of fertilizer N use of up to 25 kg grain increase/kg N is achievable with good crop and nutrient management. This corresponds to a fertilizer N need of about 40 kg N for each one ton increase in grain yield (Table 1).

Table 1. Guidelines for estimating total fertilizer N required for rice, based on crop response to fertilizer N and targeted efficiency of fertilizer N use.

Rice response to N (t/ha)	Efficiency of fertilizer N use (kg grain increase/kg applied N)	Fertilizer N requirement (kg/ha)
1	17–20	50–60
2	18–22	90–110
3	22–25	120–135
4	25	160

Young rice before the tillering stage grows slowly and does not need much N. Therefore, with SSNM only a small to moderate amount of fertilizer N is applied to young rice within 14 days after transplanting or 21 days after direct sowing. In order to achieve high yield, rice plants require sufficient N at early and mid-tillering stages to achieve an adequate number of panicles and at panicle initiation stage to increase grain number per panicle. A key ingredient for managing N to meet crop need at these critical growth stages is a method for rapidly assessing leaf N content, which is closely related to photosynthetic rate and biomass production and is a sensitive indicator of the N demand during the growing season.

The LCC is an inexpensive and simple tool for monitoring the relative greenness of a rice leaf as an indicator of the leaf N status (Witt *et al.* 2005). A standardized plastic LCC with four panels ranging in color from yellowish green to dark green has been developed through partnership of IRRI national agricultural research systems across Asia. It is 14 cm long, made of high-quality plastic, consisting of four color shades from yellowish green (No. 2) to dark green (No. 5) (IRRI 2008).

The effective management of N requires sufficient application of P, K, and micronutrients to overcome limitations of other nutrients. In the SSNM approach, fertilizer P and K are applied in sufficient amounts to overcome deficiencies and maintain soil fertility. The amounts of P and K taken up by a rice crop are directly related to grain yield. Therefore, the need of the rice crop for fertilizer P in a given field or location can be obtained from an estimate of an attainable yield target and a P-limited yield. The need of the rice crop for fertilizer K can be similarly obtained from an estimate of an attainable yield target and a K-limited yield. The P-limited yield approximates the P supplied to rice from indigenous sources such as soil, crop residue, irrigation water, organic amendments, and manures. The P-limited yield and hence indigenous P supply can be determined from grain yield for a crop not fertilized with P but fertilized with other nutrients to ensure they do not limit yield.

The K-limited yield similarly approximates the K supplied to rice from indigenous sources. The K-limited yield and hence indigenous K supply can then be estimated from grain yield for a crop not fertilized with K but fertilized with other nutrients to ensure they do not limit yield. Irrigation water can be an important indigenous source of K that is accounted for with K-limited yield in the SSNM approach but not with soil testing.

The attainable yield target, P-limited yield, and K-limited yield can be used with a nutrient decision support system to determine the amount of fertilizer P_2O_5 required to both overcome P deficiency and maintain soil P fertility and the amount of fertilizer K_2O required to both overcome K deficiency and maintain soil K fertility. Outputs of the nutrient decision support system are summarized by Witt *et al.* (2007). The need for fertilizer K depends upon the management of rice straw, which contains most of the K in a rice crop.

As a general rule for modern rice varieties with harvest indices of 0.45 to 0.55, a mature rice crop typically contains the equivalent of about 6 kg P_2O_5 within its biomass for each ton of grain yield. Hence, a 6 ton crop contains about 36 kg P_2O_5 at maturity. Two-thirds of this P is in the grain. Therefore, about 4 to 5 kg P_2O_5 per hectare is removed from a rice field for each ton of grain yield depending on the management of crop residues. Hence, for a 6-t/ha crop, about 24 to 30 kg P_2O_5/ha must be replaced using fertilizer P to maintain P balances.

Guidelines for implementing field-specific nutrient management

Nutrient management can be implemented by crop growth stage based on guidelines for fertilizer best management practices. For best effect, farmers should apply fertilizer N several times during the growing season to ensure that the N supply matches the crop need for N at the critical growth stages.

Early vegetative phase

This phase covers the period from before crop establishment up to 14 days after transplanting (DAT) for transplanted rice or up to 21 days after sowing (DAS) for wet-seeded rice. During this period apply:

- Only a moderate amount of fertilizer N because the need of rice for supplemental N is small during this period of slow initial plant growth.
- All of required fertilizer P because P is important for early crop growth especially root development and tillering.
- At least half the required fertilizer K because it can contribute to greater canopy photosynthesis and crop growth.

Use the following guidelines for the early application of N:

- Typically apply about 20 to 30 kg N/ha in seasons with yield response to N between 1 and 3 t/ha.
- Apply about 25 to 30% of the total N in seasons with yield response to N >3 t/ha.
- Eliminate early application when yield response to N is ≤1 t/ha.
- Do not use the LCC with the early N application.
- Reduce or eliminate early N application when high-quality organic materials and composts are applied or the soil N-supplying capacity is high.

Increase the N application to 30 to 50% of the total N for transplanted rice when old seedlings (>24 days old) and short-duration varieties are used.
Apply all fertilizer K before 14 DAT or 21 DAS, when the total fertilizer K requirement is relatively low (≤30 kg K_2O/ha). On sandy soils or when larger amounts of fertilizer K are required, apply about 50% of the required fertilizer K before 14 DAT or 21 DAS. In case of S deficiency, apply about 2.5 to 3.0 kg S/ha per ton of anticipated crop yield before 14 DAT or 21 DAS.

Late vegetative phase

Rice plants require N during the tillering stage to ensure a sufficient number of panicles. The need of the rice crop for fertilizer N can be determined by leaf N status, which is related to leaf color. Dark green leaves have ample N, whereas yellowish green leaves are deficient in N.
The SSNM approach with the LCC developed through IRRI provides two complementary and equally effective options for improved N management using the LCC. In the 'real-time' N management option, farmers monitor the rice leaf color at 7 to 10-day interval from the start of tillering and apply fertilizer N whenever the leaves become more yellowish-green than the critical threshold value indicated on the LCC. The doses for each N application increase in proportion to the anticipated response of the crop to fertilizer N (Table 2). In the 'fixed-time/adjustable dose' option, the time for N fertilization is pre-set at critical growth stages, and farmers adjust the dose of N upward or downward based on the leaf color. The critical time at active tillering for N application is typically about midway between 14 DAT or 21 DAS and panicle initiation. The doses for N application are adjusted based on leaf color and anticipated response of the crop to fertilizer N (Table 3).

Table 2. Proposed amounts of fertilizer N to be applied with the real-time option for N management each time the leaf color falls below the critical LCC value (from Witt *et al.* 2007).

Rice response to N (Expected yield increase over 0 N plot) (t/ha)	Application rate during period after 14 DAT or 21 DAS up to panicle initiation (kg N/ha) [a]
1–2	25
2–3	35
3–4	45

[a] Apply about 25 kg N/ha after panicle initiation up to first flowering.

The selection of an option for using the LCC can be based on farmer preferences and location-specific factors. The fixed-time/adjustable-dose option, for example, is less time-consuming and is preferred by farmers with non-rice activities and insufficient time for weekly visits to their rice fields. The real-time option is generally preferred when farmers lack sufficient understanding of the critical stages for optimal timing of fertilizer N.

Table 3. An approximate fertilizer N splitting for transplanted and wet-seeded inbred rice based on the fixed-time/adjustable-dose option for N management (from Witt *et al.* 2007).

Expected yield increase over 0 N plot (t/ha) →		1 t/ha	2 t/ha	3 t/ha	4 t/ha
Growth stage	Leaf color	Fertilizer N rate (kg/ha)			
Preplant to 14 DAT or 21 DAS		–	20	30	45
Active tillering	Yellowish green	35	45	45	60
	Intermediate	25	35	35	45
	Green	–	–	25	25
Panicle initiation	Yellowish green	35	45	45	60
	Intermediate	25	35	45	45
	Green	–	25	25	35

Reproductive phase

Panicle initiation (about 60 days before harvest of tropical rice) is a critical stage for ensuring the supply of N and K are adequate to match the needs of the crop. An insufficient supply of N at panicle initiation can result in loss of yield and profit through reduced number of grain per panicle. The LCC can be used to guide the application of fertilizer N to maintain an optimal leaf N content for achieving high rice yield with effective N management. As a rule of thumb, the need for fertilizer N increases in proportion to the response in grain yield to fertilizer N.

Guidelines for the real-time N management option with monitoring of rice leaf color at 7 to 10-day interval is given in Table 2, and guidelines for variable N rate management at panicle initiation based on the fixed-time/adjustable-dose option is given in Table 3. The more yellowish green the leaf color, the greater the need of the crop for fertilizer N.

An insufficient supply K at panicle initiation can result in loss of yield and profit through reduced grain number per panicle and reduced filling of grain. Apply at panicle initiation up to 50% of the total fertilizer K requirement when the total fertilizer K requirement is >30 kg K_2O/ha. In the case of sandy soils typically apply up to 50% of the total fertilizer K requirement even when the requirement is ≤30 kg K_2O/ha.

Ripening phase

Nitrogen absorbed during the ripening phase, in the presence of adequate solar radiation, enhances the grain filling process. Inbred rice normally does not require fertilizer N at heading or flowering if the N application at the critical growth stage of panicle initiation was adequate. Hybrid rice in high-yielding seasons can require a fertilizer N application at early heading in the particular situation when leaf color is yellowish green. As a general guideline, apply about 20 kg N/ha at early heading to hybrid rice when the expected response to fertilizer N is ≥3 t/ ha and leaf color is yellowish green (LCC value 3).

Tools for estimating fertilizer needs in rice-based cropping systems

Intensified rice-based cropping systems with high yields will be required to meet increasing demands for food, feed, fuel, and fiber. Fertilizer P and K needs by crops, as determined with the SSNM approach, are directly related to attainable yield levels; and fertilizer N needs are directly related to the crop response to N, which typically increases with increasing attainable crop yield. It is consequently valuable to know the attainable yield targets for crops when assessing probable opportunities for future crop production and the associated needs for fertilizer in intensive cropping systems.

We illustrate for Sadar Upazilla in Kushtia District how crop simulation models for rice and maize can be used to estimate attainable yield targets with best crop management practices. The estimated yields can subsequently be used to assess evolving fertilizer needs as cropping systems diversify, intensify, and increase in yield.

In Sadar Upazilla, rice–rice and rice–wheat were formerly the main cropping patterns. Starting in about 1990, maize was introduced during the Rabi season after the harvest of rice. The area of maize production subsequently expanded rapidly and replaced Boro rice and wheat. The cultivation of Boro decreased by about 50%, and wheat cultivation is now almost non-existent. Rice–rice and rice–maize are now the two predominant cropping systems. Based on interviews of farmers in Buria village in January 2008 average yields of maize are about 8 t/ha (Jagadish Timsina, personal communication, 2008). Shallow tube wells are available to provide irrigation as needed depending on rainfall.

The ORYZA 2000 (Bouman *et al.* 2001) and Hybrid-Maize (Yang *et al.* 2004) models were used to estimate climatic and genetic yield potential of rice and maize using 20 years of historical weather data obtained from the National Aeronautics and Space Administration (NASA) for Sadar Upazilla. Farmers generally transplant Aman rice from mid-July to mid-August and Boro rice from mid-January to mid-February. The yield potential of rice was consequently determined for intermediate duration rice (about 100 to 115 days duration from seed-to-seed) with transplanting on 1 August for Aman and transplanting on 1 February for Boro. Farmers generally plant maize from late November to mid-January. The yield potential for maize was determined for a hybrid with duration of 1800 growing degree days and planting on 1 December.

Yield potential for rice was higher for Boro than Aman, and yield potential of maize was much higher than for rice (Table 4). Maize captured more solar radiation during the growing season and also experienced cool environment during the grain-filling period, resulting in high yield. The yield attainable for high financial return through use of best crop and nutrient management practices was set at 80% of the yield potential (Witt *et al.*2007). The attainable yield of maize established through this technique (11.1 t/ha) was markedly higher than the currently reported average farmers' yield of 8 t/ha, indicating opportunities for future increases in maize yield through improved crop and nutrient management practices. Attainable annual yields were markedly higher for rice–maize (17.3 t/ha) than rice–rice cropping (14.1 t/ha), suggesting much higher nutrient extraction and fertilizer needs for rice-maize than rice-rice as these cropping systems approach their attainable yield potential.

Table 4. Simulated yield potential and growth duration for rice and maize planted during farmers' preferred planting times in Sadar Upazilla, Kushtia District, Bangladesh.

Season	Crop	Planting date	Yield potential (t/ha)		80% yield potential (t/ha)	Mean growth duration (d)
			Mean	Standard error		
Aman	Rice	1 August	7.7	0.2	6.2	110
Boro	Rice	1 February	9.9	0.1	7.9	121
Rabi	Maize	1 December	13.9	0.3	11.1	130

Tools for facilitating the implementation of field-specific nutrient management for rice

In order to facilitate the dissemination of improved nutrient management practices, we strive to develop and disseminate information, training materials, and simple tools targeted to building the capacity and effectiveness of local extension in the public and private sector. Simple tools are particularly needed to provide extension workers and farmers with decision-making skills, which enable effective identification and implementation of fertilizer best management practices locally adapted to specific rice-growing conditions at the field and farm level. In developing such tools we recognize that farmers vary greatly in access to relevant information for determining fertilizer needs for their field, yet they must be able to make rapid decisions on fertilizer rates and management based on the information available to them. For example, not all farmers will have soil test information for their field; and even when farmers have access to information on current fertilizer guidelines for their crop and season, their specific situation (such as crop rotation, inputs of sediment from seasonal flooding, etc) could vary from those on which the current fertilizer guidelines for their region are based.

IRRI, through its collaboration with national agricultural research and extension systems in developing and promoting improved nutrient management for rice, has aimed to develop simple computer-based decision tools, which rapidly provide fertilizer guidelines for a specific location based on the response of extension workers or farmers to about ten easy-to-answer, multiple choice questions. These decision tools use the principles of nutrient management for rice as described above with information available to the farmer to:

- Prescribe an amount of fertilizer N in the first N application near crop establishment.
- Enable dynamic adjustments for within-season rates of fertilizer N to match the needs of the crop for N.
- Estimate the total amount of fertilizer P and K required by a rice crop.
- Tailor K fertilization to their field-specific needs.

Such decision tools are based on the premise that field-specific guidelines for all applications of N during the cropping season can be developed with the following knowledge:

- The crop response (increase in grain yield) anticipated from application of fertilizer N in the field in the given cropping season with typical climatic conditions.
- The growth duration of the rice variety from transplanting to maturity in the case of transplanted rice or from seed-to-seed in the case of direct-seeded rice.

The knowledge of crop growth duration for the variety is used to approximate the dates after transplanting or direct seeding when fertilizer N should be applied to match the critical growth stages of active tillering and panicle initiation.

The anticipated crop response to N can be approximated from information provided by the farmer for:

- ♦ Grain yield typically attained in previous yields in the field for the given cropping season.
- ♦ Approximate amounts of high N containing manure or organic materials applied to the field.
- ♦ Whether the field received substantial inputs of sediment from flooding of a nearby river.

Information of organic inputs and whether the field received sediment inputs is used to adjust indigenous N supply and correspondingly reduce the anticipated crop response to N and need for fertilizer N.

Decision tools for application of fertilizer P are based on the premise that a field-specific guideline can be developed with the following knowledge:

- ♦ Grain yield typically attained in previous yields in the field for the given cropping season, which determines the total need of the crop for P.
- ♦ The indigenous P supply, which can be assessed from soil analysis, nutrient omission plots, or historical application of fertilizer P.

Fertilizer P guidelines take for granted the need to maintain soil P fertility by applying sufficient fertilizer P to match the P removed with crop harvest. If soil analysis information is not available, it is assumed that maintenance applications of fertilizer P sufficient to match P removal (about 4 to 5 kg P_2O_5/ha per ton of grain yield) are required when previous fertilizer P rates were at or above maintenance rates.

Decision tools for application of fertilizer K are based on the premise that a field-specific guideline can be developed with the following knowledge:

- ♦ Grain yield typically attained in previous yields in the field for the given cropping season, which determines the total need of the crop for K.
- ♦ The indigenous K supply, which can be assessed from soil analysis, nutrient omission plots, or historical application of fertilizer P.
- ♦ The quantity of aboveground residues retained from the previous crop.

Fertilizer K guidelines assume the need to maintain soil K fertility by applying sufficient fertilizer K to match the K removed with crop harvest. But in some cases, soil K reserves can be sufficiently high to enable mining of soil K through less application of fertilizer K than removed with crop harvest. In the absence of information on soil K reserves, the fertilizer K guidelines include early application at least a portion of the total K required to maintain K balances. The fertilizer K guidelines then enable farmers to decide through a superimposed K addition plot whether application of the remaining fertilizer K at panicle initiation provides financial benefit.

The K addition plot technique involves superimposing a small plot within a farmer’s field (IRRI 2008). The fertilizer K at panicle initiation is applied only within this addition plot.

The rice crop is otherwise managed by the farmer identically inside and outside the plot area. The farmers can then compare crop performance inside and outside the addition plot. Rice yield can be limited by insufficient supply of K even when symptoms of K deficiency are not visible during crop growth. Farmers are therefore encouraged to compare grain filling and recovery of milled grain between the plot with additional K and their adjacent field without additional K because the benefits of K on yield and profit often emerge through higher percentage of filled grain rather than a higher number of total grains.

Dissemination of fertilizer best management practices for rice

The effective uptake by farmers of a relatively knowledge intensive technology such as improved nutrient management for rice necessitates the communication of consistent and clear messages to farmers. This requires ensuring the persons providing farmers with information on nutrient management are familiar with the SSNM guidelines and how they can be used by farmers to develop improved practices for specific rice fields.

In countries across Asia, farmers often receive contrasting and sometimes contradictory recommendations on nutrient management, which arise from the different techniques (soil testing, soil mapping, yield targets, etc.) and philosophies used by different organizations. This can contribute to confusion and failure of farmers to use best management practices. Based on experiences on disseminating improved nutrient and crop management for rice through the Irrigated Rice Research Consortium (IRRC), three critical requirements have been identified to ensure widespread uptake by rice farmers of improved nutrient management practices, which adhere to SSNM principles.

1. Build agreement and harmonization among research and extension organizations and among technical experts on fertilizer best management practices.
2. Build capacity of technical experts responsible for training of trainers and flow of technical information to provincial and local extension.
3. Provide local extension workers of the public and private sector with appropriate tools and skills to identify and implement locally adapted management practices at the farm and field level.

In order to meet these critical requirements, multi-institution partnerships are required to harmonize contrasting soil- and plant-based approaches to nutrient management and to add value to existing public and private sector initiatives to disseminate technologies to rice farmers. In Indonesia, for example, a multi-institution partnership through a national work group on fertilization of food crops established in 2006 led in 2007 to endorsement of a fertilizer best management practice for rice that harmonized soil test and plant-based approaches. A Technical Team representing four key organizations was subsequently formed in 2007 to facilitate national dissemination of improved nutrient management for rice in a coordinated fashion across organizations and projects at national, provincial, and local levels. Such experiences on multi-institution partnerships for developing and disseminating a fertilizer best management practice that harmonize contrasting approaches (such as soil testing, soil mapping, omission plot technique, etc) into one set of guidelines for implementing field-specific nutrient management highlight the opportunity for fast-tracking the uptake of improved nutrient management by providing technical experts and local extension with a single consistent set of guidelines.

Acknowledgment

The current dissemination of SSNM for rice builds upon a decade of partnerships with research and extension across Asia. The process that systematically established the scientific basis for SSNM, evaluated and refined SSNM in farmers' fields through partnerships across Asia, and is now disseminating improved nutrient management for rice across Asia was made possible through more than a decade of support from the Swiss Agency for Development and Cooperation (SDC), the International Fertilizer Industry Association (IFA), the International Potash Institute (IPI), and the International Plant Nutrition Institute (IPNI).

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POTASSIUM FERTILIZATION IN RICE-RICE AND RICE-WHEAT CROPPING SYSTEM IN BANGLADESH

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Abstract

Experiments and farmers' field demonstrations were conducted in the Central part and Northwestern (NW) region of Bangladesh to study the effect of potassium fertilizer on rice and wheat yields and find out the appropriate dose of potassium fertilizer for these crops under rice-rice and rice-wheat cropping pattern. Potassium fertilization significantly increased the production of rice-rice and rice-wheat cropping system. In complete fertilized plot, the yearly grain yield of rice was roughly consistent within the range of 9-10 t ha^{-1} while in the no K applied plots the grain yield production decreased sharply with time from about 10 t ha^{-1} in 1985 to 6.2 t ha^{-1} in 2000. The initial rice yield decreased due to omission of K was not significant but the yield gap between the balanced treatment and the zero K treatment widened sharply and significantly with time. In the reverse treatment, i.e. the application of K to the plots not receiving K for the last 16 years, a dramatic yield increase by 2 t ha^{-1} was observed. The estimated nutrient balance after 16 years indicated a severe depletion of K from experimental soil. The rate of K mining from fertilized plot was 141 kg ha^{-1} yr^{-1} and from K omitted plot was 132 kg ha^{-1} yr^{-1}. Potassium fertilization at 50 kg K ha^{-1} appeared to be sufficient and economically most viable to produce optimum grain yield of rice in both dry and wet season in clay loam soil at Gazipur and 66 kg K ha^{-1} for T Aman rice and wheat in sandy loam soil in Northwestern region of Bangladesh. Crop residues incorporation at 4.5 t ha^{-1} substantially increased the rice and wheat yield, which was comparable to that of 33 kg K ha^{-1} and farmers K dose. The effect of applied K was more prominent in light textured soil than in heavy textured soil. On the other hand, wheat crop utilized the applied K more efficiently than rice crops. In research trails, K fertilization increased rice grain up to 16% over control plot in clay loam soil while 30% of rice and 53% of wheat grain in sandy loam soil. Application of K fertilizer on soil test based (STB) increased grain yield of rice up to 20% in T Aman and 24% in Boro season in the farmer's field demonstration at Gazipur while in NW region, the application of K fertilizer on STB in farmer's field increased grain yield of wheat by 86% and T Aman rice by 25% over K control plot. Response of K fertilizer to the grain yield of rice and wheat was found more prominent in farmer's field demonstration than that of research trial in experimental field.

Introduction

Potassium (K) is a major plant nutrient and its requirement for rice is quite high, even greater than that of nitrogen (N).

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The K reserve of any soil is certainly limited, and no soil can supply K to crops adequately for an indefinite period of time. Some studies on K buffering capacity, K-depletion, K release pattern and Q/1 relationships of some soils indicated that there is a difference in soils in immediate and long-term availability of K (Progress report, 1991). Intensive cropping and use of modern rice varieties for high yield caused heavy depletion of K in soils particularly in the absence of K application (Tiwari 1985). Mohanty and Mondal (1989) reported a negative K balance in rice systems at many sites in India. A negative K balance even up to 60 kg/ha applied K level with diminishing magnitude was observed in a recent study of BRRI and suggested that an amount of about 60 kg K/ha would be required to sustain soil native K for rice cropping (Ahsan *et al.* 1997). Recent study indicated that about 60% cultivable land of Bangladesh is deficient in N, P and K. Most of the area of the North Western part of the country is deficient in K. Light textured soils of these areas has low exchangeable K and farmers also use low amount of K fertilizer (Miah, 2005). As the pressure to grow more food from the same piece of land increases, the soils come under the threat of nutrient depletion. Nutrient balance study indicated a negative balance for N and K and the mining of K from Bangladesh soil is now in alarming situation. The value varied between 0 to -50 kg/ha/yr for N and -100 to -225 kg/ha/yr for K (Rijmpa and Islam 2002). Rice is the staple food of Bangladeshi people. Wheat is relatively a new crop and growing wheat in a rice-wheat cropping pattern has been getting importance as a promising system for increasing food production in the country. Rice-wheat cropping system draws a lot of potassium from the soil and taking into consideration inadequate potash fertilizer inputs, soils are often single supplier of K to plants in the Indo-Gangetic Plains. As recently reviewed by Bijay Singh et al. (2004) K removal by rice wheat cropping system in the Indo-Gangetic Plains and in China ranges from 132 to 324 kg/ha in dependence from the cropping system and the productivity.

Long-term on-farm experiments conducted in different Asian countries indicated that initial rice yield increase due to K application was not significant (Witt *et al.* 2004). However, yield increase was consistent and become larger over time. Over 16-year period, the omission of K fertilizer significantly decreased the yield of rice and the yield gap between the balanced treatment and the zero K treatment widen sharply with time (BRRI 2001). Diba *et al.* (2005) reported a positive effect of K fertilizer use on rice yield contributing parameters. The response to K fertilizer on cereal crops like wheat was reported by Shaha *et al.* (2001) and rice by Ahsan *et al.* (1997). Timsina and Connor (2001) reported that intensive rice-based cropping system including wheat may cause heavy depletion of soil K. Potassium deficiency in wetland rice has so far received limited attention. The general recommended dose of K fertilizer for MV rice in Bangladesh is ~35 kg/ha while an average crop of rice yielding 4.0 t/ha removes at least 70 kg K/ha from the soil. The present K fertilizer management practice may not be enough for sustaining a favourable K fertility status of the soil in the long run. There is a tremendous scope of K fertilizer application for increasing cereal crop production in Bangladesh. Considering these points, studies were conducted at different locations with a view to develop appropriate K-fertilizer management practices for sustainable improvement of soil health and crop production of rice-rice and rice-wheat cropping system.

Materials and Methods

Research trials and farmers' field demonstrations were conducted with varying combinations of nutrient treatments under Boro-Fallow-T. Aman and Wheat-Fallow-T. Aman cropping pattern at different locations in Bangladesh during 2003-2007. Research trials were conducted at Bangladesh Rice Research Institute (BRRI) farm Gazipur (AEZ 28, Madhupur tract, medium highland) and at Hajee Danesh University of Science and Technology (HSTU) experimental farm, Dinajpur (AEZ 1, Old Himalayan Piedmont Plain, medium highland). Farmers' field demonstrations were conducted at Gazipur (AEZ 28), and Dinajpur, Thakurgaon and Panchagar (AEZ 1). The Gazipur soils are clay loam in texture, low in fertility status and very strongly acidic to slightly acidic in reaction (Table 1). The soils of the experimental field in Northwestern region are sandy loam in texture, very strongly acidic to strongly acidic in nature, very low in total nitrogen, exchangeable K and S, very low to optimum in P and low to optimum in Zn content (Table 2). Tested cropping patterns were Boro-Fallow-T. Aman in Gazipur and Wheat-Fallow-T. Aman in NW region. The rice varieties used for Boro were BR3, BRRI dhan28 and BRRI dhan29 and in T. Aman BR11, BRRI dhan31, BRRI dhan39 and BRRI dhan41. The wheat variety used was Shatabdi.

Table1. Initial soil characteristics of the experimental sites at Gazipur.

Soil properties	Locations	
	BRRI Farm, Gazipur	Farmers' fields
pH	6.10	4.10-5.70
OM (%)	2.02 (M)	1.23 (L) -2.56 (M)
Total N (%)	0.07 (VL)	0.08 (VL) – 0.13 (L)
Av. P (ppm)	10.14 (L)	2.30 (VL) – 5.02 (VL)
Exch. K (meq/100 g soil)	0.17 (M)	0.08 (L) – 0.21 (M)
Av. S (ppm)	6.10 (VL)	3.20 (VL) – 12.90 (L)
Av. Zn (ppm)	2.80 (VH)	0.47 (L) – 2.80 (VH)
Textural class	Clay loam	Clay loam

VL = Very low, L = Low, M = Medium, Opt = Optimum, H = High, VH = Very high

Table 2. Initial soil characteristics of the experimental sites at NW region* of Bangladesh.

Soil properties	Locations	
	HDUST Farm, Dinajpur	Farmers' fields*
pH	4.70	3.60 – 4.05
OM (%)	1.13 (L)	1.17 (L) – 1.52 (L)
Total N (%)	0.06 (VL)	0.06 (VL) – 0.08 (L)
Av. P (ppm)	17.80(M)	4.53 (VL) – 28.16 (Opt)
Exch. K (meq/100 g soil)	0.05 (VL)	0.03 (VL) – 0.09 (L)
Av. S (ppm)	4.50 (VL)	2.20 (VL) – 6.10 (L)
Av. Zn (ppm)	1.21 (Opt)	0.40 (L) – 1.40 (Opt)
Textural class	Sandy loam	Sandy loam

VL = Very low, L = Low, M = Medium, Opt = Optimum, H = High, VH = Very high
* Dinajpur, Thakurgaon & Panchagorh districts

The continuous omission of some fertilizer was demonstrated in a long-term soil fertility experiment at BRRI farm Gazipur. The experiment was initiated in 1985 and has been continued to date. There was a "complete" treatment consisting of the application of recommended N, P, K, S and Zn fertilizer and other treatments "missing" the nutrient elements such as -N, -P, -K, -S and -Zn. In the research trials six potassium treatments with varying doses viz. K control (K_0), recycling of crop residues but no K fertilizer (K_{0+CR}), 33 kg K/ha (K_{33}), 50 kg K/ha (K_{50}), 66 kg K/ha (K_{66}) and farmers' fertilizer doses (K_{FP}) were tested in RCB design with 4 replications. Farmers' field demonstrations were established with three doses of K fertilizer such as K control (K_0), farmer's practice of K (K_{FP}) and soil test based K dose (K_{STB}). The soil test based flat doses of NPS and Zn was applied in all the plots. Nitrogen fertilizer was applied into 3 splits for rice and into two splits for wheat. All other fertilizers (P, K, S & Zn) were applied at land preparation. In K_{0+CR} treatment, residues of previous crop were incorporated into the soil through ploughing at 10-15 days before transplanting/sowing. Two to three rice seedling/hill were transplanted at 20 x 20 cm spacing and wheat was sown in line. The crop was harvested from 5 m^2 area at the center of each plot and rice grain weight was adjusted to 14% and wheat grain to 12% moisture content. Soil and plant samples were analyzed using standard analytical procedure (Black 1965; Jackson 1962; Olsen *et al.*1954; Page *et al.* 1982 and Yoshida *et al.* 1972). The obtained data were statistically analyzed using IRRISTAT version 4.1 (IRRI 1998) and the economic analysis was done using standard procedure.

Results and discussion

Boro - Fallow - T. Aman rice cropping pattern

The continuous omission of K fertilizer was tested in a long-term soil fertility experiment at BRRI farm, Gazipur. Over a 16-year period, the problem of especially K in the no applied K plots intensified severely with time. While the total yearly grain yield (BR3, Boro + BR11, T. Aman) with the "Complete" treatment was generally within the range of 9-10 t/ha, the total yield in the no applied K plots dropped sharply from about 10 t/ha in 1985 to 6.2 t/ha in 2000 (Fig. 1). The initial rice yield decrease due to omission of K was not significant. While the yield gap between the balanced treatment and the no applied K treatment widened sharply and significantly (p=0.05) with time. In Boro 2000, the K plots were splited to accommodate a reverse treatment, i.e. the application of K (60 kg K/ha) to the plots not receiving K for the last 16 years.

The K "reverse" treatment resulted in a dramatic yield increase by 2 t/ha (Fig. 2). In a nutrient balance estimate, it was observed that about 141 kg K ha^{-1} yr^{-1} (2,255 kg ha^{-1} in 16 years) was removed in excess of K added as fertilizer (66 kg K ha^{-1} yr^{-1}) by two modern variety rice crops giving a grain yield of around 10 t ha^{-1} yr^{-1}. On the other hand, about 132 kg K ha^{-1} yr^{-1} (2,117 kg ha^{-1} in 16 years) was removed from the soil where K was not added as fertilizer (K omitted plot) by two MV rice crops giving a grain yield of 6.2 t ha^{-1} (Fig. 3).

Higher biomass production and K concentration in plot tissue in K fertilized plot compared to the no applied K plot may explain the excess mining of K from the K added plot. These results indicated the need for modifying the recommended K fertilizer doses for the MV rice-rice crop production system in flood free land where yearly K replenishment due to alluvial deposition does not occur.

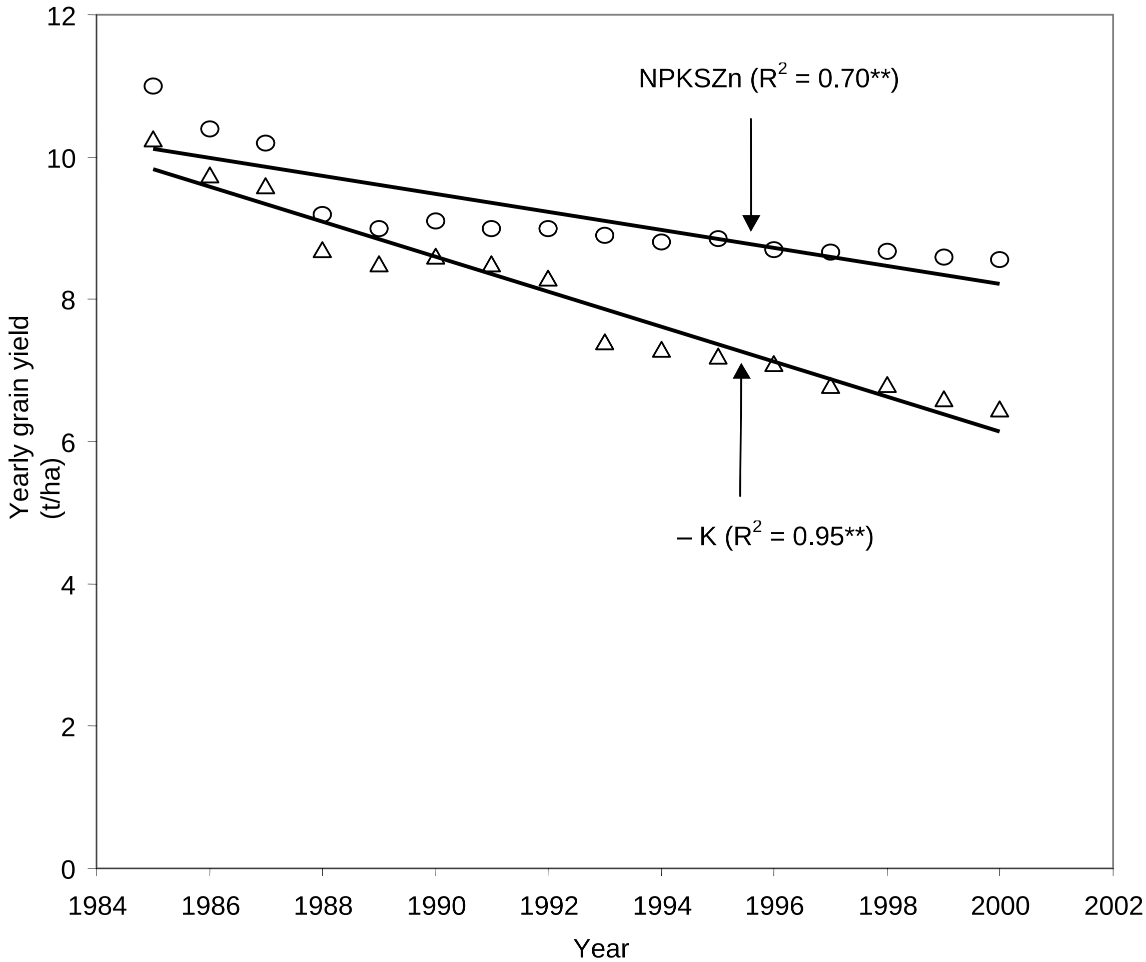

Fig.1. Total yearly grain yield of wetland MV rice under balanced and K missing fertilizer, BRRI farm, Gazipur, 1985-2000.

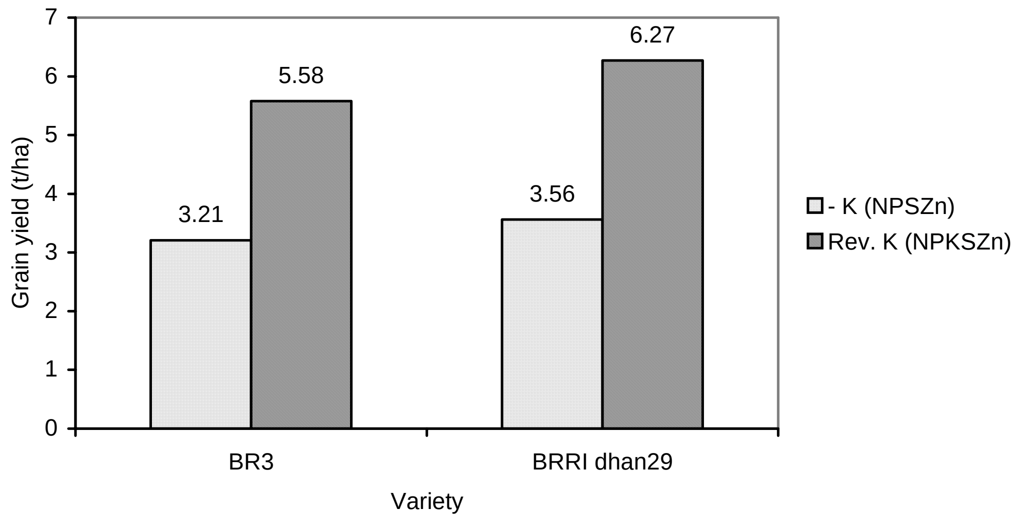

Fig. 2. Potassium response of MV rice (Boro 2000) to K fertilization in plots receiving no K fertilizer for 16 years.

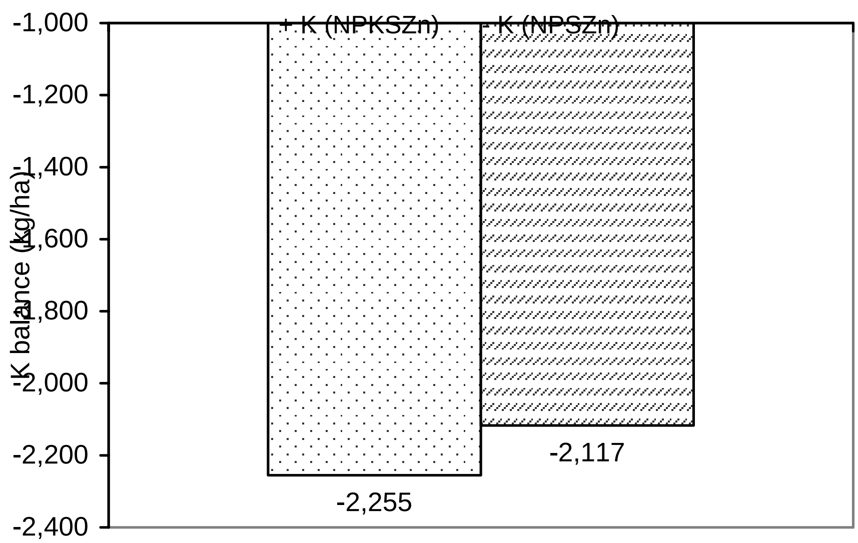

Fig. 3. Long-term omission effect of K on the K balance after 16 years of the wetland MV rice under Boro-Fallow-T. Aman cropping pattern, BRRI, Gazipur, 1985-2000.

It is apparent from the research trial conducted at BRRI farm at Gazipur that the application of potassium fertilizer increased grain yield of rice in any season (Table 3). The increase of grain yield due to application of K fertilizer was not significant in the first crop (T Aman 2003) while in the subsequent T Aman and Boro seasons significantly higher grain yield was found with K-fertilization either from crop residues or from chemical fertilizer over control. The grain yield was increased with the increase of applied K doses up to 50 kg/ha in both T Aman and Boro seasons and above this K-level, no appreciable influence in yield was observed.

Incorporation of crop residue (rice straw) into soil at 4.5 t/ha contributed significantly to get comparable grain yield of rice in successive crop growing seasons as produced with chemical K-fertilizer (Table 3). The average grain yield of five T Aman and four Boro seasons indicates that the grain yield of rice increased from 11 to 17% in T Aman and 5 to 15% in Boro season due to different doses of K application either through chemical fertilizer or from crop residues. The yearly average production of rice grain was increased from 8% with farmers' fertilization practice to 16% by applying 50 kg K/ha over K controls (Table 3).

In farmers' field demonstrations, K-fertilization positively influenced the grain yield of rice in any season. Potassium application on soil test basis (K_{STB}) produced the highest grain yield of rice followed by K_{FP} and K-control plots in both T Aman and Boro season. The performance of K_{STB} appeared to be superior in terms of seasonal and yearly average yield of rice grain over K_{FP}. The percent increase in yearly rice grain production estimated from K_{STB} plot was almost double (24%) to that estimated from farmers' fertilized plot (13%) over K control plot (Table 4). The response of added K to the grain yield of rice was found more prominent in dry season than that of wet season.

Wheat - Fallow - T. Aman cropping pattern

The results of research trial conducted at Hajee Danesh University of Science and Technology experimental farm indicated that the use of K fertilizer in sandy loam soil of NW region of Bangladesh significantly increased the grain yield of both rice and wheat over control (Table 5). It is evident that farmers' practice for K (25 and 30 kg K/ha in rice and wheat, respectively; K_{FP}) was not enough to produce high yields in either of the cereals. Application of K at 66 kg/ha produced the highest grain yield of both rice and wheat in all the seasons.

Potash fertilizer application was more efficient in wheat in the dry season as compared with the wet monsoon rice season (Fig. 4). For instance, the highest rate of 66 kg K/ha increased grain yield of rice on the average by 30% but the comparative figure for wheat was 53% (Table 5). In general, the additional grain yield obtained by potash application was between 0.69 to 0.90 t/ha for rice and 0.65 to 1.23 t/ha for wheat (Fig. 4). As compared with the K_0 treatment, farmers achieved an additional 0.46-0.60 t/ha when using their regular practice (K_{FP}) or through the application of crop residues (K_{0+CR}; Fig. 4).

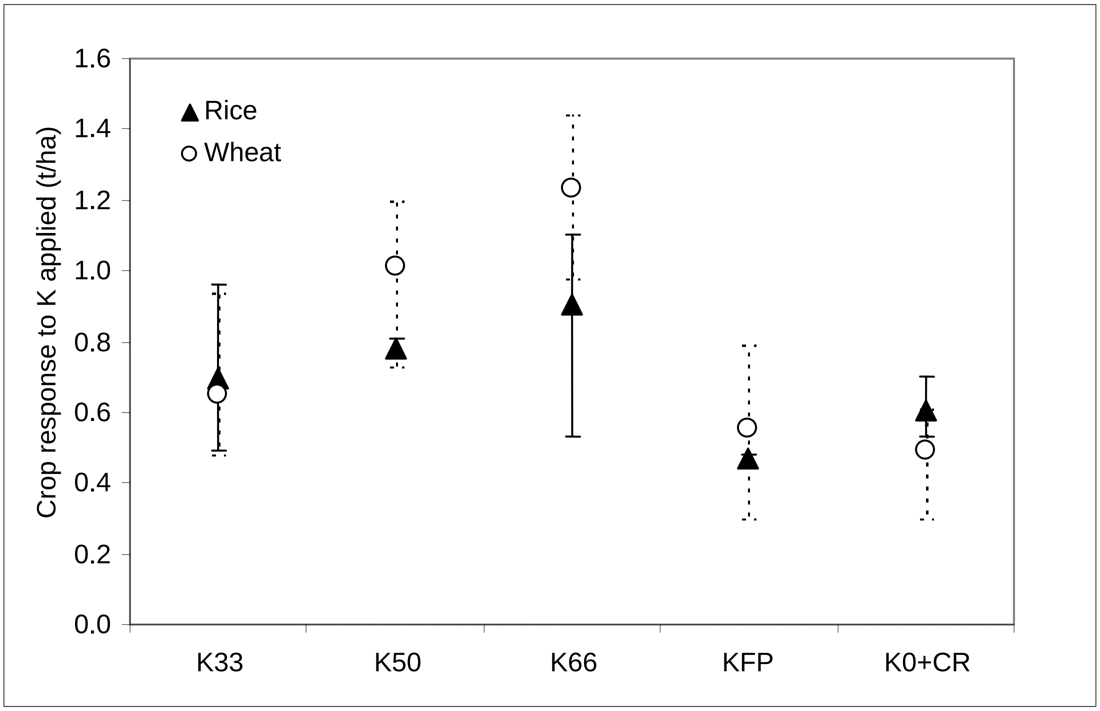

Fig. 4. The average yield response for potassium treatments in rice and wheat (based on the results from the HDSTU experimental farm).

Recycling of crop residues significantly increased the grain yield over K_0, with grain yields statistically similar to those of K_{33} and K_{FP} for both rice and wheat (Table 4). Crop residue incorporation increased grain yield of the two crops on average by 20-21% as compared with the K_0 treatment. Thus, potash fertilizer application on light textured soils gave higher crop productivity as compared with crop residue incorporation alone without potash fertilizer. As the farmers in Bangladesh generally remove straw from their fields, recommended rates of potash fertilizer need to be applied to optimize crop K nutrition and to preserve the soil from K mining.

Soil test-based K fertilization (K_{STB}) significantly increased the grain yield of both rice and wheat over K_0 and K_{FP} treatments in farmers' field demonstrations (Table 6). Again, the contribution of K fertilizer to grain yield production was found to be more prominent in wheat than that in rice. On average, the use of K fertilizer in recommended rates in the farmers' fields produced 25% higher rice grain yield and 86% higher wheat grain yield as compared with the K_0 treatment.

Potassium use efficiency, percent recovery and apparent K balance

Agronomic efficiency of applied K fertilizer

Table 7 illustrates the effect of different doses of applied K fertilizer on the K use efficiency of wetland rice under Boro-Fallow-T Aman cropping pattern. The T Aman rice 2003 was the 1st crop of the experimentation and the efficiency of applied K was found relatively lower in this crop compared to those of the succeeding Boro and T Aman crops of the tested cropping pattern. Increase of K doses beyond 33 kg/ha in T Aman and 50 kg/ha in Boro season deceased the K use efficiency in rice. The efficiency of K was found more prominent in dry season rice than that of wet season rice. Better vegetative growth coupled with increased grain yield production in dry season than that in wet season in K fertilized plot might explain the results.

Table 6. Effect of K fertilizer use on the grain yield of rice and wheat (t/ha) on farmers' fields at NW region of Bangladesh.

Treatment	Rice					Wheat				
	2003 1st crop	2004 3rd crop	2005 5th crop	Mean yield	Yield increase (%)	2004 2nd crop	2005 4th crop	2006 6th crop	Mean yield	Yield increase (%)
K_0	3.31	3.27	3.17	3.25	-	1.52	1.84	2.59	1.98	-
K_{FP*}	3.68	3.81	3.60	3.70	14	2.79	2.73	2.84	2.79	41
K_{STB**}	3.89	4.16	4.14	4.06	25	3.72	3.60	3.71	3.68	86

*K_{FP} = Farmers practice only for K, based on the average of 25 local farmers that applied 25 and 30 kg K/ha, in rice and wheat, respectively.
**K_{STB} = K application according to Soil Test Basis (STB): $K_{43\text{-}65}$ (av. K_{58}) in Rice and $K_{72\text{-}99}$ (av. K_{87}) in Wheat season

Notes: The results are the average yields of 5 farmers' fields per season (except in 4 fields during the Rice 2005 season and 3 fields during the Wheat 2005 season)
Basic application of N-P-S-Zn according to Soil Test Basis (STB)
Rice variety: BRRI dhan31, BRRI dhan39 & BR11; Wheat variety: Shatabdi

Table 7. Agronomic efficiency (kg grain/kg K) of K fertilizer applied to rice in Boro-Fallow-T. Aman cropping pattern, BRRI farm, Gazipur, 2003-2006.

Treatment	T. Aman						Boro				
	2003	2004	2005	2006	2007	Mean	2004	2005	2006	2007	Mean
K_{33}	4.9	9.4	8.5	32.4	19.1	19.1	17.9	14.9	14.9	4.8	13.1
K_{50}	2.6	10.8	8.4	23.2	11.6	11.6	16.6	19.4	11.8	13.0	15.2
K_{66}	1.5	12.3	5.5	16.4	5.5	8.2	7.7	13.0	10.8	9.7	10.3

Alike Cazipur site, the efficiency of K fertilizer was found relatively lower in the 1st crop than those of the succeeding crops under Wheat-Fallow-T Aman cropping pattern (Table 8). In the 1st T Aman crop, the efficiency of K fertilizer was slightly increased with the increasing level of K up to 66 kg/ha while in the succeeding T Aman crops the highest efficiency was observed at 33 kg K/ha and then declined with further increase of applied K level. The wheat crop utilized K fertilizer more efficiently than that of T Aman rice. It appears from the mean efficiency data of three wheat crops that wheat may utilized K fertilizer more efficiently when applied within the rate of 33-50 kg/ha.

Table 8. Agronomic efficiency (kg grain/kg K) of K fertilizer applied to rice and wheat in Wheat-Fallow-T. Aman cropping pattern, HSTU farm, Dinajpur, 2003-2006.

Treatment	T. Aman				Wheat			
	2003	2004	2005	Mean	2004	2005	2006	Mean
K_{33}	15	19	19	18	28	16	15	20
K_{50}	15	16	15	16	24	22	15	20
K_{66}	17	16	8	14	19	22	15	19

Percent recovery of potassium

Percent recovery of K ranged from 53-79% in T Aman rice and 42-82% in wheat crop (Table 9). In T Aman season, percent recovery exhibited a decreasing trend with increasing applied K level while in wheat crop no consistency was observed in % K recovery with applied K level. The average data indicated the higher % K recovery in T Aman season than that of wheat in Rabi season.

Table 9. Effect of applied K fertilizer on the K use efficiency (%) of T Aman rice and wheat, HDSTU farm, Dinajpur.

Treatment	T. Aman rice			Wheat			
	1st crop 2003	3rd crop 2004	Mean	2nd crop 2004	4th crop 2005	6th crop 2006	Mean
K_{33}	79	79	79	82	53	57	64
K_{50}	64	57	61	63	94	42	66
K_{66}	57	53	55	59	64	44	56
K_{FP}	66	59	63	58	99	68	75

Note: The data of T. Aman rice 2005 is not included

Apparent K balance in the soil

The net K balance was calculated using a simplified method based on major K inputs, e.g. K from inorganic fertilizer, organic sources and irrigation water and major outputs of above ground plant uptake. The negative K balance was observed in all K treated plots except the soil.

Where crop residues were applied at 4.5 t/ha on oven dry basis. Maximum depletion occurred in soil when K was not applied. Application of K fertilizer minimized the rate of K depletion and the trend of mining decreased with increasing applied K level. Incorporation of crop residues at 4.5 t/ha on oven dry basis or applied K at 66 kg/ha as inorganic fertilizer substantially reduced the K depletion from the soil under Rice-Wheat cropping pattern (Table 10).

Table 10.The apparent soil K balance after 5 crops in Wheat-Fallow-T. Aman cropping pattern, HDSTU farm, Dinajpur, 2003-2006.

Treatments	K (kg/ha after 5 crops)*		
	Added**	Uptake	Balance
K_0	17	208	-192
K_{33}	182	324	-142
K_{50}	267	368	-102
K_{66}	347	391	-45
K_{FP}	157	307	-150
K_{0+CR}	333	321	11

*The data of T. Aman rice in 2005 are not included
**K added (kg/ha/yr): 7.1 through irrigation water and 124 through crop residues (Rice straw = 68 + Wheat straw = 56)
Note: Assumed water requirement = 25 and 50 ha-cm in wheat and T. Aman rice, respectively

Economic analysis

Economic analysis of the potassium fertilization experiments conducted at Gazipur was done with the mean data of 5 crops for T Aman rice and with 4 crops of Boro rice. The results are presented in Tables 11-12. In clay loam soil at Gazipur, potassium fertilizer applied at 50 kg K/ha in both T Aman and Boro seasons appeared to be most economic in terms of net additional income. While on the basis of value cost ratio (VCR), farmers' fertilization practice in T Aman and 50 kg K/ha in Boro season was found most suitable. It is noted that the additional income earned due to K-fertilization was much more in Boro rice than that of T Aman rice.

In sandy loam soil of NW region of Bangladesh, the maximum additional income in both T Aman rice and wheat were obtained from the same treatment where K-fertilizer was applied at 66 kg/ha (Table 13-14). Applied K from chemical sources contributed higher benefit than that of crop residue incorporation in both rice and wheat production. The additional income earned resulting from K-fertilization was much higher in wheat than that of rice. In case of farmers' field demonstrations, K applied on the basis of soil test always contributed to considerably higher additional benefit than that of farmers' fertilization practice especially in the wheat crop (Table 14). In all treatments, the VCR value was found to be more than the acceptable limit (VCR=2), but the treatments with crop resides incorporation showed the lowest VCR.

Table 11. Economics of potash fertilizer application to T Aman rice (mean of five crops), Gazipur.

Location	Treatment	Grain yield	Yield increase	Value of extra production	Cost of potash (MOP)	VCR	Net additional income	
		(t/ha)		(Tk/ha)(1)			Tk/ha	USD/ha
BRRI farm, Gazipur	K_0	3.25	-	-	-	-	-	-
	K_{33}	3.74	0.49	4,900	924	5.3	3,976	58
	K_{50}	3.82	0.57	5,700	1,400	4.1	4,300	62
	K_{66}	3.80	0.55	5,500	1,848	3.0	3,652	53
	K_{FP}(2)	3.61	0.36	3,600	504	7.1	3,096	45
	K_{0+CR}(3)	3.66	0.41	4,100	2,250(4)	1.8	1,850(4)	27(4)
Farmers' fields	K_0	3.57	-	-	-	-	-	-
	K_{FP}(2)	3.92	0.35	3,500	504	6.9	2,996	43
	K_{STB}(5)	4.28	0.71	7,100	1,148	6.2	5,952	86

(1) Bangladesh Taka (USD 1 = Tk 69)
(2) K_{FP} = Farmers practice only for K, based on the average of 25 local farmers that applied 18 kg K/ha
(3) CR = Crop residues at 4.5 t/ha
(4) Input cost and additional income with crop residue
(5) K application according to Soil Test Basis (STB): $K_{22\text{-}53}$ (av. K_{41})

Table 12. Economics of potash fertilizer application to Boro rice(mean of four crops), Gazipur.

Location	Treatment	Grain yield	Yield increase	Value of extra production	Cost of potash	VCR	Net additional income	
		(t/ha)		(Tk/ha)(1)			Tk/ha	USD/ha
BRRI farm, Gazipur	K_0	4.94	-	-	-	-	-	-
	K_{33}	5.38	0.44	4,180	924	4.5	3,256	47
	K_{50}	5.70	0.76	7,220	1,400	5.2	5,820	84
	K_{66}	5.62	0.68	6,460	1,848	3.5	4,612	67
	K_{FP}(2)	5.23	0.29	2,755	1,036	2.7	1,719	25
	K_{0+CR}(3)	5.64	0.70	6,650	2,250(4)	3.0	4,400(4)	64(4)
Farmers' fields	K_0	4.41	-	-	-	-	-	-
	K_{FP}(2)	5.14	0.73	6,935	1,036	6.7	5,899	85
	K_{STB}(5)	5.64	1.23	11,685	1,876	6.2	9,809	142

(1) Bangladesh Taka (USD 1 = Tk 69)
(2) K_{FP} = Farmers practice only for K, based on the average of 25 local farmers that applied 37 kg K/ha
(3) CR = Crop residues at 4.5 t/ha
(4) Input cost and additional income with crop residue
(5) K application according to Soil Test Basis (STB): $K_{34\text{-}82}$ (av. K_{67})

Table 13. Economics of potash fertilizer application to T Aman rice (mean of three crops), NW region.

Location	Treatment	Grain yield	Yield increase	Value of extra production	Cost of potash (MOP)	VCR	Net additional income	
		(t/ha)		(Tk/ha)(1)			Tk/ha	USD/ha
HDSTU farm, Dinajpur	K_0	2.98	-	-	-	-	-	-
	K_{33}	3.67	0.69	6,900	924	7.5	5,976	87
	K_{50}	3.76	0.78	7,800	1,400	5.6	6,400	93
	K_{66}	3.88	0.90	9,000	1,848	4.9	7,152	104
	K_{FP}(2)	3.44	0.46	4,600	700	6.6	3,900	57
	K_{0+CR}(3)	3.58	0.60	6,000	2,250(4)	2.7	3,750(4)	54(4)
Farmers' fields	K_0	3.25	-	-	-	-	-	-
	K_{FP}(2)	3.70	0.45	4,500	672	6.7	3,828	55
	K_{STB}(5)	4.06	0.81	8,100	1,624	5.0	6,476	94

(1) Bangladesh Taka (USD 1 = Tk 69)
(2) K_{FP} = Farmers practice only for K, based on the average of 25 local farmers that applied 25 kg K/ha
(3) CR = Crop residues at 4.5 t/ha
(4) Input cost and additional income with crop residue
(5) K application according to Soil Test Basis (STB): K_{43-65} (av. K_{58})

Table 14. Economics of potash fertilizer application to wheat (mean of three crops), NW region.

Location	Treatment	Grain yield	Yield increase	Value of extra production	Cost of potash	VCR	Net additional income	
		(t/ha)		(Tk/ha)(1)			Tk/ha	USD/ha
HDSTU farm, Dinajpur	K_0	2.32	-	-	-	-	-	-
	K_{33}	2.97	0.65	7,150	924	7.7	6,226	90
	K_{50}	3.33	1.01	11,110	1,400	7.9	9,710	141
	K_{66}	3.55	1.23	13,530	1,848	7.3	11,682	169
	K_{FP}(2)	2.88	0.56	6,160	840	7.3	5,320	77
	K_{0+CR}(3)	2.81	0.49	5,390	2,250(4)	2.4	3,140(4)	46(4)
Farmers' fields	K_0	1.98	-	-	-	-	-	-
	K_{FP}(2)	2.79	0.81	8,910	868	10.3	8,042	117
	K_{STB}(5)	3.68	1.70	18,700	2,436	7.7	16,264	236

(1) Bangladesh Taka (USD 1 = Tk 69)
(2) K_{FP} = Farmers practice only for K, based on the average of 25 local farmers that applied 30 kg K/ha
(3) CR = Crop residues at 4.5 t/ha
(4) Input cost and additional income with crop residue
(5) K application according to Soil Test Basis (STB): K_{72-99} (av. K_{87})

Conclusion and recommendation

Potassium fertilization significantly increased the production of Rice-Rice and Rice-Wheat cropping system. Initially, the decrease of yield of rice and wheat due to omission of K was not significant but the yield gap between the balanced fertilized and the no applied K plot widened sharply and significantly with time. Long-term omission of K severely intensified the K problem. Crop residue may be a reasonable additional source of potassium for crop nutrition but the highest productivity is achieved with mineral potash fertilizer use. Light textured soil responded notably compared to heavy textured soil to applied K. The response of grain yield to added K was found to be more prominent in dry rice season than that of wet rice season; and in wheat compared to rice. Application of K fertilizer at 50 kg K/ha at each crop in Rice-Fallow-Rice cropping pattern in clay loam soil and at 66 kg K/ha in each wheat and rice crop in Wheat-Fallow-Rice cropping pattern in sandy loam soil appeared to be economically most viable K fertilizer doses. These results indicated the need for increasing the present recommended K fertilizer dose for the MV Rice-Rice and Wheat-Rice crop production system in flood free land where yearly K replenishment due to alluvial deposition doses not occur.

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BALANCED FERTILIZATION FOR SUSTAINABLE YIELD AND QUALITY IN TROPICAL FRUIT CROPS

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Abstract

India needs to increase its fruit production and productivity, which warrant judicious nutrient management. The need for balanced fertilization has been well documented in tropical fruit crops like mango, banana, citrus, papaya, pineapple and sapota. Integrated nutrient management studies conducted in these crops resulted in enhanced fruit yield and quality concomitant with saving nutrients also. Fertigation studies conducted in banana resulted in higher yield with quality fruit besides saving of nutrients. However, such studies are lacking in other fruit crops like mango, citrus, pineapple, sapota etc. The results of various studies on balanced fertilization in tropical fruit crops have been discussed.

Key words: Tropical fruits; Nutrition; Balanced fertilization; Yield and quality

Introduction

India needs 92 million tonnes of fruits to have balanced nutrition for its 1,130 million populations. Although the country has achieved fairly good production level of fruits (43 million tones), it's hardly sufficient to meet only 46% of our country's requirement. This warrants us to increase the production and productivity of fruit crops in India. Judicious nutrient management is often regarded as one of the important aspects to increase the productivity of horticultural crops particularly fruit crops. Efficient and rational use of the fertilizers is imperative not only for obtaining more yields per unit area on a sustainable basis, but also to conserve the environment.

The fruit plants generally need higher amount of potassium followed by nitrogen and phosphorus in order. For a precise estimate of the nutrient requirement in fruit trees, it is necessary to determine not only the quantities removed annually by the fruits and new shoots but also those accumulating over the years in other plant parts and proportion of the currently absorbed fertilizer nutrients moving into different parts.

Studies have indicated that the bulk of nutrient requirement of the developing fruits and new growth is met by the endogenous reserves of the tree. It is, therefore, necessary to monitor the current status of tree for making meaningful fertilizer recommendation for which leaf analysis appears to be quite useful. The leaf nutrient levels required for the optimum production in some important fruit crops are presented in Table 1. Efforts on the nutritional management program should be directed towards the maintenance of these levels in tree leaves before flowering. Knowledge on the active root zone is also essential for the efficient utilization of applied nutrients, so that the nutrients placed around this zone are made available to the plant.

In the following text, the role of balanced fertilization for sustainable yield and quality in important tropical fruit crops is discussed.

Table 1. Optimum leaf nutrient status of some important fruit crops.

Fruit	Nutrients									
	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
	(%)						(ppm)			
Mango	1.23	0.06	0.54	1.71	0.91	0.12	171.0	66.0	25.0	12.0
Banana	3.29	0.44	3.11	2.12	0.24	-	-	-	-	-
Citrus	2.50	0.14	0.90	4.20	0.43	0.25	90.0	112.5	62.0	10.5
Sapota	1.66	0.08	0.80	0.83	0.48	0.07	100.0	39.3	15.0	6.7
Papaya	1.66	0.50	5.21	1.81	0.67	0.38	-	-	-	-
Pineapple	1.40	0.16	3.70	-	-	-	-	-	-	-

Mango

Although mango grows well even in poor soils because of its deep and extensive root system. In view of the vegetative growth it makes annually and the removal of nutrients through the harvest, it needs regular fertilization for maintaining proper growth and heavy yield of crop every year. In most parts of India, bearing mango trees are not at all manured or even if it is manured, it is unbalanced. However, evidence indicates that regular manuring of bearing trees is essential to maintain the productivity of the trees. The Tamil Nadu Agricultural University recommends 50 kg farmyard manure, 1.0 kg each of N and P and 1.5 kg K year^{-1} bearing tree^{-1}**.** Ladani *et al.* (2004) suggested application of 1.5 kg N, 0.5 kg P and 1.2 to 1.5 kg K tree^{-1} to get higher yield. Recently, it has been established that incorporation of SOP at 25-50% of K requirement (i.e., 1.5 kg K_2O ha^{-1}) of mango increased the fruit yield besides improving the fruit quality particularly TSS, ascorbic acid and carotenoid contents (Kumar *et al.* 2007). Similarly, foliar spraying of SOP at 2-4% thrice; first during peanut stage followed by two sprays at an interval of 15 days, improved the yield and quality of fruits (Fig. 1) especially the pulp colour (Kumar *et al.* 2007). There is no systematic study with fertigation in mango. However, Sivakumar (2007) at TNAU conducted an experiment in mango cv. Ratna planted under HDP during 2005-07 to study the influences of N and K nutrients applied through fertigation.

The results showed that fruit weight, number of fruits per tree and yield per tree besides the fruit quality parameters were observed to be highest by balanced application of 100 percent 'recommended dose of nutrients' through fertigation (Table 2).

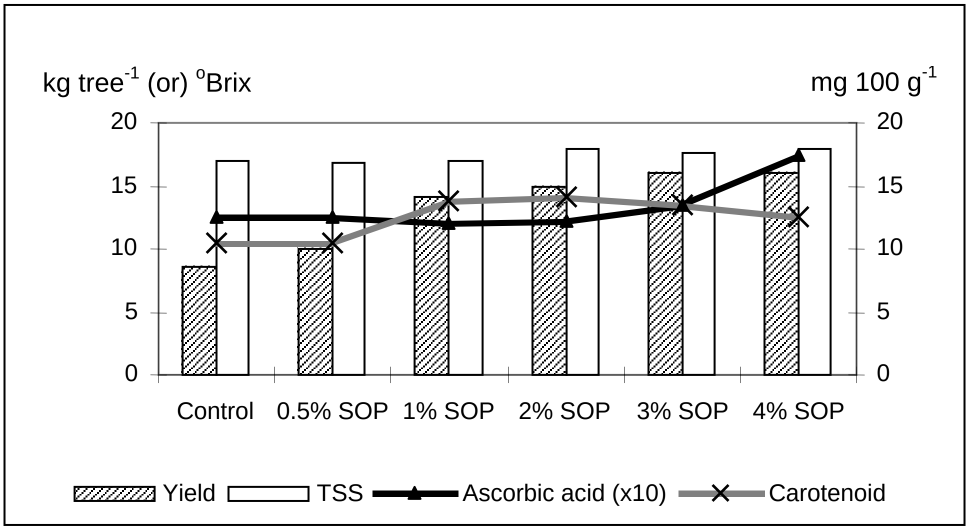

Fig. 1. Effect of foliar spray of SOP on Mango cv. Alphonso.

Table 2. Effect of different nutrient levels on yield and quality attributes of mango cv. Ratna.

Treatment	Number of fruits tree^{-1}	Mean fruit weight (g)	Fruit yield (kg tree^{-1})	Fruit TSS (^{o}Brix)	Ascorbic acid content (mg 100 g^{-1})	Carotenoid content (mg 100 g^{-1})
T1	116.50	364.62	40.89	19.66	36.95	4.18
T2	126.70	340.89	40.23	19.96	39.56	4.16
T3	142.70	436.32	54.06	22.69	44.62	5.28
T4	160.00	465.32	59.89	24.93	48.92	5.82
CD (0.05)	**6.14**	**12.50**	**1.43**	**1.09**	**2.12**	**0.15**

T1: 100% of RDF as soil application
T2: 100% N + 100% P + 50% K of RDF through fertigation
T3: 100% N + 100% P + 75% K of RDF through fertigation
T4: 100% N + 100% P + 100% K of RDF through fertigation
RDF: (800:400:800 g NPK plant^{-1} year^{-1})

Banana

Banana generally requires high amount of mineral nutrients for proper growth and production. Nutrient uptake studies (Fig. 2) reveal that most of the nutrient uptake occurs 4-6 months after planting, followed by at fruit maturity phase. Studies on uptake of nutrients in tissue culture banana cv. Robusta (AAA) also revealed that N, P and K uptake increased linearly till shooting stage (Nalina 2002).

Banana cultivation in India is polyclonal with an array of varieties under cultivation. The systems of culture are diverse; therefore, fertilizer recommendations are also diverse in India (Table 3). As muriate of potash (MOP) is commonly used as the source of potassium, the chloride toxicity is often met in banana, hindering crop growth, yield and quality especially at amounts greater than 1,200 kg per ha (Nalina 2002).

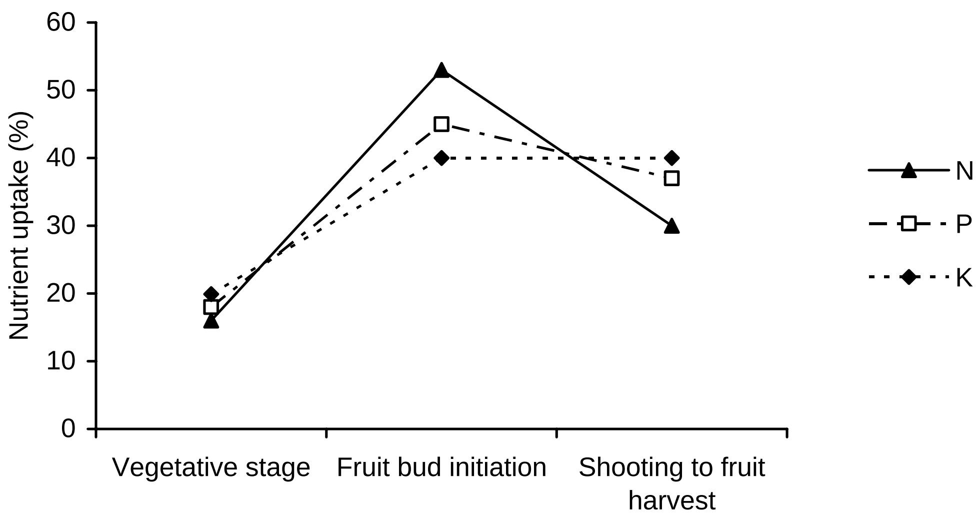

Fig 2. Nutrient uptake in banana at different growth stages.

Table 3. Fertilizers recommendation (g plant^{-1}) to banana crop in various states in India.

States	N	P	K
West Bengal	240	45	240
Kerala	225	225	225
Tamil Nadu	110	35	330
Goa	75	75	240
Assam	110	35	330
Bihar	125	80	225
Orissa	80	32	90
Uttar Pradesh	200	100	250

Hence, SOP has been tested as a substitute for MOP in banana. Ramesh Kumar (2004) tried various combination of SOP and MOP to supply the recommended dose of K_2O, i.e. 330 g of K_2O per plant to cv. Robusta, and found that soil application of SOP improved the bunch weight and quality as compared to 100% through MOP. But the prohibitive cost of SOP is the limiting factor. Hence, Ramesh Kumar and Kumar (2007) recommend post shoot foliar spraying of SOP 1.5% twice; first at the time of last hand opening and second one month from first spraying to improve the bunch weight and quality of fruits in certain commercial varieties of banana (Fig. 3).

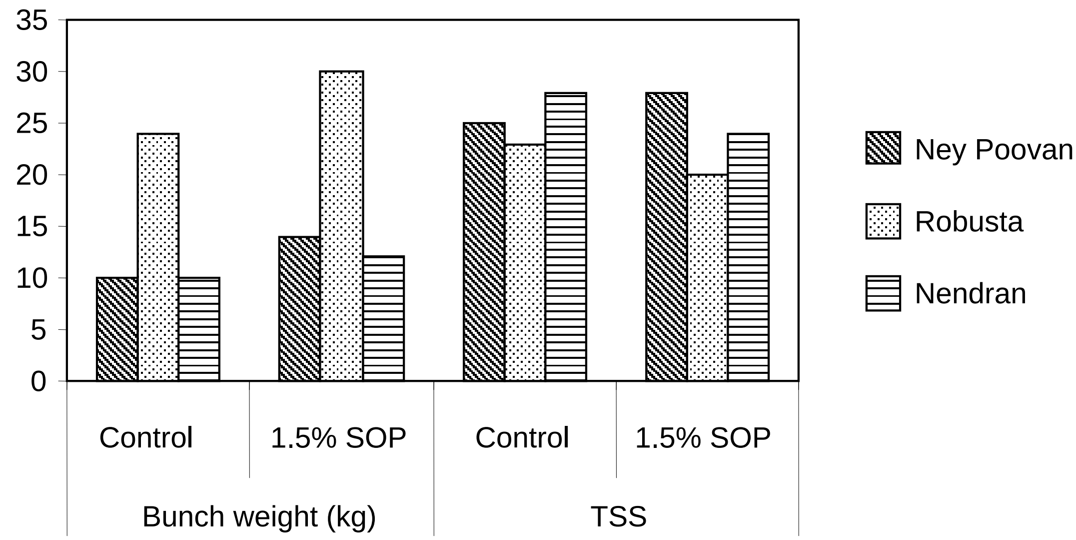

Fig 3. Influence of post shooting spray of certain nutrients on bunch weight and TSS of banana fruits.

Fertigation is particularly useful in improving yield and quality of banana besides improving the nutrient use efficiency. Mahalakshmi (2000) revealed that under both the normal and high density system of planting, fertigation was effective in improving the yield and maintaining fruit quality (Table 4).

Table 4. Effect of Fertigation on banana cv. Robusta (AAA).

Water + Fertilizer	Bunch weight (kg)	Yield (t ha^{-1})	% increase over conventional	No. of hands	No. of fingers	TSS
Normal planting system						
Plant crop 25 LPD + 100:30:150 g NPK $plant^{-1}$*	38.00	95.00	61.07	9.34	163.94	19.29
Ratoon crop 25 LPD + 150:30:225 g NPK $plant^{-1}$**	44.42	111.05	61.07	13.47	261.27	20.10
High density planting system						
50 LPD + 450:90:675 g NPK $plant^{-1}$**	34.99	174.88	196.51	10.22	173.38	21.20
Conventional						
200:30:300 g NPK $plant^{-1}$	23.59	58.98	-	8.12	118.01	22.13

*50% recommended dose
**75% recommended dose

Tissue-cultured (TC) banana cultivation is expanding in India as farmers are now realizing its advantages due to its rapid growing, early and high yielding characters. Nalina (2002) justified that the application of 150% of recommended NPK (i.e. 165:52.5:495 g) in four splits, viz. 2, 4, 6 and 8 months after planting, was found essential to increase the plant's growth and development, yield and quality in the plant and ratoon crops of TC banana.

Citrus

Improper and inadequate nutrition is one of the major causes of citrus decline in India (Chadha *et al.* 1970). Studies on the decline of mandarins in Kerala showed that poor nutrient status of soil (Iyer and Iyengar 1956) and neglect and lack of manuring are the main causal factors. Thirty tonnes of citrus fruits remove 270 kg N, 60 kg P_2O_5, 350 kg K_2O, 40 kg MgO and 15 kg S from the soil (Tandon and Kemmler 1986).

Different states recommend different amounts of NPK for mandarin and other important citrus species in India which vary from 300-400 g of N, 200 to 375 g of P_2O_5 and 100 to 600 g of K_2O per plant per year. Recently, integrated nutrient management (INM) is being advocated in citrus. Studies conducted at Tinsukia (Assam) by Borah *et al.* (2001) revealed that maximum yield with appreciable tree vigour and fruit quality of Khasi mandarin could be obtained from balanced nutrition of the plants through combinations of organic (neem cake) and inorganic fertilizers (Table 5). Results of a study conducted on 20 year old seedling trees of sweet orange cv. Sathgudi (Seshedri and Madhavi, 2001) revealed that the maximum yield and cost benefit ratio with better fruit quality could be obtained by the balanced nutrition through 400:150:300 g NPK plant^{-1} year^{-1} along with organic fertilizer (castor cake @ 7.5 kg). Similarly, integrated nutrient management studies conducted at Akola revealed that application of chemical fertilizers along with neem cake significantly increased the yield with better quality fruits (Ingle *et al.* 2001).

Table 5. Effect of organic and inorganic nutrition on yield and quality of Khasi mandarin plants.

Treatments	No of fruits plant^{-1}	Yield (kg plant^{-1})	Juice (%)	Ascorbic acid (mg 100 g^{-1})	TSS (°Brix)
600:300:600g NPK plant^{-1}	805	118.01	46.33	48.27	14.35
600:300:600g NPK plant^{-1} + Neem cake @15 kg plant^{-1}	1072	203.55	55.66	57.26	15.26
CD (0.05)	19.66	10.45	1.05	3.50	0.21

Experiment conducted in Tamil Nadu revealed that application of P-enriched farm yard manure (0.5 kg P_2O_5 tree^{-1} mixed with 20 kg farm yard manure) along with 700 g N and 600 g K_2O tree^{-1} recorded the highest yield and improved the fruit quality of mandarin. Ingle *et al.* (2003) found that in Nagpur mandarin, number and weight of fruits and total soluble sugars were highest with application of 800 g N, 300 g P_2O_5, and 600 g K_2O along with 7.5 kg neem cake per plant per year. Tiwari *et al.* (1999) also obtained maximum yield of sweet orange with the application of 800 g N, 300 g P_2O_5, 600 g K_2O plus 15 kg neem cake tree^{-1} year^{-1}.

Fertigation has been recently introduced in citrus and varying response has been reported. Shirgure *et al.* (2001) found that fertigating Nagpur mandarin with NPK 50:140:70 kg ha^{-1} is good in improving the tree vigour, yield and quality of fruits. Application of 75% recommended amount of N and K through drip irrigation was found ideal for sweet oranges under Maharastra, Andhra Pradesh and Punjab conditions.

Secondary and micronutrient deficiencies are common in almost all citrus species. Each state has its own recommendations which involve application of $ZnSO_4$ (0.3 to 0.5%), $MgSO_4$ (0.2 to 0.3%), $MnSO_4$ (0.1 to 0.3%), $CuSO_4$ (0.3%), $FeSO_4$ (0.2 to 0.3%) and Borax (0.05 to 0.1%) two to three times on the new flushes to get good yield and quality fruits (Bojappa and Bhargava 1993).

Papaya

The nutritional demand of papaya differs from other fruit crops because of its tremendous yield potential, precocious bearing and indeterminate growth habit with simultaneous vegetative growth, flowering and fruiting. The nutrient uptake studies conducted at Tamil Nadu Agricultural University (Veerannah and Selvaraj 1984) revealed that among the important nutrients, the demand for K was more, nearly twice as that of nitrogen in papaya (Fig. 4).

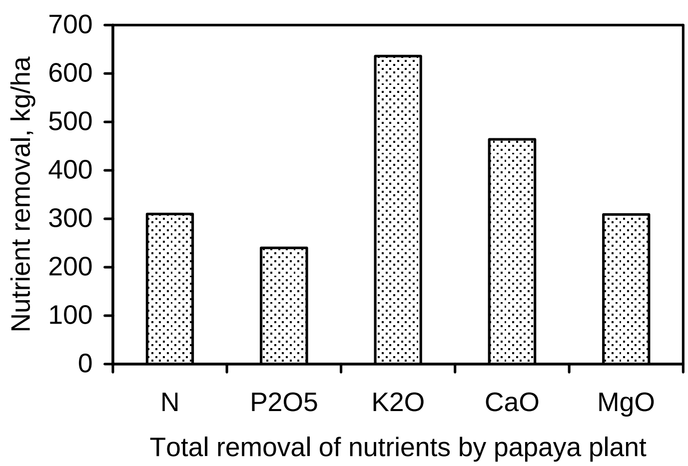

Fig. 4. Total removal of nutrients by papaya plant.

Role of balanced fertilization with N, P and K has been well established in many crop plants. However, information on this line is lacking in papaya. Trials conducted at Tamil Nadu Agricultural University under the IPI collaboration project on the role of graded doses of K_20 (i.e., 0, 150, 300 and 450 g $plant^{-1}$) along with 300 g each of N and P_2O_5 per plant per year (Kumar *et al.* 2006) recorded the importance of potassium nutrition in significantly influencing the fruit weight, fruit number and fruit yield per plant (Fig. 5).

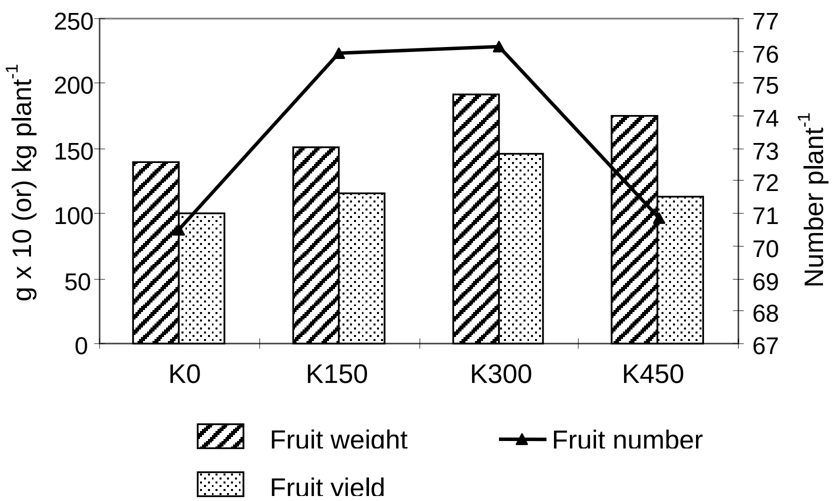

Fig.5. Effect of potassium on yield traits in papaya.

Besides, Kumar *et al*. (2006) found that potash fertilizer use improved major quality parameters of papaya fruits such as the sweetness of papaya (TSS), latex yield and its quality.

Papain produced from papaya latex is useful in tenderizing meat and other proteins through the process of hydrolysis (or breakdown) of proteins. Thus, enzyme activity is an important quality parameter of papain. The enzyme activity of latex as assessed in terms of Tyrosine unit per mg of papain revealed the influence of potassium nutrition on it (Table 6).

Table 6. Effect of potash application on the enzyme activity (Tyrosine unit mg of papain^{-1}) in the latex of cv. C0-2.

Treatment (g plant^{-1} year^{-1})	Tyrosine (Tu mg^{-1})	
	December'06	June'07
$N_{300}P_{300}$	99.5	109.5
+ K_{150}	100.4	129.3
+ K_{300}	136.6	185.5
+ K_{450}	195.9	172.2

Papaya being a perennial crop and the nutrient is required at all stages of growth continuously, split application of fertilizer is found beneficial. According to Sulladmath *et al*. (1984) and Irulappan *et al*. (1984), six splits were found to be good while Ravichandrane *et al*. (2002) recommended twelve splits to get higher yield and quality of fruits in CO 2 papaya variety. Jeyakumar *et al*. (2001) scheduled the nutrient application under drip fertigation system at weekly intervals.

Pineapple

Pineapple is cultivated in different types of soils but sandy loams and laterite soils of sub mountainous region are considered more suitable and favourable. Pineapple is a shallow feeder grown on loose and poor soils but has high N and K requirement. Nutrient removal / uptake studies showed that pineapple requires large quantity of K followed by N to give high yield (Martin and Prevel 1981).

Trials conducted at Assam (Mohan and Ahmed 1987) and West Bengal (Sen 1985) conditions stressed the importance of balanced nutrition to get higher yield of pineapple. TNAU recommends FYM @ 40-50 t ha^{-1} besides 60 g of N, 40 g of P and 12 g of K per plant in 2 splits at 6^{th} and 12^{th} month after planting to get higher yield.

Sapota

No systematic studies on the nutrient uptake or removal in sapota are available. However, Avilan *et al*. (1980) reported from the analysis of fruits and seeds of 8 to 10 year old sapota trees that the plants required 1.69 kg K_2O, 1.16 kg N, 1.12 kg Ca, 0.17 kg P_2O_5 and 0.14 kg MgO to produce 1,000 kg of fruits. Sapota growing states like Andhra Pradesh, Karnataka, Maharastra and Tamil Nadu recommend different doses for obtaining higher yield (Table 7). Integrated nutrient management has also gained popularity in many states.

Table 7. Fertilizer recommendation for full bearing sapota trees in certain states of India.

States	Age	N	P_2O_5	K_2O	Farm Yard Manure
		(kg ha^{-1})			(kg $tree^{-1}$)
Andhra Pradesh	11 & above	400	160	450	-
Karnataka	11 & above	400	160	450	50
Maharashtra	10^{th} year	500	-	-	10-15
Orissa	Adult	45	150	-	15 kg farm yard manure + 250 g Stearameal
Tamil Nadu	Adult	150	150	250	50

Future thrust

The future research on nutrition on tropical fruit crops should encompass the following key topics:

1. Systematic long term experiments on major tropical fruit crops like mango, sapota, citrus need to be taken up with graded levels of N, P and K so as to assess the individual effect of these major nutrients and also their interaction on yield and quality.
2. Considering the present situation of global warming, it is necessary to go for integrated nutrient management, involving various sources of organic manures, organic cakes and biofertilizers including mycorrhiza besides chemical fertilizers in almost all tropical fruit crops.

3. Nutrient recycling especially in fruit crops like banana which produce high biomass sometimes affect the nutrient response.
4. Fertigation is gaining popularity in all horticultural crops, however, research on these aspect in perennial fruit crops like mango, sapota, citrus is totally lacking. Liquid bio fertilizers are available now. Their effect on feeding the fruit crops through drip system has to be standardized for all the fruit crops.

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INTEGRATED NUTRIENT MANAGEMENT FOR SUSTAINABLE YIELD OF MAJOR VEGETABLE CROPS IN BANGLADESH

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Abstract

The production of vegetables (1.37 million tons) in Bangladesh is inadequate and to meet the demand, the yield has to be increased by at least 8 times (up to 10.96 million tons) within 2015. But gradual increase in cropping intensity with imbalanced fertilization has compelled to deplete soil fertility in Bangladesh. In these contexts, integrated nutrient management (INM) approach has been examined especially in vegetable crops by Soil Science Division, Bangladesh Agricultural Research Institute (BARI), for yield sustainability and restoring soil fertility. The aim of the present paper is to provide some of the key findings of the related research as rendered by BARI during the recent years (2000-2007). INM package formulated with poultry manure (at 5-10 t ha^{-1}) in addition to 50-75% recommended dose (RD) of chemical fertilizers produced significantly higher yield of tomato, cabbage, broccoli, okra as well as homestead vegetable cropping patterns, namely radish-tomato-red amaranth-Indian spinach and tomato-okra-Indian spinach over sole use of chemical fertilizers. The same dose of poultry manure (PM) may supplement the requirement of 30-50% RD of chemical fertilizers when they are applied on the basis of integrated approach. In particular, PM left substantial amount of plant nutrients after the harvest of first crop (broccoli), which in combination with supplemental nitrogen provided a good yield of second crop (okra). Moreover, PM appeared as the best source of organic manure over cow dung in respect of yield sustainability and regeneration of soil fertility. Further depletion of soil fertility can be minimized with integrated use of poultry manure and chemical fertilizers. Moderate dose of poultry manure in combination with chemical fertilizer appeared as cost undominated providing higher economic return. Integrated nutrient management approach has also been found to be sustainable in case of cabbage with tomato intercropping system. The yield of carrot was optimized, provided that potassium was integrated with NPS fertilizers and cow dung. Integrated nutrient management package may, therefore, bring yield sustainability for vegetable crops in Bangladesh if it is widely and properly practiced by the farmers following scientists' recommendations.

Key word: Integrated nutrient management; Vegetable crops; Soil fertility; Sustainable yield

Introduction

Vegetables play an important role in a balanced diet of human beings by providing not only energy-rich food but also supplying vitamins and minerals. Comparatively, vegetables are one of the cheapest sources of natural nutritive foods. In developing countries like Bangladesh, where the pressure of population on land is continuously increasing, vegetables may play a significant role in supplying a balanced diet.

Considering the present area (197,508 ha) and yield (1.371 million tons), the production of vegetables in Bangladesh is inadequate (BBS 2005). The production of vegetable has to be increased by at least 8 times (up to 10.96 million tons) to meet the demand while potato by 2 times (up to 7.54 million tons) within 2015. Normally, vegetable crops give higher yield per unit area as compared to cereal crop. Presently, the yield per unit area of most vegetables is very low in Bangladesh compared to many other countries. For example, the average yield of tomato is very low in our country (7.26 t ha^{-1}) compared to other tomato growing countries such as India (15.14 t ha^{-1}), China (30.34 t ha^{-1}), Japan (52.84 t ha^{-1}), USA (65.22 t ha^{-1}) and Egypt (34.00 t ha^{-1}) (FAO 1997). Vegetables have a great potential for using idle or seasonally under employed farm workers to increase family and total cash earnings. In addition, vegetable culture, being of short duration, is generally labour intensive and more number of crops can be taken from unit area. It is suitable for increasing the income of small farmers and it provides one of the most important methods of increasing the amount of food on per hectare basis. Vegetable production also makes more effective use of land and labour resources for agricultural development.

Unfortunately, the cultivable land area of Bangladesh (8.3 million ha) is shrinking at least at 1% each year due to non-agricultural uses. Increasing cropping intensity to meet the demands for food for a swelling population has led to mining out the inherent plant nutrients from the crop fields, thereby fertility status of soils severely declined in Bangladesh over the years (Ali *et al*. 1997). Because of cumulative negative nutrient balance the farming system has become unsustainable. A crop production system with high yield targets can't be sustainable unless nutrient inputs to soil are at least balanced against nutrient removal by crops (Bhuiyan *et al*. 1991). The use of chemical fertilizers as a supplemental source of nutrients has been steadily increasing but they are not applied in balanced proportion; for example, of the total fertilizer used in the country, urea alone constitutes about 80% (BARC 2005). Moreover, organic matter content in Bangladesh soils is very low, the majority being below the critical level (1.5%), and it gradually depleted by 5 to 36% during the period of 1967-1995 (Ali *et al*. 1997).

Targeting high yield with high cropping intensity is the most logical way to raise the total production from the limited land resources. Since the nutrient turnover in soil plant system is considerably high in intensive vegetables cultivation, neither the chemical fertilizers nor the organic manure alone can help achieve sustainable production. Even with balanced use of only chemical fertilizer high yield level could not be maintained over the years because of deterioration in soil physical and biological environments. In these contexts, and as a further response to economic recession and also for soil fertility conservation and improvement, the approach of integrated nutrient management (INM) has been proposed. 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. The main aim of the INM approach is to tap all major sources of plant nutrients in a judicious way to ensure their efficient use. The INM approach helps to restore and sustain soil fertility and crop productivity. It may also help check the emerging deficiency of micronutrients.

The INM favorably affects the physical, chemical and biological environment of soils. Considering the above perspectives, Soil Science Division of Bangladesh Agricultural Research Institute (BARI) conducted numerous experiments with vegetable crops like tomato, cabbage, cauliflower, broccoli, pea, sweet pepper, etc., and also with tuber crops (potato), adopting integrated nutrient management approach and developing balanced fertilizer recommendation with respect to yield sustainability and economic profitability. The aim of the present paper is to provide some of the key findings of research as conducted by BARI during the recent years.

Materials and Methods

The present paper is entirely a review paper. It is written as adapting and citing some notable research findings of Soil Science Division, BARI, conducted during recent years (2000-2007). However, traditional methods for field trials and standard laboratory procedures were followed to conduct respective experiments. Interested readers are suggested to study cited papers as mentioned in the reference list for detail information on materials and methods followed as well as results obtained.

Results and Discussion

Tomato

Application of organic manure from two sources such as cow dung (CD) and poultry manure (PM) along with different portions from recommended dose of chemical fertilizer (RD) increased the fruit yield of tomato significantly even over sole use of chemical fertilizer (Noor *et al.* 2006). Three years' results showed (Table 1) that the highest mean fruit yield (71.8 t ha^{-1}) was obtained in the T_1 treatment (100% RD + 2.5 t PM ha^{-1}), which was significantly higher over all other treatments except T_5 (50% RD + 5 t PM ha^{-1}) and T_6 (50% RD + 10 t PM ha^{-1}). The second highest yield (68.2 t ha^{-1}) was obtained from the T_6 treatment, which was statistically identical with T_2, T_3 and T_5 but significantly higher over the rest of the treatments. The third highest yield (66.5 t ha^{-1}) was recorded in T_5 (50% RD + 5 t PM ha^{-1}), which was statistically at par with T_1, T_2, T_3 and T_6. These findings revealed that addition of 5 t PM ha^{-1} was sufficient enough to reduce by 50% the dose of chemical fertilizer from the conventional recommendation. It was also revealed that the application of 100% RD of chemical fertilizer produced 234% higher yield over the control (native fertility), whereas 50% RD gave only 154% increase in yield but this yield gap (15 t ha^{-1}) can be minimized with the addition of 5-10 t PM ha^{-1} integrating with 50% RD of chemical fertilizer. Moderate yield (60.2 t ha^{-1}) was obtained when 10 t ha^{-1} of cow dung along with 50% RD of chemical fertilizer were applied, that was statistically identical with the T_3 treatment (100% RD). Therefore, for moderate yield goal and where PM is not available, CD can be used instead of PM ensuring that CD is good in quality. Only 30% of nitrogen in cow dung becomes available to the first crop and about 60-70% P and 75% K become available to the subsequent crops (Gaur *et al.* 1994). On the other hand, plant nutrients in PM become more available for the first crop (Noor *et al.* 2006).

Table 1. Yield of tomato as influenced by organic manure and chemical fertilizer.

Treatment	Chemical fertilizer	PM	CD	Yield (t ha^{-1})				Yield increase (%)
		t ha^{-1}		2002-03	2003-04	2004-05	Mean	
T_1	100% RD*	2.5	0	75.0a	70.8a	69.6a	71.8	282
T_2	100% RD	0	2.5	66.1bc	64.5bc	61.7bc	64.1	241
T_3	100% RD	0	0	64.8bc	63.1bc	60.7bc	62.9	234
T_4	50% RD	0	0	48.1d	46.6de	48.7de	47.8	154
T_5	50% RD	5	0	68.1ab	65.4ab	66.1ab	66.5	254
T_6	50% RD	10	0	70.8ab	67.2ab	66.5ab	68.2	263
T_7	50% RD	0	10	60.3c	61.0c	59.4c	60.2	220
T_8	25% RD	10	0	52.1d	50.5d	52.6d	51.7	175
T_9	25% RD	0	10	45.4de	42.5ef	48.0de	45.3	141
T_{10}	0	10	0	40.7e	39.5f	38.8f	39.7	111
T_{11}	0	10	10	28.8f	25.0g	24.0g	25.9	38
T_{12}	Control	0	0	19.9g	19.1h	17.4h	18.8	-
CV (%)				7.3	5.90	6.10	-	-

*RD (Recommended dose of chemical fertilizer, kg ha^{-1}) = $N_{150}P_{45}K_{80}S_{25}Zn_2B_1$ **Source: Noor *et al.*(2006**.)

Note (for all tables):

- Means followed by common letter(s) do not differ significantly at 5% level by DMRT
- CD = cow dung and PM = poultry manure

Broccoli

In another study, Noor *et al*. (2007a) found that the T_1 treatment (100% RD + 2.5 t PM ha^{-1}) was the optimal combination for the highest curd yield of broccoli (24.4 t ha^{-1}), which was significantly higher over all other treatments except T_6 (50% RD + 10 t PM ha^{-1}) (Table 2).

Table 2. Curd yield of broccoli as influenced by integrated use of organic manure and chemical fertilizer at Joydebpur, Gazipur.

Treatment	Chemical fertilizer	PM	CD	Yield (t ha^{-1})			Yield increase (%)
		t ha^{-1}		2002-03	2003-04	Mean	
T_1	100% RD*	2.5	0	25.34a	23.5a	24.42	510
T_2	100% RD	0	2.5	21.5cd	19.9bc	20.70	417
T_3	100% RD	0	0	20.0d	18.3cd	19.15	379
T_4	50% RD	0	0	10.58f	10.9ef	10.75	169
T_5	50% RD	5	0	22.6bc	20.7bc	21.67	442
T_6	50% RD	10	0	24.4ab	22.2ab	23.30	482
T_7	50% RD	0	10	19.3d	17.2d	18.22	355
T_8	25% RD	10	0	14.6e	13.0e	13.80	245
T_9	25% RD	0	10	9.4fg	10.1f	9.75	144
T_{10}	0	10	0	9.16fg	9.54fg	9.34	133
T_{11}	0	10	10	7.42g	7.61g	7.51	88
T_{12}	Control	0	0	3.80h	4.20h	4.00	-
CV (%)				8.6	9.2	-	

*RD (kg ha^{-1}) = $N_{140}\,P_{45}\,K_{80}\,S_{25}Zn_2B_1Mo_{0.5}$ **Source: Noor *et al.* (2007.)**

The second highest yield (23.3 t ha^{-1}) was recorded exactly in the T_6 treatment, which was statistically at par with T_1 and T_5 (50% RD + 5 t PM ha^{-1}) but significantly higher over the rest of the treatments. These findings revealed that addition of 5 t ha^{-1} of PM could reduce the dose of chemical fertilizers by 50% when integrated nutrient management approach was followed. Moderate yield (18.2 t ha^{-1}) was obtained when cow dung (at 10 t ha^{-1}) was applied instead of poultry manure along with 50% RD of chemical fertilizer, which was statistically at par with the T_3 treatment (100% RD of chemical fertilizer). These results suggested that, if poultry manure is not available, cow dung can be used in place of PM along with 50% RD of chemical fertilizer for moderate yield goal.

Residual effect of organic manure on okra

It was observed that nutrient residue left by the T_6 treatment from previous broccoli crop (50% RD + 10 t PM ha^{-1}) in addition to the renewed application of 50% N-recommended rate produced significantly higher yield (11.77 t ha^{-1}) of okra (Noor *et al*. 2007a) (Table 3). The sole residue of chemical fertilizer (T_3) along with supplemental N produced moderate yield (9.17 t/ha), which was statistically at par with the T_7 treatment (50% RD + 10 t CD ha^{-1} applied to broccoli plus supplemental 50% RD of N) but they differed significantly from the residue of T_6 (50% RD of chemical fertilizer + 10 t PM ha^{-1} applied to broccoli). These findings revealed that the T_6 treatment might have left substantial amount of plant nutrients after the harvest of the first crop (broccoli), which in combination with renewed application of 50% N was appeared to be good enough to get the satisfactory yield (11.8 t ha^{-1}) of okra (var. BARI Dherosh-1).

Table 3. Effect of N fertilizer use together with residual effect of organic manure and chemical fertilizers* on the yield and yield contributing characters of okra at Joydebpur, Gazipur.

Treatment	N fertilizer	No. of fruits $plant^{-1}$		Fruit yield (t/ha)			Yield increase (%)
		2002-03	2003-04	2002-03	2003-04	Mean	
T_1	100% RD**	34.8a	29.3a	13.72a	10.88a	12.31	611
T_2	100% RD	28.6bc	23.3bc	11.26bc	8.48bc	9.87	470
T_3	100% RD	27.3bc	22.0c	10.48bc	7.86bc	9.17	430
T_4	50% RD	17.3d	15.0d	4.55e	4.72de	4.64	168
T_5	50% RD	30.2b	24.8b	11.78b	8.86b	10.32	496
T_6	50% RD	33.6a	27.9a	13.34a	10.24a	11.77	580
T_7	50% RD	26.1c	21.6c	10.00c	7.46c	8.73	405
T_8	25% RD	19.8d	16.8d	7.56d	5.66d	6.61	282
T_9	25% RD	13.5e	11.3e	4.30e	4.58f	4.44	157
T_{10}	0	17.0d	14.2d	3.90e	3.38ef	3.64	110
T_{11}	0	11.5e	9.2e	3.52e	2.98f	3.25	88
T_{12}	Control	7.4f	5.1f	1.86f	1.60g	1.73	-
CV (%)		7.4	5.1	9.8	10.8		

* Residue of broccoli treatment with organic manures and chemical fertilizers (see Table 2)
RD (kg ha^{-1}) = N_{150} **Source: Noor *et al*. (2007.)

Cabbage

The evaluation of organic manure application in reducing the requirement in chemical fertilizer and in obtaining sustainable yield of cabbage was done using 3 levels each of cow dung and poultry manure (0, 5 and 10 t ha^{-1}) as well as oil cake (0, 2.5 and 5.0 t ha^{-1}) in Grey Terrace Soil under AEZ-28 of Gazipur during 2000-01 and 2001-02. The use of OC (2.5 and 5.0 t ha^{-1}) and PM (10 t ha^{-1}) proved superior to lower dose of PM (5 t ha^{-1}) and CD (5 and 10 t ha^{-1}) (Table 4). The highest mean head yield (87.1 t ha^{-1}) was obtained from the T_8 treatment (70% RD + 5 t OC ha^{-1}), which was significantly higher over all other treatments except T_6 (70 % RD + 10 t PM ha^{-1}) and T_7 (70% RD + 2.5 t OC ha^{-1}). The second highest mean yield (84.8 t ha^{-1}) was recorded from the T_7 treatment followed by T_6, which was statistically identical with T_8 but significantly higher over the rest of the treatments. It was observed that OC and PM showed better results than CD in terms of yield and yield components of cabbage. Smith (1950) reported that uric acid, which constituted 60 percent of N in PM changes rapidly to ammoniacal form and then to nitrate which might be utilized by plants. Moreover, PM contained growth promoting hormones, which may help produce better root growth (Brown 1958). As such, a package of 70 % recommended dose of chemical fertilizer (kg ha^{-1}: $N_{175}P_{25}K_{56}S_{28}B_{1.4}Mo_{0.7}$) along with 5 t PM ha^{-1} appeared as the best suited combination for yield sustainability and economic profitability. However, rich farmers may use either 10 t PM or 2.5 t OC ha^{-1} instead of 5 t PM ha^{-1} along with 70% RD for higher gross margin. Use of 10 t PM or 2.5 t OC ha^{-1} is sufficient enough to reduce 30% chemical fertilizers form the present conventional recommendation (Noor *et al*. 2005)

Table 4. Yield of cabbage as influenced by integrated use of organic manure and chemical fertilizer at Joydebpur during 2001-02 and 2002-03.

Treatment	Chemical fertilizer	CD	PM	OC	Head yield (t ha^{-1})			Yield increase (%)
		t ha^{-1}			2000-01	2001-02	Mean	
T_1	100% RD*	0	0	0	67.36b	61.82cd	64.59	208
T_2	70% RD	0	0	0	52.86d	45.24e	49.05	134
T_3	70% RD	5	0	0	60.44c	57.22d	58.83	181
T_4	70% RD	10	0	0	70.76b	65.56c	68.16	225
T_5	70% RD	0	5	0	73.32b	74.86b	74.09	253
T_6	70% RD	0	10	0	81.28a	81.80ab	81.54	289
T_7	70% RD	0	0	2.5	84.88a	84.62a	84.75	304
T_8	70% RD	0	0	5	87.25a	86.94a	87.10	316
T_9	Control	0	0	0	22.14e	19.78f	20.96	-
CV (%)					5.6	6.4	-	-

*RD (kg ha^{-1}) = $N_{250}P_{36}K_{80}S_{40}B_2Mo_1$

Source: Noor *et al.*(2005.)

Carrot

The highest root yield (20.0 t ha^{-1}) of carrot was obtained (Islam *et al.*, 2006) with 125 kg K ha^{-1} application when it was integrated with $N_{120}P_{40}S_{20}$ (kg ha^{-1}) and cow dung at 5 t ha^{-1}, providing 2 irrigations at 20 and 40 days after sowings in Grey Terrace Soil under AEZ-28 of Gazipur region during 2000-01 and 2001-02 (Table 5).

Table 5. **Effect of potassium and irrigation on the yield of carrot at Joydebpur, Gazipur.**

Treatment	Irrigation level	K dose (kg ha^{-1})	Yield (t ha^{-1})			Yield increase (%)
			2000-01	2001-02	Mean	
T_1	I_0 (No Irrigation)	0	8.3	8.5	8.4	-
T_2		75	9.2	9.2	9.2	9.3
T_3		100	9.2	9.2	9.2	9.3
T_4		125	9.7	9.4	9.6	14.3
T_5	I_1 (One Irrigation at 20 DAS)	0	8.4	9.4	8.9	6.0
T_6		75	8.5	10.5	9.5	13.1
T_7		100	12.7	14.4	13.6	61.9
T_8		125	15.9	16.1	16.0	90.5
T_9	I_2 (One Irrigation at 40 DAS)	0	8.6	10.0	9.3	10.7
T_{10}		75	13.5	15.2	14.4	71.4
T_{11}		100	15.7	16.4	16.1	91.7
T_{12}		125	18.5	18.4	18.5	120.2
T_{13}	I_3 (Two Irrigation at 20 & 40 DAS)	0	9.4	10.7	10.1	20.2
T_{14}		75	16.2	16.9	16.6	97.6
T_{15}		100	18.6	20.5	19.6	133.3
T_{16}		125	19.0	21.0	20.0	138.1
$LSD_{0.05}$			1.63	2.30	-	-
CV (%)			7.7	10.1	-	-

Note: Blanket dose of $N_{120}P_{40}S_{20}$ (kg ha^{-1}) + cow dung at 5 t ha^{-1} **Source: Islam *et al.(* 2006.)**

Homestead vegetable cropping

Investigations were carried out with radish–tomato-red amaranth-Indian spinach cropping pattern in the homestead area of Joydebpur (AEZ 28) during 2000-01 and 2001-02 on adopting integrated nutrient management approach (Noor *et al.*, 2007b). The first two crops were fertilized with 3 levels (0, 5 and 10 t ha^{-1}) each of poultry manure (PM) and cow dung (CD) in combination with different portions of recommended dose (RD) of chemical fertilizers. The second two crops were fertilized with 3 reduced doses (0, 2.5 and 5.0 t ha^{-1}) of PM and CD along with different portions of the RD of N fertilizer. It was revealed that the amount of 75% RD along with 5 t PM ha^{-1} (T_5) appeared to be the suitable combination providing a mean yield of 62.3 and 90.2 t ha^{-1} for radish and tomato, respectively, which was statistically identical with the T_6 treatment (75% RD + 10 t PM ha^{-1}) but significantly higher over the rest of the treatments (Table 6).

Moreover, an amount of 75% RD along with 2.5 t PM ha^{-1} (T_5) showed overall best results providing the mean yield of 16.1 and 47.7 t ha^{-1} for red amaranth and Indian spinach, respectively, which was statistically at par with the yield obtained from PM (at 5 t ha^{-1}) in combination with same dose of N but significantly higher over the rest of the treatments. The sole application of either organic manure or chemical fertilizers yielded inferior results over their integrated use. The same treatment was also economically profitable as it provided higher marginal rate of return.

An experiment in tomato-okra-Indian spinach cropping pattern was conducted (Noor *et al*. 2007c) on Grey Floodplain Soil under AEZ 8 at farmers' homestead of Elenga, Tangail, during 2005-06. First crop (tomato) was fertilized with 2 levels (0 and 10 t ha^{-1}) each of poultry manure (PM) and cow dung (CD) while the second crop (okra) was fertilized with 3 levels (0, 5 and 10 t ha^{-1}) each of PM and CD along with different portions of the recommended dose of chemical fertilizers for the respective crops. The third crop (Indian spinach) was fertilized with different portions of the RD of nitrogen only. Results showed that an amount of 75% RD of chemical fertilizer in combination with 10 t PM ha^{-1} (T_2) produced the highest yield of tomato (66.4 t ha^{-1}) while 5 t PM ha^{-1} in addition to 75 % RD (T_2) produced the highest yield (20.8 t ha^{-1}) of the second crop – okra, that was statistically identical to 100% RD (T_1) of chemical fertilizer for both the crops (Table 7). Nutrient residue of first two crops along with 75% RD of supplemental N (T_2) gave statistically identical yield (34.7 t ha^{-1}) with 100% RD (T_1) for the third crop – Indian spinach. In the first tomato crop, the application of 10 t PM ha^{-1} along with 50% RD of chemical fertilizer (T_4) produced moderate yield (58.7 t ha^{-1}), which was statistically identical with 100% RD of chemical fertilizers (T_1). Thus, these findings revealed that 10 t PM ha^{-1} may reduce the use of chemical fertilizers to 50% RD without compromising the significant yield loss. In another study, Noor *et al*. (2006) also observed almost a similar kind of response. Therefore, an amount of 75% RD of chemical fertilizer along with 10 t PM ha^{-1} for the first crop (tomato), 75% RD in addition to 5 t PM ha^{-1} for the second crop (okra) and 75% RD of N for the third crop (Indian spinach) appeared as the best suited combination for tomato-okra-Indian spinach cropping pattern in respect of yield sustainability and maintenance of soil fertility in the study area (AEZ 8).

Table 7. Yield of vegetables in tomato-okra-Indian spinach cropping pattern as influenced by integrated use of chemical fertilizers and organic manure at homestead of Elenga, Tangail, during 2005-06.

Tr.	Chemical fertilizer	Tomato		Okra		Indian spinach		Yield (t ha^{-1})			Tomato equivalent yield (t ha^{-1})
		PM	CD	PM	CD	PM	CD	Tomato	Okra	Indian spinach	
		t ha^{-1}									
T_1	100%RD*	0	0	0	0	0	0	64.2ab	9.7ab	36.2a	102.7
T_2	75% RD	10	0	5	0	0	0	66.4a	20.8a	34.7ab	104.5
T_3	75% RD	0	10	0	5	0	0	60.2b	18.8abc	32.5abc	95.76
T_4	50% RD	10	0	10	0	0	0	58.7b	17.3bcd	30.8bc	91.78
T_5	50% RD	0	10	0	10	0	0	53.3c	15.4cd	28.4c	73.1
CV (%)								6.5	9.8	7.3	

*RD (kg ha^{-1}) = $N_{150}P_{40}K_{80}S_{20}Zn_2B_1$ for tomato; $N_{120}P_{35}K_{70}S_{15}Zn_2B_1$ for okra and N_{120} for Indian spinach

Source: Noor *et al*. (2007.)

Cabbage with tomato intercropping system

A field experiment with cabbage and tomato intercropping system was conducted (Shil *et al*. 2007) on Calcareous Dark Grey Floodplain Soil under AEZ 11 at RARS, Jessore during 2005-06 and 2006-07. Treatments were formulated with 2 sets of plant population (PP) and 4 doses of nutrient management (NM) package. Plant population included PP_1 (100% cabbage + 20% tomato) and PP_2 (100% cabbage + 30% tomato). Nutrient management package was formulated with NM_1 (crop removal based dose), NM_2 (FRG'05 based dose), NM_3 (IPNS based dose) and NM_4 (native fertility – control). Results showed that the highest mean yield (56.1 t ha^{-1}) of cabbage was obtained with FRG'05 based dose (NM_2), which was statistically identical with NM_1 (crop removal based dose) but significantly higher over NM_3 (IPNS based dose) and control (Table 8). In a case of intercrop (tomato), the highest fruit yield (10.9 t ha^{-1}) was also recoded in the NM_2 treatment but it was significantly higher over the rest of the packages. The reason for the lower yield in the NM_1 treatment might be an excess use of nutrients than the requirement of the crop as the yield was lower than the target. The reduction of nutrients (as equal to the contribution of cow dung) from the NM_2 package to formulate the NM_3 package due to addition of cow dung might not be well compensated within one season, which might has contributed to the lower yield in the NM_3 (IPNS based) package. Therefore, cow dung should be used without reducing the chemical fertilizer from the NM_2 package to formulate IPNS based dose (NM_3).

Table 8. Yield of cabbage and tomato as influenced by nutrient management and plant population under intercropping system at Jessore during 2005-06 and 2006-07.

Treatment	Head yield of main crop (cabbage)		Fruit yield of intercrop (tomato)	
	2005-06	2006-07	2005-06	2006-07
	t ha^{-1}			
Plant population (PP)				
PP_1 (100% main crop + 20% intercrop)	44.50	42.26	6.60b	7.43b
PP_2 (100% main crop + 30% intercrop)	42.88	40.34	7.41a	8.43a
Significance level	NS	NS	*	**
Nutrient management (NM)				
NM_1 (crop removal based dose)	55.97a	51.87ab	8.07kb	8.98b
NM_2 (FRG 2005 based dose)	57.77a	54.45a	9.99a	11.75a
NM_3 (IPNS based dose)	50.02b	49.47b	7.81b	8.57b
NM_4 (control)	10.99c	11.42c	2.14c	2.43c
Significance level	*	*	*	**
CV (%)	9.7	10.3	11.5	12.5

*P < 0.05; **P < 0.01 **Source: Shil *et al. (*2007.)**

Nutrient balance

There were no so much in-depth studies so far regarding apparent nutrient balance for vegetable cultivation. However, an apparent nutrient balance was estimated on the basis of nutrient added to the soil and the amount of nutrient uptake by the crops in cabbage with tomato intercropping system.

The study revealed that all the nutrients showed positive balances in the NM_1 treatment (crop removal based dose) that might be due to the lower yield than the target, caused by short span winter (Fig. 1). Phosphorus balance was highly positive in the NM_2 package (FRG'05 based dose) and also in NM_3 (IPNS based dose) while N and K balances were negative. The higher amount of P addition compared to the uptake (requirement) coupled with the lower yield might be the main reasons for P build-up in NM_1 & NM_3 packages. However, S and Zn balances were positive for all the treatments except control (Shil *et al.* 2007).

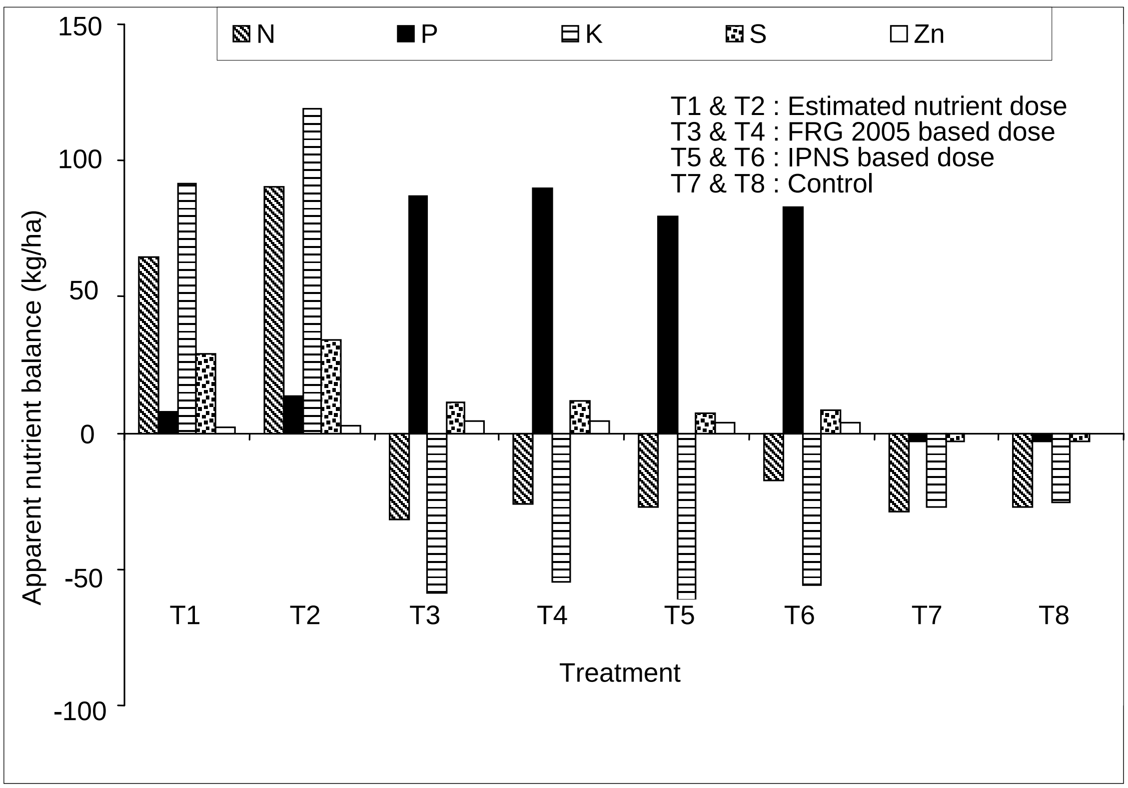

Fig. 1. Apparent nutrient balances for different treatments under cabbage with tomato intercropping system at RARS, Jessore during 2005-06.

Soil fertility status

Studies regarding the post-harvest soil fertility status after the cultivation of vegetable crops were not done widely so far. However, the fertility status of post-harvest soil after the cultivation of tomato under integrated nutrient management approach revealed (Noor *et al.* 2006) that the content of organic matter slightly improved (by 18%) when higher rate of poultry manure was applied (Table 9). The status of P, K and S was increased by 33, 12 and 7%, respectively, over the initial level when the higher dose of poultry manure in combination with chemical fertilizers were applied. N status was not noticeably improved and further deterioration was revealed: the soil treated with the lowest rates of nutrients showed declining trend. The deterioration of soil fertility was more acute in absolute control plots.

Table 9. Pre- and post-harvest soil fertility status of tomato plots grown under integrated nutrient management approach at Central Farm, BARI, Joydebpur, during 2004-05.

Treatment	pH	OM (%)	Total N (%)	K (meq/100 g)	P	S	Zn	B
					ppm			
Initial								
	6.1	1.9	0.09	0.21	12	10	1.5	0.35
Post-harvest								
T_1	6.2	1.9	0.10	0.18	22	13	1.8	0.35
T_2	6.2	2.2	0.08	0.17	21	12	1.7	0.32
T_3	6.3	1.8	0.08	0.15	20	12	1.6	0.30
T_4	6.1	1.7	0.07	0.14	19	11	1.6	0.28
T_5	6.0	1.9	0.09	0.14	18	12	1.7	0.29
T_6	6.1	2.1	0.11	0.16	20	13	1.9	0.34
T_7	6.2	1.8	0.09	0.14	17	11	1.7	0.25
T_8	6.1	1.9	0.10	0.13	14	11	1.7	0.22
T_9	6.0	1.7	0.07	0.13	14	10	1.6	0.23
T_{10}	5.9	1.8	0.08	0.12	16	12	1.7	0.24
T_{11}	6.1	1.7	0.07	0.10	14	10	1.5	0.20
T_{12}	6.0	1.7	0.06	0.09	13	10	1.3	0.18
Critical level	-	-	0.12	0.20	14	14	2.0	0.20

Note: Treatment details are shown in Table 1.
Source: Noor *et al.,* 2006.

Cost and return

The purpose of marginal analysis is to reveal how the gross margin from investment increases as the amount of investment increases (Perrin *et al.* 1976). Economic analysis revealed that higher dose of organic manure along with chemical fertilizer gave lower marginal rate of return (MRR) due to higher cost involvement (cost dominated) even if its gross margin was higher. However, moderate dose of organic manure along with chemical fertilizer appeared as cost un-dominated showing higher MRR as well as economic benefit in most cases. Considering the gross margin, economic benefit (MRR), quality (shape, size and appearance) and quantity (yield) of the product, cost and availability of manures, soil fertility regeneration, the moderate dose of poultry manure (5 t ha^{-1}) along with 50-75% chemical fertilizer from the present recommendation may be regarded as the best suited combination for the cultivation of major vegetable crops.

Conclusions

Following conclusions may be drawn from the above findings:

- Yield of different vegetables increased substantially due to integrated use of both organic manure and chemical fertilizers.
- Poultry manure appeared as the best source of organic manure over cow dung.
- Integrated use of both chemical fertilizer and poultry manure may reduce the use of chemical fertilizer from the present conventional recommendation.

- Further depletion of soil fertility may be checked with positive trend of improvement.
- Moderate dose of poultry manure along with chemical fertilizer appeared as cost un-dominated providing higher marginal rate of return.

Recommendations

Moderate dose of poultry manure (5 t ha^{-1}) along with 50-75% recommended dose of chemical fertilizer for the respective crop may be recommended for the major vegetable crops and their patterns for yield sustainability and improvement of soil fertility in Bangladesh.

Future research suggested

Further research should be undertaken on location specific (agro-ecological zone based) appropriate INM system for different crops and cropping patterns through integrating chemical fertilizers and all possible sources of organic manures depending on their availability and considering their environmental, agronomical and economical perspectives as well as possibilities.

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INTEGRATED NUTRIENT MANAGEMENT FOR SUSTAINABLE YIELD OF MAJOR SPICE CROPS IN BANGLADESH

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Abstract

Spices being an indispensable ingredient of the daily diet are still falling behind with a yearly deficit of 1.18 million tons. Because of shrinking land resources, there is hardly any scope to raise the area and production of spice crops horizontally. As a result, the high demand of spices could only be met up by increasing it's per hectare yield. But intensive crop cultivation with imbalanced fertilization resulted in severe degradation of soil fertility in Bangladesh. To meet this challenge Soil Science Division, Bangladesh Agricultural Research Institute (BARI) developed balanced fertilizer recommendations for the major spice crops through Integrated Nutrient Management (INM) approach. The present paper documents some of the key findings of the related research as conducted by BARI during the recent years (2000-2007). Nitrogen (@120 kg ha^{-1}) and sulphur (@20 kg ha^{-1}) produced significantly higher yield of onion bulb, when they are integrated with other nutrients (P_{40} K_{75} Zn_5 kg ha^{-1}) along with cowdung (5 t ha^{-1}). Boron @1.30 kg ha^{-1} together with recommended dose of other nutrients optimized the seed yield of onion at Bogra. Garlic yield can be maximized with 2.5 t ha^{-1} poultry manure in combination with zinc (@ 5 kg ha^{-1}) and boron (@1 kg ha^{-1}) providing with recommended dose of other nutrients. Soil test based fertilizer (STB) dose along with cowdung (@ 5 t ha^{-1}) produced significantly higher yield of chilli. Zinc and boron contributed significant yield increase for dry chilli. Ginger and turmeric yield also maximized with integrated use of zinc and boron in the deficient soil of hilly region. The yield of coriander was optimized with the integrated use of NPKS fertilizers providing two irrigations at 22 and 40 days after sowing. The yield of black cumin can be increased significantly with integrated use of N_{100} P_{33} K_{58} S_{25} kg ha^{-1} both at Faridpur and Bogra. The above mentioned fertilizer packages also appeared as economically profitable as they provided higher economic return in most cases. Further investigations are needed to observe the post harvest soil fertility status, nutrient uptake and balance especially for the major spice crops when they are extensively cultivated in different soil under varied locations.

Key words: Soil fertility; Integrated nutrient management; Balanced fertilization; Spice crops; Sustainable yield

Introduction

Spices have become an integral part of daily diet of the people of the Asian countries including Bangladesh. They stimulate the appetite, zest to food, enhance the test and delight the gourmet. Spice crops have highly nutritional as well as medicinal value.

Moreover, there is a great possibility in the diversification of spice exports to the international markets. Powders of chillies, turmeric, cumin etc have started their way to foreign countries in appreciable quantities. In addition, some spices like zinger and turmeric can easily be grown in the hilly region, which may bring a potential area under successful crop cultivation. In Bangladesh, on the basis of acreage, demand and yield of crops like onion, garlic, chilli, zinger and turmeric are considered as major spice crops while coriander, black pepper, fenugreek, mint, bay leaf, black cumin, cardamom etc as minor. The area under spice crops cultivation is 2, 53, 000 ha with an annual production of 4, 25,000 tons but we have still yearly deficit of 11,75,000 tons (BBS 2003). Moreover, the area under spice cultivation is gradually decreasing due to expansion of boro rice and non-agricultural uses of land. Because of shrinking land resources, there is a limited scope to raise the area and production of the crop horizontally. Therefore, the high demand of spices can only be met up by increasing it's per hectare yield. Besides, the average yield of most of the spice crops in Bangladesh is too low compared to the neighboring countries. For example, the average yield of onion is very low (4.12 t ha^{-1}) compared to the average yield (17.0 t ha^{-1}) of the onion growing countries (FAO 1999). Again, the average yield of dry chilli in Bangladesh is only 700-800 kg ha^{-1} where in the neighboring countries the yield recorded up to 1000-1200 kg ha^{-1}. The major factors responsible for lower yield are insufficient as well as degenerated high yielding varieties, degradation of soil fertility, imbalanced fertilization, etc.

However, intensive crop cultivation using high yielding varieties of crops with imbalanced fertilization has led to mining out the inherent plant nutrients and thereby fertility status of the soils severely declined in Bangladesh, which is now becoming a very alarming issue for the scientists and policy makers (Bhuyian 1995).

Deficiency of micronutrients like Zn, B, Mn, and Mo has been reported in many parts of the country particularly northwestern region. Deficiency of Ca and Mg are also prevalent in calcareous soils. Moreover, organic matter content in Bangladesh soils is very low, the majority being below the critical level and it is depleting gradually due to higher decomposition rates caused by tropical climate coupled with inadequate use of organic manures in to soil. The major reasons for the depletion of soil fertility in Bangladesh are;

i) The increased intensity of cropping, especially changes in crop sequence with HYV, makes current management practices, including fertilizer use less effective.

ii) More fertilizers are being used on lands with poorer soils or uncertain irrigation facilities.

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

iv) Deficiencies of secondary and micronutrients are prevalent.

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

The cumulative negative nutrient balance has resulted in the degradation of land. Most of the Bangladeshi farmers use only urea as a source of N but fertilizers carrying other essential nutrients seldom applied. For example, the average P use in Bangladesh is 9 kg ha^{-1} compared with 68 kg ha^{-1} N use (Saleque *et al*. 1995). On an average, our farmers use only 90 kg nutrients ha^{-1} annually (70 kg N + 11 kg P + 5 kg K + 2 kg S) (Hoque *et al*. 1998). In 1993, seven million metric tons of N, P, K, Mg and Ca were depleted from soils in low-income countries like Bangladesh, Indonesia, Myanmar, Philippines, Thailand and Vietnam (Murter1996). If erosion at this rate continues unabated, yield may decrease by 16.5% in Asia and 14.5% in Africa by 2020 (Scherr and Yadav 1996).

However, targeting high yield with a high cropping intensity is the most logical way to raise the total production from the country's limited land 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.

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). The main aim of the INM approach is to tap all the major sources of plant nutrients as illustrated in Fig. 1 in a judicious way and to ensure their efficient use (Roy 1986).

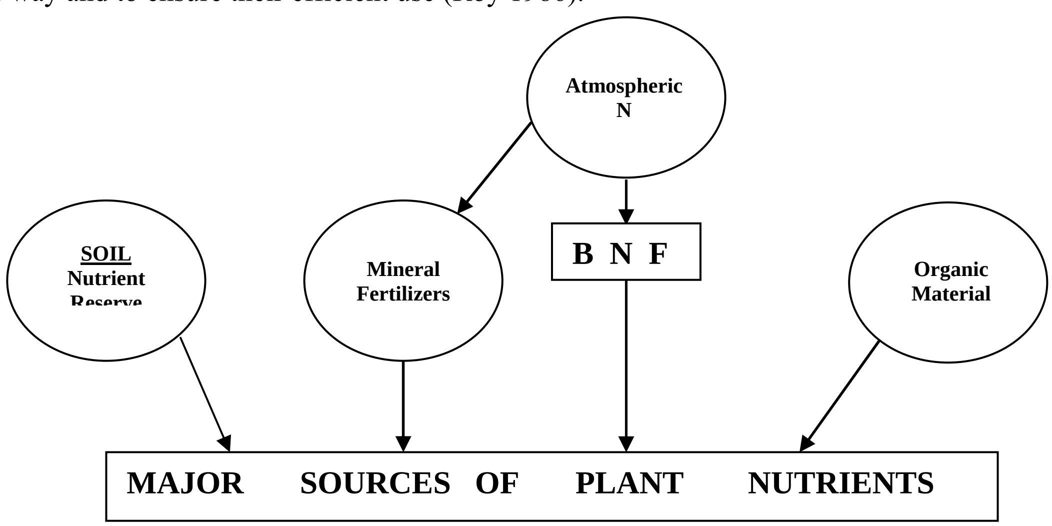

Fig.1 Major Sources of Plant Nutrients.

The goal of INM 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 for future generations (Gruhn *et al*. 2000).

During the last two decades, the INM approach has been adopted in Bangladesh agriculture. In this regard, Soil Science Division of Bangladesh Agricultural Research Institute (BARI) conducted various experiments on spice crops like onion, garlic, chilli, ginger, turmeric, coriander, black cumin etc using INM approach to develop balanced fertilizer recommendations in achieving yield sustainability, economic profitability and to rejuvenate soil fertility. The purpose of the present paper is to provide some of the key findings of the related research as conducted by BARI during the recent years.

However, this review paper has been written to demonstrate the research findings and their benefits regarding integrated nutrient management approach for sustaining spice crop productivity in Bangladesh.

Materials and Methods

The present article is mainly a review paper. Research works regarding nutrient management for spice crops (except onion) has not been done extensively so far as like many other crops. However, with the establishment of Spice Research Center (SRC) in the late nineties, research works on spice crops has been strengthened. However, the present paper furnishes some of the notable findings of the research as conducted by Soil Science Division (BARI) during the recent years (2000-2007). In these contexts, traditional methods for field trials and standard laboratory procedures were followed to carry out respective experiment. Readers those who are interested can get in detail information regarding materials and methods followed and subsequent results obtained if they read the paper of their choice as mentioned in the reference list.

Results and Discussion

Onion

Yield of onion bulb optimized (17.2 t ha^{-1}) with 120 kg ha^{-1} N and 40 kg ha^{-1} S when they integrated with P_{40} K_{75} Zn_5 kg (ha^{-1}) along with cowdung (@ 5 t ha^{-1}) in Grey Terrace Soil under AEZ-28 of Gazipur (Table-1). The said treatment (N_{120} S_{20} kg ha^{-1}) contributed 153% higher yield over control (N_0S_0). It was also observed that the yield of onion increased linearly up to 160 kg N ha^{-1} but in case of sulphur, the yield increased linearly up to 40 kg S ha^{-1}, then declined with subsequent higher dose. However, the yield recorded with 160 kg N ha^{-1} was statistically identical with 120 kg N ha^{-1}. As such, treatment package T_{11} (N_{120} S_{40} kg ha^{-1}) was appeared as suitable along with a blanket dose of $P_{40}K_{85}Zn_5$ kg ha^{-1} and cowdung 5 t ha^{-1} for maximizing the yield of onion in Grey Terrace Soil of Gazipur (Nasreen and Farid 2004).

Table 1. Yield of onion as influenced by nitrogen and sulphur in Grey Terrace Soil at Gazipur during 2003-2004.

Treatment			Yield (t ha^{-1})	% increase in yield over control
Tr. No.	Levels of N (kg ha^{-1})	Levels of S (kg ha^{-1})		
T_1	0	0	6.8 i	-
T_2	80	0	8.9 h	30.9
T_3	120	0	11.0 fg	61.8
T_4	160	0	11.3 fg	66.2
T_5	0	20	8.6 hi	26.5
T_6	80	20	12.8 ef	88.2
T_7	120	20	14.6 de	114.7
T_8	160	20	14.6 de	114.7
T_9	0	40	10.8 g	58.8
T_{10}	80	40	15.3 bcd	125.0
T_{11}	120	40	17.2 a	152.9
T_{12}	160	40	16.8 abc	147.1
T_{13}	0	60	10.7 gh	57.4
T_{14}	80	60	15.1 cd	122.1
T_{15}	120	60	17.0 ab	150.0
T_{16}	160	60	16.4 abcd	141.2
CV (%)			**9.1**	**-**

Blanket dose: P_{40} K_{85} Zn_5 kg ha^{-1}and cowdung 5 t ha^{-1} Source : Nasreen *et al*. (2004)
Figures in a column having same letter(s) do not differ significantly at 5% level by DMRT

One of the major reasons for the low onion production is the scarcity of quality seeds. The present production can hardly meet 50% of the total requirement (Naher *et al.* 2003). However, benefits of applying balanced fertilizer in combination with boron to onion seed crop was reported by many scientists (Bokshi *et al.* 1989; Naher *et al*. 2003 and Hossain 2000). In this regard, Shil *et al*. (2007a) observed response of onion seed to boron fertilization. The highest seed yield (589 kg ha^{-1}) was obtained with 1.0 kg B ha^{-1}, which was significantly higher over rest of the boron doses. Applied boron contributed 8-37% higher yield over boron control. As such, boron @ 1.0 kg ha^{-1} along with a blanket dose $N_{100}P_{50}K_{120}S_{40}Mg_{12}Zn_4$ kg ha^{-1} and cow dung 5 t ha^{-1} was appeared as the best suited combination for maximizing the yield of onion seed in the study area (Bogra). However, a positive but quadratic relationship was observed between applied boron with onion seed yield (Fig. 2). From the quadratic response function the optimum - economic dose of boron was worked out to be 1.30 kg ha$^{-1.}$

Table 2.Yield of onion seed crop as influenced by boron at Bogra during 2005 -06 and 2006-07.

Treatment Levels of B (kg ha^{-1})	Seed yield (kg ha^{-1})			% increase in yield over control
	2005-2006	2006-2007	Mean	
T_1 (B_0)	451.8d	412.0d	431.9	-
T_2 ($B_{0.5}$)	516.0c	463.7bcd	489.9	13.4
T_3 ($B_{1.0}$)	594.3a	583.7a	589.0	36.4
T_4 ($B_{1.5}$)	571.5ab	513.3b	542.4	25.6
T_5 ($B_{2.0}$)	532.8bc	490.0bc	511.4	18.4
T_6 ($B_{2.5}$)	497.3cd	438.3cd	467.8	8.3
CV (%)	**7.9**	**7.8**	**-**	**-**

Figures in a column having same letter(s) do not differ significantly at 5% level by LSD
Source : Shil *et al.* (2007) Blanket dose: N_{100} P_{50} K_{120} S_{40} Mg_{12} Zn_4 kg ha^{-1} and cowdung 5 t ha^{-1}

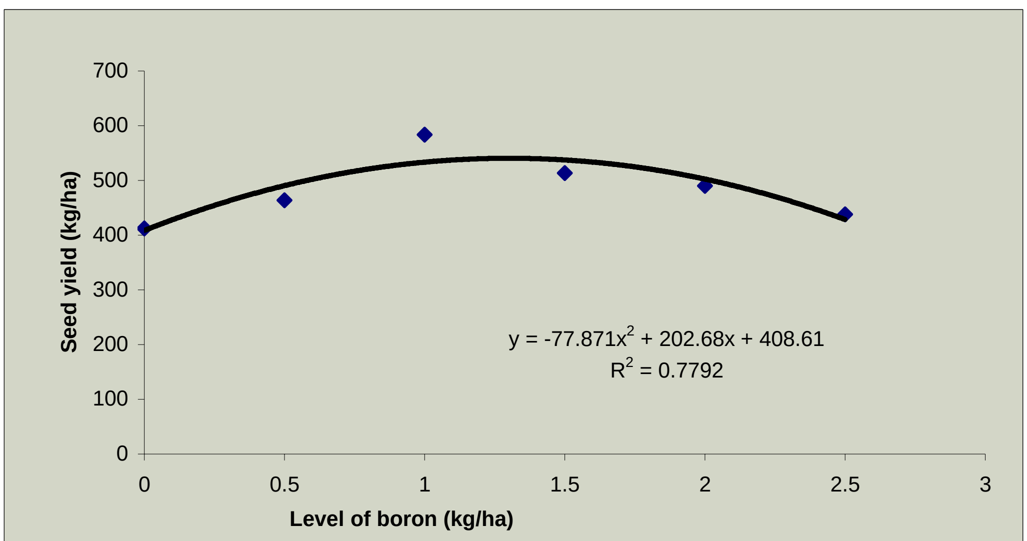

Fig. 2. Response of onion seed crop to boron levels at SRC, Bogra.

Garlic

The yield of garlic increased significantly due to integrated use of chemical fertilizers and poultry manure (Table 3). The highest bulb yield (7.3 t ha^{-1}) was recorded due to integrated use of Zn_5 B_1 kg ha^{-1} and poultry manure @ 5 t ha^{-1} (T_6) in combination with the blanket dose of N_{150} P_{50} K_{100} S_{40} kg ha^{-1}, which was statistically identical with reduced dose of poultry manure (@ 2.5 t ha^{-1}) along with same dose of other nutrients (T_5). The said treatments (T_5 and T_6) produced significantly higher yield over rest of the treatments (Nasreen and Farid 2005). Integrated use of chemical fertilizer and poultry manure brought 367-387% increased yield over control (without fertilizer) while zinc, boron and poultry manure contributed 46 - 52% increased yield over their control (T_1). Thus, integrated use of poultry manure @ 2.5 t ha^{-1} and Zn_5 B_1 kg ha^{-1} along with the said blanket dose found suitable for the cultivation of garlic in Grey Terrace Soil at Gazipur.

Table 3. Yield of garlic as influence by poultry manure, Zinc and Boron in Grey Terrace Soil at Gazipur during 2004-2005.

Tr. No	Levels of Zn (kg ha^{-1})	Levels of B (kg ha^{-1})	Poultry manure (t ha^{-1})	Weight of individual bulb (g)	Bulb yield (t ha^{-1})	% increase in yield over control
T_1	0	0	0	13.4 e	4.8 e	220
T_2	0	0	5	16.7 d	5.9 d	293
T_3	5	0	0	18.4 c	6.5 c	333
T_4	0	1	0	18.1 c	6.5 c	333
T_5	5	1	2.5	19.8 b	7.0 ab	367
T_6	5	1	5	22.1 a	7.3 a	387
T_7	5	1	0	19.9 b	6.7 bc	347
T_8	Absolute control			8.14	1.5	-
CV (%)				**4.6**	**10.0**	**-**

Figures in a column having same letter do not differ significantly at 5% level by LSD
Blanket dose: N_{150} P_{50} K_{100} S_{40} kg ha^{-1} Source: Nasreen and Farid (2005)

Chilli

Recommended dose (RD) of chemical fertilizer (N_{100} P_{60} K_{100} S_{20} Zn_2 B_1 kg ha^{-1}) in combination with 5 t ha^{-1} cow dung (CD) produced the highest yield of dry chilli both at Bogra (1.74 t ha^{-1}) and Hathazari (1.36 t ha^{-1}), which was statistically identical with 125% RD of chemical fertilizer but both of them produced significantly higher yield over rest of the treatments (Table 4). Again, 75% RD in combination with 5 t CD ha^{-1} (T_4) produced moderate yield (1.55 and 1.20 t ha^{-1} for Bogra and Hathazari, respectively), which was statistically at par with 100% RD (T_1). These findings reveal that addition of 5 t CD ha^{-1} can reduce the 25% chemical fertilizer from the conventional recommendatin (Hoque *et al.*2004). Thus, the yield of chilli can be maximized and sustained when 5 t ha^{-1} of cow dung is integrated with chemical fertilizers (N_{100} P_{60} K_{100} S_{20} Zn_2 B_1 kg ha^{-1}) for both Bogra and Hatahazari (Chittagong).

Zaman and Talukder (2007) conducted an experiment on chilli at Jamalpur and found that the highest dry yield of chilli (2.15 t ha^{-1}) can be obtained integrating soil test based (STB) fertilizer dose (N_{120}

Table 4. Effect of chemical fertilizers and cowdung on the yield and of Chilli at Bogra and Hathazari during rabi seasons of 2003-2004.

Treatment			Bogra		Hathazari	
Notation	Chemical fertilizer (kg ha^{-1})	Cow dung (t ha^{-1})	Dry Chilli yield (t/ha)	% increase in yield over control	Dry Chilli yield (t/ha)	% increase in yield over control
T_1	100% RD	0	1.51b	70	1.18b	69
T_2	125 %RD	0	1.69a	90	1.33a	90
T_3	100% RD	5	1.74a	96	1.36a	94
T_4	75 % RD	5	1.55b	74	1.20b	71
T_5	0	10	1.14c	28	0.89c	27
T_6	0	0	0.89d	-	0.70d	-
CV (%)			**5.3**		**6.9**	

Figures in a column having same letter do not differ significantly at 5% level by LSD
RD= Recommended Dose Based on FRG'97= $N_{100} P_{60} K_{100} S_{20} Zn_2 B_1$ kg ha^{-1}
Source: Hoque *et al*. (2004)

P_{60} K_{120} S_{18} Zn_2 $B_{0.5}$ kg ha^{-1}) with 5 t ha^{-1} of cowdung (Table 5). However, STB fertilizer dose for high yield goal in absence of cowdung (T_1) produced the second highest yield (1.67 t ha^{-1}), which was

Table 5. Yield of chilli as influenced by chemical fertilizer and organic manure at Jamalpur during 2006-2007.

Treatment		Fruits $plant^{-1}$	Dry chilli yield (t ha^{-1})	% increase in yield over control
Notation	Combination			
T_1	Soil Test Based (STB) for HYG	40.74b	1.67b	126
T_2	STB+ 5 t CD ha^{-1}	55.95a	2.15a	191
T_3	50% of STB + 5 t CD ha^{-1}	34.45b	1.14c	54
T_4	Recommended dose based on FRG'2005 for HYG	40.10b	1.05c	42
T_5	Farmers practice (FP)	36.65b	1.19c	61
T_6	Native fertility (control)	18.18c	0.74d	-
CV(%)		16.7	14.6	

Figures in a column having same letter do not differ significantly at 5% level by LSD
Soil Test Base (STB)= $N_{120}P_{60}K_{120}S_{18}Zn_2B_{0.5}$ kg ha^{-1} & Cow dung 5 t ha^{-1}

RD Based on FRG'2005= $N_{100}P_{60}K_{100}S_{20}Zn_2B_1$ kg ha^{-1} Source: Zaman and Talukder (2007)

Significantly higher over rest of the treatments except T_2 (STB + 5 t CD ha^{-1}). However, 50% STB along with 5 t CD ha^{-1} (T_3) produced moderate yield (1.10 t ha^{-1}), which was statistically similar to T_4 (FRG '05 based dose) and T_5 (farmers practices). However, farmers can get 130% higher yield if they integrated STB fertilizer dose and cowdung for the cultivation of chilli in Jamalpur region.

Moreover, chilli was found responsive to both zinc and boron fertilization in the deficient soil of Bogra under AEZ-25 (Table 6). The highest yield of dry chilli (1136 kg ha^{-1}) was obtained from Zn_3B_1 kg ha^{-1}, which was closely followed by Zn_3B_2 (T_{10}), $Zn_{4.5}B_2$ (T_{11}) and they were significantly higher over control (Zn_0B_0), single application of either zinc or boron (Shil *et al*. 2007b). The yield benefit over control varied from 9-60% due to interaction effect when the highest yield advantage was obtained with Zn_3B_1 and the lowest in $Zn_{1.5}B_1$. However, a positive but quadratic relationship was observed between dry chilli yield and added zinc (Fig-3) and added boron (Fig-4). From the quadratic response function, the optimum economic dose found to be 4.03 and 1.70 kg ha^{-1} for zinc and boron respectively. Thus, a package of $Zn_{4.03}$ and $B_{1.70}$ kg ha^{-1} along with a blanket dose of $N_{130}P_{60}K_{80}S_{20}Mg_{10}$ kg ha^{-1} and cowdung 5 t ha^{-1} appeared as the best suited combination for maximizing the yield of chilli in the study area (Level Barind Tract, Bogra).

Table 6. Yield of Chilli as influenced by zinc and boron fertilization at Bogra.

Treatment			Yield of Dry Chilli (kg ha^{-1})			% increase in yield over control (Zn_0B_0)
Code	Zn (kg ha^{-1})	B (kg ha^{-1})	2005-2006	2006-2007	Mean	
T_1	0	0	735d	685d	710	-
T_2	1.5	0	761cd	725cd	743	5
T_3	3.0	0	795cd	809cd	802	13
T_4	4.5	0	783cd	805cd	794	12
T_5	0	1.0	772cd	766cd	769	8
T_6	1.5	1.0	778cd	774cd	776	9
T_7	3.0	1.0	1102a	1169a	1136	60
T_8	4.5	1.0	1003ab	996b	1000	41
T_9	0	2.0	763cd	754cd	759	7
T_{10}	1.5	2.0	847cd	863c	855	20
T_{11}	3.0	2.0	1027a	1051ab	1039	46
T_{12}	4.5	2.0	1029a	1066ab	1048	48
T_{13}	0	3.0	748cd	723cd	736	4
T_{14}	1.5	3.0	816cd	838c	827	16
T_{15}	3.0	3.0	985ab	1012b	999	41
T_{16}	4.5	3.0	876bc	855c	866	22
CV (%)			**8.6**	**10.0**	**-**	**-**

Figures in column having same letter(s) do not differ significantly at 5% level by DMRT
Blanket dose: $N_{130}P_{60}K_{80}S_{20}Mg_{10}$ kg ha^{-1}& cow dung 5 t ha^{-1} **Source : Shil *et al*. (2007)**

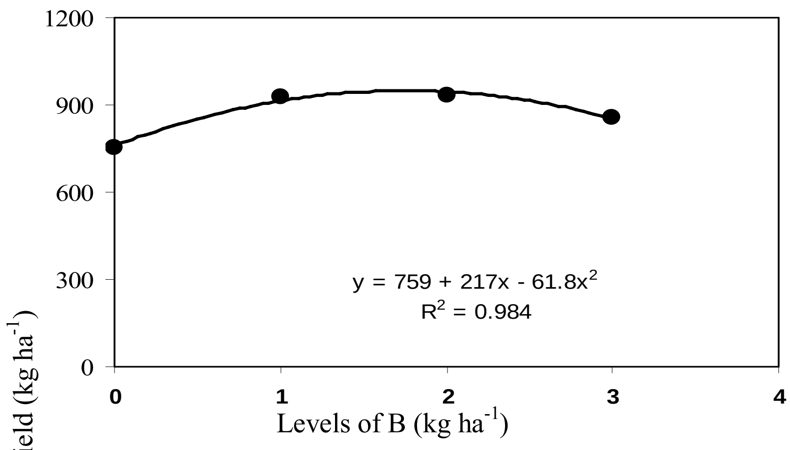

Fig. 3. Response of chilli to boron fertilization.

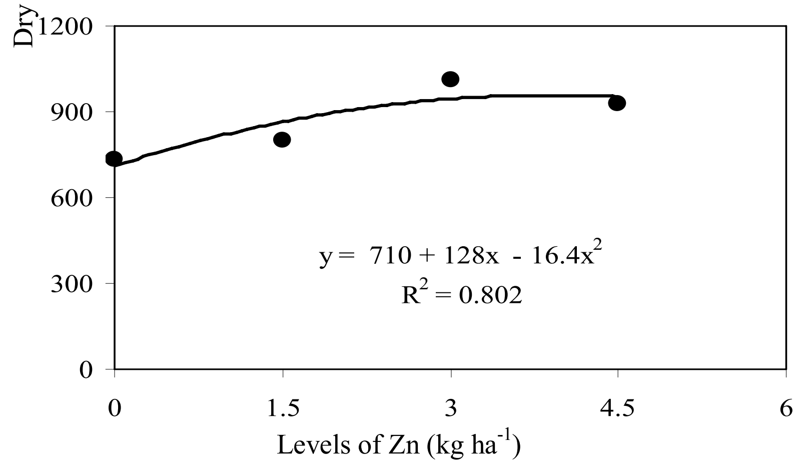

Fig. 4. Response of chilli to Zinc fertilization.

Turmeric

Turmeric responded significantly to zinc and boron fertilization in Brown Hill Soil of South Eastern Hilly Region at Khagrachari during 2004-2005 and 2000-2006 (Halder 2007a).The highest rhizome yield of turmeric (27.5 and 28.9 t ha^{-1}) was obtained due to integrated use of $Zn_{4.5}$ $B_{3.0}$ kg ha^{-1} along with the blanket dose, which was significantly higher over all other combinations (Table7). The said treatment package produced 141% increased yield over control (Zn_0B_0). The crop responded significantly and linearly to Zn and B application up to 4.5 kg ha^{-1} of Zn and 3.0 kg ha^{-1} of B might be due to deficiency of Zn and B in the experimental soil.

The increase in the rhizome yield might be attributed to the cumulative effect of finger weight per plant, number of fingers per plant and finger size.

Almost similar tread of results were observed by Sugtto and Mafutuchah (1995); Pranjal and Supriya (1994). The said dose of Zn and B was also found economically profitable as it produced highest gross margin along with highest marginal rate of return.

Table 7. Yield of Turmeric as influenced by zinc and boron fertilization at Ramgarh, Khagrachari.

Treatment			Finger yield of Turmeric (t ha^{-1})			% increase in yield over control (Zn_0B_0)
Code	Zn	B	2004-2005	2005-2006	Mean	
	(kg ha^{-1})					
T_1	0	0	11.2 l	12.2 l	11.7	-
T_2	1.5	0	13.0 k	13.6 k	13.3	13.7
T_3	3.0	0	13.9 j	14.2 jk	14.1	20.5
T_4	4.5	0	14.1 ij	14.7 j	14.4	23.1
T_5	0	1.0	14.7 i	14.7 j	14.7	25.6
T_6	1.5	1.0	14.8 hi	15.2 j	15.0	28.2
T_7	3.0	1.0	15.5 h	16.2 i	15.9	35.9
T_8	4.5	1.0	16.4 g	16.5 hi	16.5	41.0
T_9	0	2.0	16.7 fg	17.0 gh	16.9	44.4
T_{10}	1.5	2.0	16.7 fg	17.6 fg	17.2	47.0
T_{11}	3.0	2.0	17.3 ef	18.3 f	17.8	52.1
T_{12}	4.5	2.0	17.5 e	19.3 e	18.4	57.3
T_{13}	0	3.0	21.5 d	22.3 d	21.9	87.2
T_{14}	1.5	3.0	23.7 c	24.2 c	24.0	105.1
T_{15}	3.0	3.0	25.0 b	26.2 b	25.6	118.8
T_{16}	4.5	3.0	27.5 a	28.9 a	28.2	141.0
CV (%)			**4.3**	**5.6**		

Figures in column having same letter(s) do not differ significantly at 5% level by DMRT
Blanket dose:N_{130} $P_{3\ 5}K_{80}$ S_{20} kg ha^{-1}& cow dung 5 t ha^{-1} Source : Halder *et al.* (2007a)

Ginger

Like turmeric, integrated use of zinc and boron produced significantly higher yield of ginger in Brown Hill Soil of South Eastern Hilly Region at Khagrachari during 2004-2005 and 2005-2006 (Table 8). The response was positive and linear in nature for both zinc and boron (Halder *et al.* 2007b). The interaction effect between Zn and B regarding rhizome yield of ginger was significant. The highest rhizome yield (25.5 and 26.8 t ha^{-1}) was recorded with T_{16} ($Zn_{4.5}$ $B_{3.0}$ kg ha^{-1}) along with the blanket dose, which was significantly higher over all other treatments. The said package contributed 136% higher yield over control (Zn_0 B_0). These results are in agreement with the findings of Pandey (1992) who reported that micronutrients along with the blanket dose of NPK significantly increased the rhizome yield of ginger. Roy *et al.* (1992) reported that micronutrient like Zn, Fe and B increased the rhizome yield of ginger significantly and progressively.

The present dose ($Zn_{4.5}$ $B_{3.0}$ kg ha^{-1}) also brought economic profitability proving highest marginal rate of return. Thus, Zn@ 4.5 kg ha^{-1} and B@ 3.0 kg ha^{-1} along with the blanket dose of N_{180} P_{50} K_{120} S_{20} kg ha^{-1} and cowdung 5 t ha^{-1} was found suitable for maximizing the yield of ginger in South Eastern Brown Hill Soil of Chittagong Hill Tract (AEZ 29).

Table 8. Yield of Ginger as influenced by zinc and boron fertilization at Ramgarh, Khagrachari.

Treatment			Rhizome yield of Ginger (t ha^{-1})			% increase in yield over control (Zn_0B_0)
Code	Zn (kg ha^{-1})	B	2004-2005	2005-2006	Mean	
T_1	0	0	10.5 n	11.7 l	11.1	-
T_2	1.5	0	12.0 m	13.0 j	12.5	12.6
T_3	3.0	0	12.7 l	13.3 j	13.0	17.1
T_4	4.5	0	11.0 n	12.3 k	11.7	5.4
T_5	0	1.0	15.1 k	17.3 h	16.2	45.9
T_6	1.5	1.0	16.3 j	16.7 i	16.5	48.6
T_7	3.0	1.0	17.0 i	17.6 h	17.3	55.9
T_8	4.5	1.0	17.4 i	17.7 h	17.6	58.6
T_9	0	2.0	18.3 h	18.0 g	18.2	64.0
T_{10}	1.5	2.0	19.5 g	20.6 f	20.1	81.1
T_{11}	3.0	2.0	20.2 f	21.0 e	20.6	85.6
T_{12}	4.5	2.0	21.1 e	22.3 d	21.7	95.5
T_{13}	0	3.0	22.0 d	22.8 d	22.4	101.8
T_{14}	1.5	3.0	22.9 c	23.7 c	23.3	109.9
T_{15}	3.0	3.0	23.8 b	24.5 b	24.2	118.0
T_{16}	4.5	3.0	25.5 a	26.8 a	26.2	136.0
CV (%)			**5.1**	**5.4**	**-**	**-**

Figures in column having same letter(s) do not differ significantly at 5% level by DMRT
Blanket dose: N_{180} P_{50} K_{120} S_{20} kg ha^{-1}& cow dung 5 t ha^{-1} Source: Halder *et al*. (2007)

Coriander

Coriander responded significantly to NPKS fertilization both at Gazipur (AEZ 28) and Bogra (AEZ 25) during 2001-2002 (Rahman *et al*. 2002). The highest seed yield of coriander (1364 and 1624 kg ha^{-1} for Gazipur and Bogra, respectively) was obtained due to integrated use of N_{120} P_{36} K_{48} S_{15} kg ha^{-1} providing with two irrigations each at 22 and 45 days after sowing (Table 9). The same treatment also brought economic benefit providing highest gross margin.

Table 9. Yield of coriander as influenced by integrated use of irrigation and fertilizer at Gazipur and Bogra during 2001-2002.

Treatment						Seed yield (kg ha^{-1})	
Code	No. of irrigation	Chemical fertilizer (kg ha^{-1})				Gazipur	Bogra
		N	P	K	S		
T_1	I_0 (No irrigation)	0	0	0	0	433 k	305 g
T_2		40	12	16	5	667 ij	428 fg
T_3		80	24	32	10	900 def	523 f
T_4		120	36	48	15	950 de	724 e
T_5	I_1 (One irrigation at 22 DAS)	0	0	0	0	550 jk	545 f
T_6		40	12	16	5	751 ghi	764 e
T_7		80	24	32	10	851 efg	955 d
T_8		120	36	48	15	1017 cd	976 d
T_9	I_2 (Two irrigation at 22 and 45 DAS)	0	0	0	0	667 ij	754 e
T_{10}		40	12	16	5	817 fgh	1248 c
T_{11}		80	24	32	10	1117 bc	1558 ab
T_{12}		120	36	48	15	1364 a	1624 a
T_{13}	I_3 (Three irrigation at 22, 45 and 75 DAS)	0	0	0	0	700 hi	980 d
T_{14}		40	12	16	5	1006 cd	1440 b
T_{15}		80	24	32	10	1245 ab	1578 a
T_{16}		120	36	48	15	1177 b	1648 a
CV (%)						**10.4**	**7.7**

Figures in column having same letter(s) do not differ significantly at 5% level by DMRT
Source: Rahman *et al*. (2002)

Black cumin

Black cumin (*Nigella Sativa* L.) is one of the popular spice crops due to its medicinal and aesthetic values. It grows well in Faridpur, Jessore, Kushtia, Pabna, Borga and Rangpur. Even though most of the soil and climatic condition of Bangladesh are suitable for black cumin cultivation but the crop did not show its yield potential probably due to imbalanced fertilization. In this regard, studies were conducted simultaneously in Calcareous Grey Floodplain Soil under AEZ-12 at Faridpur and Grey Terrace Soil under AEZ-25 at Bogra during 2005-2006 and 2006-2007 (Noor *et al*. 2007). Black cumin responded significantly to NPKS fertilization both at Faridpur and Bogra (Table10). The highest seed yield both at Faridpur (849 and 979 kg ha^{-1}) and Bogra (831 and 1073 kg ha^{-1}) was obtained due to integrated use of $N_{75}P_{30}K_{45}S_{20}$kg ha^{-1} (T_4). The seed yield of black cumin increased significantly and progressively up to 75, 30, 45 and 20 kg ha^{-1} of N, P, K and S, respectively but declined with subsequent higher dose of the respective nutrients. Thus, a positive and quadratic relationship was observed between the added nutrients with the seed yield (Fig 5-Fig 8). From the quadratic response function, the optimum economic dose was found to be 100, 31, 56 and 25 kg ha^{-1} of N P K S, respectively at Faridpur. The optimum economic dose for Bogra was calculated to be 100, 33, 58 and 25 kg ha^{-1} of N, P, K and S respectively. Therefore, the yield of black cumin can be increased and sustained with the integrated use of $N_{100}P_{33}K_{58}S_{25}$ kg ha^{-1}. Almost similar kinds of results were reported by Datta *et al*.(1994).

Table 10. Integrated effect of chemical fertilizers on the yield of black cumin at Faridpur and Bogra during 2005-2006 and 2006-2007.

Treatment					Seed yield (kg ha^{-1})			
Code	Chemical fertilizer (kg ha^{-1})				Faridpur		Bogra	
	N	P	K	S	2005-2006	2006-2007	2005-2006	2006-2007
T_1	0	0	0	0	414g	408d	393f	456d
T_2	0	30	45	20	549f	565c	534e	591cd
T_3	50	30	45	20	682d	858ab	670d	933ab
T_4	75	30	45	20	849a	986a	831a	1082a
T_5	100	30	45	20	794b	979a	777b	1073a
T_6	75	0	45	20	572ef	588c	556e	613c
T_7	75	15	45	20	704cd	797b	683cd	866b
T_8	75	45	45	20	829ab	966a	813ab	1063a
T_9	75	30	0	20	561ef	578c	544e	602cd
T_{10}	75	30	30	20	717cd	863ab	698cd	936ab
T_{11}	75	30	60	20	837a	970a	816ab	1068a
T_{12}	75	30	45	0	589e	597c	570e	627c
T_{13}	75	30	45	10	726c	802b	713c	874b
T_{14}	75	30	45	30	821ab	959a	804ab	1053a
CV (%)					4.3	10.8	4.8	10.0

Figures in column having same letter(s) do not differ significantly at 5% level by DMRT
Blanket dose: $Zn_2 B_1$ kg ha^{-1} **Source: Noor *et al.* (2007)**

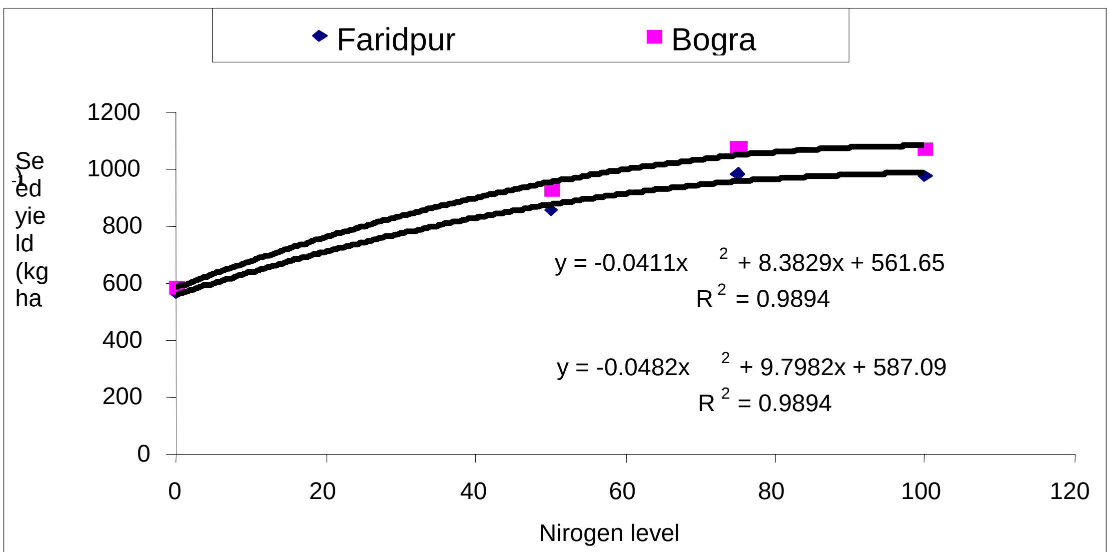

Fig. 5. Response of blackcumin to nitrogen at Faridpur and Bogra.

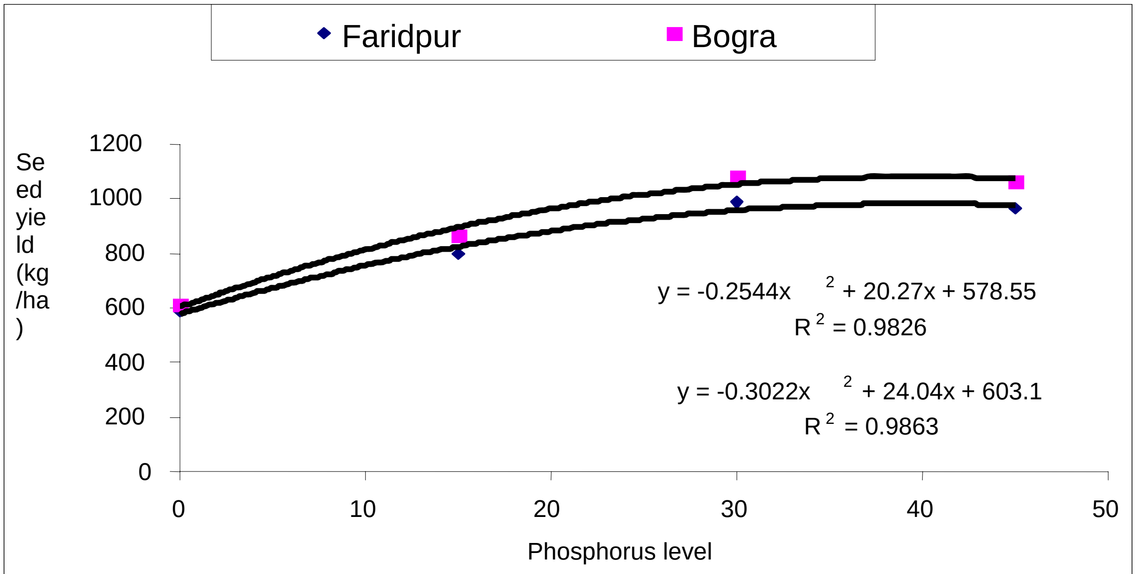

Fig. 6. Response of blackcumin to phosphorus at Faridpur and Bogra.

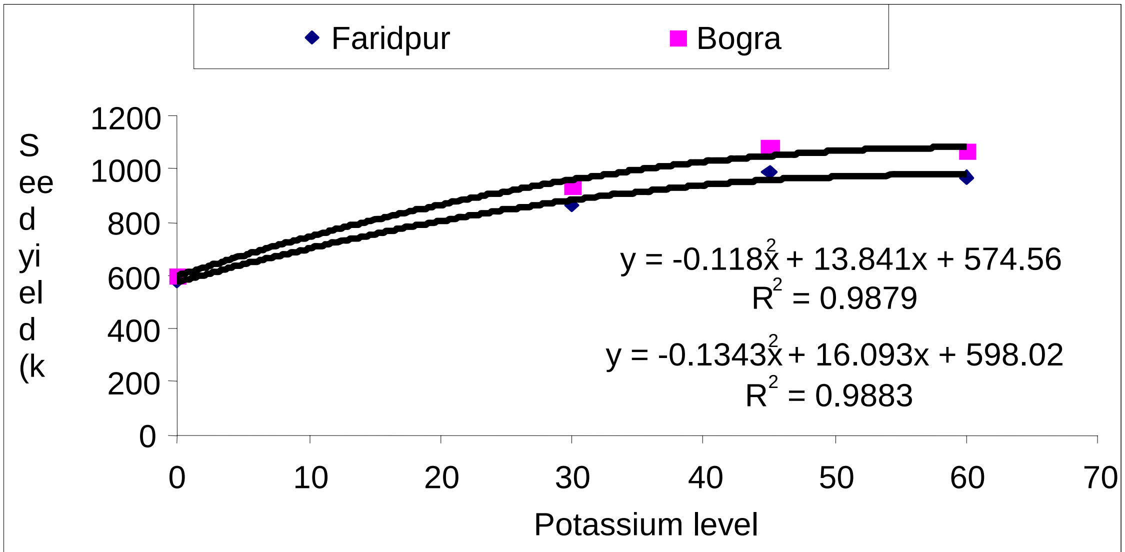

Fig. 7. Response of blackcumin to potassium at Faridpur and Bogra.

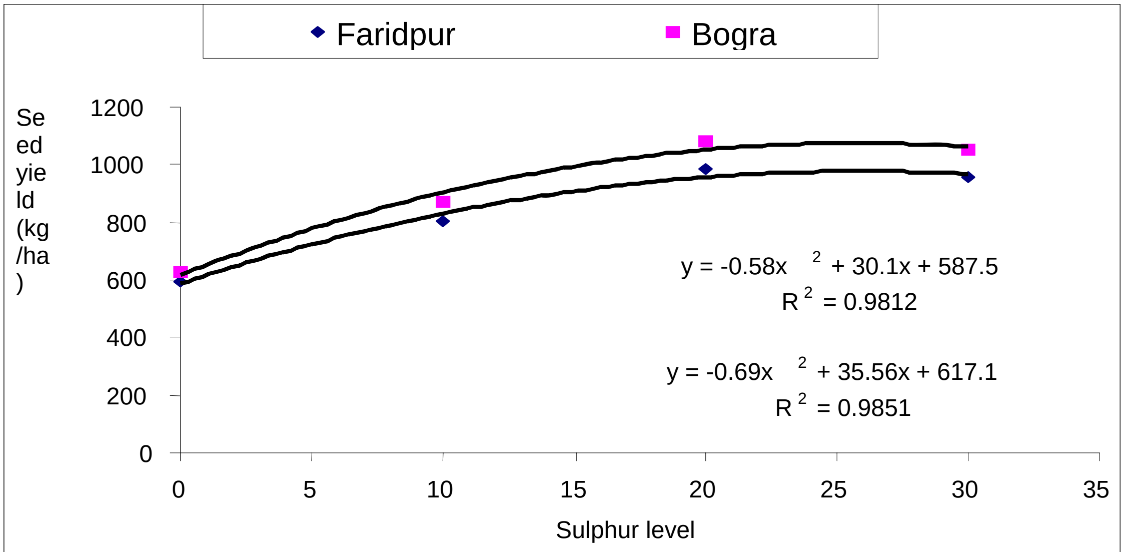

Fig. 8. Response of blackcumin to sulphur at Faridpur and Bogra.

Conclusions

- Experimental evidence suggests that Bangladesh has a great potentiality to increase the production of spice crops. The yield of major spice crops like onion, garlic, chilli, turmeric, ginger can be increased substantially if the recommended balanced fertilization packages are used through integrated nutrient management approach;
- Crops like chilli, garlic, turmeric, ginger appear as very responsive to zinc and boron fertilization. The potential area of CHT region can be brought under successful and profitable ginger and turmeric cultivation if they are fertilized with zinc and boron along with recommended dose of other fertilizers and manure;
- Use of chemical fertilizer can be reduced substantially when they are integrated with poultry manure especially for garlic, onion and chilli cultivation and
- The prescribed fertilizer packages as mentioned in the text may bring economic profitability providing with higher net return in most cases.

Recommendations

- The developed fertilizer packages may be recommended for the cultivation of spice crops in Bangladesh for yield sustainability economic profitability and regeneration of soil fertility and
- Zinc and boron fertilization are carefully prescribed for the successful cultivation of chilli, ginger, turmeric, onion and garlic especially for the deficient soils.

Future Research Suggested

- The prospect, possibility and strategy for the cultivation of spices in the homestead should be thoroughly investigated;
- Location specific appropriate INM system for different spice crops including different sources of organic manure on the basis of their availability and economical and environmental possibilities should be strengthened;
- Studies regarding nutrient management on the pattern based spice crop should be done with high priority and
- Information regarding the post harvest soil nutrient status, nutrient residue and their carried over effect for the subsequent crop(s), nutrient uptake and balance should be generated through systematic and extensive research especially when fertilizer trials on spice crops are undertaken.

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PUTTING POTASSIUM IN THE PICTURE: ACHIEVING IMPROVED NITROGEN USE EFFICIENCY

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Abstract

Both nitrogen and potassium are macronutrients, used in large quantities to achieve high yields and quality. While potassium is benign to the environment, nitrogen fertilizer which is applied but not utilized by plants can have a significantly detrimental effect. Even though the theory of the 'Law of the Minimum' and scientific findings showing the interaction between nitrogen and potassium are well known, imbalanced fertilization and ignorance of the importance of potassium often leads to suboptimal levels of nitrogen use efficiency (NUE). Balanced fertilization is commonly carried out to enable high NUE. Comparing results from various locations show that typical values of agronomic efficiency (AE) and partial factor productivity (PFP) of nitrogen in cereals are 10-30 and 40-80 kg/kg, respectively. These values can be used as benchmark figures for good agricultural practice. Several experiments made by IPI, demonstrate the role and scale of effect of potassium on NUE, either through a significant increase of PFP or AE_N or both of these indices. In these experiments, the application of potassium improves PFP and AE_N by 20 to 100% in cereals, potato and sugar beet crops. The analysis of dozens of experiments conducted by IPI in recent years on various crops in Asia and Europe show that on average, a typical K application of 30-150 kg K_2O/ha can increase NUE by approximately 10-40%. Applying potassium and improving nutrient management practices offer an immediate and rewarding strategy to raise NUE and thereby reduce the undesirable flow of nitrogen into the environment.

Introduction

The role of mineral fertilizers to sustain world agriculture and enable sufficient production to feed the world's population is without question (Smil 2001; Stewart *et al.* 2005). The higher productivity achieved through the use of fertilizers has spared millions of hectares of natural ecosystems that otherwise would have been converted to agriculture. Indeed, during the last 40 years, productivity of major cereal crops has more than tripled; nevertheless, imbalanced nutrient application which leads to mining of nutrients from soils is still a major cause of low crop yields in many parts of the developing world, Africa being an extreme example (Dobermann 2007). Moreover, imbalanced and poorly monitored nitrogen application limits yields and induces large losses of reactive nitrogen to the environment (Cassman *et al*. 2002), at significant cost to society (Mosier *et al.* 2001). Furthermore, as nitrogen-fertilizer application rates per unit arable land are projected to increase in the future to reach 115 kgN/ha by 2080, double today's figure (Tubiello and Fischer 2007), efficient use of this 'engine for growth' nutrient is of utmost importance.

One of the immediate measures to improve nitrogen use efficiency (NUE) is to apply 'balanced fertilization'. In general, this approach meets the principles set out by Sprengel (1787–1859), and later by Liebig (1803-1873), in which they established the theory of the 'Law of the Minimum'. Liebig stated the law in three parts: "1. By the deficiency or absence of one necessary constituent, all others being present, the soil is rendered barren for all those crops to the life of which that one constituent is indispensable. 2. With equal supplies of the atmospheric conditions for the growth of plants, the yields are directly proportional to the mineral nutrients supplied in the manure. 3. In a soil rich in mineral nutrients, the yield of a field cannot be increased by adding more of the same substances." (For more details on the origin of the theory of mineral nutrition of plants and the law of the minimum, see der Ploeg et al. 1999.)

While these principles are well demonstrated for any nutrient in deficiency in productive commercial systems and many field experiments and trials, the interaction between potassium and nitrogen provides an additional argument for balanced fertilization with potassium. The term 'interaction' is used to describe the effect in which the addition of two nutrients, achieves a higher result as compared with the sum of results of applying each separately (Gething 1993). This paper describes the benefits of K application on nitrogen use efficiency leading to increased production performance. Results from experiments, including those conducted by IPI and analysis of the nitrogen – potassium interaction will be discussed.

Nitrogen and potassium in the plant

Potassium is a highly versatile and mobile nutrient in plants. It is involved in all major physiological processes including assimilation and transport of assimilates and the conversion of these assimilates into storage products such as sugar, starch, protein and oil/fats (Marschner 1995; Epstein and Bloom, 2005). Potassium and nitrogen are both taken up and required in relatively high amounts, but whereas potassium remains mostly in ionic form, nitrogen as nitrate or ammonium is assimilated and metabolized into proteins and other N containing compounds. Some interactions between these two macronutrients in physiological processes of importance in relation to efficient N utilization for crop yield and quality are considered below.

Uptake, assimilation and metabolism of N

Research from 40 years ago clearly shows how K plays a major role in nitrogen assimilation and metabolism. The model described by Ben Zioni *et al.* (1971) proposed a mechanism by which NO_3 reduction in the shoot controls NO_3 uptake by the roots (Fig. 1). According to this model, K and NO_3 are taken up by the root and translocated in the xylem to the shoot, where for every NO_3 ion reduced, an equivalent of malate is formed. Subsequent experimental research has in general confirmed the relevance of this concept in those plant species in which the shoot presents the major site of nitrate reduction (Kirkby and Knight 1977, Kirkby and Armstrong 1980).

The model has had to be modified for those plant species in which nitrate is reduced more predominantly in the root and also for when nitrogen is taken up as NH_4 –N or in molecular form by legumes (Raven and Smith 1976, Kirkby 1981). Regardless of these modifications, however, K plays a major role as a cation in the transport of N assimilates in plants.

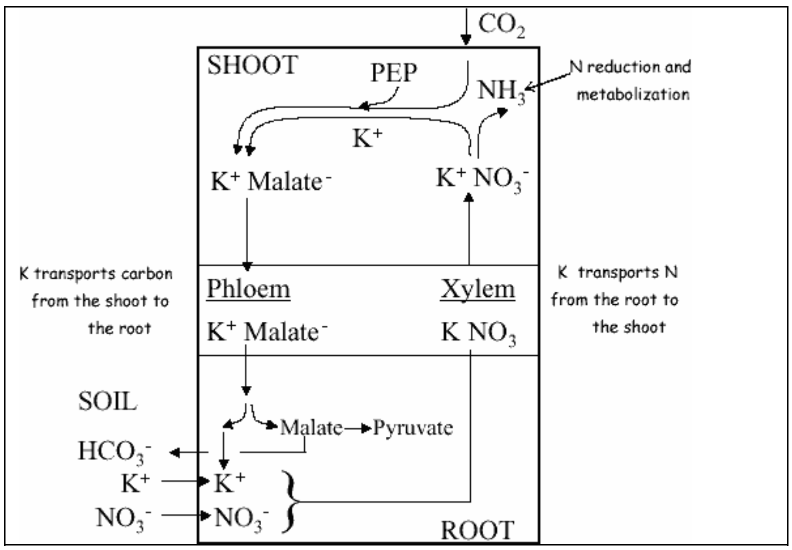

Fig. 1. Circulation of K between shoot and root in relation to nitrate and malate ransport. PEP= phosphoenol pyruvate (Marschner 1995). (After the model of Ben Zioni *et al*. 1971).

Potassium is also of importance in the metabolism of nitrogen. Mengel and Kirkby (2001) report that protein level in plants that received K was much higher than when K supply was restricted. Moreover, the lack of metabolism of nitrate to protein, leads to increased nitrate levels in the plant, which may induce undesirable effects such as increased disease and lower quality of produce. Hence, insufficient potassium supply impairs the reduction of NO_3, increases the levels of nitrate in the shoot and depresses the amount of metabolized protein (Mengel and Kirkby 2001; Fig. 2).

Effect of NK interactions on crop's quality

Severe potassium deficiency also leads to the synthesis of toxic amines such as putrescine and agmatine (Smith and Sinclair 1967), compounds that were later suggested as indicators to establish potassium deficiency in Lucerne (Smith *et al.* 1982). More recently in soybean, Walter and DiFonzo (2007) have also reported that K deficiency leads to higher percentage of aspargine in the phloem, and as this amino acid is important for aphid nutrition, it explains the association between low K in the plant and a higher pest incidence and disease occurrence.

The effect of NK interaction on crop quality can be expressed by the lower nitrate accumulation in the tissue. For example, cabbage stored during 4 months showed a substantial loss in weight (35%) and serious incidence of spot necroses as a result of imbalanced fertilization with NP only. In contrast, balanced fertilization with potassium improved shelf-life (weight loss 27%) and the incidence of spot necroses was considerably lower. After 4 months, the heads of these plants had also a rather favourable K:N ratio of 1.18, in comparison with the cabbage heads of the NP control plants which contained substantially higher levels of nitrate (K:N 0.49). Comparable results were also found in carrots and red beet in Russia (Krauss 2001).

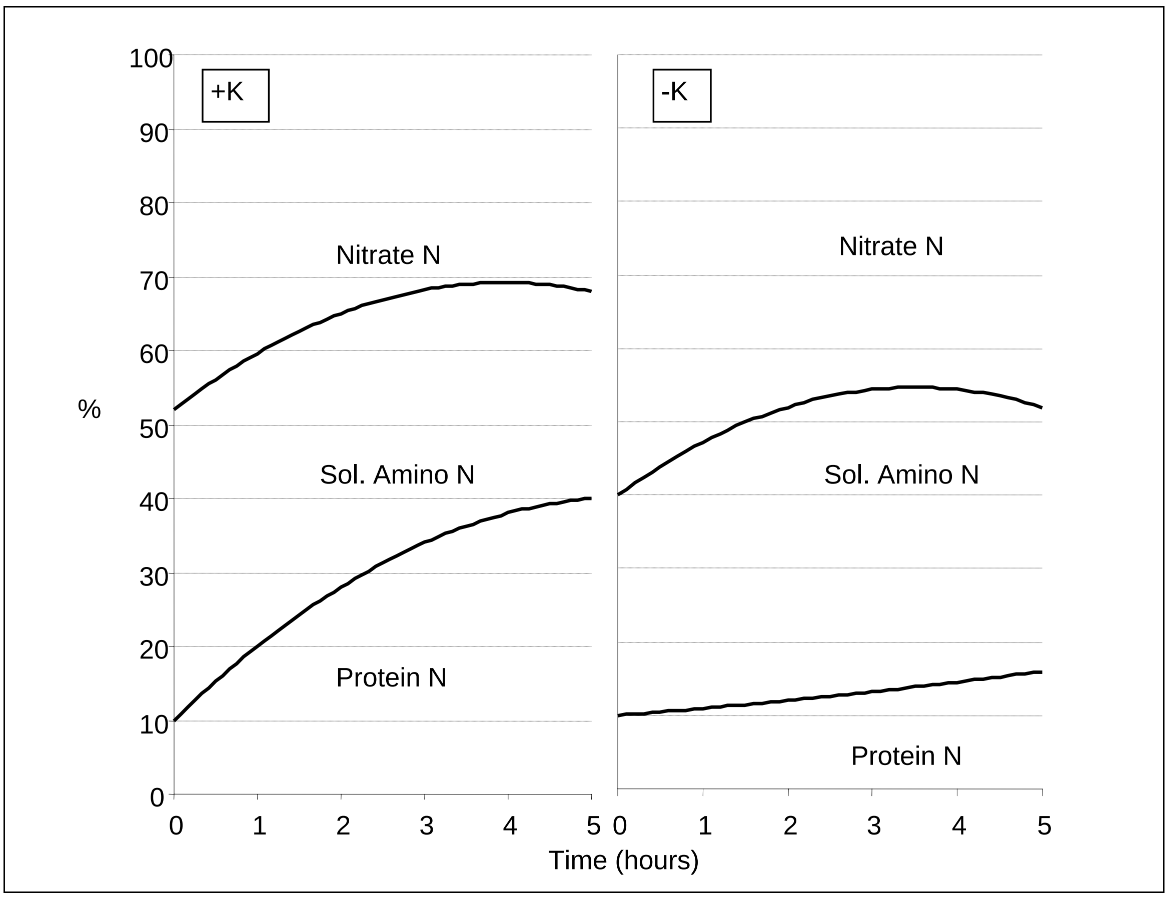

Fig. 2. Effect of K supply on incorporation of ^{15}N labelled nitrate into the soluble amino acid and into the protein fraction.
Source: Mengel and Kirkby (after Koch and Mengel 1974) 2001. pp 498.

Another example of the role of balanced fertilization with potassium is demonstrated with the reduced levels of acrylamide (AA) in potato. AA in certain foodstuffs is suspected to be 'likely carcinogenic for humans' (Anonymous 1994), but as its carcinogenic potential has no safety limits, AA intake should be kept to a minimum (Gerend´as *et al.* 2007). Among various food products, fried potato products like crisps, and french fries, contain appreciable amounts of AA (>2mg/kg DM; Gerend´as *et al.* 2007). AA is formed during processing from endogenous precursors, namely reducing sugars (glucose and fructose) and free asparagine (Asn). Gerend´as *et al.* (2007) showed that with higher N levels, Asn (and reducing sugars) in potatoes tripled at low K and increased at only 50-60% in medium and high K levels, demonstrating the role of K in reduction of AA precursors concentrations (Gerend´as *et al.* 2007, Fig. 3).

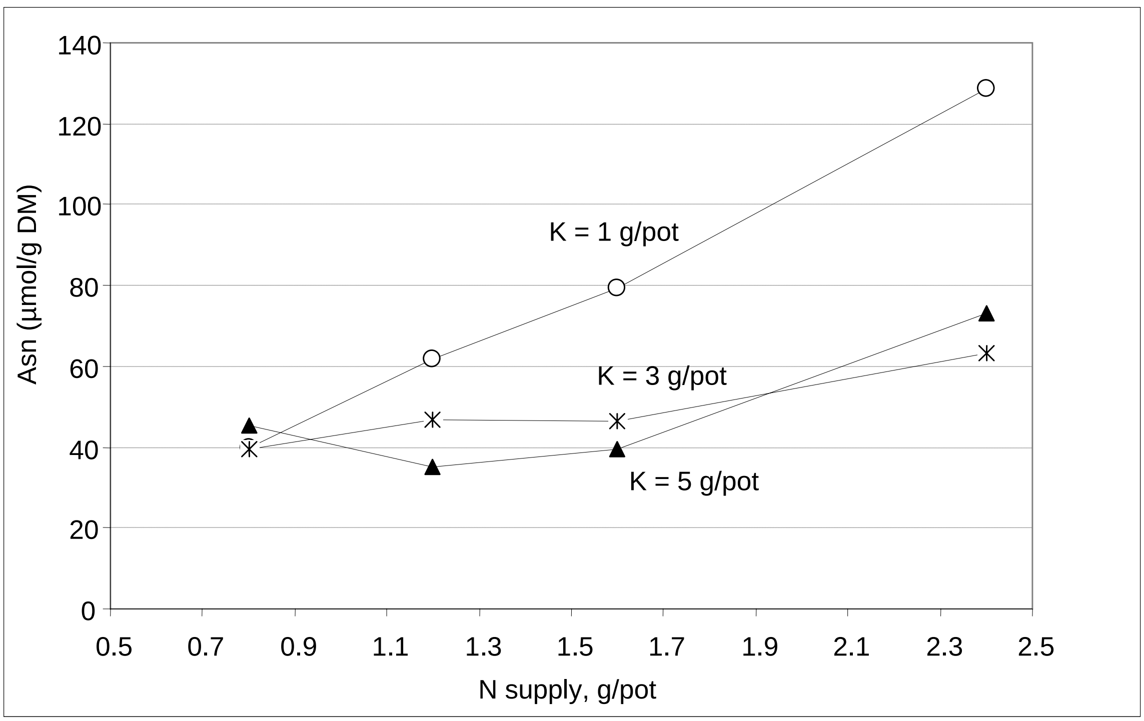

Fig. 3. Asparagine (Asn) levels in DM of potato tubers at the time of harvest as influenced by the N and K supply. (Adapted from Gerend´as *et al*. 2007).

Typical response curve to N and K levels

A typical NK interaction and its effect on barley grain yield gain from balanced fertilization with potassium are described in Fig. 4. Higher nitrogen uptake (by larger yield) is clearly the result of higher potassium supplied. K application can triple the efficiency of nitrogen use, and hence, may well meet the needs for a more economic use of nitrogen fertilizers as well as decreasing 'N leaky practices' which leads to N cascading into and within the environment. Fig. 4. demonstrates that as uptake and utilization of N are promoted by K, the effect of nitrogen on crop production will only be optimal if the plants are adequately supplied with potassium.

The interaction of N and K described in Fig. 4. was studied with barley in hydroponic culture. At a low K level (10 ppm K) an increase of N supply slightly increased, then depressed yield, whilst at medium and high K concentration (50 and 200 ppm), higher N rates increased yields. Maximum yield was obtained with high K and N (both at 200 ppm).

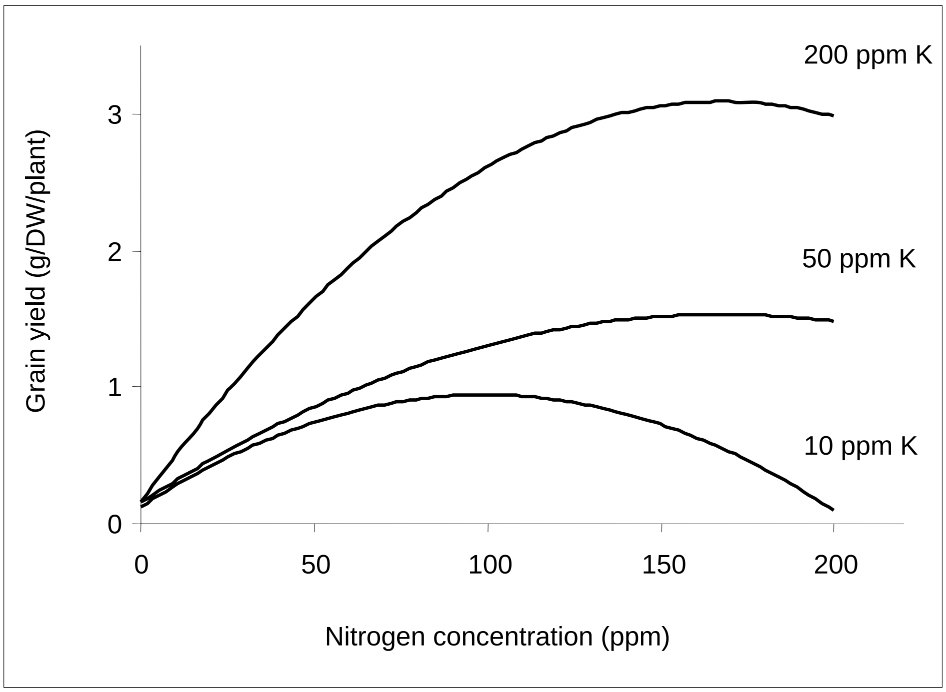

Fig. 4. Response of grain yield of barely grown in hydroponic culture to increasing levels of N, at three levels of potassium supply. (Source: http://www.ipipotash.org/slides/kipp2.html; after Marschner 2001).

The role of management practices in increasing nitrogen use efficiency

Nutrient use efficiencies can be determined through various indices. The most common and practical indices used for agronomic purposes at farmers' fields are (after Dobermann 2007):

- AE = Agronomic efficiency of applied nutrient, measured as kg yield increase per kg nutrient applied. AE = $(Y-Y_0)/F$. Typical values for AE_N in cereals are 10-30 kg/kg or >25 kg/kg in well managed systems or at low levels of N use (Dobermann 2007).
- PFP = Partial factor productivity of applied nutrient, measured as kg harvested per kg nutrient applied. PFP = Y/F. Typical values for PFP_N in cereals are 40-80 kg/kg or >60 kg/kg in well managed systems or at low levels of N use (Dobermann 2007).

Other indices reflect characteristics of nutrients release from soil and fertilizers and the ability of plants to acquire nutrients and transform them into economic yield.

The recently published experiment titled "The performance of site-specific nutrient management (SSNM) for irrigated, transplanted rice in Northwest India" (Khurana *et al*. 2007) has allowed a comparison for the two indices AE_N (agronomic efficiency of N) and PFP_N (partial factor productivity of N) under two management practices, namely farmers' practice (FP) and that of SSNM at six sites across the Punjab, India. As shown in Table 1, increases of as much as from 37 to more than 100% in AE_N (average 83%) and 2 to 55% (average 27%) in PFP_N were obtained comparing SSNM with FP. The two different management regimes SSNM and FP differed in a few respects relating to nutrient supply: N application in SSNM was 8% less as compared with FP, and the application was split differently; P application with SSNM was on average 12 kg/ha as compared with only 3 kg/ha on the FP plots; Potassium was not applied at all in the FP regime (as farmers believed that K supply from irrigation was sufficient) whereas it was applied at 30 kg/ha with SSNM.

Table 1. Effect of site-specific nutrient management (SSNM) on Agronomic Efficiency of N (AE_N) and Partial Factor Productivity for N (PFP_N) in irrigated, transplanted rice fields at six sites in Punjab, India, during 2003 and 2004 (Adapted from Khurana *et al*. 2007).

Site	AE_N			PFP_N		
	FP	SSNM	Increase (%)	FP	SSNM	Increase (%)
	kg grain/kg N			kg grain/kg N		
1	9.27	18.3	97	36.7	51.2	40
2	8.31	16.4	97	31.9	45.4	42
3	9.69	13.3	37	49.2	50.0	2
4	13.0	16.4	26	42.3	43.6	3
5	8.32	17.1	106	29.0	40.0	38
6	7.56	17.9	137	23.1	35.7	55
All (1)	8.79	16.1	83	34.7	44.2	27

(1) All = combined data averaged for all six sites and 2 yr (2003 and 2004). Values shown are based on measurements from 8 to 11 fields at each site. FP = Farmers' practice. SSNM = Site Specific Nutrient Management.

Obviously, not only does K contribute to the higher NUE, but as the authors mention so too does the better split of the N applications and the balanced fertilization with N, P and K. The superiority of SSNM management brought approx 15% more income and a significant, unmeasured, benefit to the environment.

Dobermann (2007) lists the average AE_N and PFP_N for cereals in different world regions (Table 2). Clearly, the gaps between regions are large and demonstrate the importance of reliable irrigation to achieve higher efficiencies. It also gives an indication of the scope of improvement that can be achieved.

Table 2. Average N use efficiency fro cereals in different regions.

Region / crop	Water supply	AE_N	PFP_N
		kg grain/kg N	
Maize, USA	Rain-fed and irrigated	12	61
Maize, USA	Irrigated	23	94
Maize, Indonesia	Rain-fed and irrigated	17	46
Rice in S, E and SE Asia	Irrigated	12	49
Rice in West Africa	Irrigated	17	46
Wheat in North India	Irrigated	11	44

(Source: Dobermann 2007).

Gerend´as *et al*., 2007 demonstrated the interaction between N and K in potato grown in pots. Fig. 5 demonstrates how K application improves the yield response to the N applied. In terms of N efficiency, when K is applied at 1g/pot, yield response to N was 90 g/g; at 3 g K/pot, yield response more than doubles to 202 g/g and at K=5 g/pot, response to N was at 250 g/g. This means that the addition of potassium markedly improved the response of potato to the N applied by almost threefold.

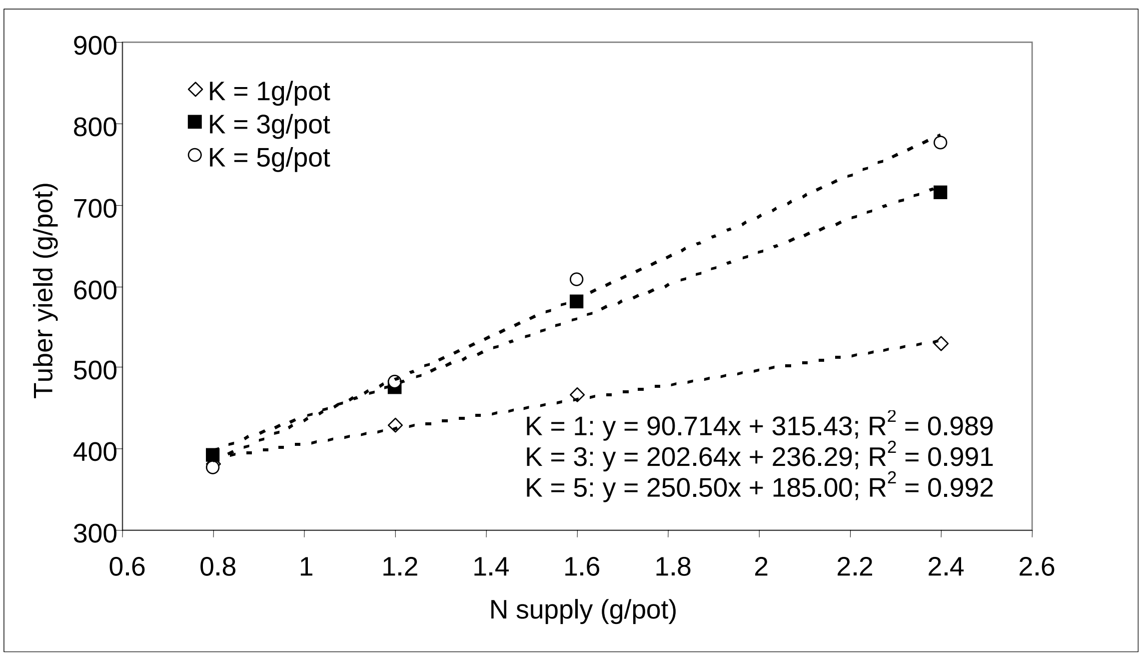

Fig. 5. Tuber yield response to N applied under three levels of K. (Adapted from Gerend´as *et al*. 2007).

Results from experiments

The International Potash Institute (IPI) is involved in many research projects around the world to study and demonstrate the benefits from potash application. Through the years, IPI has conducted thousands of on-farm experiments and demonstrations in many regions showing the role of potassium in effective and sustainable nutrient management.

With the increasing concern over reactive nitrogen in the environment, there is a need to re-emphasize the immediate opportunities that by rather simple steps can be taken to improve nutrient management.

In this paper we have chosen to present two examples from Bangladesh and India and a summary from many of other IPI experiments, which demonstrate how to achieve higher NUE through improved potash fertilization practices.

IPI-BRRI experiment in Bangladesh
(This example is based on Islam *et al*. 2007)

The general recommended application rate of potash fertilizer for modern rice varieties in Bangladesh is about 35 kg K/ha, whereas an average crop of rice yielding 4.0 t/ha removes at least 70 kg K/ha from the soil (*note elemental basis is used here*). The present K fertilizer management practice may thus not be adequate to sustain soil K fertility status in the long term. A research trial and farmers' field demonstrations with several combinations of potash fertilizer rates were conducted under a wheat-rice (transplanted Aman) cropping pattern in NW regions of Bangladesh during 2003-2006. The research trial was carried out at the Hajee Danesh University of Science and Technology (HDSTU) experimental farm, Dinajpur (Old Himalayan Piedmont Plain, medium highland) and the farmers' field demonstrations at Dinajpur, Thakurgaon and Panchagar. The soils of the experimental fields are sandy loam in texture, and strongly to very strongly acidic in nature. They are very low in total nitrogen, and in exchangeable K and S, as well as being very low to optimum in P and low to optimum in Zn content.

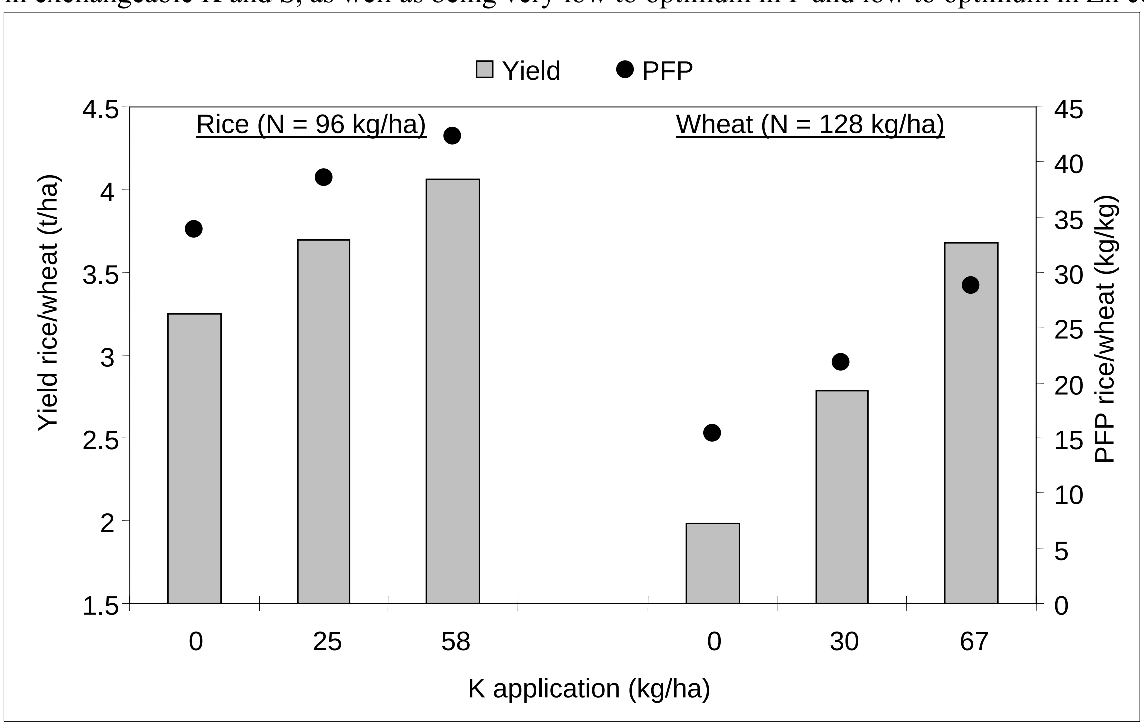

Fig. 6. Rice and wheat yields and PFP with increasing levels of potassium, at 96 and 128 kg N/ha in rice and wheat, respectively. Results are from five farmers' fields and the average of three years (2003-2005).

In this experiment, medium levels of potassium (25 and 30 kg K/ha in rice and wheat, respectively) were applied as the average farmers' practice in the region (25 farmers), while the high K levels (58 and 87 kg K/ha in rice and wheat, respectively) were made according to soil tests. Soil tests were also used to establish nitrogen levels and P, S and Zn applications for rice and wheat.

Yields of rice and wheat increased with additional K (Fig. 6), as did also the PFPs of these two crops. In wheat, K application doubled PFP from 15 to 30 kg/kg, while in rice the effect on PFP was positive, but smaller. However, these PFP values are rather low, especially that of wheat, indicating that the production system was limited by other factors.

IPI-PRII-CPRI experiment in Northern India
(This example is based on Imas and Bansal 2002)

In field experiments jointly conducted by IPI, PRII and CPRI at Shimla and Jalandhar in 1998-1999, balanced N and K fertilization increased tuber yield. In addition, increasing K doses decreased the yield of small grade tubers and increased the proportion of large marketable tubers. Potassium application also dramatically decreased the incidence of late blight. In 1998, a maximum yield of 40.8 mt/ha was obtained at Kufri (Shimla) when applied 180 kg N/ha, 100 kg P_2O_5/ha and 150 kg K_2O/ha, against a tuber yield of only 14.6 mt/ha for the control plots.

The yield response to nitrogen application differed according to the level of K applied (Fig. 7). In this experiment, application of potassium did not change the response curve to nitrogen, however, in terms of PFP, K application of 75 kg K_2O/ha contributed additional 11% and 150 kg K_2O/ha increased PFP (of N) by 35%. Clearly, the application of K brought a much higher value for the N applied.

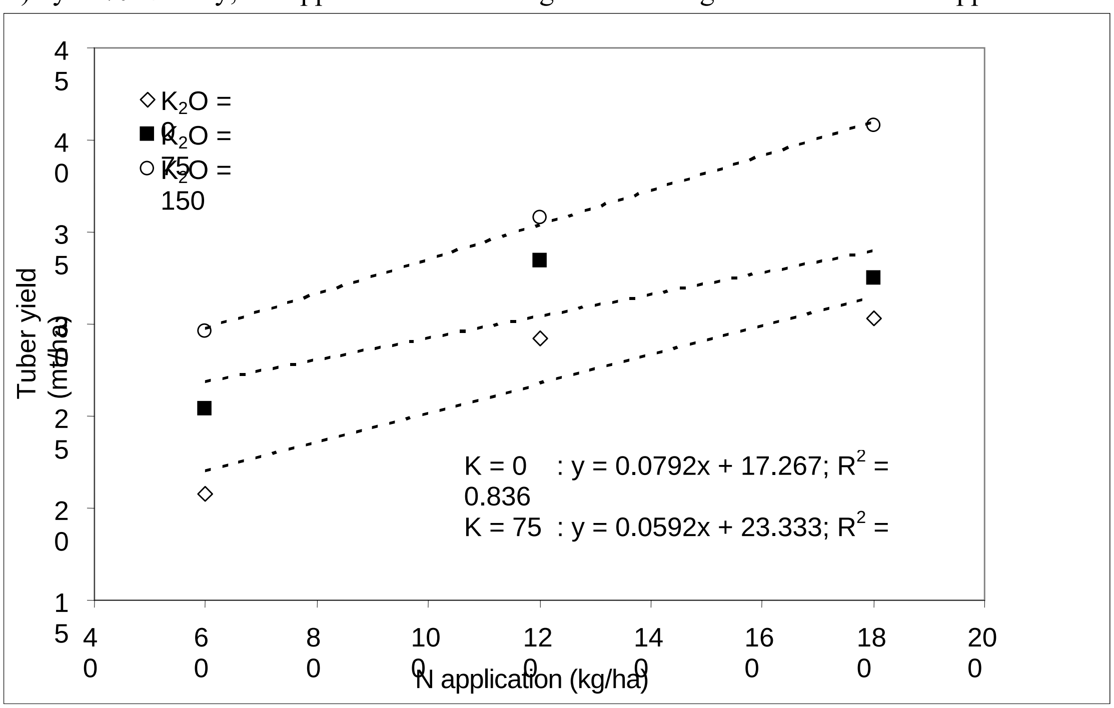

Fig. 7. Yield response of potatoes to nitrogen at three levels of K application. Shimla 1998. (Adapted from Imas and Bansal 1999).

To summarize, additional results from IPI experiments showing results of improved NUE in various crops in Asia and Europe are presented in Table 3. In the examples shown, we compare a constant level of N application with increasing levels of applied potassium. In addition to the increased yield obtained (yield increase, kg/ha), we have calculated the increase in NUE (%) by attributing the higher yield to the same N application.

As shown in Table 3, a typical gain of 10 to 30% increase in NUE is achieved by applying a moderate dose of potassium to maize, rice, wheat, rye and sunflower. When combining potassium application and advanced water management (e.g. fertigation), gains can be much higher (70% increase in NUE in fertigated sugarcane in India; see Table 3). Potassium proves to be an efficient supplement for increasing the nitrogen use efficiency over a wide range of crops, soils and agro climatic conditions.

Table 3. Typical yield increases and increased NUE achieved at IPI on-farm experiments in various crops in Asia and Europe. (Published also at IFA, Fertilizers & agriculture 9/2007 issue; http://www.fertilizer.org/ifa/publicat/f&a/2007_09pt.asp).

Crop	Country	Analyzed parameter	N rates(1)	K rates	Yield increase(2)	Increase in NUE(3) (%)
			kg/ha			
Maize	India	grain	125	30-90	200-1,300	18 (6-29)
	China(4)	grain	150-300	75-180	200-1,800	18 (5-29)
	Ukraine	grain	30	30	720	15.5
Rice	Bangladesh	grain	100	33-66	690-900	26.3 (23-30)
Rape seed	China(5)	seeds	180	112.5-187.5	142-704	44 (35-53)
Sugar cane	India(6)	cane	240-340	85-200	2,200(7)	70
Sunflower	Hungary(8)	seeds	80	100-200	200-1,100	(10-30)
	India	seeds	60	30-90	400	18
Wheat	China(9)	grain	180-300	75-150	200-1,370	19 (2-26)
Winter rye	Belarus(10)	grain	90	60-120	230-610	(10-23)

(1) N rates in these experiments were kept constant
(2) Yield increase in response to potassium fertilization
(3) Average and range in brackets
(4) Average of 5 locations in Shandong and Hebei provinces
(5) Average of 2 locations in Hubei province
(6) Fertigation (drip) experiment
(7) Increase in yield was achieved also due to inclusion K through the fertigation system
(8) Average of 3 years
(9) Average of 3 locations in Shandong and Hebei provinces
(10) Conducted on 4 different K level soils (104-299 mg/kg available K)

Note: All experiments were conducted by IPI coordinators during the past 7 years.

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SOIL FERTILITY HISTORY, PRESENT STATUS AND FUTURE SCENARIO IN BANGLADESH

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Abstract

A review of soil fertility research and development activities in Bangladesh has been made since their initiation in 1905. Initial soil fertility studies were carried out mainly on rice, jute and winter vegetables to find out the doses of organic fertilizer materials most suitable for their optimum yield. The studies were strengthen when chemical fertilizers were introduced during fifties. The responses to nitrogen, phosphorus and potassium were noticeable when the cultivation of high yielding varieties of rice, wheat and other crops was started. Fertilizer recommendation on various crops was first made on the basis of soil tracts and later on 18 soil types under 20 physiographic units. The advanced information on soils of the country was generated by newly created Department of Soil Survey in early sixties. Up to 1984 six fertilizer recommendation guides were in use for helping the extension workers in suggesting fertilizer doses for different crops. After 1980, more advances on soil fertility studies were available and new guide entitled "1985 FERTILIZER RECOMMENDATION GUIDE FOR MOST BANGLADESH CROPS" was published. This guide introduced the concepts of soil testing and yield goals for making sound fertilizer recommendation. This guide was revised and updated in 1989, 1997 and 2005.The present guide just like the last two contains two parts: Part I dealing with cropping pattern based generalized fertilizer recommendation for moderate yield goals for the major AEZs and Part II dealing with the principles for making location specific fertilizer recommendations for crops for different yield goals on the basis of soil test values. Bangladesh has wide variety and complexity of soils, which are depleted and are in urgent need of replenishment with organic manure and fertilizers if projected crop production target is to be obtained. Promotion of balanced fertilization practices generated on different crops and cropping patterns at the various National Agricultural Research System (NARS) institutes are transferred through DAE, different NGOs/private companies directly involved in agricultural development activities. Proper soil fertility management emphasizing balanced fertilization in the country where food security is so crucial for poverty stricken people, where about 2 million people are added to the total population every year and where natural resources including agricultural land are shrinking day by day, must be promoted to increase production, to reduce poverty as well as to improve livelihood of the farmers. The field level officials of DAE, BADC, NGOs and private agrochemical companies should be trained properly so that they can carry the messages of modern soil fertility management practices to the doorsteps of the farmers who will increase crop productivity and maintain soil health at high fertility state for generations to come.

Introduction

Bangladesh is the largest deltaic floodplain in the world with a total area of 147570 km^2 of which 88892 km^2 is occupied by major rivers and estuaries. The great delta is flat throughout and stretches from near the foothills of the Himalayas Mountain in the north to a southern irregular deltaic coastline that faces the Bay of Bengal. The country is mostly surrounded by India except for a short (about 200 km) southeastern frontier with Burma. She lies between $20^0$34″ and 26^o38″ north latitude, and 88^o01″ and 92^o41″ longitude.

Bangladesh is one of the densely populated countries in the world with about 150 million people. The population density is around 974 people per km^2 with annual growth rate of 1.54 percent (BER 2005). Agriculture is the life force of her economy. The country has been a food deficit area for long time and has about 8.2 million hectares of cultivated land with average cropping intensity of about 185 per cent (BBS 2005). Soil is the most important natural resource. The majority of the country's soils are alluvial. Hill and terrace soils represent only 20 per cent of the country and 8-10 per cent of the cultivable land. Agro ecologically the country has been divided into thirty regions. The principal crops grown include rice, wheat, maize, jute, sugarcane, winter and summer vegetables, tropical fruits, oilseeds, pulses, tuber crops, tobacco and tea.

Soil fertility has been engaging the attention of soil scientists and agronomists of the country since late fifties. Till the introduction of fertilizer responsive high yielding varieties in sixties, it was mostly subsistence agriculture with very low yields without showing any stress on soil fertility. The data from agricultural research station before 1965 hardly showed any significant response to added P and K. Even with N, the responses were not significant. After the introduction of high yielding varieties and launching intensive cropping for maximum crop production per unit area and per unit time, rapid depletion of soil fertility has been observed almost all over the country. The most widely deficient nutrients in the soils are nitrogen, phosphorus, potassium and sulphur. Zinc deficiency is prevalent in calcareous soils and light textured soils where cropping intensity has been increased. Boron deficiency is also being observed in many areas and may be considered as one of the responses for causing sterility in wheat, sunflower, mustard and deformed fruits in papaya. Magnesium is being observed deficient in Old Himalayan Piedmont Plain soils and Acid Brown Hill soils.

The present paper is written with the objective of narrating a brief description on the soil fertility history, present status and future scenario in Bangladesh.

Soil Fertility History

Early Period (British India)

Soil fertility research in this part of the world now called Bangladesh was initiated as early as in 1905 when Agricultural Research Laboratories and Experimental Station (Monipuri Farm) were established at Tejgoan located in the central part of capital city Dhaka of East Bengal and Assam. Soil fertility study was conducted under the research division called Agricultural Chemistry.

Initial studies were mainly carried out to see the beneficial effects of cow dung and bone meal on aus and aman rice. Later on, effects of liming and green manuring were included as treatments. All the initial studies showed that cow dung, bone meal, liming and green mauring were beneficial in increasing the grain yield of rice.

With the passage of time the fertility trials were continued with different bulky and concentrated organic manures such as town compost, compost, farmyard manure, mustard oilcake and fish manure singly and in combination with bone meal, chemical fertilizers such as rock phosphate, kossiphos, ammonium sulphate, muriate of potash, etc.

The experiments conducted were simple in nature and gradually extended from Monipuri Farm to different multilocation sites of Comilla, Faridpur, Rajshahi, Barisal and other places. The trials were carried out beyond partition period of the subcontinent into India and Pakistan i.e. these were started during 1943-44 and continued up to 1953-54. The results of these experiments clearly showed that the application of organic manure and chemical fertilizers improved the fertility of soils and thereby increased the yields of rice. The yield increases were variable among the seasons as well as between years. Mustard oilcake and fishmeal proved superior to other organic manure. Among the chemical fertilizers the effect of ammonium sulphate was found distinct and prominent in increasing the yield rice.

Pakistan Period (East Pakistan)

Just after independence more emphasis was given on soil fertility research. Trials with ammonium sulphate, bone meal/super phosphate/thomasphosphate/hyperphosphate/cow dung/compost/water hyacinth compost and other chemical fertilizers or organic manure were continued on aus and aman rice as well as winter vegetables.

At the same time the farmers were made acquainted with chemical fertilizers and encouraged to use them along with cow dung for increasing yields of their crops. As a result, chemical fertilizer use in East Pakistan (now Bangladesh) began in1951 with the import of 2698 tons of ammonium sulphate. The use of urea and triple super phosphate (TSP) was introduced in 1957-58. The fertilizer consumption increased from 2698 tons in 1951-52 t0 68017 tons 1961-62. This trend of consumption increased steadily with time and reached peak value of about 4.45 million tons in 2007.

During the early sixties it was felt necessary to classify the country's soils and to generate information on their nutrient status. Accordingly, on the basis of their origin and properties, the soils of the country were broadly classified into seven tracts. A large number of soil samples were collected from different tracts, analyzed and presented in Table 1. On the basis of analytical data of a large number of soil samples, it was found that East Pakistan soils, on average, contained 0.10 percent nitrogen, 0.10 percent P_20_5, 1.03 percent K_20, 1.10 percent CaO and 4.42 percent organic material. These figures were proposed to take as the standard for the East Pakistan soils. On this basis of analysis, it was described that the soils of Madhupur tract were deficient in nitrogen, phosphorus, potash, calcium and organic matter, but deficient in nitrogen and phosphate and so on.

Table 1. Nutrient status of soil tracts of East Pakistan (Bangladesh).

Soil Tracts	N (%)	P_2O_5 (%)	K_2O (%)	CaO (%)	Loss on ignition (%)	pH
Madhupur	0.08	0.08	0.74	0.48	3.77	5.5-6.0
Barind	0.07	0.07	0.90	0.34	3.33	5.0-6.5
Gangatic	0.10	0.13	1.18	2.66	4.42	7.0-8.5
Teesta	0.10	0.11	0.96	0.25	4.15	6.0-6.5
Brahmaputra	0.12	0.02	1.05	0.62	4.61	5.5-6.8
Coastal	0.11	0.12	0.40	1.00	5.44	Saline
Tentative average	0.10	0.10	1.03	1.16	4.42	-

On the basis of nutrient status of soils and a large number of fertilizer trials conducted all over the country it was found necessary that different fertilizer combinations were required for different soil tracts. Accordingly, fertilizer recommendation for different crops were formulated and published for the first time under the caption FERTILIZER USE IN EAST PAKISTAN in January 1961. As an example, fertilizer dose for aus paddy is shown below:

Fertilizer Recommendation per acre for paddy crop for Brahmutra, Gangatic and Saline Tracts

Aus paddy	Maund	Seers
Ammonium sulphate or Urea	1 0	35 35
Bone meal or Triple Super Phosphate	1 0	35 35

1 maund = 37 kg 1kg=0.925 seer

Better results were obtained when 5 tons of cow dung or compost was applied per acre. In that case only 1 maund 10 seers of ammonium or 25 seers of urea was applied per acre.

Most of the cultivators did not have sufficient cow dung to meet the requirement of both aus and aman crop. Whatever cow dung the farmers could afford to apply on paddy crop, it was suggested to apply on aus crop. Because bulky organic manure like cow dung could help aus crop stand unfavorable drought conditions. Cow dung was applied at the time of general preparation of land. Ammonium sulphate or urea and bone meal or triple super phosphate was added applied broadcast at the time of final preparation of land.

The Department of Soil Survey after its creation carried out reconnaissance surveys during the years 1961-70 and classified the soils of the country into 18 general soil types under 20 soil units. It was felt necessary to make fertilizer recommendations for these general soil types, which could be more realistic than the recommendations made before. In the meantime a scheme entitled “ Rapid Soil Fertility Survey and Popularization of the Use of Fertilizer in East Pakistan” initiated in July 1957 with 50 experimental centers all over the country was modified and expanded under the name of East Pakistan Soil Fertility and Soil Testing Institute from November 1963 with 200 experimental centers.

Fertilizer trials were carried out with different combinations of NPK fertilizers on different crops in the farmers' fields all over the country.

The Second Fertilizer Recommendation Guide entitled "Soil Fertility Investigation in East Pakistan" was published in 1967 on the basis of the results of experiments carried out up to 1966 for different soil tracts of the country. With progress of soil survey made in the country, more information regarding soils became available and fertilizer recommendations were revised on the basis of results of experiments carried out up to 1969 for different soil parent material units. The recommendations were published in the book entitled "Studies on Fertilizer and Soils of East Pakistan".

Bangladesh period

Fertilizer recommendations in independent Bangladesh were made for different soil units on the basis of a large of experiments carried from July 1970 to June 1975 on various crops throughout the country. The recommendations were reported under chapter VI in the book "FERTILIZER TRIALS IN FARMERS' FIELD IN BANGLADESH" published in July 1976. The book was revised with more up to date information and published again in July 1981.

In the meantime Bangladesh Agricultural Research Council (BARC) constituted a subcommittee on fertilizer to review the situations of fertilizer recommendation practices for different crops. On the basis of studies undertaken, the subcommittee prepared the "Fertilizer Guide for Major Crops of Bangladesh" and it was published as BARC's first fertilizer recommendation guide in 1979. Soil unit was considered as the most important criterion for fertilizer recommendation. The main drawback of the guide was that most recommendation was made on assumption but not specific studies.

BARC coordinated soil test crop response correlation studies by BARI, BINA, DU, BAU, BJRI and SRDI during 1980-84 made a breakthrough in soil fertility research. This project generated most advanced research findings in the areas of soil analysis, plant nutrition and responses of crops to the application of fertilizers in greenhouse and experimental fields and also soil survey information. Based on this information the second fertilizer recommendation guide entitled "1985 FERTILIZER RECOMMENDATION GUIDE FOR MOST BANGLADESH CROPS" was published by BARC in 1985. This guide introduced the concepts of soil testing and yield goals for making sound fertilizer recommendation.

After 1985, many advances in the field of soil fertility and fertilizer management were made by the different agricultural research institutes during 1985 -89. At the same time a computerized data base on land type, soil type, hydrology and agro climatic parameters was developed and used in compiling the AEZ map of Bangladesh. By using all these information the fertilizer recommendation guide (FRG) of 1985 was revised and published in 1989.

The guide contained two parts: Part I dealt with cropping pattern based generalized fertilizer recommendation for moderate yield goals for the major AEZs and Part II dealt with the principles for making location specific fertilizer recommendations for crops for different yield goals where specific soil analytical data and their interpretations are available.

As time passed on more advances were made on soil fertility and fertilizer management research. It was felt necessary to revise the guide with new information and findings. Accordingly, the guide was revised and published in 1997. The major distinguishing features of this guide were that it recommended fertilizer application for four soil fertility levels for both high and moderate yield goals. All fertilizer nutrients were expressed as elemental forms. Just like 1989 guide, two approaches have been used:

- The first one is the development of location specific fertilizer for crops and cropping patterns based on soil test values and target yields
- The second one is the general fertilizer recommendation for moderate yield goals and land category based cropping patterns for different agro ecological zones where soil test values are not available.

The guide dealt with principles rather than blanket recommendations.

After publication of 1997 guide considerable progress has been made on soil fertility and fertilizer management research and extension by the NARS institutes and the extension department. All these information have been incorporated in the present Fertilizer Recommendation Guide 2005 published in November 2005. The FRG 2005 includes information on more crops, and cropping patterns, updated nutrient status of different agro ecological zones, nutrient balance status, soil and fertilizer management based on IPNS concept, fertilizer management in multiple cropping system, minimum tillage, hill farming and additional information on the quality control aspects of fertilizers.

The Fertilizer Recommendation Guide 2005 has been prepared mainly for the extension personnel in developing location specific fertilizer recommendation for different crops and cropping patterns. This guide just like 1997 one deals more with principles rather than blanket recommendation. The major features of this guide are as follows:

- Updated recommendation of fertilizers for different crops based on varieties and yield target
- Changing crops and cropping patterns
- Updated soil nutrient status of different AEZs
- Updated critical limits of nutrients
- Nutrient balance
- Liming of acid soils
- Socioeconomic impacts of balanced fertilization
- Increasing nutrient use efficiency with emphasis on deep placement of nitrogen
- Soil and fertilizer management based on IPNS concept

- Fertilizer management in multiple cropping systems
- Fertilizer management in crops under no/minimum tillage system
- Fertilizer management in problem soils (saline, peat, acid sulphate and char lands)
- Fertilizer management in hill farming
- Fertilizer management in risk environment
- Quality control of fertilizers
- Maintenance of organic matter in soils.

Present Soil Fertility Status

Although Bangladesh is a small country, it has wide variety and complexity of soils at short distances due to a diverse nature of physiography, parent materials, lands, hydrology and drainage conditions. This has been further complicated by human interferences. As a result continuous changes are taking place in the soil fertility status due to organic matter depletion, nutrient deficiency/toxicity, drainage impedance/water logging followed by degradation of soil physical and chemical properties and soil salinity/acidity. The fertility status of Bangladesh soils is extremely variable. Most of the soils are depleted and are in urgent need of replenishment with organic manure and fertilizers if projected crop production target is to be obtained.

Nitrogen

Nitrogen is generally considered as the key nutrient in Bangladesh agriculture because of its low supply in the soils. Most of the agricultural soils are critically deficient in this nutrient. The main reasons for such deficiency are due to:

- intense decomposition of organic matter
- rapid removal of mineralized products under high leaching conditions and
- crop removal.

Total nitrogen content of Bangladesh soils range from 0.032% in the Shallow Red-Brown Terrace Soils to 0.20% in Peat Soils. The approximate values of total nitrogen used to interpret soil test values are:

- Low: up to 0.090-0.181 %
- Medium: 0.181-0.270%
- Optimum: 0.271-0.360%

For upland crops in loamy to clayey soils. In light textured soils, somewhat lower values are used to interpret the soil test results for upland crops. For wetland rice, soil test values for nitrogen interpreted as low, medium and optimum are 0.090-0.180, 0.181-0.271 and 0.271-0.360%, respectively. The soil-testing laboratories of the NARS institutes use these critical levels for total nitrogen in soil. The critical nitrogen content in plant varies with crops, cultivars and growth stages.

Nitrogen being the most important nutrient element in soils plays the most vital role in crop production in Bangladesh. Except few leguminous crops, all other crops respond dramatically to applied nitrogen irrespective of soil types, growing seasons and cultivars used. Practically high yielding varieties of different crops such as wheat, maize, potato, sweet potato, cabbage, brinjal, tomato, cauliflower and banana are highly responsive and need ample supply of fertilizer nitrogen to express their yield potentials; while cotton, tobacco, mustard and sugarcane are substantially responsive. Pulses and other legumes are less responsive to applied nitrogen in Bangladesh soils. For some leguminous crops a starter nitrogen dose is considered essential for higher nodulation and production.

In Bangladesh, modern rice covers more than 70% of the total rice areas and about 80% produce of the total rice, the average production remains around 2.79 t/ha which is far less than the potential of the modern rice (5-7 t/ha). Rest of the area under rain fed agriculture using local rice cultivars produces on average 1.16 t/ha.

Responses of modern rice to applied nitrogen have been studied extensively throughout the country by a series of fertility trials. The average yield increase due to fertilizer N varies from 30 to 75%. In some cases, without applied N modern rice showed almost complete failure, while application of 100 kg N/ha along with other nutrients resulted in a very successful crop yielding 6-7 t/ha.

Phosphorus

Phosphorus is the second most important nutrient element limiting successful crop production. It becomes unavailable or fixed in the soils through a variety of ways. In acidic terrace and brown hill soils, phosphorus is largely fixed by iron and aluminum oxides at low pH, while in calcareous soils fixation occurs by calcium-magnesium carbonates. The net result of fixation is a decrease in the immediate availability of native and applied phosphorus.

In medium and heavy textured soils, the available P contents up to 7.50 μg g^{-1} soil is interpreted as low, 15.1-22.5 μg g^{-1} soil as medium and 22.51-30.0 μg g^{-1} soil as optimum for upland crops. In light textured soils, somewhat lower values are considered to interpret soil P as low, medium and high. For wetland rice, soil P contents of 6.0-12.0 μg g^{-1}soil are considered as low, 12.1-18.0 μg g^{-1} soil as medium and 18.0-24.0 μg g^{-1} soil as optimum. The critical level of P by the Olsen method, which is extensively used for rice, has been considered as 8.0 μg g^{-1}soil in Bangladesh so long.

Appreciable response of wetland rice to P fertilization is rarely observed in Bangladesh soils. On the other hand, P is considered as one of the major constraints to successful production of legumes and upland crops such as chickpea, groundnut, wheat, maize, cotton, mustard, brinjal, tomato, lady's finger etc. Significant role of phosphate application in sustaining and building up soil fertility for various upland crops is well recognized.

Potassium

Potassium is the third major plant nutrient recently identified as deficient in most Bangladesh soils. The previous idea about the sufficiency of potassium in Bangladesh soils might be true for local crop varieties with low yield potentials.

One-ton wheat/ha or 2-ton rice/ha can be obtained from soils where K would be a limiting factor continuously without K fertilizers. The crop intensification with high yielding and hybrid varieties has shown widespread deficiency of potassium in Bangladesh soils on potato, sweet potato and other root crops, sugarcane, fruit, onion, garlic, fibre crops and HYV cereals. It has been recorded that a 5 ton/ha rice crop will remove more than 110 kg K which is to be made available to plants in less than 3 months time and many of our old and highly weathered soils may not have potential to supply K at this rate.

Alluvial soils of Bangladesh are comparatively rich in potash bearing minerals than the terraces that are older and show evidences of extensive weathering of 2:1 type minerals and potash bearing minerals. These soils may not release K fast enough to match the crop requirements especially the modern varieties to sustain yields. Potassium may also be leached and deficiency of K may become a production constraint in light sandy soils of recent alluvium with high percolation rate (72 mm/day).

The critical levels of potassium for Bangladesh soils have been determined 0.09-0.18 meq/100g soil as low, 0.18-0.27 meq/100g as medium, 0.27-0.36 meq/100 g as optimum and above 0.36 meq/100 g high.

Sulphur

Sulphur has been recognized as the fourth major nutrient limiting crop production as early as 1980. In the past very little attention was paid to this nutrient until 1977 when sulphur deficiency in wetland rice was first detected at the Bangladesh Rice Research Institute (BRRI) farm and on nearby farmers' fields. Since then sulphur deficiency in Bangladesh soils is becoming widespread and acute. Variable amount of available S ranging from as low as 2 $\mu g\ g^{-1}$ soil to as high as 75 $\mu g\ g^{-1}$ soil has been reported.

The use of high analysis fertilizers such as urea, triple super phosphate, muriate of potash and diammonium phosphate, cultivation of modern varieties, increasing cropping intensities and limited application of organic manure have all contributed to the intensification of the S deficiency problem in the soils of Bangladesh. The problem is more severe in wetland rice than in upland crops as anaerobic condition, under which rice is grown, reduces sulphate and makes it unavailable to plants. Among the upland crops, oilseeds are most affected by S deficiency problems. Beneficial effects of sulphur fertilization have been observed on mungbean, black gram and chickpea. The critical level of sulphur for Bangladesh soils has been determined as 10 $\mu g\ g^{-1}$ soil.

Calcium and Magnesium

The pH values of Bangladesh soils generally range between 5.8 and 7.0 with exception observed in acid hill soils and calcareous soils. Thus, most of our soils have adequate Ca and Mg saturation on the exchange surface. Recent investigations have reflected that acid hill soils and Old Himalayan piedmont soils are extremely low in exchangeable Ca and Mg. The critical levels for these two nutrients are as 2.00 and 0.5 meq100g $^{-1}$. Magnesium deficiency problems have been observed on potato, cotton, sugarcane and tea grown on these soils and added Mg has brought about an appreciable increase in yields. Although Ca is also inadequate in these soils, applications of TSP and gypsum to supply P and S satisfactorily meet the Ca demand of crops, thus correcting the Ca deficiency properly.

Zinc

The importance of zinc in crop nutrition has received considerable attention during eighties in Bangladesh. The incidence of zinc deficiency is widespread in most calcareous and alkaline soils. The problem is more acute in wetland rice culture.

The critical levels of available soil zinc content as established by different extracting procedures are:

Extractant	Critical limit
Dithizone + NH_4OAC	Light soils: 1.0 ppm Heavy and Calcareous Soil: 2.0 ppm
DTPA	0.8 ppm
EDTA + $(NH_4)_2Cl_3$	1.5-1.8 ppm
0.05 N HCL	1.0 ppm

The critical level of Zn in rice plant tissue is generally considered as 20 ppm.

Yield responses of rice to zinc fertilization have been well documented in different soils of Bangladesh where zinc contents were below the critical level. Bangladesh Rice Research Institute (1986) identified zinc deficiency as the greatest yield limiting factor for rice after N at Rajshahi (with pH 7-8 and less than 1.0 ppm available Zn) and recorded remarkably higher grain yield with added Zn.

Both native and applied Zn remains distributed into a number of chemical forms, the relative abundance of which varies in different soils depending on their physio-chemical properties. Zinc in soil may be divided into five chemical forms such as (i) water soluble, (ii) easily exchangeable, (iii) organically complex, (iv) occluded by oxides, carbonates or phosphates and (v) held by primary minerals. A satisfactory residual effect of applied zinc on subsequent crop is generally expected. There are some reports indicating that zinc applied at recommended rate to wetland rice may provide the subsequent upland crop with adequate zinc nourishment. Zinc sulphate is the main source of zinc used in Bangladesh agriculture.

Boron

Although taken up in tiny quantities, boron deficiency may lead to serious consequences regarding economic yield of various crops. Boron deficiency in Bangladesh was first observed in reverine soils of Teesta on wheat causing sterility in grains (Islam 2006). Light textured soils of the country are deficient in available boron where significant leaching loss of borate ions might have depleted soil boron level. The available boron content of the major soils of Bangladesh varies between 0.1 and 1.9 ppm. But most of the light textured soils of Rangpur, Dinajpur and terrace soils of Gazipur and hill soils of Srimangal contain low level of available B (0.1-0.3 ppm). The critical level of available soil boron used to interpret the soil test result is 0.2 ppm. However, 0.45-1.00 ppm is considered to be optimum for upland crops. Studies showed that sterility problems in wheat, chickpea and mustard grown on sandy soils of Rangpur were significantly improved by the application of boron. The wheat yield after boron treatment was increased by more than 50% and was contributed by increased number of grain per spike. Thus, it was reported that boron deficiency might be a causative factor for sterility problems. Yields of vegetables like cauliflower, cabbage, broccoli and tomato were found to increase (14-52%) due to B fertilization.

Other Micronutrients

Other micronutrients like Fe, Mns, Cu, Mo and Cl have attracted less attention in Bangladesh agriculture. Generally they are seldom needed to be applied in crop production in most soils. However, recently Cu and Mn application in Calcareous Soils have appeared to be beneficial for higher yield in some field trials. Recent studies have also indicated that Mo deficiency is widespread in cabbage and legumes like groundnut acid soils. Appreciable yield increases of these crops in presence of added molybdenum have also been recorded. Deficiency of Cl has been detected in coconut and betel nut plants. But proper potassium fertilization with muriate of potash prevents the occurrence of Cl deficiency problems in most cases. Iron is the only micronutrient present in available form abundantly Bangladesh soils.

Management of Problem Soils

Bangladesh has salt affected soils, acid sulphate soils and few other problem soils. Salt affected soils in the country occupy a quite significant portion of total cultivable land. Year round monitoring soil and water salinity levels of some representative sites have been completed. Research may be carried out to in future to develop appropriate soil and crop management practices for best possible utilization of this vast tract of land.

Fertilizer Recommendation

Fertilizer recommendation for single crops and cropping patterns are usually made by following the guidelines clearly stated in “The National Fertilizer Recommendation Guide” which is revised and published from time to time by the Bangladesh Agricultural Research Council in consultation with NARS scientists engaged in soil fertility and fertilizer management research activities.

Upazila Soil Use Guide published and updated by SRDI from time to time is also a useful guide for site-specific fertilizer recommendation. Each guide has at least 100-150 site-specific information on soils nutrient status, topography, hydrology, vegetation and drought.

Fertilizer recommendations are usually made on the basis of soil fertility classes; yield goals and farmers’ management ability. For high yield goal fertilizer recommendation, one should have site-specific information on nutrient status of soils as well as the crops. If the site-specific information on the soils is not available, moderate yield target may be fixed and the information available about agro ecological region in the guide may be used to find out the fertilizer doses.

Research on site-specific N management using leaf color chart in Bangladesh is in progress at the Bangladesh Rice Research Institute.

Balanced Fertilization

Balanced fertilization is the key to successful crop production and maintenance of good soil health. It is important to see how close nutrient addition and removal by crops match with each other.

According to current statistics, the farmers of Bangladesh use 215 kg nutrients (N: 149 kg, P_2O_5: 37 kg, K_2O: 22 kg and S + Zn + B + others: 7) ha/year from chemical fertilizers, while the estimated removal is around 280 -350 kg/ha. From organic and natural sources about 50-70 kg nutrients are added to the soil system every year. One nutrient balance study made by DAE-SFFP (2002) from a typical Boro- Fallow – T. Aman cropping pattern (10 t grain yield) is shown below:

	N (kg/ha)	P (kg/ha)	K (kg/ha)
Nutrient uptake cropping pattern	180	27	180
Leaching losses from: Soil Fertilizer	12 17		6
Erosion	12	2	12
Gaseous losses: Organic N fertilizer	24 68		
TOTAL OUTPUT	313	29	198
Fertilizer	170	25	75
Organic manure (5t/ha)	20	12	24
Incorporated crop residue	25	3	25
Nonsymbiotic fixation	10		
Atmospheric deposition	8	1	2
Sedimentation/weathering		2	10
Irrigation water	2	6	21
TOTAL INPUT	235	49	157
BALANCE	-78	20	-41

It is quite evident from the study that severe mining of N and K are going on in the country's soil system. That's why the productivity of the soils is low and decline in crop yields has been recorded in many areas.

In view of the continuous nutrient depleting situations, the adoption of IPNS, which is a modern system of nutrient management, can only provide ideal nutrition for a single crop/crops grown in a pattern. The major objectives of IPNS may be conceptualized as follows:

- To build up an optimum combination of nutrient resources based on soil test values for nutrient supply for their efficient utilization
- T avoid over-exploitation of nutrient resources
- To maintain long-term soil fertility and to prevent soil degradation

Keeping all the above objectives in view, research and demonstration on all possible combinations of chemical fertilizers, organic manures, biofertilizers and green manuring are being carried out by NARS institutes, GO/ NGOs and other agricultural development organizations under different agro ecological zones using various crops and cropping patterns.

Extension Activities for Promoting Balanced Fertilization

Extension activities on balanced fertilization have been undertaken by various research institutes, GO/NGOs and development partners through out the country. Technologies generated on balanced fertilization practices for different crops and cropping patterns at the various National agricultural Research System (NARS) institutes and also at the agricultural and general universities are transferred to the end users through various mechanisms. One of the main mechanisms is the Department of Agricultural Extension, which directly takes the technology to the farmers' fields for demonstration. Besides DAE, different NGOs directly involved in agricultural development activities also take the fertilizer use technology to the doorsteps of the farmers.

The different NARS institutes arrange training programs for extension and NGO personnel through which they are trained about the beneficial aspects of the technology. For example, BRRI arranges training program on rice production technology in which various aspects of soil fertility management are covered. BARI organizes similar programs on various mandated crops such as wheat, pulses, oilseeds, tuber and root crops, different summer and winter vegetables, fruits, spices and condiments, and also on farming systems where fertilizer use technology is the key issues. BARI OFRD conducts research on various crops and cropping patterns as well as on farming system right in the farmers' fields and homesteads. BINA, BSRI, BJRI, BTRI and SRDI also organize training programs for the extension officers and NGO personnel for transfer of soil related technology.

BARC's Technology Transfer and Monitoring Unit (TTMU) also serve as a vehicle in between research institutes and agricultural development agencies. TTMU also helps transfer of promising NARS institutes' technology to the farmers' fields through different projects funded by the government as well as donors and development partners.

International Fertilizer Development Center has been playing a significant role in developing and disseminating fertilizer use technology in the country since long.

Other important donor projects such IFAD SAIP, ADB NW Crop Diversification and FAO/UNDP project on food security in DAE are also making significant contribution to agricultural development in the country.

NARS Institutes' activities

Different research organizations have been working to find out the balanced and appropriate fertilizer use technologies both at their research stations and also in the farmers' fields on their mandated crops and crop based patterns on the basis of soil test values. The residual values of the applied nutrients are taken into consideration for the succeeding crops in the patterns for adjusting the fertilizer doses for the whole pattern. BARI deals with all crops except rice, jute, sugarcane and tea. Rice is the mandated crop for BRRI, sugarcane for BSRI and tea for BTRI. BINA has no specific mandate, but can work for rice, jute, pulses, oilseeds and vegetables.

The universities can work for any crops. All the above research institutes develop balanced nutrient use technologies for moderate and high yield goals both on single as well as cropping patterns at their research stations located to their main campus and regional/substations across the country.
BARI OFRD verifies generated nutrient use technologies at the different Farming System Research and Development sites as well as in the farmers' fields under various agro ecological regions in the country. BRRI Rice Farming Research Division also verifies the balanced fertilizer use technologies both on rice and rice-based cropping patterns at their Farming System Research and Development site as well as in the farmers' fields.

Every year BARI On Farm Research Division (OFRD) carries out a large number of on-farm soils fertility and fertilizer management trials throughout the country under different agro ecological zones. The trials are generally grouped under three categories:

- Cropping pattern based fertilizer management
- Crop response to added nutrients
- Verification of fertilizer management practices.

The cropping pattern based fertilizer management trials include promising and dominant patterns with legume crop in between two cereal crops; vegetable based pattern with jute as one of the crops; and multiplication verification trial on nutrient management packages. Some of the important cropping patterns which were under trial during 2005-06 and 2006-07 are as follows:

- Mustard - Boro - T. Aman
- Mungbean - T. Aus - T. Aman
- Maize – Mungbean - T. Aman
- Wheat – Mungbean – T. Aman
- Cauliflower- Stem Amaranth – Jute
- Potato – Jute – T. Aman
- Potato – T. Aus – T. Aman
- Potato – Boro – T. Aman

Under crop response to added nutrients a large number of field trials on various crops grown in different patterns and environments were carried out. The verification trials on fertilizer management practices conducted include also a large number of trials to find out the effects of different nutrients on the growth and yield of different crops such as potato, cabbage, cauliflower, tomato, summer onion, maize, chili, mungbean and banana. Some useful on-going programs worth mentioning are as follows:

- Effect of boron on mustard, wheat and papaya
- Effect of phosphorus and molybdenum on chickpea

- Effect of different composts on okra and papaya
- Screening of green manuring crops for better adjustment and contribution to cropping pattern under organic farming.

The responses of different legumes such as mungbean, lentil and garden pea to newly developed biofertilizers were also evaluated in the farmers' field.

A review of the apparent nutrient balance for most of the cropping patterns has shown that severe mining of nitrogen and potassium is going on. In some patterns phosphorus mining is also noted. Some examples have been given below to show the extent of nutrient depletion.

Table 2. Apparent nutrient balances in some dominant cropping patterns of Bangladesh (OFRD 2006-07).

Mustard-Boro-T. Aman

Treatments	Nutrient uptake (kg/ha)			Nutrient added (inorg. +org.) (kg/ha)			Apparent nutrient balance (kg/ha)		
	N	P	K	N	P	K	N	P	K
T_1	235	40	231	207	48	179	-152	8	-52
T_2	282	48	279	288	66	212	-167	17	-32
T_3	266	46	264	288	65	247	-151	19	-17
T_4	243	42	218	245	35	95	-115	2	-123
T_5	218	37	214	210	38	51	-106	18	-164

Wheat-Jute-T. Aman

Treatments	Nutrient uptake (kg/ha)			Nutrient added (inorg.+org.) (kg/ha)			Apparent nutrient balance (kg/ha)		
	N	P	K	N	P	K	N	P	K
T_1	208	39	274	78	42	85	-130	4	-189
T_2	227	43	297	105	57	133	-122	14	-164
T_3	242	45	318	105	57	133	-137	12	-185
T_4	152	40	282	80	33	61	-72	-7	-221
T_5	211	39	278	90	52	95	-121	13	-183

Wheat-Mungbean-T. Aman

Treatments	Nutrient uptake (kg/ha)			Nutrient added (inorg.+org.) (kg/ha)			Apparent nutrient balance (kg/ha)		
	N	P	K	N	P	K	N	P	K
T_1	304	57	217	153	38	64	-251	-19	-153
T_2	333	63	239	214	52	88	-258	-11	- 151
T_3	310	58	222	214	52	88	-235	-6	-134
T_4	302	57	215	180	36	65	-239	-21	-150
T_5	289	54	210	181	47	60	-226	-7	-150

IFDC activities

The International Fertilizer Development Center (IFDC) has been playing a significant role in developing and disseminating nutrient use technologies in the country since long. IFDC in cooperation with BRRI and BARI developed USG technology, which is promising and can ensure N use efficiency and at that same time can reduce 30-40% doses of N as recommended by National Fertilizer Recommendation Guide.

Through the Adapting Nutrient Management Technologies (ANMAT) project supported by the International Fund for Agricultural Development (IFAD), IFDC undertook a pilot program in cooperation with partners in NGOs for farmer participatory evaluation, adaptation and adoption of deep placement of fertilizer briquettes as an alternative fertilization practice for farmers in Bangladesh.

Current statistics show that at the moment at least 3000 urea briquette machines were in operation to produce about 0.15 million ton urea super granules of 1-3 g size, which could cover an area of 1000000 ha. The government allocated more than 0.15 million ton urea to those companies that were engaged in producing super granules.

USG application for rice: Application of urea super granules is made in the center of four hills at alternate two rows at a depth of 6-8 cm with two 1g granules for T Aman and T Aus rice and with three 1g granules or one 3g mega granule for Boro rice. This application is equivalent to 113 kg USG for T Aman and T Aus, and 170 kg USG for Boro rice. The best soils suitable for USG technology are clay, silty clay and clay loam.

USG application for upland crops: The application of USG on cabbage, cauliflower and brinjal has been experimented by BARI OFRD in farmers' fields at the Farming Systems Research and Development site, Palima and Sadar Upazila of Tangail district during 1999-00 and 2001-02.

The experimental results have shown that the highest yield of cabbage, cauliflower and brinjal have been obtained from recommended USG-N which are less than10-20% prilled urea-N.

IPI activities

IPI-BRRI activities

Since 2003, IPI has started activities on balanced fertilizer use in rice based cropping systems in Bangladesh in cooperation with BRRI. Under the IPI funding, BRRI has been conducting both on-station and on-farm trials to find out the response of rice to K fertilization. During 2004-05 as many as 9 trials were carried out in the farmers' fields in the Northwestern and central region of Bangladesh on rice-rice and rice-wheat cropping patterns. In research trial K fertilization increased the T. Aman rice grain up to 30% and wheat grain up to 53% over K control. On the other hand, in farmers' field demonstration soil test based (STB) applied K increased grain yield of wheat by 86% and T. Aman rice by 25% over K control plot. Response of rice and wheat to applied K fertilizer was more prominent in farmer's field demonstration than that of research trial in experimental farm. The trials are showing distinct and prominent responses to K additions indicating K is a limiting factor for higher yields in these areas.

IPI-BFA activities

The Bangladesh Fertilizer Association (BFA) is another partner of IPI training programs for fertilizer dealers. One fertilizer dealers training program was organized by IPI-BRRI-BFA on 12 December 2005 in Dhaka and another at Tangail on 17 September 2006 on the Importance of Balance Fertilization for Crop Production.

DAE activities

The Department of Agricultural Extension (DAE) is the largest extension organization that has the network up to grassroots' level generally known as block. Each block is headed by a Sub-Assistant Agricultural Officer (former Block Supervisor) who takes the message of balanced fertilization and disseminate among the farmers through various means.

Fertilizer Types and Grades

The farmers of Bangladesh use mainly single or straight fertilizers as sources of their nutrients. Urea, TSP, DAP, SSP and MOP are the widely used straight fertilizers. Among them, urea shares about 66%, TSP 11%, SSP 4.3%, DAP 4.3% and MOP 9% of the total fertilizer use. Gypsum, ammonium sulphate, zinc sulphate, boric acid, magnesium sulphate and potassium sulphate account for the rest.

The government of Bangladesh has recommended 6 crop specific grades of mixed or blended fertilizers for balanced application of nutrient elements in the crop fields. These grades are:

1. NPKS (8-20-14-5) for HYV Rice
2. NPKS (10-24-17-6) for HYV Rice
3. NPKS (10-15-10-4) for Sugarcane
4. NPKS (14-22-15-6) for Sugarcane
5. NPKS (12-16-22-6.5) for Wheat and other Rabi crops
6. NPKS (12-15-20-6) for Wheat and other Rabi crops

Among the six grades, different companies produce only rice grades. At present as many as10 companies are producing NPKS mixed fertilizers.

Domestic Production of Fertilizers

In Bangladesh urea, TSP and SSP are produced in the local industries, which can partly meet the total demand of the country. About 60000 phosphogypsum is produced as a byproduct from TSP factory. At present there are six urea and one TSP fertilizer factories in the country. Bangladesh Chemical Industries Corporation (BCIC) is responsible for operation of all fertilizer factories in the country. All these fertilizer factories have the capacity to produce 2321000 tons of urea, 12000 tons of ammonium sulphate, 65000 tons of TSP and 120000 tons of SSP. Additional requirements of urea are met up from import. Additional requirements of TSP and gypsum are also imported. All MOP and DAP are imported.

There are more than 50 small zinc sulphate manufacturing factories in the country. These factories can produce 10/12 thousand tons granular monohydrate and crystalline heptahydrate zinc sulphate. Some companies produce small amounts of boric acids also.

Use of Organic Manure

Organic fertilizers including cow dung, poultry manure, compost, crop residues, and green manure were traditionally and preferentially used in the country until 1950 when the chemical fertilizers were introduced through a project entitled "Rapid Soil Testing and Popularization of Chemical Fertilizers".
As a result, the use of chemical fertilizers increased dramatically and steadily. The increases were more significant and pronounced when high yielding varieties of rice and wheat were introduced.
Because of recent energy crisis, the cost of chemical fertilizers in the international market has gone up and organic fertilizers have once again been gaining popularity. Environmental pollution due to use of chemical fertilizers has also become an international issue. Proper processing of organic wastes and residues for use in agriculture appears to be promising and this can reduce the environmental pollution to a great extent.

Organic fertilizers, which are now being used in the country, can be broadly classified under four major categories:

- i) Bulky organic fertilizer
- ii) Green manure
- iii) Concentrated organic fertilizer
- iv) Nutrient enriched organic fertilizer

Use of Biofertilizers

Use of biofertilzers in Bangladesh agriculture could not yet make any significant contribution. BARI and BINA have been experimenting with different crop specific biofertilizers since 1980. Their contribution to yield increases range from 5-15% where the native population of the microbes is low. The introduction and expansion of soybean in Noakhali and Lakhsmipur was made by MCC that supplied the inoculums from a laboratory established at Majdecourt, Noakhali.

In addition to Rhizobia, there are free-living microorganisms like Azotobacter, Clostridium, and Azospirilum in or on soils that can fix atmospheric nitrogen. There is also a group of organisms known as blue -green algae that fix atmospheric nitrogen. N fixed by these organisms play a significant role in meeting the nitrogen requirement of our crop plants.

The use of phosphate solubilizing bacteria (PSB) and arbuscular mycorrhizal (AM) fungi as a technology for field application is still at the experimental stage.

Use of Plant Growth Regulators (PGR)

The farmers of Bangladesh could not harvest additional yield advantage of crops due to use of plant growth regulators, although the role of growth regulators in various physiological and biochemical processes is well known. However, the farmers are now convinced and have started using growth regulators for increasing yields of various crops.

At present, more than 60 countries have been using growth regulators/stimulants to increase yields of different crops. Growth regulators are used in small amounts that are enough to stimulate the growth. The yield increases range from 10 to 30% or even more. Different agrochemical companies are now marketing as many as 25 growth regulators in the country.

Methods of Fertilizer Application

The farmers of Bangladesh usually apply fertilizers through broadcasting for most field crops and banding for some plantation and row crops. The most common practice is to apply all fertilizers including organic manure at the time of final preparation of land for rain fed crops. For irrigated crops, nitrogen fertilizer is applied in two to three installments depending on the life cycle of crop**.**

Soil Health Maintenance

Bangladesh having an ever-increasing population and limited cultivable land is forced to maximize crop yields per unit area through intensive use of land and soil resources. As a result, continuous mining of nutrients from the soil system is going on. The farmers of Bangladesh are poor and illiterate, and have tended to only exploit the soils rather than maintain them in a healthy fertile state.

Soil organic matter is alarmingly low in all soil types of the country (Appendix 3). It is generally around 1% in most and around 2% in few soils that is not conducive to the soils in productive state.

Table 9 shows the nutrient uptake of different field and horticultural crops. It indicates that nutrient removal is much higher than addition. Although the use of chemical fertilizer is increasing per ha/year, but still due to intensification of cropping the removal is much higher indicating continuous pressure being put on soil resources. According to current statistics, the nutrient use /ha/year was 192 kg, while the removal was more than 240 kg. The negative pressure must be minimized so that the supply and uptake of nutrients are in balanced. It is strongly suggested that the Integrated Plant Nutrition System (IPNS) should be followed for nutrient management. This system provides ideal nutrition for a crop through a proper combination of various nutrient sources and their optimum utilization along with maintenance of soil productivity. The major objectives of IPNS are as follows:

1. To provide an ideal nutrition system for various soil-plant situations
2. To build up an optimum combination of nutrient resources for nutrient supply for its efficient utilization
3. To avoid over exploitation of nutrient resources
4. To maintain long-term soil fertility and to prevent soil degradation.

The other measures that should be taken to maintain soil health include appropriate crop rotations every alternate year in such away that rice should be at least one crop in each rotation. It is desirable to have one-grain pulse in between two cereal crops. Where time permits, green-manuring crops such as sesbania, cowpea etc may be grown for up to 50 or more days to harvest maximum biomass for soil health improvement.

Liming

Although Bangladesh is a small country, she has great diversity of soils. Except Calcareous Floodplain and coastal saline soils, all other soils are slightly to strongly acidic. Strongly acid soils are not productive soils. Very strongly acidic soils have been identified from acid sulphate and brown hill areas. Red soils of Madhupur and Old Himalayan Piedmont plain soils in northwestern part of Bangladesh have also been rated as strongly acidic.

Because of the increasing cropping intensity and fertilizer use in the above soils during the last two decades, the acidity has gone up unexpectedly. From every harvest, the crops take up lots of calcium and magnesium. As a result, acidity in these soils is increasing day by day. For every 100 kg use of urea, 74 kg calcium carbonate is needed to reduce the acidity. During monsoon time there is some surface runoff of acidity from the soil.

Liming has many favorable functions in the soils. It increases nitrogen and phosphorus availability, makes potassium more efficient, furnishes calcium and magnesium for plant nutrition, encourages activity of beneficial bacteria and reduces the harmful effects of aluminum. Liming also improves the physical conditions of the soils by decreasing its bulk density, increasing its infiltration capacity and increasing its rate of percolation.

Standardization of Fertilizers and Plant Growth Regulators

The government makes standardization of fertilizers and fertilizer materials through a gazette entitled “The Fertilizer Control Order” which is revised and published from time to time. The last gazette was published in February o6, 1999 as Fertilizer (Management) Law. There are two committees- one National Standardization Committee headed by Secretary, Ministry of Agriculture and another Technical Sub-Committee (Fertilizer) convened by Member-Director (NRM), BARC. The Technical Sub-Committee (Fertilizer) looks after any new fertilizer and fertilizer material including feasibility, field experiment by NARS institutes and quality control by government approved five laboratories at BSTI, BARI, BINA, DU and SRDI. The National Standardization Committee after getting recommendation from the Technical Sub-Committee approves the material for manufacture/import and use in Bangladesh agriculture. The government’s approval appears in gazette notification published by the Deputy Director, Bangladesh Forms and Publication Office, Dhaka. The National Standardization Committee has so far standardized more than 80 fertilizers and fertilizer materials including plant growth regulators.

Soil Testing Services

Soil testing services in Bangladesh is weak and not satisfactory up to the standard, as one could have expected after installing all modern equipments and instruments at all the laboratories. Soil Resource Development Institute (SRDI) and the soil laboratories at the NARS institutes provide soil-testing services to the farmers at limited scale, although SRDI’s 15 regional laboratories located at different parts of the country are designed to analyze at least 75000 samples of the farmers.

The Department of Agricultural Extension with a view to providing soil-testing services to the farmers has procured 460 soils testing kits and distributed among 428 upazilas, 20 nurseries and 12 Agricultural Training Institutes (ATI). After initial runs with the supplied chemicals all the kits now become nonfunctional for want of consumable chemicals and operational funds.

Arsenic Contamination

Arsenic is one of the most abundant elements in earth's crust and occurs in Bangladesh as geological deposits in alluvial sediments at shallower depths. Arsenic poising in drinking water containing more than 0.05 mg Asl^{-1} in shallow tube wells in 59 districts out of 64 districts have been identified. To meet the growing demand for food, the farmers of Bangladesh are forced to cultivate high yielding varieties of Boro rice that require a large volume of irrigation water. Irrigation with arsenic contaminated ground water increases its concentration in soil and eventually arsenic enters the food chain through crop uptake and poses long-term risk to human health.

Transfer of Fertilizer Use Technology

The fertilizer use technology generated on different crops and cropping patterns at the various NARS institutes are transferred though various mechanisms. One of the main clients is the Department of Agricultural Extension, which directly take the technology to the farmers' fields for demonstration. Upazila Agricultural Officers with the help of Sub-Assistant Agricultural Officers (former Block Supervisors) play a key role to transfer the technology. Besides DAE, different NGOs directly involved in agricultural development activities also take the fertilizer use technology to the doorsteps of the farmers.

Soil Fertility Future Scenario

Bangladesh has no alternative but to maximize crop yields per unit area through intensive use of land and soil resources. Future soil research and development should be directed towards maximizing crop yields per unit area in intensive cropping systems as well as making the achieved yield levels sustainable through fighting intelligently against soil deterioration.

Soil organic matter level is alarmingly low in all soil types of the country. It is generally around 1% in most and around 2% in few soils. So research should be carried out on organic matter build up through green manuring/organic manuring and assessment of their contribution to soil fertility and crop production in different agro-ecological zones (AEZs) of the country.

The poor efficiency of applied N in wetland rice culture as well as in upland crops has been always a problem in world's agriculture. Bangladesh should continue her efforts to search effective and usable means of improving N use efficiency.

Soil test crop response correlation studies should be strengthened and carried out following local procedure of soil test, greenhouse studies and field trials to generate reliable information for fertilizer recommendations.

Continuous trials with various cropping patterns are essential for evaluating long term fertilization effects on soil and yields. For sustained high yields without depleting soil nutrients it is recommended to not only consider soil values and yield, but also to evaluate nutrient input and uptake/removal balances including fertilizers, manures and biological sources.

Maximum strength yield (MY) and maximum economic yield (MEY) research should be strengthened under the leadership of soil scientists with a view to optimizing requirements of multiple crop growth factors in a multidisciplinary system to attain the maximum yields possible and maximum economic yields for the agro-ecological situations of the experimental results.

Bangladesh has salt affected soils, acid-sulphate soils, acidic soils and few other soil problems. Salt affected soils in the country occupy a quite significant portion of the total cultivable land. Research should be carried out in future to develop appropriate soil and crops management practices for best possible utilization of these land resources.

In hilly areas of Bangladesh, topographic farmers and faulty cultivation practices have been encouraging soil erosion at unusually high rates. Erosion of top fertile soils is leaving behind unproductive eroded land. The future soil research in the erosion prone areas should cover estimation of annual soil loss, and development of suitable soil and water conservation practices.

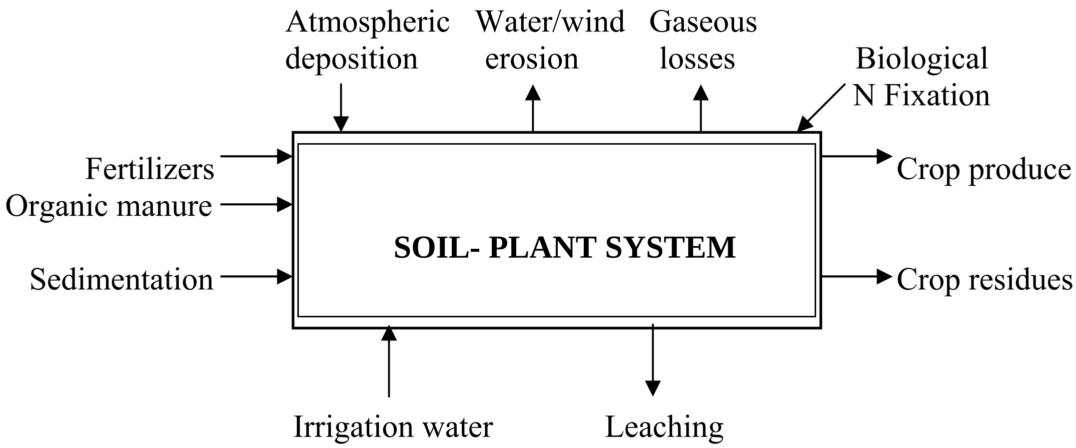
In Bangladesh, no research in the past was directed towards degradation and pollution of soil environment through various ways and means. In future, soil research should be undertaken in these new areas with the main objectives of assessing degree and kind of soil degradation and pollution and identifying probable factors.

City wastes represent a potential storehouse for an immense quantity of energy and nutrients. Research may be undertaken to develop technologies for producing compost using suitable compost activator, which will help to maintain the soil health and sustain agricultural production.

Biological nitrogen fixation is another important research area where soil microbiologists of the country have been devoting their utmost efforts. Future research and development in this area should be strengthen.

Conclusions and Recommendations

Proper soil fertility management emphasizing balanced fertilization is one of the most important cultivation techniques that ensure optimum supply of nutrients for successful crop production and maintenance of soil health. The supply of nutrients to the soil – plant system comes from various sources, the most important sources being the organic manure and chemical fertilizers.



At present more than 4.3 million tons of chemical fertilizers pricing to more than US $ 5538 millions are being used along with 70 million tons of organic manure. The use efficiency of the chemical fertilizers are low and unsatisfactory because of imbalanced or under use/sometimes over use resulting in huge wastage which the country cannot afford. Therefore, the practice of balanced fertilization should receive top priority to sustain/increase crop productivity when food security is so crucial for poverty stricken people, when the country is facing challenges of increasing population and shrinking natural resources including agricultural land and also when there exists big gap between research and farmer's yield.

The field level DAE & Bangladesh Agricultural Development Corporation (BADC) officials, NGO personnel involved in agricultural development and officials of different private agricultural input supplying companies should be trained properly about the modern methods of soil fertility management. These officials will in turn train the farmers who will adapt balanced fertilization practice in their farms for increasing crop productivity to reduce poverty as well as to improve livelihood and at the same time maintaining soil health at high fertility state for generations to come.

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DEVELOPMENT OF FERTILIZER RECOMMENDATIONS IN BANGLADESH

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Introduction

There has been a continuous rise in the use of inorganic fertilizers, 3.8 million tons in 2005, compared with 1.8 million tons in 1989 and 3.0 million tons in 1997 (year of publishing previous Fertilizer Recommendation Guide). During the last decade, there has been a sharp change in practice of cropping sequences and in seed-crop husbandry. Fertilizer use efficiency at farm level is still very low. This necessitates updating the current practices for fertilizer use for different crops grown in the varied range of environments.

Plant nutrition and soil fertility are, of course, key factors in production capacity if wise decisions are made for their management. Accurately speaking, current information is indispensable in making correct management decisions. After 1997, considerable progress has been made on soil fertility research by different national research institutes in the country. All these data have been collected and incorporated in the revised fertilizer recommendation guide 2005.

Genesis of fertilizer recommendation in Bangladesh

Early period (organic to organic + inorganic)

Farmers in early days, before the introduction of inorganic fertilizers relied on organic manures to replenish the soil fertility of their lands. Soil fertility studies were initiated as early as 1911 to provide information on what type of organic manures should be used for rice. The beneficial effects of cow dung and bone meal on Aus and Aman rice were investigated until 1923. With the passage of time, the fertility trials were continued with different bulky and concentrated organic manures such as town compost, compost, FYM, mustard oilcake and fish meal singly and in combination with chemical fertilizers such as rock phosphate, ‘kossiphos’, ‘niciphos’, diammophos, ammonium sulphate, murate of potash. The trials were started during 1943-44 and continued up to 1953-54.

Pakistan period

During the Pakistan period, the following developments in soil fertility management took place:

- Trials with organic manures and chemical fertilizers were continued on rice as well as winter vegetables.

- Farmers acquainted with chemical fertilizers and encouraged to use them along with organic manures.
- Chemical fertilizer use in East Pakistan (now Bangladesh) began in 1951 with the import of 2,698 tons of ammonium sulphate.
- The use of urea and TSP was introduced in 1957-58.
- Murate of potash (MP) was added to fertilizer schedule from 1960.
- Until 1960 it was the era to popularize inorganic fertilizer materials.
- During early sixties country's soils were broadly classified into seven tracts and their nutrient status was analyzed.
- On the basis of the nutrient status and fertilizer trials conducted it was found necessary that different fertilizer combinations were required for different soil tracts.
- Fertilizer Recommendations for different crops and different soil tracts were formulated and published in January 1961 under the caption "FERTILIZER USE IN EAST PAKISTAN".
- The Department of Soil Survey after its creation carried out reconnaissance surveys during the years 1961-70 and classified the soils of the country into 17 general soil types.
- Fertilizer recommendations for these general soil types were published in 1967 entitled "Soil Fertility Investigation in East Pakistan", the seemed Fertilizer Recommendation Guide.
- The Guide is again revised in 1969 entitled "Studies on Fertilizer and Soils of East Pakistan".

Bangladesh period

- Fertilizer Recommendations for different soil types were made in 1976.
- FAO/UNDP Fertilizer Demonstration and Distribution Project, during its first phase (1975-80), conducted on-farm trials and demonstrations mainly on local/local improved varieties of crops on *single crop basis.*
- The Bangladesh Agricultural Research Council (BARC) had published the First Fertilizer Recommendation Guide (FRG) "Fertilizer Guide for Major Crops of Bangladesh" in 1979. Findings of the soil fertility trials under field conditions were incorporated in that guide.
- Trials and demonstrations continued during 1980-83 with the assistance of UNDP to develop and verify soil and location specific fertilizer recommendations for HYV of different crops but still continued with approach of *single crop based fertilizer recommendation.*
- Later on, data generated by different organizations in the areas of soil analysis, plant nutrition, crop response to fertilizer application and soil survey were taken into account while publishing the Second Fertilizer Recommendation Guide "1985 Fertilizer Recommendation Guide for most Bangladesh Crops" in 1985. This Guide had provided fundamental principles for fertilizer recommendation on the basis of soil test and crop response.

- The efforts continued during 1983-86 with change in approach from *single crop based fertilizer recommendation to cropping systems based soil fertility and fertilizer management.* After 1985, a good progress in the soil fertility and fertilizer management research has been made in our country. During the period, a computerized data base on land type, soil and hydrology and agro climatic parameters has been developed and subsequently used in preparing the AEZ map of Bangladesh. Information on soil fertility and land type-wise major cropping patterns along with crop management practices in different agro-ecological zones are compiled. Fertilizer Recommendation Guide of 1985 was updated and published in 1989. The FRG-1989 had two parts: Part 1 dealt with the principles for making soil analysis based location specific fertilizer recommendation of single crop and Part 2 dealt with cropping pattern based fertilizer recommendation for moderate yield goals for AEZs.
- Under the financial assistance from DANIDA, the Integrated Soil Fertility and Fertilizer Management Project (SFFP) started its activities as a follow up to previous the FAO supported Fertilizer project.
- With the advancement of time and research progress, the FRG-1989 was further revised and updated in 1997. The guide of 1989 with incorporation of SFFP contribution was published in 1997. Main features of the FRG-1997 were: (i) interpretation of the soil test values based on critical limits for different nutrients was updated and classified into six categories, and (ii) recommended fertilizer doses for phosphorus and potassium were shown as P instead of P_2O_5 and K instead of K_2O for uniformity and simplicity. It recommends fertilizer application for four soil fertility levels for both high and moderate yield goals.
- The present *Fertilizer Recommendation Guide-2005* is a revised and updated version of the FRG-1997.

Major features of Fertilizer Recommendation Guide 2005

The following major factors were considered for fertilizer recommendations:

• Diversity of agro ecological regions	• Soil nutrient levels
• Major cropping patterns	• Crop response to added nutrient and management
• Land type	• Calcareous/non calcareous/red soils
• Soil texture	• Rainfed/irrigated condition
• Soil pH	• Rationale of fertilizer application
• Soil organic matter status	• Resource base of farmers and yield goals

Updated	New inclusion
• Updated recommendation of fertilizers for different crops based on varieties and yield target	• Nutrient balance
• Changing crops and cropping patterns	• Liming of acid soils
• Soil nutrient status of different AEZs	• Increasing nutrient use efficiency with an emphasis on deep placement of nitrogen
• Critical limit of nutrients	• Soil and fertilizer management based on IPNS concept
• Rationale of fertilizer application	• Fertilizer management in multiple cropping systems
	• Fertilizer management in crops under no/minimum tillage system
	• Fertilizer management in problem soils (saline, peat, acid sulphate and charlands)
	• Fertilizer management in hill farming
	• Fertilizer management in risk environment
	• Quality control of fertilizers
	• Maintenance of organic matter in soils

Updated rationale of fertilizer application

Fertilizers behave differently in the soil-plant system. Some fertilizers, namely those containing P, S and Zn, have considerable residual effect and only a fraction of the total applied amount is recovered by a single crop. In such cases, application of fertilizer in full dose to each crop is not economical. In view of this, as well as major variations in soil characteristics, the rationales for the application of potassium, sulphur and zinc have been updated as follows:

i) Availability of potassium is high in soil with high content of K-bearing minerals. Generally, K supplying ability of light textured, terrace and piedmont soils is low. Again, the K requirement of crops, particularly rice, tuber crops, jute, sugarcane, many fruits, vegetables and spices is high. On the other hand, crop residues are not being recycled in the field. Consequently, most intensive cropped areas show a large K mining (130-165 kg K/ha/yr), which is about 80% of total nutrient mining (175-215 kg of N+P+K+S/ha/yr). The following principles/rationales need to be followed in making potassium recommendation in crops and cropping patterns.

- Response of crops to added K fertilizer is not clear in many cases, potassium application should be considered as maintenance dose even at optimum level of soil K.
- Potassium application can be reduced by 30-40% in the subsequent crops after potato, maize, tobacco, sugarcane, vegetables and spices when high doses of K fertilizer are used.
- The K dose may be reduced by 20-40% in subsequent crops if 2-4 tons of crop residues/rice straw per hectare is properly recycled into soils.
- Since release of K is high in Kharif season due to high temperature, potassium application may be reduced by about 10-15% of recommended dose.

ii) Sulpher availability is high under upland culture and low under wetland rice culture. The element has substantial residual effect. Crops grown under wetland condition should receive full dose of S. Upland crops (except oil seeds, maize, vegetables and spices) following wet conditions (Kharif-II season) may receive 50% of the recommended S dose. For oil seeds, maize, vegetables and spices crops, the full dose of S application is recommended.

iii) Zinc availability is low in calcareous and wetland rice soils. Zinc should be applied to both Rabi and Kharif crops when grown in calcareous soils (AEZs 10, 11, 12 and 13). For two or three rice-rice cropping patterns, full amount of Zn needs to be applied to the 1st crop and 50% rate to the 2nd or 3rd crop. In non-rice-rice cropping pattern (except maize, potato, vegetables and spices), Zn should be supplied to rice crop only. Zn needs to be added to a full rate for growing maize, potato, vegetables and spices.

New inclusion

Nutrient balance

Nutrient balance is the sum of nutrients inputs minus the sum of nutrients outputs; the balance may be positive or negative. To achieve sustainability, the quantity of nutrients inputs and outputs could be equal. Nutrient mining may eventually cause soil degradation and affect crop production. On the other hand, excess nutrient accumulation may lead to soil and water pollution.

In calculating nutrient balance, fertilizer, manure, BNF, deposition (rain), sedimentation (flood) and irrigation water can be regarded as nutrients inputs, and the crop produce, crop residues, leaching, gaseous losses (leaching and denitrification) and soil erosion as nutrients outputs (Fig. 1). The most vital routes for nutrients inputs are fertilizer and manure, and that for nutrients outputs are crop produce and crop residues. Hence, these major inputs and outputs can be considered for calculating nutrient balance to understand partial or apparent nutrient balance. Nutrient balance values vary with locations, cropping systems and nutrient management practices.

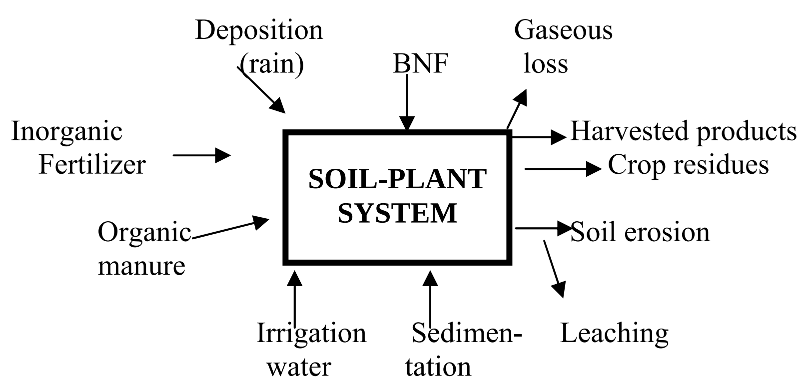

Fig. 1. Nutrient input-output system.

With passage of time, nutrient balance is becoming more negative (Fig. 2). Again, land use with higher cropping intensity may show higher negative balances (Fig. 3).

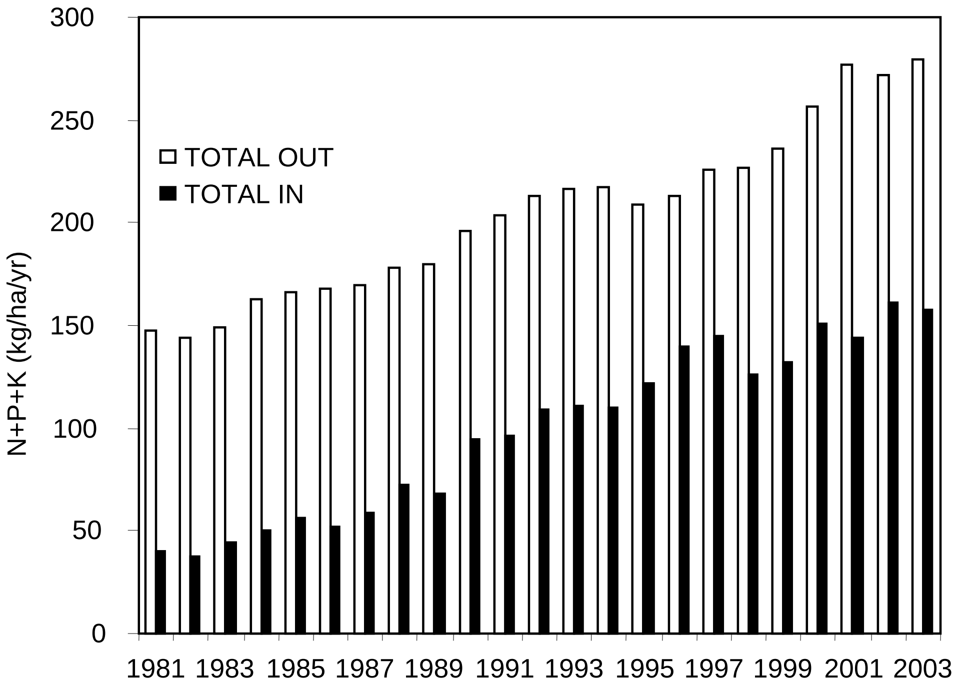

Fig. 2. Total N + P + K input and output (kg/ha) in Bangladesh.

On the other hand, the addition of organic manure may help reduce negative balances; the magnitude depends on the types and amounts of manure. Any reduction of removal of crop residues would have positive influence on nutrient balance and this is especially important for K. Nutrient balance appears to be less negative in Barind areas (AEZs 25, 26 and 27) in comparison with the Brahmaputra, Ganges and Meghna Floodplains (e.g. AEZs 9, 11, 12, 13 and 17) (Fig. 4 and 5). Incorporation of grain legume residues (e.g mungbean) can reduce nutrient depletion to a considerable extent. Thus, grain legume based patterns (e.g. mustard-mungbean-T. Aman rice, wheat-mungbean-T. Aman rice, lentil-mungbean-T. Aman rice, etc.) are suggested at farm level.

Although the nutrient balance value tells us little about available nutrient status of soils, it has important implications when considering the future long-term total status of nutrients in soils. To minimize nutrient depletion, it is not justified to just increase the use of inorganic fertilizers, rather the organic sources of plant nutrients, especially cow dung, poultry manure, solid waste, etc., need to be considered.

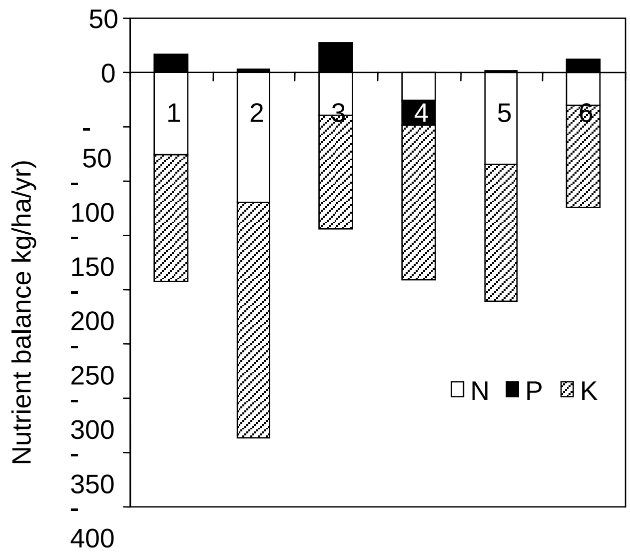

Fig. 3. Nutrient balance in different cropping patterns:
1 = Boro-Fallow-T. Aman, 2 = Boro-T. Aus-T. Aman,
3 = Boro -GM-T. Aman, 4 = Mustard-Boro-T. Aman,
5 = Wheat-T. Aus-T. Aman, 6 = Wheat-Mungbean-T. Aman

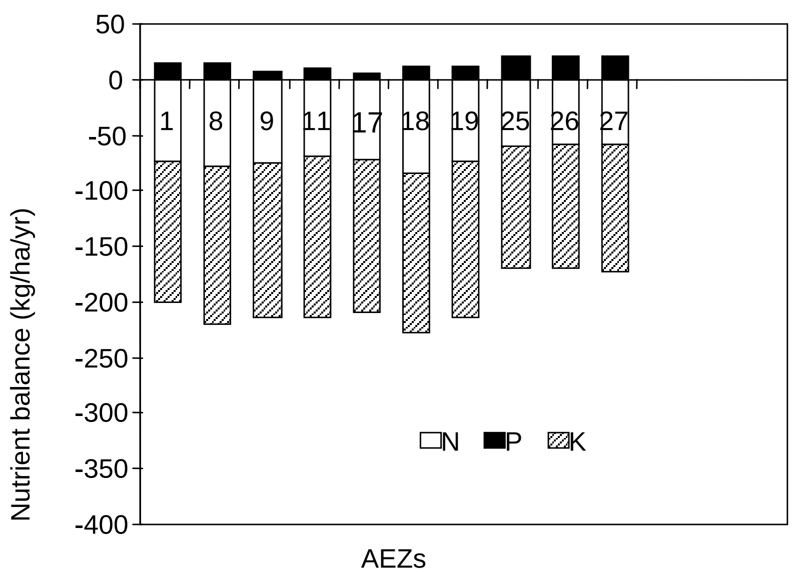

Fig. 4. Nutrient balance in Boro-Fallow-T. Aman pattern of different AEZs.

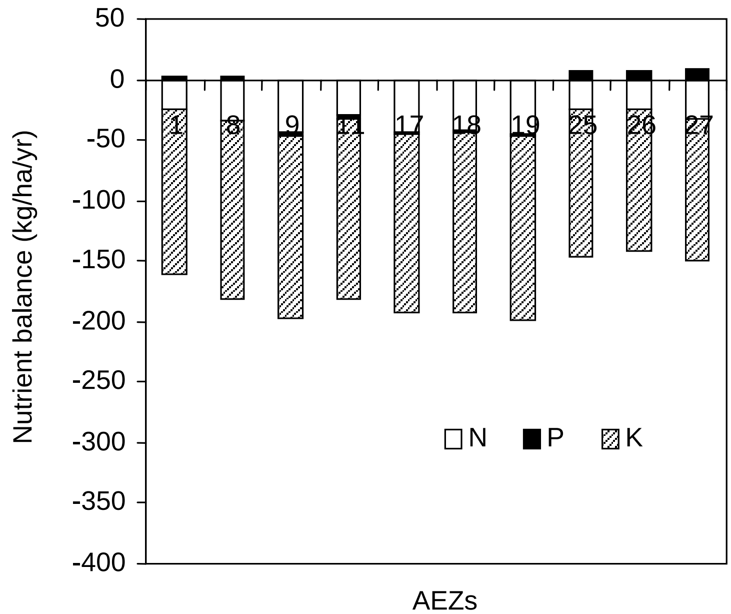

Fig. 5. Nutrient balance in wheat-fallow-T. Aman pattern of different AEZs.

Deep placement of N fertilizers

Uptake of deep-placed N can be elongated by placing it at lower depths and away from the plant. Fertilizer recovery in the wetland rice plant tops is found significantly higher for deep placed as USG/UMG than for split-applied urea. About 40% nitrogen can be saved by using USG or UMG in rice and 20% in vegetable and fruit crops (viz. cabbage, cauliflower, tomato, potato and papaya).

The amount of USG or UMG should be adjusted to the recommended dose of N for different crops and soils. The granules (USG/UMG) need to be placed after 5-7 days of transplanting of rice at 8-10 cm soil depth at the centre of every four hills between rows 1 and 2, between rows 3 and 4, and so on. Recommended numbers of USG ball for each vegetable plant should be applied at 6-10 cm apart from base of plant and into 6-8 cm deep as ring method at 10-15 days after transplanting.

The main benefit of USG/UMG placement is that N losses through NH_3 volatilization, nitrification, denitrification and runoff are significantly minimized. Deep-placed N as USG/UMG is less subject to algal immobilization and uptake by aquatic weeds than broadcast and/or incorporated urea. These two factors contribute to the improved nitrogen use efficiency of USG/UMG in the wetland rice.

Soil and fertilizer management based on IPNS concept

IPNS Concept

The basic concept of Integrated Plant Nutrition System (IPNS) is ‘the management of all available plant nutrient sources, organic and inorganic, to provide optimum and sustainable crop production conditions within the prevailing farming system'.

Therefore, in IPNS, an appropriate combination of mineral fertilizers, organic manures, crop residues, compost, N-fixing crops and bio-fertilizers is used according to the local ecological conditions, land use systems and the individual farmer's social and economical conditions.

Before establishing the need for mineral fertilizers, it should be estimated what is available and what is the plan nutrient value of organic manure, FYM, crop residues, compost and other organic materials. Only then we should try to complement the shortfall in required plant nutrients with inorganic fertilizers.

Elements of IPNS

The following elements of IPNS can be considered:

Natural resources: Soil supply, water supply (irrigation), deposition by rain or dust and natural BNF.

Organic nutrient sources:

- Crop residues are important for recycling of a good percentage of nutrients taken up by the plant, which are gradually returned to the soil. Besides, it will also apply organic matter to the soil.
- Green manure increases the working capital of nutrients by nutrient mobilization (by taking up nutrients from the soil and making them available to the following crop through decomposition, N-fixation or by saving nutrients from leaching). Organic material will be added to the soil as incorporation of green manure.
- Nitrogen fixation by bacteria and other microorganisms through biofertilizers is an important source for non-inorganic nitrogen supply to the cropping system.
- Preservation and application of organic manures (e.g. bio-slurry, cow dung, poultry manure, FYM) or compost (e.g. water hyacinth). Important criteria of organic manures are the dry matter content, total and quick-acting nitrogen, C/N ratio, etc.
- Organic wastes can also be considered for supplying plant nutrients and/or organic matter, e.g. press mud from sugarcane, oilcakes, 'night soil' or (treated) sewage sludge, etc. Proper care should be taken in terms of hygiene and crop and soil quality (polluting agents).

Mineral resources: Inorganic fertilizers.

The Research Institutes and BAU investigated and found IPNS as the most suitable, efficient and environmentally and socially acceptable methods of Integrated Nutrient Management. From the field trials conducted by OFRD (BARI), it appeared that the average total grain yield of wheat-rice sequence was 3.4 t/ha/yr without any added fertilizers or manures (Fig. 6), and the yield increased to 7.9 t/ha/yr when nutrients were added from both inorganic and organic sources following IPNS approach.

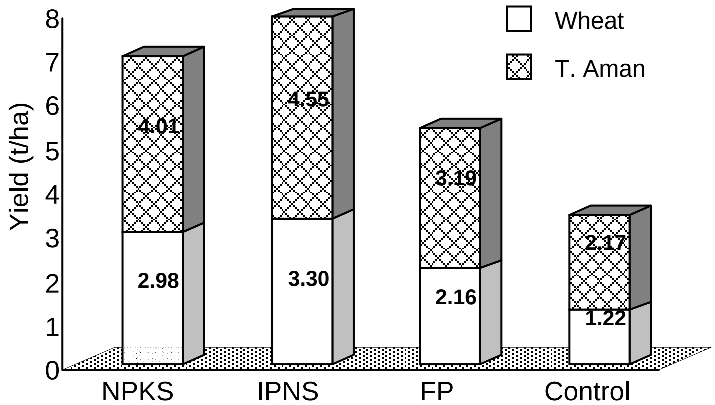

Fig. 6. Yield of wheat and rice grown in wheat-rice sequence as influenced by different nutrient management packages.

Computation of IPNS

Under farmers' condition, the following approach in relation to IPNS is suggested. First, an assessment should be made of the possible plant nutrient and organic matter sources available within the farming system. Then it should be established what the approximate plant nutrient contribution of these sources is (nutrient content, nutrient release). Some assessment of the soil fertility status in the field can be made, using the information available with the farmer from his own field plus possible soil sample for additional information. It can be helpful to have an idea about the soil nutrient supply capacity by knowing the natural or biological yield of a certain crop (yield without fertilization).

Together with the farmer a realistic yield target should be set, taking into account his resources, possible risks, etc. Then the question remains how best to complement the shortfall between targeted plant nutrient demand by the crop and the approximate organic plant nutrient supply, with inorganic fertilizer. Finally, the correct doses of different types of fertilizers (organic + inorganic) should be properly applied at the correct time and place to optimize fertilizer use efficiency.

In other words: How best to manage the plant nutrient sources in the prevailing farming system to reach the intended yield goal taking into account the farmers resources.

Computations:

First, establish the total need of plant nutrients from the AEZ table or from your own calculation.

Second, estimate how much is supplied from other sources like FYM, cow dung, poultry manure, brown/green manure, legumes, crop residues, etc.

An average figure for the nutrient (N, P, K, S, etc.) values (kg/ha) of different organic materials of per 1,000 kg material is available in an appendix of the FRG 2005.

Finally, you subtract the values of organic source from the total need and you will get the actual need for mineral/external fertilizer in terms of plant nutrients.

Therefore, you can calculate the amount of fertilizer material (urea, DAP, TSP, SSP, MOP, gypsum, zinc sulphate, etc.) in kg/ha. You will make the same calculations for all three seasons.

Areas for further improvement

More research is needed on nutrient management in risk-prone ecosystems, in multiple cropping systems, no-tillage/minimum tillage systems and in hill farming. Ecosystem based more information on mineralization and nutrient release pattern of organic materials need to be generated for standardization of organic fertilizers. Further research is needed on fertilizer management for traditional fruits and their quality.

Conclusion

Soil and fertilizer management is very complex and dynamic in nature. With the advancement of research and development of technology there would be continuous need for updating fertilizer recommendation.

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ROLE OF MICRONUTRIENTS IN BALANCED FERTILIZATION FOR SUSTAINABLE CROP PRODUCTION IN BANGLADESH

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Introduction

Plants contain more than 90 elements, but only 16 elements are recognized as essential for higher plants, nine of them being known as macronutrients (C, H, O, N, P, K, Ca, Mg and S) and seven as micronutrients (Fe, Mn, Zn, Cu, B, Mo and Cl). Macronutrients are normally present in plant tissues at concentrations of more than 0.1% and micronutrients at less than 100 $\mu g\ g^{-1}$ (dry weight basis). Micronutrients are also called minor nutrients or trace elements. Although micronutrients are required by plants in small quantities, they are equally important as macronutrients for the normal growth and development of plants. Thus, for sustainable crop yields, balanced fertilization with all the nutrients that are deficient in soils should be taken into account. This is essential in view of continuous mining of soil nutrients over decades without adequate replenishment.

Until 1980, the farmers of Bangladesh used to supply three nutrients (N, P and K) to the soil and, thereafter, application of S and Zn particularly for rice cultivation was found necessary. In 90's, B deficiency of crops is reported. There is sporadic information for Cu, Mo and Mn deficiencies of crops (Bhuiyan *et al*. 1998; Khanam *et al.* 2000; Ferdoush *et al*. 2003). Deficiencies of Fe and Cl are not yet reported in the country. Depletion of soil organic matter, unbalanced use of fertilizers, minimum use of manure, increasing cropping intensity, use of modern varieties, nutrient leaching and light textured soils have favoured the emergence of micronutrient deficiency in soils of Bangladesh.

Zinc in the balanced fertilization

Zinc deficiency is the most widespread micronutrient deficiency in the world (Fageria *et al*. 2002). Welch (1993) states that high proportion of cereal-based foods with low levels of Zn in the diet can be a major factor for widespread occurrence of zinc deficiency in human. In Bangladesh, zinc fertilization is a common practice in crop production and it is particularly important for crops grown in calcareous soils and also for rice grown in wetland soils (Akhter *et al*. 1990; Jahiruddin *et al*. 1994; Islam *et al*. 1996; Alam *et al*. 2000). Several institutes in Bangladesh, especially BAU, BINA and BARI in 1980s and onwards have conducted a good number of field trials with micronutrients.

The works are mostly concentrated on the two micronutrients, zinc and boron since these two elements are found deficient in soils. Main objectives of these experiments are to see the crop response to micronutrients and to find out the dose of micronutrients application for different crops and cropping patterns in the country.

Zinc requirement for maize-mungbean-rice pattern

The experiment was conducted at the Regional Agricultural Research Station (RARS), Jessore (AEZ 11) for three years during 2002-06. The soil was calcareous with 8.1 pH, 1.44% organic matter and 0.58 $\mu g\ g^{-1}$ Zn contents. Zinc application was made at 0, 2 and 4 kg ha^{-1} for maize (cv. Pacific 984, Thai hybrid) and at 0, 1 and 2 kg ha^{-1} for rice (cv. BRRI dhan33), with no Zn application for mungbean (cv. BARI mung 5). Every plot received a blanket dose of N, P, K, S and B.

All the crops responded significantly to Zn application. The grain yield of maize due to application of 4 kg Zn ha^{-1} was significantly higher than that obtained with 2 kg Zn ha^{-1}, as observed in the first year, but in the subsequent years the two yields were identical (Table 1). Similar results were also obtained with stover yield. There was a residual effect of Zn on the second crop (mungbean). Again, for the third crop (T. Aman rice), reduction of Zn dose by 1 kg ha^{-1} was possible when mungbean residue was added to the soil. Thus, the optimum rate of Zn for the maize-mungbean-rice cropping system was found to be 4-0-2 kg ha^{-1} for the first year and 2-0-2 kg ha^{-1} for subsequent years particularly when mungbean residue was removed, and such rates for mungbean residue incorporation being 4-0-1 and 2-0-1 kg ha^{-1}, respectively.

Table 1.Effects of Zn on the grain and stover yields of maize in maize-mungbean–rice cropping pattern.

Zn rate (kg ha^{-1})	Grain yield (t ha^{-1})			Stover yield (t ha^{-1})		
	2003-04	2004-05	2005-06	2003-04	2004-05	2005-06
Zn_0	8.31c (0.36*)	7.07b (0.25)	6.83b (0.39)	7.79c (0.47)	7.21b (0.27)	6.86b (0.57)
Zn_2	10.47b (0.41)	9.64a (0.20)	10.15a (0.53)	10.18b (0.62)	9.88a (0.46)	9.52a (0.64)
Zn_4	10.84a (0.38)	10.19a (0.29)	10.83a (0.32)	10.73a (0.46)	10.02a (0.47)	10.12a (0.49)

***Values in parenthesis indicate standard deviation.**

Note (for all tables): Mean values followed by same letter are not significantly different as per DMRT at $P<0.05$.

Zinc uptake and balance

Total Zn uptake (grain + stover/straw) by three crops (maize, mungbean and rice) per year varied from 0.43 to 1.31 kg ha^{-1} against the addition of 0–6 kg Zn ha^{-1} yr^{-1} (Fig. 1). Obviously, the Zn uptake was higher with higher rate of Zn addition. An amount of 0.43-0.45 kg Zn ha^{-1} was removed through 1-crop cycle from the Zn control plots. When Zn was supplied at 1 kg ha^{-1} over 1-crop cycle, the Zn uptake was 0.51–0.53 kg ha^{-1}. Similarly, at 2, 3, 4, 5 and 6 kg ha^{-1} Zn addition in a year, the Zn removal by the three

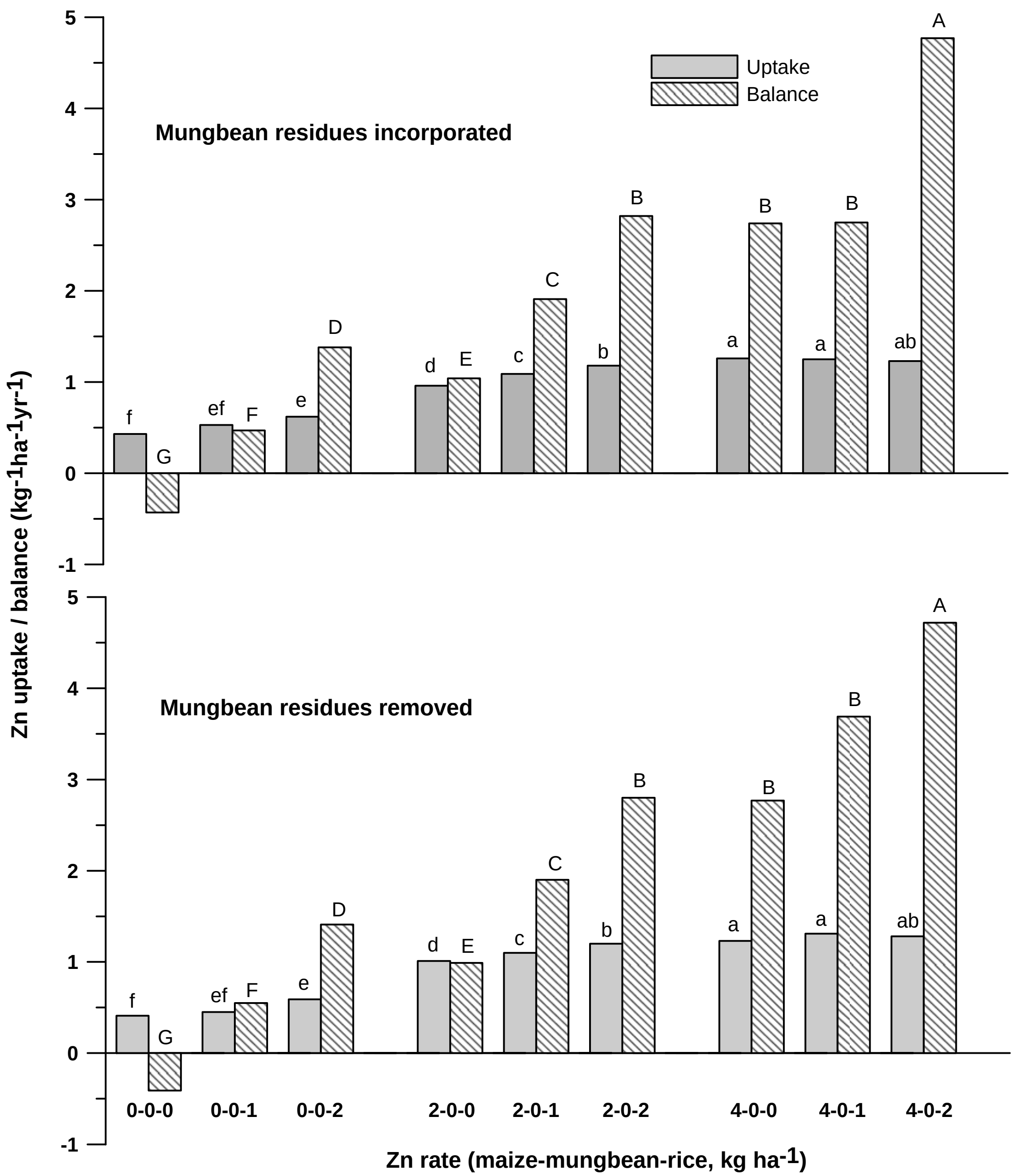

Fig. 1. Uptake and apparent balance of zinc for the maize-mungbean-rice cropping pattern.

Note: Bars denoted by same letter (lowercase letter for uptake and uppercase for balance) are not significantly different.

crops was 0.59-0.96, 1.09-1.10, 1.20–1.26, 1.25–1.31 and 1.23–1.28 kg ha^{-1}, respectively. The apparent balance for Zn (difference between Zn addition through fertilizer and Zn removal by crops) was positive

(0.47-4.77 kg ha^{-1} yr^{-1}), except two cases where Zn was not added at all throughout the cropping sequence. However, a significant portion of the unused Zn had been fixed by the calcareous soil as evidenced by the soil analysis result that the plant available Zn content of soil had increased to 0.72 mg kg^{-1} as maximum from initial level of 0.58 mg kg^{-1}, and the level had come down to 0.55 mg kg^{-1} when Zn was not at all added, over three years.

Zinc efficiency of maize varieties

The experiment was performed over three years in the same farm land (RARS, Jessore) to screen out maize varieties for Zn efficiency. Except BARI hybrid maize 3 and BARI maize 6, all other varieties showed significant response to Zn application. The Zn efficiency of different maize varieties was calculated as the ratio of grain yields due to Zn control and Zn addition, multiplied by 100 (Peleg *et al*. 2007). This is also called tolerance index (%). The varieties exhibited a wide variation in Zn efficiency, 72-95% (Fig. 2). Varieties BARI hybrid maize 3 and BARI maize 6 showed above 90% Zn efficiency.

According to Zn efficiency ratio (%), the varieties followed the order: BARI hybrid maize 3 > BARI maize 6 > Khoibhutta > Mohor > Barnali > BARI hybrid maize 1 > BARI hybrid maize top 1 > Pacific 984. Three varieties such as Pacific 984, BARI hybrid maize 1 and BARI hybrid maize top 1 had Zn efficiency below 80%.

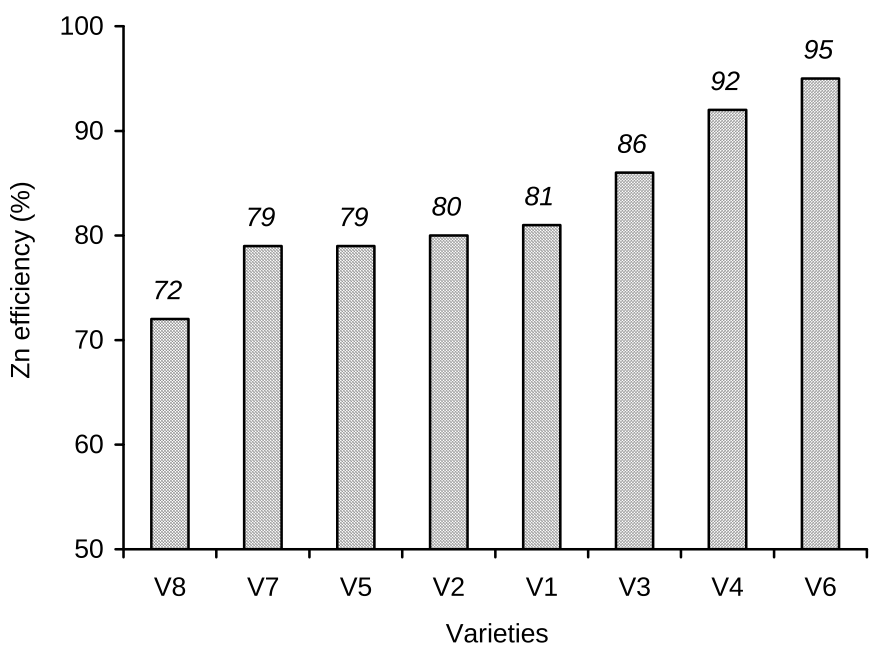

Fig. 2. Zinc efficiency of different varieties of maize, mean of 3 years (V1 -Mohor, V2-Barnali, V3 -Khoibhutta, V4-BARI maize 6, V5 -BARI maize hybrid maize 1, V6 -BARI hybrid maize 3, V7 -BARI hybrid maize top 1,V8 -Pacific 984).

Considering yield potential of different varieties under Zn treatment, Thai hybrid Pacific 984 recorded the highest yield (10.46 t ha^{-1}, mean of 3 years) followed by Bangladeshi hybrid BARI hybrid maize 3 (9.03 t ha^{-1}), and composite variety Khoibhutta yielded the lowest (5.57 t ha^{-1}). Of the eight varieties tested, BARI hybrid maize 3 and BARI maize 6 were found Zn in-responsive (Zn efficient) and the others Zn responsive (Zn-inefficient). Farmers can grow Zn efficient varieties without Zn application to soil.

Zinc fortification of wheat seed

Biofortification of food crops with Zn by either breeding for higher uptake efficiency or by fertilization can be an effective strategy to address widespread dietary deficiencies in human populations (Graham *et al*. 2001). Plants emerged from seeds with low concentrations of Zn could be highly sensitive to biotic and abiotic stresses (Obata *et al*. 1999). Zinc enriched seeds can perform better with respect to seed germination, seedling health, crop growth and finally yield advantage (Cakmak *et al*. 1996).

Three Zn application methods viz. seed priming, soil application and foliar spray were tested on 10 wheat genotypes (2 varieties and 8 advanced lines) at BAU Farm, Mymensingh (AEZ 9) having 0.7 µg g^{-1} soil Zn content. Evaluation was made in terms of yield and Zn loading of seed. Every plot was given a recommended dose of N, P, K, S and B. The highest grain yield was obtained from seed priming of Zn which was identical with soil application of Zn. Foliar application of Zn did not produce higher grain yield over control (Table 2). Zn concentration of wheat grain was in the range of 25.46-to 41.71 µg g^{-1}. The highest grain Zn content was observed with seed priming Zn treatment, which, however, was not significantly different from soil Zn treatment. Zn control had the lowest grain Zn concentration. The yield as well as Zn concentration also varied considerably with wheat genotypes.

Table 2. Effects of different methods of Zn application on yield and Zn concentration of wheat.

Zn treatments	Yield (kg ha^{-1})		Zn concentration (µg g^{-1})	
	Grain	Straw	Grain	Straw
Control	2,725b	4,883b	25.96b	9.48b
Soil application	2,992a	5,579a	36.72ab	14.30a
Foliar application	2,804b	4,942b	30.86b	13.63a
Seed priming	3,054a	5,463a	41.71a	14.50a
SE (±)	24.41	71.24	0.952	0.436

Boron in the balanced fertilization

Next to zinc, boron deficiency is widespread in Bangladesh. The most B deficient areas are Dinajpur, Rangpur, Bogra, Sirajganj, Comilla and Sylhet. This element deficiency is common in Rabi crops such as mustard, wheat and chickpea (Jahiruddin *et al*. 1995; Islam *et al*. 1997; Haque *et al*. 2000). Boron influences more reproductive development rather than vegetative. It causes grain sterility. Brassica crops are more sensitive to boron deficiency. On the other hand, its slight excess application may cause toxic effect on crops. Again, crop species and varieties may differ in their sensitivity to boron deficiency (Rerkasem and Jamjod 1997; Kataki *et al.* 2001; Ahmed *et al*. 2007).

Boron requirement for wheat-rice pattern

The field trials were conducted in three locations: Bangladesh Agricultural University (BAU) Farm, Mymensingh; Regional Agricultural Research Station (RARS) Farm, Jamalpur and On-Farm Research Division (OFRD) Farm, Rangpur. The B doses were 0, 0.5, 1, 1.5, 2 and 2.5 kg ha^{-1}. The layout was kept undisturbed for two years. Transplant Aman rice (second or last crop of a year) was grown on the same plots with and without added B to evaluate direct and residual effects of boron. In every location, each plot received an equal dose of N, P, K, S and Zn.

The grain yield of wheat was significantly influenced by boron application. Generally, the yield increased as the B dose increased (Table 3), however, successive increments of added boron gave successively smaller increases in grain yield indicating that yield response function is quadratic ($y = a + bx + cx^2$), not linear. Thus, the yields due to application of 1, 1.5, 2 and 2.5 kg B ha^{-1} were statistically identical. Again, application of boron at 0.5 kg B ha^{-1} did not influence grain yield significantly over control. Transplant Aman rice responded a little to B application indicating that 1 kg B ha^{-1} yr^{-1} is sufficient to correct B deficiency for the two crops (wheat and rice).

Table 3. Response of grain yield of wheat (kg ha^{-1}) to different rates of boron application.

B rate (kg ha^{-1})	BAU Farm, Mymensingh		OFRD Farm, Rangpur		
	2001-02	2002-03	1997-98	1998-99	1999-00
0.0	2,011b	2,121b	3,183c	3,333b	3,027c
0.5	2,271b	2,345b	3,615b	3,710ab	3,717b
1.0	3,493a	3,588a	4,109a	3,960a	4,170a
1.5	3,510a	3,693a	4,073a	4,003a	4,143a
2.0	3,554a	3,725a	4,055a	3,974a	4,204a
2.5	3,583a	3,714a	4,032a	4,003a	4,137a

Boron efficiency of wheat varieties

Several sand culture and field experiments were conducted to screen out 37 Bangladeshi wheat varieties and advanced lines for boron (B) efficiency against Thai B efficient (Fang 60) and inefficient (SW 41 and E 12) varieties. Performances of wheat genotypes were evaluated with respect to pollen viability, grain set index and grain yield. Wheat genotypes responded differently to boron deficiency. Pollen viability was found to be 67% in Kanchan, 35% in Gourab, 80% in Sourav, 90% in Fang 60 and 25% in SW 41 where B was not added. Pollen viability of all varieties was above 90% when boron was applied. Based on grain set index, Sourav was found to be a moderately boron efficient variety (Table 4). Thus, Sourav can be regarded as a breeding material for development of new wheat varieties for tolerance to B deficiency so that these varieties can be successfully grown without B fertilization.

Table 4. Frequency distribution of boron efficiency in wheat genotypes.

Boron efficiency class[a]	GSI (%) in B_0	Number of varieties	Mean GSI (%) in each class[b]		
			B_0	B_{10}	Field[c]
Very inefficient	0-20	7	9.8	84.5	28.2
Inefficient	21-50	27	31.7	83.5	47.0
Moderately inefficient	51-70	3	53.7	88.4	62.0
Moderately efficient	71-85	0	ne	ne	ne
Efficient	>85	0	ne	ne	ne
Fang 60 (Efficient)[d]			82.5	97.1	84.3
SW 41 (Inefficient)[d]			29.9	85.5	33.8
E 12 (Very inefficient)[d]			16.8	85.5	38.8

[a]Rerkasem and Jamjod (1997), [b]ne = no entry, [c]Soil with 0.1 mg B kg^{-1}, [d]Thai varieties (used as checks).

Boron requirement for mustard-rice pattern

The experiments were conducted at the OFRD Farm and FSRD site in Rangpur. Boron was applied at the rates of 0, 0.5, 1, 1.5, 2 and 2.5 kg ha^{-1}. The soil had 0.19 µg g^{-1} B content. Nitrogen, P, K, S and Zn were applied at a standard rate to all the plots in both locations. There was a significant positive effect of boron on the seed yield of mustard (cv. Improved Tori-7), the yield did not vary significantly between 1 and 2.5 kg B ha^{-1} (Table 5). The optimum dose of boron was found to be 1 kg B ha^{-1}. Seed yield was positively correlated with the number of pods per plant and with the number of seeds per pod. There was no significant effect of added or residual boron on T. Aman rice.

Table 5. Response of seed yield of mustard (kg ha^{-1}) to different rates of boron application.

B rate (kg ha^{-1})	OFRD Farm, Rangpur		FSRD site, Rangpur	
	1997-98	1998-99	1997-98	1998-99
0.0	571c	471c	592c	577c
0.5	875b	787b	920b	933b
1.0	1,193a	1,092a	1,173a	1,167a
1.5	1,185a	1,104a	1,150a	1,123a
2.0	1,188a	1,095a	1,103a	1,127a
2.5	1,187a	1,102a	1,127a	1,113a

Boron efficiency of mustard varieties

Eight varieties representing three species: *Brassica campestris*, *Brassica napus* and *Brassica juncea* were tested for their response to B application. Mustard varieties differed widely in their response to B treatment (0 and 1 kg B ha^{-1}) and they followed the order: *B. napus* > *B. campestris* > *B. juncea* varieties (Fig. 3). It appeared that the *Brassica napus* varieties (BARI sarisha 2, 3 and 8) responded the highest, *Brassica juncea* (BARI sarisha 5 & 6) responded medium and *Brassica campestris (*BARI Sarisha 1, 4 & 7) had the lowest response.

Thus, BARI sarisha 10 and BARI sarisha 11 (*B. juncea*) can be regarded as a breeding material for development of new mustard varieties with B deficiency tolerance characteristics. Farmers can get good harvest of crops without B supplement if B efficient varieties are chosen.

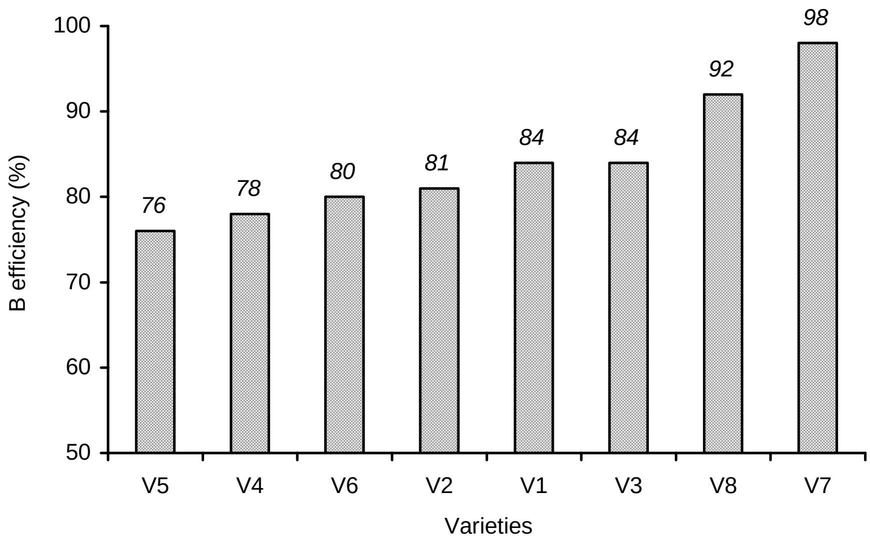

Fig. 3. Boron efficiency of different varieties of mustard, mean of 3 years (V1 -BARI sarisha 6, V2- BARI sarisha 9, V3 - BARI sarisha 12, V4- BARI sarisha 7, V5 - BARI sarisha 8, V6- BARI sarisha 13, V7 -BARI sarisha 10, V8- BARI sarisha 11).

Inclusion of micronutrients in the fertilizer packages

The scientists of BRRI, BARI and BINA have conducted some field trials by inclusion of micronutrient(s) in the fertilizer management packages for different crops and cropping patterns (Tables 6-8). It appeared that zinc application had a significant influence on rice and boron supplement on potato and chickpea, with no appreciable influence of copper and molybdenum on the crops.

Table 6. Effect of fertilizer management packages on rice yield (t ha^{-1}) in Boro- T. Aman pattern at BRRI R/S, Comilla (BRRI 2006).

Treatment	N-P-K-S-Zn rate (kg ha^{-1})	Boro rice			T. Aman rice		
		2000	2001	2002	2000	2001	2002
T_1	Control	3.29	3.26	2.67	3.03	3.46	4.45
T_2	95-20-40-10-1	5.71	5.71	4.96	3.86	4.13	5.42
T_3	132-17-45-20-0	5.46	6.63	5.31	4.51	5.04	5.51
T_4	132-17-45-20-0	5.79	5.56	4.94	3.87	4.78	5.62
T_5	132-17-100-20-0	5.58	6.72	4.65	4.26	5.28	5.55
T_6	100-31-42-0-0	6.15	5.60	5.27	3.74	3.99	4.92
$LSD_{0.05}$		0.70	0.32	0.73	0.27	0.28	0.42

Note: T_2- fertilizers (FRG'97), T_3- fertilizers (soil test basis), T_4- fertilizers + rice straw, T_5- fertilizers + cow dung, -T_6- farmers' practice.

Table 7. Effect of fertilizer management packages on the crop yields in potato-Boro-T. Aman pattern at Syedpur (OFRD, BARI 2006).

Treat.	N-P-K-S-Mg-Zn-B rate (kg ha^{-1})	2002-03			2003-04		
		Potato	Boro	T. Aman	Potato	Boro	T. Aman
T_1	95-17-98-12-10-2-1	23.15c	4.23b	4.32b	22.13c	3.82c	3.19b
T_2	135-25-140-17-15-3-1.5	26.07b	4.62a	4.87a	25.04b	4.25ab	4.06a
T_3	105-15-110-17-15-3-1.5	27.46ab	4.86a	5.18a	26.46ab	4.33a	4.26a
T_4	100-20-50-8-0-1-0	22.81c	4.22b	4.21b	21.75c	4.89bc	3.34b
T_5	110-48-160-20-0-4-1	29.12a	4.01b	4.27b	27.59a	3.71c	3.42b
T_6	Control	10.42d	1.93c	2.18c	9.48d	1.70d	1.77c

Note: T_3 contains 10 t ha^{-1} cowdung and T_5 7.5 t ha^{-1}cowdung.

Table 8. Effects of Zn, B and Mo on the yield of chickpea at Godagari, Rajshahi (BINA 2006).

Treatment	Zn-B-Mo rate (kg ha^{-1})	2000-01		2001-02	
		Seed yield	Stover yield	Seed yield	Stover yield
		t ha^{-1}			
T_1	Control	1.29b	1.55e	1.24d	2.12e
T_2	2-0-0	1.39b	1.80e	1.30cd	2.20de
T_3	0-2-0	1.50ab	2.00cd	1.35bc	2.18de
T_4	0-0-2	1.40b	1.95cd	1.46b	2.24cd
T_5	2-2-0	1.65ab	2.60b	1.62a	2.34b
T_6	2-0-2	1.55ab	2.15c	1.39bc	2.31bc
T_7	0-2-2	1.60ab	2.45b	1.63a	2.36b
T_8	2-2-2	1.79a	2.95a	1.71a	2.44a

***Note:* Every treatment received a blanket dose of $N_{10}P_{20}K_{30}S_{15}$**

Conclusion

Micronutrients have a great role in the balanced fertilization programme to achieve higher and sustainable crop yields. With advancement of time and increasing cropping intensity accompanied with use of HYVs (including hybrids), new nutrient deficiencies are arising. Among the micronutrients, zinc and boron deficiencies are prominent. Zinc is particularly deficient in calcareous and submerged soils. Maize and rice are the most sensitive crops to zinc deficiency. Again, zinc fertilization is important for improvement of crop yield as well as nutritional (e.g. protein) and seed quality. Boron deficiency is much observed in Rabi crops, particularly mustard, wheat and chickpea and less reported on rice. One time micronutrient application could be sufficient for the 2-3 crops.

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EFFECT OF BALANCED FERTILIZATION ON ARSENIC AND OTHER HEAVY METALS UPTAKE IN RICE AND OTHER CROPS

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Abstract

Balanced fertilization of low land rice culture has not proven to be effective in avoiding arsenic accumulation. Accumulation of As has been found to be higher in BRRI-dhan 29 than in BRRI-dhan 28 grown under similar condition. The accumulation of a few heavy metals also indicated that balanced fertilization does not play any significant role in their accumulation. On the other hand, excess P over the required amount could help decrease accumulation of As in an upland crop of kangkong. When amaranthus was grown with balanced fertilizer, half that of balanced and one and a half times more than the balanced fertilizer, the balanced fertilizer could keep the accumulation of the heavy metals in the minimum. It seems that cropping system has a role to play in the accumulation of As and heavy metals when they are fertilized. The paper presents some findings in this regards.

Introduction

Balanced fertilization is the key to efficient fertilizer use for sustainable high yields. Long-term experiments demonstrate that utilization of nitrogen (N) alone, or N and phosphorus (P) created deficiencies of potassium (K) that can only be overcome by application of K fertilizers. Although dramatic increases in N, P and K fertilizer consumption in Bangladesh have taken place, the use of P and K fertilizers is low compared to N. Research on balanced fertilization remains a high research priority to achieve efficient plant nutrient utilization. In short-term experiments, N fertilizer alone had a good effect. However, with time this proved to be a poor practice. High and stable yields can only be achieved and maintained when N, P and K are combined rationally. Furthermore, applying organic manure along with NPK fertilizer has been found to be beneficial because it supplements P and K, adds some secondary and micronutrients, and improves the physical and biological characteristics of the soil (Sikder *et al*. 2007). Improving fertilizer use efficiency is essential and should be a common practice in farming. Bangladesh is beset with the problem of As contamination not only through drinking water but through food chain due to irrigation with As-laden water (Imamul Huq *et al*. 2006a).

Field crops receiving As through irrigation water might show yield differences and accumulation of the toxic element which could be avoided by proper nutrient balance in the growth medium. One of the quality criteria with which the consumer selects food at the market is whether the food is produced in environmentally acceptable ways. Maintaining a balanced nutrition requires judicious fertilization practice. The present paper attempts to highlight the necessity and effect of balanced fertilization on plant quality particularly as it concerns accumulation of arsenic and a few heavy metals.

Material and Methods

Sampling site

The area where groundwater As contamination has not been reported was sought. As such a farmer's field in Dhamrai Thana near Dhaka, Bangladesh was selected for soil sampling (Fig. 1). The georeference of the sampling site is $23^{o}54.776'$ N and $90^{o}10.938'$ E. The soil thus selected belongs to the Dhamrai soil series; general soil type is Non-Calcareous Grey Floodplain soil (GST No. 6); USDA soil taxonomy is Typic Andoaquept and FAO- UNESCO Legend is Chromi-Eutric Gley Sol.

Collection and preparation of soil sample

The bulk soil samples representing 0-15 cm depth from the surface were collected by composite soil sampling method as suggested by the soil survey staff of the United States Department of Agriculture (USDA 1951). The collected soil samples were air dried; visible roots and debris were removed from the soil samples and discarded. Then a portion of the larger and massive aggregates were broken by gently crushing them by a wooden hammer and were screened through a 0.5 mm stainless steel sieve. The sieved samples were then mixed thoroughly for making the composite sample. These soil samples were used for various laboratory analyses. The bulk soil samples were screened through a 2 mm sieve and used for pot experiment.

Experimental setup

Two different pot experiments were carried out in the net house of the Department of Soil, Water and Environment, University of Dhaka, Bangladesh. In one experiment, arsenic at the rates of 0, 10, 20 and 40 mg/kg soil was mixed with the soils before one week from sowing of the rice seeds. Clay pots of 5L sizes were used. The pots were filled with 5 kg of soil. The pots were arranged randomly in the net house. Two different varieties (BRRI dhan-28 and BRRI dhan-29) of rice seeds were collected from Bangladesh Rice Research Institute (BRRI).

The other experiment was carried out with four imposed treatments of As at the rates of 0, 0.5, 1.0 and 2.0 mg As/L in irrigation water. In this experiment only BRRI dhan-28 was used. The soils used were sterilized in an autoclave (at 15 psi, 121^{0}C temperatures for 15 minutes) in batches of 5 kg. The pots were inoculated with a green and blue green algae cultivated in the laboratory (Imamul Huq *et al*. 2007). Treatments of arsenic were applied with irrigation water. Algal samples of 90 days aged were inoculated to each pot in equal amount (15 ml).

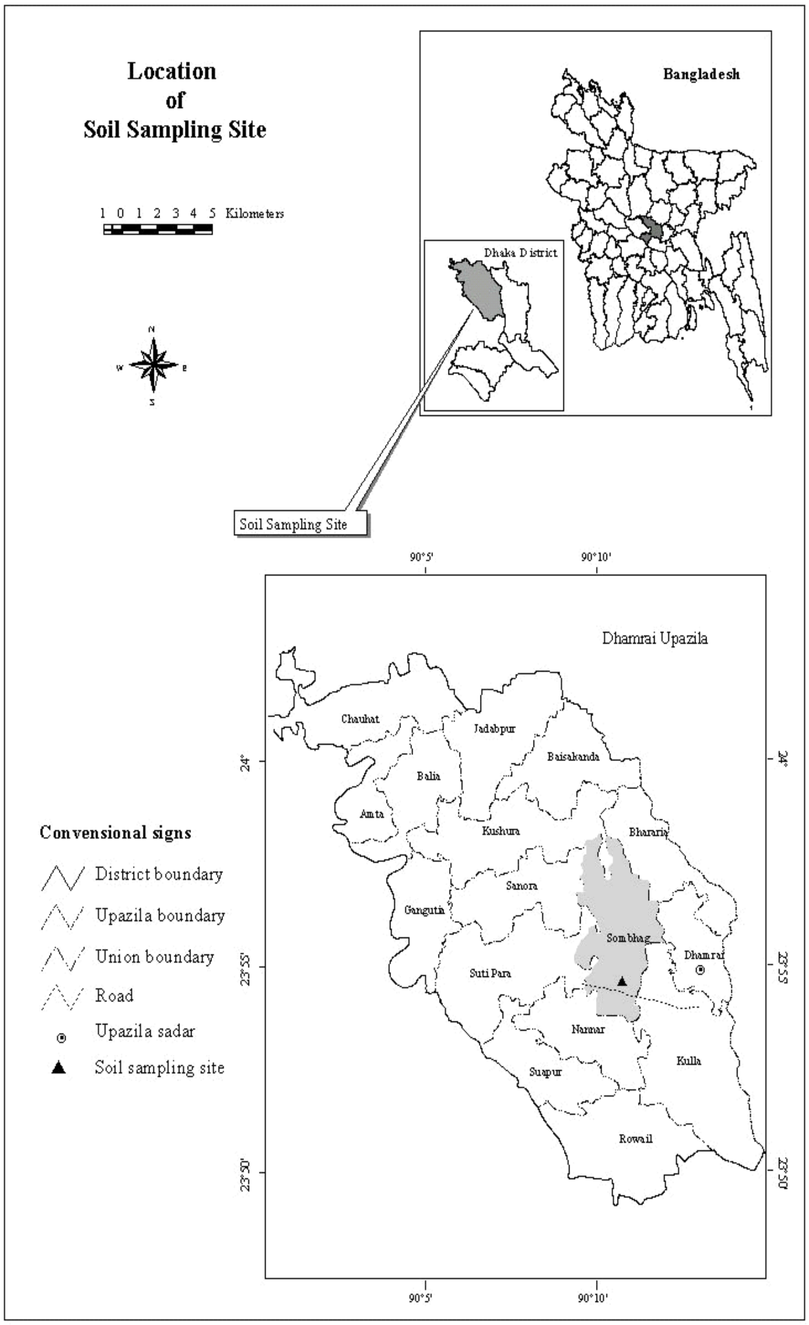

Fig. 1. Location map showing the geographic position of the sampling site.

Method of rice cultivation

The background level of As in soil was 1.6 mg/kg. This was taken as control. Sodium meta- arsenite was used as source of arsenic. All experiments were done in triplicates. The nutritional (N, P, K and S) requirement was calculated on the basis of "Soil Test Value Interpretation" as recommended by the Bangladesh Agriculture Research Council (BARC, 2005). This means that the soils were balanced fertilized. According to this recommendation the required amount of N, P, K and S for the given soil were met from the fertilizer sources urea, TSP, MOP and $ZnSO_4$ respectively. The whole of TSP, MOP, $ZnSO_4$, and 1/3 of the urea fertilizer were applied at time of soil preparation. Rice seeds were dipped in water and kept over night and then kept 2 to 3 days in dark condition for germination. The germinated seeds were sown directly in pots and were allowed to grow. The pots were thinned to 3 plants after seedling were established. Of the rest 2/3 urea fertilizer, 1/3 was applied after 35 days from seed sowing and the final 1/3 was applied during the panicle initiation stage of rice plant. Various cultural operations were made whenever necessary. Weeds were removed manually. Different agronomic characters of the plants were observed during the growth period.

Collection of plant samples

Rice plants of BR-28 and BR-29 were harvested after 120 days and 140 days from germination, respectively. The plants were harvested by uprooting them manually. The grains were collected two days before the harvest. The harvested roots were washed with tap water to dislodge the adhering soil, then with deionized distilled water several times to remove solutes from the ion free space. The aerial portions of the plants were also washed. The plant samples were separated into root, straw and grain. The collected plant samples were first air dried and then oven dried at 70°±5°C for 48 hours. The dried plant samples were then ground and were sifted through a 0.2 mm sieve. Algal samples from the pots were also collected at harvest. After harvest, soil samples from each pot were also collected from the rhizosphere and these soil samples were prepared following the procedures as described earlier.

Laboratory analysis

Various physical, chemical and physiochemical properties of the soils were determined following procedures described in Imamul Huq and Alam (2005). Soil, plant and algae were analyzed for total arsenic by hydride generation atomic absorption spectrometry (HG-AAS). Other heavy metals were analyzed by atomic absorption spectrometry (AAS). Arsenic of the plant and algae samples was extracted with HNO_3 and of the soil with aqua regia solution (Portman and Riley 1964). Certified reference materials were used through the digestion and analyzed as part of the quality assurance/quality control protocol. Reagent blanks and internal standards were used where appropriate to ensure accuracy and precision in the analysis of arsenic and other heavy metals. Each batch of 10 samples was accompanied with reference standard samples to ensure strict QA/QC procedures.

The experimental data were statistically analyzed by using the common statistical software MINITAB 13.0. The amount of uptake (mg/100 plants) by different plant parts and the plant as a whole were calculated. The uptake was calculated using the concentration in dry matter and dry weight of plant parts and the result is expressed as mg/100 plants:

Uptake = Concentration in dry matter × dry weight of plant part

Results and Discussion

Initial characteristics of the soil

The collected soil sample was analyzed in the laboratory before the set up of the experiment to see the nutrient status of the soil. Some important soil properties are presented in Table 1.

Table 1. Some properties of the soil sample

Properties	Values
pH (soil: water = 1:2.5)	6.36
Electrical conductivity	0.07 µS
Sand	7%
Silt	49%
Clay	44%
Texture	Silty clay
Organic matter	1.4%
Total nitrogen	0.15%
Total phosphorous	0.05%
Total potassium	0.32%
Total sulphur	0.21%
Arsenic	1.65 mg/kg
Zinc	0.4 mg/kg
Lead	18.10 mg/kg
Cadmium	0.5 mg/kg
Iron	2%
Manganese	1.6%

Agronomic parameters

Symptoms of any abnormality in the rice plants were noted during the experiment. Both the varieties showed severe symptoms of toxic effect at higher As concentration and the symptoms became pronounced with time of exposure of the plants to arsenic stress. The symptoms delayed seedling emergence, reduced plant growth, caused yellowing and wilting of leaves and finally reduced grain yield. Brown necrotic spots were also observed on old leaves of the plants growing at 20 and 40 mg/kg As treatment in both the varieties. At the initial stage of growth, plant height did not differ with the control plants. But at maturity, plant heights decreased with increasing arsenic treatment. Plants of both the rice varieties grown on 40 mg As/kg treated soil showed the minimum plant height. This decreasing trend of plant height with increasing As treatment was not statistically significant. It was also clear that arsenic did not readily cause plant height reduction but the progressive accumulation of arsenic in plants with the time of exposure caused the plant height reduction. A reduction in plant heights with increasing As concentration have also been reported in rice plants (Yamare 1989; Barrachina *et al*. 1995). Fresh as well as dry matter production of the two varieties decreased with increasing As treatment. Maximum weights were noted for the control plants whereas the minimum values were for plant growing at 40 mg/kg As treatment. No differences in either fresh weight or dry weights were observed due to varietal difference. The grain yield remarkably decreased as a result of higher As doses. A yield reduction of more than 40 and 60% for BR-28 and Iratom-24, respectively in As treated soil has also been reported (Hossain *et al*. 2005).

Arsenic accumulation

Arsenic concentrations in different parts (root, straw and grain) of rice plants of the two varieties are presented in Fig. 2. It is important to note that in the control plants of BR-29 there were some As accumulation and that could perhaps be due to the background As in the soil (1.6 mg/kg).

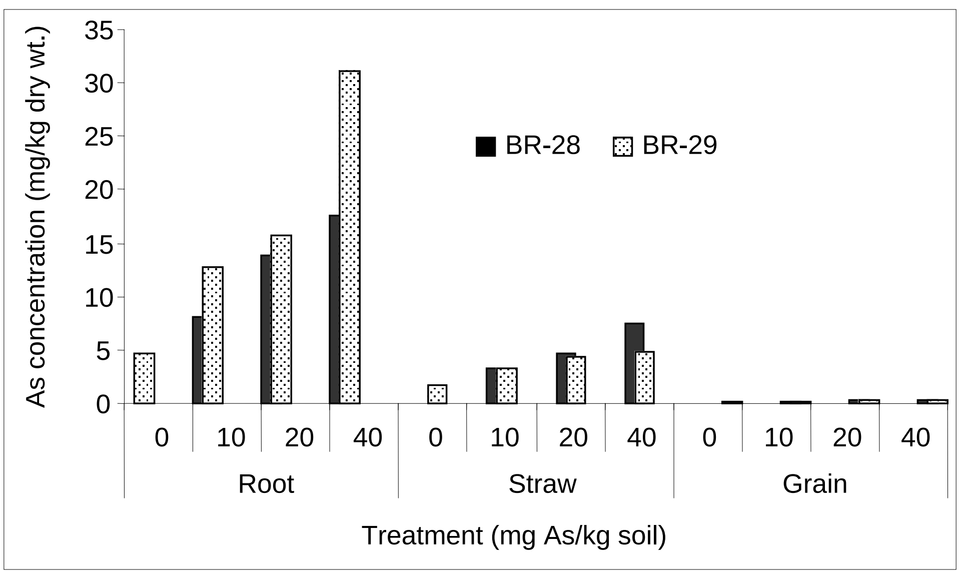

Fig. 2 Arsenic concentrations in different parts of BR-28 and BR-29.

Arsenic concentration in root of both the varieties increased with increasing As treatment. However, arsenic concentration in the roots of BR-28 was not significant. On the other hand, arsenic concentration in roots of BR-29 was significant ($p = 0.009$). In general, the roots accumulated higher As than the other parts. As concentration in roots of BR-29 was more than that of BR-28. Arsenic concentration in straw followed the same pattern as for roots.

The magnitude of the increasing trend varied considerably between the two varieties. Arsenic accumulations in rice grain were almost similar though there was a variation between the varieties. However, in none of the varieties the grain As concentration did exceed the maximum permissible limit of 1.0 mg of As/kg (NFA 1993). This Australian standard is taken as a reference as there has been no standard adopted yet in Bangladesh situation. Arsenic accumulation in rice grain was not significant for any of the variables.

Comparison among the plant parts

Maximum amount of As accumulation was observed in root followed by straw and grain. Similar observations have also been reported earlier (Marin *et al*. 1992; Xie and Huang, 1998). Abedin *et al*. (2002) showed the rice tissue As concentration in the order: root>straw>husk>grain. Roots of BR-29 accumulated more As than BR-28. This means that, in BR-29, As concentrated more in the roots and translocated less to the upper parts of the plant whereas in BR-28, As was translocated to the upper parts of the plants giving rise to a more risk of As ingestion. On the other hand, although As in straw was less translocated, yet grains of BR-29 accumulated more As than BR-28. Transfer factor values (greater than 0.1) indicated that rice plant has strong affinity to As accumulation (Farrago and Mehra 1992) for all treatments.

Comparison between the two varieties

Arsenic accumulation varied in different plant parts of the two varieties but there was no significant difference between the two varieties in As accumulation except in roots ($t = 3.27$, $p = 0.047$) for BR-29. Roots of rice variety BR-29 concentrated more As than BR-28 resulting less in straw whereas in grain As concentration was higher for BR-29 than BR-28.

Arsenic uptake

It was clear that in all parts of both the varieties As uptake was high. Arsenic uptake by the whole plants was significant only in plants ($p = 0.01$) for BR-28; it appears. Thus, that BR-28 is more susceptible to As accumulation than BR-29.

Iron uptake

The mean values of iron content in rice plants of BR-28 and BR-29 are presented in Table 2. Fe content in root, straw and grain of both the varieties increased with increasing As treatment, showing a synergistic relation between As and Fe. The highest amount of Fe accumulation was found in roots followed by straw and grain. Yamare (1989) showed that As levels of >2.5 mg/kg caused decrease in plant N, P, K, and Mg contents while Fe concentration in plants increased at the same level of As.

Table 2. Iron content (%) in rice plants of BR-28 and BR-29

Treatment (mg As/kg soil)	Iron content (%)					
	Root		Straw		Grain	
	BR-28	BR-29	BR-28	BR-29	BR-28	BR-29
0	0.65	0.50	0.03	0.02	0.05	0.04
10	0.56	0.56	0.09	0.05	0.05	0.03
20	0.66	0.45	0.08	0.10	0.07	0.05
40	1.20	1.00	0.09	0.09	0.10	0.06

Manganese uptake

The mean values of manganese concentration in different parts of the two rice varieties are presented in Table 3. Manganese concentration was found to be decreased with increasing As treatment in soil showing antagonistic relationship with As. In this experiment roots contained lower amount of Mn compared to straw and grain. Similar amount of Mn was accumulated by the two varieties.

Table 3. Manganese content (mg/kg dw) in rice plants of BR-28 and BR-29.

Treatment (mg As/kg soil)	Manganese content (mg/kg dw)					
	Root		Straw		Grain	
	BR-28	BR-29	BR-28	BR-29	BR-28	BR-29
0	165	195	415	395	323	450
10	145	210	308	412	240	425
20	100	115	267	285	251	500
40	170	167	325	274	174	239

For the 2nd experiment visual observations were also made and some agronomic parameters were recorded on the growth and yield of rice plant. No symptom of As toxicity was visible in the treated plants.

Effect of arsenic on plant growth and yield

Of the various growth and yield parameters, plant heights (cm), fresh weight of plants (g) and grain yield (t/ha) were considered. No marked differences were observed for the mean height of rice plants for As treatments. However, there had been a slight decrease in the fresh weights of rice. At 2.0 mg/L As treatment, rice showed a decrease of more than 16% from control. ANOVA test was done for fresh weight and the p value was 0.277 for treatment effect. The low p value confirms the significant effect of algae on fresh matter production of rice plants. The grain yield (t/ha) was not remarkably decreased as a result of higher As doses. At lower doses of As in irrigation water (0.5 and 1 mg/L) rice yield was slightly increased over the control treatment though the increase was not significant. The maximum yield of rice plants was observed at 0.5 mg/L treatment with the value being 7.07 t/ha. At high dose (2.0 mg/L) of As yield of rice decreased compared to lower doses of As.

Arsenic content in rice plants

From the result, it is evident that, arsenic accumulation increased with increasing arsenic concentration in irrigation water. Arsenic contents were higher in roots than shoots. The highest concentration of arsenic in roots was found to be 66.23 mg/kg (2.0 mg As/L dose) and the lowest was obtained for control (3.76 mg of As/kg). No detectable arsenic (the detectable level of As in the machine used – Varian Spectra 220 – is 0.0002 mg/kg) was found in grain. The mean values (for three replications) of arsenic concentration in root and shoot of rice are presented in Fig. 3. It is important to note that in control plants there were some As accumulation and perhaps that was due to the presence of water extractable As in soil.

ANOVA test was done for the root arsenic and it was found to be highly significant with the p value of 0.00. The statistical analyses revealed that presence of algae has been instrumental in reducing the entry of As into the rice roots. The highest concentration of As in straw was 6.62 mg/kg at 2.0 mg/L treatment.

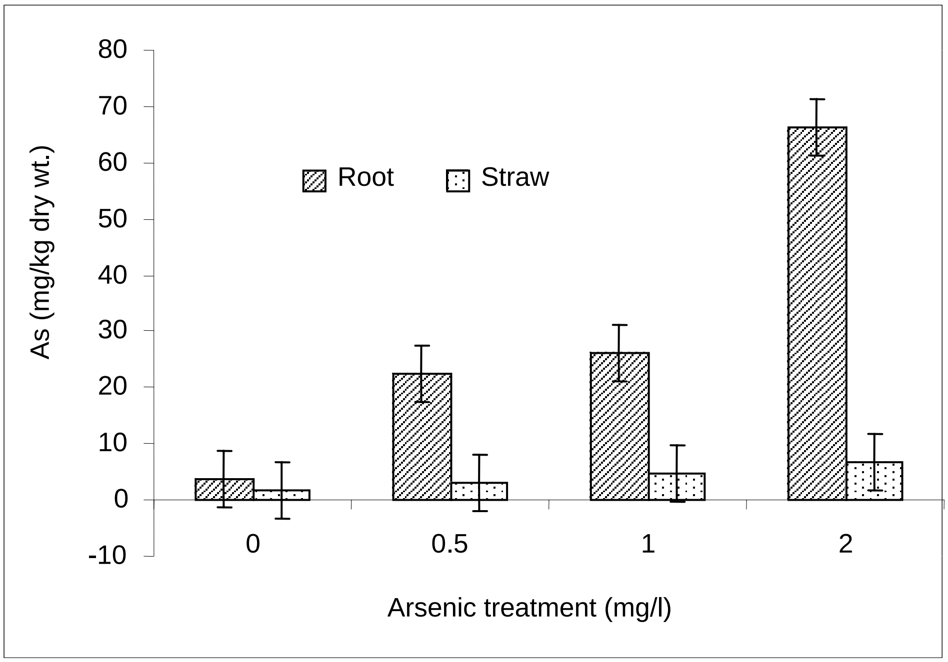

Fig. 3. Arsenic contents in root and straw of rice plant.

Uptake of Arsenic

The amount of As uptake by different plant parts (root and straw) and the whole plant are presented in Table 4. The total uptake of As by plant root at 2.0 mg of As/L in irrigation water was the maximum, the value being 162.93 mg/kg dry weight. The total uptake of As by plant straw at 2.0 mg of As/L was 24.43 mg/kg dry weight. When total plant uptake was considered it was observed that the total uptake of As by plant at 2.0 mg of As/L dose of treatment in irrigation water was the maximum, the values being 187.4 mg/kg dry weight.

Table 4. Arsenic (mg/kg) accumulations in root, straw and plant.

Treatment (mgAs/L)	As (mg/kg)		
	Root	Straw	Plant as a whole
0.0	10.94	7.52	18.50
0.5	63.56	12.69	76.30
1.0	66.89	18.62	85.50
2.0	162.93	24.43	187.40

Arsenic and other heavy metals accumulation in algae

Arsenic and other heavy metals content in algae after harvest were also analyzed and are presented in Table 5. When concentration of As in solution was increased, As concentration in algae also increased. The pot experiment showed that algae accumulated more than 85% of As from the growth media over the control treatment. The result indicates that algae could accumulate arsenic if it is present in solution. The higher the concentration of arsenic in solutions the greater will be the accumulation.

Table 5. Arsenic and other heavy metals in algae.

Treatment (mg As/L)	As	Pb	Cd	Zn
	(mg/kg)			
0.0	2.16	1.70	1.43	31.40
0.5	3.35	0.97	0.33	53.15
1.0	8.05	1.30	0.10	61.70
2.0	16.42	1.00	0.08	25.70

Besides arsenic, lead, cadmium and zinc concentration was higher at control than the treatment. Although there had been no lead, cadmium and zinc application yet it was found that there has been some lead, cadmium and zinc in algae in all the treatments. At 1 mg As/L of irrigation water an increase of about 26% in lead concentration was observed but at higher concentration of As treatment (2 mg As/L) there has been a decline of lead in algae. The accumulation of cadmium decreased gradually with increasing arsenic concentration in irrigation water. At 1 mg As/L of irrigation water an increase of about 50% in zinc concentration was observed over the control treatment but at higher concentration of As treatment (2 mg As/L) there had been a decline of zinc in algae. Similar observation was found by Imamul Huq *et al*. (2005). The result also indicated that the algae accumulate other heavy metals if present in the solution. In the present experiment it is possible that lead, cadmium and zinc were added to the solution as contaminants with the fertilizer materials as well as with the arsenic salt that was applied. It needs to be mentioned here that the cultured algae applied to rice plants contained some arsenic, lead, cadmium and zinc.

Arsenic and other heavy metals in soil after the harvest of rice plant

After the harvest of rice plant, the pot soils were analyzed and the results are shown in Table 6. The data indicated that algae could accumulate substantial amounts of arsenic applied to soil and thereby reduced the concentration of As in soil as well as the accumulation of arsenic in the growing rice.

Table 6. Arsenic and other heavy metals in soil after harvest.

Treatment (mg As/L)	As	Pb	Cd	Zn
	(mg/kg)			
0.0	1.01	0.74	0.17	6.20
0.5	2.14	0.74	0.13	5.10
1.0	3.76	0.79	0.20	6.70
2.0	6.47	0.81	0.25	6.80

In a separate experiment with a different soil BRRI-dhan 29 was grown on fertilized soil monoliths. One of the monoliths received As contaminated water as irrigation water at the rate of 0.5 mg/L while the other monoliths received irrigation through fresh water. Arsenic was not detected in any part of the BR-29 rice plants grown with fresh water (Table 7). It could be due to the fact that the water did not contain any As and the amount soluble was not large enough to cause any detectable accumulation in the growing rice. This gives an indication that fresh water irrigation can minimize As accumulation in plants even if the soil contains As. Similar observations were made by Imamul Huq (personal communication) with crops like arum, kangkong and amaranthus. Though there was no accumulation of As in any parts of the plants, Fe accumulated in a large amount in the roots while in other organs Fe was not detectable. Other elements like Zn and Mn accumulated in all parts of the plants, more in the roots and unfilled grains than either shoot or root. For the plants receiving As-contaminated water irrigation, As was found in the roots and shoots but no As was detected in the grains. Root accumulated as usual higher amount of As than shoot. This again confirms the observations that when irrigation water contains As, there will be an accumulation of the element in the crops receiving the irrigation (Imamul Huq *et al*. 2006a; Imamul Huq *et al*. 2006b; Farid *et al*. 2003).

Table 7. Concentration of different elements in different parts of BR-29.

Plant parts	Fresh water irrigation				As-contaminated water irrigation			
	As (ppm)	Mn (%)	Zn (%)	Fe (ppm)	As (ppm)	Mn (%)	Zn (ppm)	Fe (ppm)
Root	0.00	0.91	0.066	1018.1	6.95	0.65	0.093	100.65
Shoot	0.00	0.31	0.026	0.00	0.12	0.56	0.032	145.00
Grain	0.00	0.24	0.041	0.00	0.00	0.28	0.038	0.00
Unfilled grain	0.00	0.45	0.056	0.00	0.00	0.31	0.071	0.00
Husk	0.00	0.38	0.056	0.00	0.00	0.40	0.046	108.70

In a different experiment with a leafy vegetable *Ipomea aquatica*, phosphorus was varied at different levels; *e.g.* no phosphorous, the required amount, 1.5 times of the required amount, 2.0 times the required amount and 2.5 times of the required amount. The soils were spiked with As at 10, 20 and 40 mg/kg soil. The objective of the experiment was to verify the possibility of using higher P rates to reduce As accumulation in plants. Two soils – one calcareous (Gopalpur series) and the other non-calcareous (Dhamrai series) were included in the study. The As spiking rates were similar in both the soils. However, the P application rate varies because of the soil requirements. Along with As accumulation, the accumulation of Fe, Mn and Zn were also assessed in the plant parts.

It was observed that the addition of P could alleviate As accumulation in both shoots and roots of *Ipomea aquatica* in both soils (Tables 8 and 9). The decrease in As accumulation was more in the non-calcareous than the calcareous soil. With increasing P application, uptake of the native soil As by roots showed a decreasing tendency. It became apparent from this experiment that increasing high amount of P in soil could reduce As uptake in plant by reducing its phytoavailability.

According to Kabata-Pendias and Pendias (1984), arsenic is less toxic when the plant is well supplied with phosphorus. The phytotoxicity of arsenic is reduced with high phosphorus availability. Arsenic is chemically similar to phosphorus (Barrachina *et al*. 1995) and roots take up arsenic and phosphorus by the same mechanism (Meharg and Macnair 1991). So, the chance of As – P interaction should always be expected. The results also tend to indicate that at high soil-As levels P fertilization will have positive effect on lowering the As accumulation in roots grown in both Dhamrai and Gopalpur soil.

Table 8. Arsenic uptake (mg/100 plants) by plant parts in Gopalpur soil (calcareous soil).

Phosphorus (mg/kg)	Arsenic (mg/kg)							
	As_0		As_{10}		As_{20}		As_{40}	
	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot
P_0	3.70	0.25	24.06	15.28	96.36	24.26	177.22	26.63
P_1	3.18	0.39	30.50	12.39	60.62	28.13	132.80	32.98
P_2	2.25	0.35	28.68	17.25	61.25	24.22	129.45	34.46
P_3	2.84	0.07	30.15	12.39	82.90	23.06	143.45	20.62

Table 9. Arsenic uptake (mg/100 plants) by plant parts in Dhamrai soil (non-calcareous).

Phosphorus (mg/kg)	Arsenic (mg/kg)							
	As_0		As_{10}		As_{20}		As_{40}	
	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot
P_0	0.54	0.20	19.69	1.65	24.48	2.93	25.31	3.55
P_1	0.19	0.16	13.98	2.39	17.17	4.68	20.41	5.25
P_2	0.17	0.27	4.84	2.80	17.17	4.14	19.95	4.56
P_3	0.01	0.19	5.92	1.35	14.21	1.88	18.20	2.35

The concentration of Fe in Gopalpur and Dhamrai soil as affected by increasing concentration of P are represented in Table 10. Iron is the only micronutrient element, which has been found to be synergistic with arsenic (Barrachina *et al*. 1995). The tendency of Fe accumulation in plant roots grown in Gopalpur (calcareous) and Dhamrai (non-calcareous) soil was found almost same. Yamare (1989) also found an increase in iron concentration in rice with the increase in As concentration. Gopalpur calcareous and Dhamrai non-calcareous soil didn’t show any substantial difference in accumulation of Fe in plant shoots.

It was clearly observed that Mn was found to be increased with increasing As and P treatments showing synergistic relationship with both As and P (Table 10). Neither soil did show any significant difference in Mn release. The Mn accumulation in plant roots was found to be increased in all level of P. But the rate of accumulation in roots for both soils was found to be almost same. From the observation, it can be said that in almost all cases, a significant amount of Mn accumulated in roots and shoots. However, in the non-calcareous soil, Mn accumulated more in shots than in the roots.

Table 10. Accumulation of Fe and Mn in plant parts in Dhamrai and Gopalpur soil.

Soils	Phosphorus (mg/kg)	Fe (%)		Mn (mg/kg)	
		Root	Shoot	Root	Shoot
Non-calcareous (Dhamrai soil)	P_0	0.069	0.012	50.13	131.32
	P_1	0.048	0.002	45.87	125.26
	P_2	0.051	0.015	60.35	147.95
	P_3	0.059	0.010	56.27	168.52
Calcareous (Gopalpur soil)	P_0	0.012	0.038	71.60	30.43
	P_1	0.079	0.051	57.48	94.55
	P_2	0.115	0.039	65.60	101.25
	P_3	0.085	0.076	20.28	133.23

Yet, in another field experiment that was carried out with amaranthus and where balanced fertilization was practiced, the accumulation of heavy metals was studied. There were three different fertilizer rates, *viz.* ½ the required amount (F_1) of fertilizer (N, P, K and S); the required amount (F_2) and 1½ times the required amount (F_3) along with a control (F_0). It was observed that iron, zinc and manganese content in amaranthus was lower when it was grown with balanced fertilization than the control as well as when it was grown with both less and more amount of required fertilizer. Lead and cadmium content in amaranthus, however, increased with increasing rate of fertilizer application in soil (Table 11).

Table 11. Effect of different treatments of fertilizer on heavy metal content in amaranthus.

Treatment	Fe	Zn	Mn	Pb	Cd
	(%)			(mg/kg)	
F_0	0.21	0.028	0.015	<0.002	1.17
F_1	0.23	0.023	0.014	35.50	1.29
F_2	0.18	0.017	0.011	54.74	1.72
F_3	0.21	0.018	0.018	65.03	2.39

Conclusion

It is apparent from the above observations that balanced fertilization in low land rice culture, though is necessary to keep the yield levels at optimum, can not avoid the accumulation of As and other heavy metals in them. On the other hand, upland crops like kangkong and amaranthus behave differently to balanced fertilization. Balanced fertilization can improve the crop nutrient quality vis-à-vis As and other heavy metal accumulation in them. Further research is underlined to investigate in depth of these phenomena in fields.

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