Integrated Plant Nutrition System Modules for Major Crops and Cropping Systems in South Asia

Edited by

Kinzang Gyeltshen

Sheetal Sharma

SAARC Agriculture Centre

South Asian Association for Regional Cooperation (SAARC)

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FOREWORD

South Asia has 43.28% of arable land available for food production to meet the demand for food of 1.8 billion populations with limited land resources. The population is increasing at the rate of 1.2% annually and it is estimated that 35% of world's poor lives in South Asia with 16.1% of its population below extreme poverty line. The region has 279 million people undernourished with prevalence of undernourishment and food insecurity of 14.7% and 14.4% respectively (FAO, 2019). Climate change is predicted to have severe consequences for South Asia, particularly in agriculture sector which employs 43% of the total employment. Over 70 % of our population lives in rural area and majority of the population depends their livelihoods on the surrounding natural environment, triggering rapid degradation of natural resources. Land degradation is one of the major problems in all South Asian countries which limits the regional aim to enhance food production for growing populations.

An expanding South Asian's population and the urgency of eradicating hunger and malnutrition, call for determined policies and effective actions to ensure sustainable growth in agricultural productivity and production. Agricultural intensification to enhance food production leads to land degradation and threaten the sustainability of agriculture. As a result, an Integrated Plant Nutrition System (IPNS) approach was increasingly recognized to enhance crop and soil productivity through a balanced use of mineral fertilizers with organic and biological sources of plant nutrients to ensure sustainability of food production. Given the importance of the IPNS approach, SAARC Agriculture Centre has organized the Regional Expert Consultation Meeting on *"Developing of Country Specific IPNS Modules for Major Crops and Cropping Systems"* to assess the implementation status of IPNS and gather IPNS modules available in the region. The country papers presented during the meeting by the National Focal Experts of South Asian countries were incorporated in this book. It is encouraging to note that all countries in South Asia are striving hard to implement IPNS approach to enhance sustainable food production and maintain soil productivity. Mainstreaming IPNS in agricultural system is the only means to achieve food security for burgeoning population with the limited land area.

This book '**Integrated Plant Nutrition System Modules for Major Crops and Cropping Systems in South Asia**' is published to share information on the status of natural resource degradation, availability of organic and inorganic fertilizers, need to adopt IPNS approach, IPNS modules for major crops and cropping systems, issues and challenges associated with the adoption of IPNS approach at the farm level in South Asian countries. The policy measures, research and extension support with regard to IPNS were put in place in all countries of South Asia. However, additional requirements of appropriate policy interventions, research innovations, effective extension services and need for joint coordinated efforts of the stakeholders were also included in the publication.

Dr. S. M. Bokhtiar
Director
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Chapter 1

An Overview of Integrated Plant Nutrition System Modules for Major Crops and Cropping Systems in South Asia

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Introduction

Integrated Plant Nutrition System (IPNS) is an approach to enhance crop and soil productivity through a balanced use of mineral fertilizers in combination with organic and biological sources of plant nutrients in different crops and cropping systems to ensure sustainability of food production. Mainstreaming IPNS approach is crucial for the agricultural system in South Asia, as the region has to meet the demand for food of 1.8 billion populations with limited land resources and when its population is increasing at the rate of 1.2% annually (World Bank, 2019). According to World Bank's Report 2019, 35% of world's poor live in South Asia and 16.1% of its population live below extreme poverty line. South Asia has 279 million people undernourished with prevalence of undernourishment and food insecurity of 14.7% and 14.4% respectively (FAO, 2019). Climate change is predicted to have severe consequences for South Asia, particularly in agriculture which employs 43% of total employment.

Given the challenging scenario of the region to meet the need of food on one hand, and on the other hand only 43.28% of arable land is available for food production with 0.11 hectare (ha) per person (World Bank, Agricultural land '% of land area'). High population growth and increasing demand on agriculture for food security and livelihoods are exacerbating serious threat in South Asia, where soils have also been affected by intensive agriculture and a heavy reliance on agrochemical inputs. Traditional practices to sustain soil fertility, such as fallowing and crop rotations are increasingly neglected due to the need to keep land in continuous cultivation and at the same time organic matter in rural areas is in short supply. As a result, there is a decline in soil organic matter that is not being replaced by farmyard manure, organic fertilizers or agronomic practices. To counteract all these challenges, South Asia is striving to propagate and mainstream IPNS approach despite many issues and hindrances to enhance crop production and maintain soil productivity for food and nutrition security in the region.

Natural Resource Degradation

Over 70 % of our population lives in rural area and majority of the population depends their livelihoods on the surrounding natural environment, triggering rapid degradation of natural resources. South Asia is geographically located in one of the fragile ecological setting and most vulnerable to climate change. Indeed, the ongoing degradation of soils and ecosystems in our region threaten the sustainability of food production. Arable land in the region is annually shrinking at an alarming rate due to salinization, desertification, floods, erosions and infrastructure development induced by higher economic growth. Land degradation is one of the major problems in all South Asian countries, as high as 36% of the total geographical areas of some of the countries are affected by land degradation. South Asian's land is subjected to various kinds of land degradation which consist of water erosion, wind erosion, chemical and physical degradation. Inappropriate practices of agricultural farming and lack of knowledge on good agriculture practices at the farm level induce land degradation in numerous ways. There is limited arable land in the region which is shrinking annually; the current rate of degradation of existing cultivable land and climate change impacts further exacerbate the regional aim to enhance food production for growing populations.

South Asia is vulnerable to impacts of climate change and large number of populations living below poverty line will be the first victims of climate change if the major climate change-induced impacts occur. Climate change is already posing serious threat to water scarcity, food scarcity and energy security in the region. Apart from numerous adverse impacts of climate change, increased frequency and severity of extreme events such as floods, droughts and cyclones, high rainfall and subsequent sedimentation of water reservoirs, rapid recession of glaciers and flooding in the valleys, reduce agricultural activities due to increase heat and water stress leading to the degradation of natural resources. It is increasingly realized to take serious and concerted efforts to mitigate and adapt to climate change impacts. Many of the countries in the region already have national climate action plans encompassing all measures to mitigate and adapt to climate change impacts. These action plans are imperative to counteract the growing climate change impacts on soil and land degradation. Surface and ground water pollutions, water scarcity, drying up of water sources, encroachment of salt water into productive land, air pollution are some of the common problems across the countries in the region.

All South Asian countries have developed various national policies, strategies and plans to prevent soil and land degradations for sustainable agriculture practices and also for economic and environmental benefits. South Asian countries have land-use policy and planning put in place to ensure protection of land from degradation and manage the land for various specific purposes in sustainable manner in accordance with the plan. Most of the countries have National Action Programs to combat land degradation and National Adaptation Programs of Action to climate change. The goals of these national programs are to prevent and mitigate land degradation through sustainable land management practices and maintain economic, ecological and aesthetic values of the landscapes. In addition, these programs encompasses soil conservation activities, promotion of remote sensing, assessment and monitoring of degraded lands, reclamation of degraded land and improved coordination and capacity building of the stakeholders.

Organic and Inorganic Plant Nutrient

Organic matter in soil is not only to supply nutrients to crops, but it also enhances soil structure, water storage, cation exchange capacity and biological activity. Despite number of positive functions of organic matter, soils of all South Asian countries are suffering from low content of organic matter mainly due to continuous removal of crop biomass, continuous use of chemical fertilizers without adequate applications of compost and other organic fertilizers and climate change impacts on soil properties. There are wide range of sources of organic manure starting from cattle waste, compost, and farmyard manure to concentrated organic manure like oil cakes, animal meals, ash etc. It was also reported that significant quantity of urban wastes were generated in almost all countries of the region, if these wastes are treated well for safe-use in the agricultural field. However, the common issue for all countries is the non availability of organic manure in sufficient quantity, as these manures generated from the sources were used for different purposes by the farmers and the labor cost of handling and application of manure is very high. In addition to the above organic manure, most of the countries in the region practice green manuring and started using biofertilizers as per the guidelines and recommendations developed by the National Research Institutions.

South Asia is the second largest fertilizer consumer in the world with 149% of fertilizer consumption and 160 kilograms per hectare consumption in arable land (World Bank, Fertilizer Consumption '% of fertilizer consumption'). Chemical fertilizer played a pivotal role in food production to feed huge populations of South Asia for the last couple of decades. Without this fertilizer supplement, South Asia could not have achieved the present stage of food and nutrition security. Chemical fertilizer is one of the main components of IPNS approach and the region is striving hard to mainstream IPNS at the farm level, given the multiple benefits of practicing this approach. All countries of the region import huge quantity of chemical fertilizers annually to meet the demand of crop nutrients to enhance food production. It is essential to highlight that respective Governments of the countries in the region have provided significant subsidies in the form of cash, transportations, subsidy at the sources, etc and at the same time, regulate fertilizer pricing and quality. Some of the countries have provided subsidy on imported fertilizers as high as 53%, but if the fertilizers are highly subsidized, there is risk of using it excessively which will result in issues of soil contaminations and other adverse environmental impacts. To prevent excessive use of fertilizers, some of the countries have introduced Nutrient-based Subsidies for fertilizers based on the soil conditions and also provide subsidy for secondary and micronutrients fertilizers to ensure efficient use of these fertilizers. Regional Governments considered fertilizer subsidy policy as one of the most sensitive policies for the general population because it directly links with large number of rural populations using fertilizer for their survival.

Integrated Plant Nutrition System Approach

An expanding South Asian's population and the urgency of eradicating hunger and malnutrition, call for determined policies and effective actions to ensure sustainable growth in agricultural productivity and production. Assured access to nutritionally adequate and safe food is essential for individual welfare and for national, social and economic development as well. Agricultural intensification, one of the basic strategies to enhanced food production is dependent on increased flows of plant nutrients to the crops for securing high yields. Unless supported by adequate nutrient augmentation, the process of agricultural intensification would lead to land degradation and threaten the sustainability of agriculture. It has been increasingly recognized that plant nutrient needs in all countries of South Asia can best be provided through an integrated use of diverse plant nutrient resources. Neither organic alone nor chemical exclusively can sustain the production sustainability of intensively cultivated soil. An integrated plant nutrition system enables the adaptation of plant nutrition and soil fertility management in different cropping and farming systems to site characteristics, taking advantage of the combined and harmonious use of organic, mineral and bio-fertilizer nutrient resources to serve the needs of food production for food security and also for economic, environmental and social viability in the region.

IPNS is a holistic approach and proven concept aimed at optimizing nutrient use from agronomic, economic and environmental perspectives. This concept increases nutrient use efficiency of all nutrients sources to enhance sustainable crop production and at the same time maintain soil productivity with minimal environmental impacts. Mainstreaming IPNS in agricultural system is the only means to achieve food security for burgeoning population with the limited land area. South Asian's attention on the need for large-scale adoption of IPNS and propagation of its concept and methodology to the farm level application requires scientific community, extension workers, decision-makers, and concerned stakeholders with clear understanding on the subject. Stakeholders' coordinated efforts will help in mainstreaming the IPNS in agricultural system to support the ongoing efforts directed to enhance sustainable agricultural production. South Asian countries have carried out numerous researches on IPNS to develop modules, guidelines, manuals for major crops and cropping systems of different agro-ecological zones. Based on the research findings, required institutions and infrastructures were developed in order to create enabling environment to help farmers adopt IPNS concept. However, wider adoption of IPNS in the region could not be spearheaded as there are number of challenges to motivate farmers to adopt the concept.

IPNS Modules for Major Crops and Cropping Systems

In all countries of South Asian, Agriculture Research and Development Institutions were well established to meet the demand of agricultural research needs of the respective countries. Country papers of all countries have highlighted the presence of well-built and efficient research systems in respective countries. IPNS modules should be developed based on the principles of IPNS approach which is a balanced use of mineral fertilizers in combination with organic and biological sources of plant nutrients in different crops and cropping systems to enhance fertilizer use efficiency and soil productivity. It is very encouraging to note from country papers that IPNS modules for all major crops and cropping systems of respective countries were developed through series of research and field tests *(find modules of major crops and cropping systems in respective chapters of the country papers)*. These modules were made available to extensions and farmers in the form of guidelines and fertilizer recommendations for implementation of IPNS based modules in the field.

IPNS must be a Joint Effort of all Concerned Stakeholders

Policy makers, research, extension, agribusiness, the fertilizer industry and farmers each have key roles to play for successful implementation of IPNS approach (Alley and Vanlauwe, 2009). This group of stakeholders must cooperate and coordinate among themselves to achieve popularization and for wider adoption of IPNS approach effectively at the farm level. It is established from the country papers that all countries of the region have developed certain level of collaboration and cooperation among all the stakeholders with some limitations. Policy makers provided support to build laboratories and research institutions and further granted funding for capacity building of extensions and farmers in the region. Fertilizer subsidy policy is implemented in all countries despite difference in the form of subsidies so that ideal situations are created to the farmers to practice IPNS. Policy direction pertaining to adoption of IPNS from the decision makers was found to be adequate.

Research communities played an important role in broadening knowledge of IPNS under various conditions and developed IPNS tools for extensions and farmers. It is found that research communities have developed IPNS modules for major crops and cropping systems in different agro-ecological zones and disseminated the modules to all stakeholders in most of the countries. Researchers have also developed simple tools like leaf color chart and rapid soil tests kits to determine organic and inorganic fertilizer applications rates. Although, researchers produce guidelines and training materials for extensions and farmers, there is still a gap to be bridged between researcher and other two stakeholders at the field level for the effective implementation of IPNS. There is ample room to promote stronger linkages among researchers, extensions and farmers in nutrient management. With regard to the countries having fertilizer industries, researchers' coordination with fertilizer industries is found to be crucial so that the industries produce only the required nutrients as advised by the research institutes to prevent using nutrients which is not required by the soil and to avoid adverse environmental impacts.

Extensions have major role to link policy makers, researchers and the farmers. They have got most important task to raise awareness about the approach of IPNS taking into consideration the economic, social and environmental benefits. It is indicated from the country papers that farmers have very little knowledge of IPNS and farmers were not willing to adopt IPNS approach as they prefer to use only chemical fertilizers for fast return of their investment. There is a wider gap here to close by means of policy and research interventions by creating ideal situations for farmers to adopt IPNS approach. Capacity building of extensions and farmers were found to be vital to influence farmers to practice IPNS widely for sustainable crop production and maintain soil productivity. Farmers have the most important role to play in the domain of IPNS approach, where participatory approach is crucial if the region wants to spearhead this approach. Other stakeholders are just enablers to create ideal situations for farmers to mainstream IPNS approach in their farming systems. In South Asia, the linkages and coordination among the stakeholders are not at the level required to popularize and influence farmers to practice IPNS. The region has ample room to further strengthen coordination and cooperation among and between stakeholders to achieve the goals of holistic approach of IPNS. Increasing the level of coordinated efforts of all stakeholders mentioned above will definitely lead to the effective implementation of IPNS approach at the farm, village and catchment levels to increase nutrients use efficiency for the benefit of farmers, environment, economy and ultimately for the sustainable food production in the region.

IPNS Approach – The Way Forward

The content of country papers following this chapter explicitly indicated that all countries of the region are striving so hard to adopt IPNS approach on a wider scale, given the overall benefits of practicing this approach. All possible ways and means were put in place for the management of soil fertility through IPNS approach in the region despite challenges and hindrance mentioned in each country papers. The following are the 'IPNS approach – the way forward' developed based on the review of country papers of the eight countries of South Asia:

- It is observed in all countries of the region that there are challenges to popularize and adopt IPNS approach actually at the farm, village and catchment levels because of number of intricacies and issues associated with the implementation of IPNS approach. Currently, its implementation in the field is in small scale in spite of number of policy measures, research innovations, extension awareness programs through field demonstrations were put in place. This clearly shows that the region had to put more efforts to create favorable environment for the farmers at the grassroots level to practice IPNS without much impediments;
- All countries have common issues like non-availability of organic manure, plant residues not recycling back into the soil, expensive organic manure and labor intensive, high handling cost, financial constraints, non-subsidy of organic manure against highly subsidized chemical fertilizers, absence of licensed and regulated organic and compost outlets, etc. to practice IPNS approach. To overcome these issues, policy interventions are required to subsidize organic manure like that of chemical fertilizers, establish credit facilities, offer incentives to farmers practicing IPNS, provide funding for research and capacity development of extensions and farmers and also provide essential infrastructures. As IPNS approach is dynamic, researchers should continue to carry out research, establish reference farm to display the IPNS approach's benefits to decision makers, extensions and farmers, develop tools to create awareness, build capacity of extensions for effective service delivery to the farmers, etc. Extensions should disseminate and convince farmers about the IPNS approach using latest methods and tools, schedule periodic training and field demonstrations;

- The regional countries have established number of soil testing laboratories in districts, provided soil test kits, disseminated IPNS approach fertilizers recommendations, impart awareness training on the subject, etc. to provide required information and educate farmers to adopt IPNS. Despite all these efforts, IPNS is not gaining momentum in our region because of number of issues and challenges associated with it. Therefore, it is imperatives to develop simplified tools which will help extensions or farmers to easily understand IPNS and take decision. One of the important tools would be holistic computerized or mobile phone applications tools which are user-friendly for extensions or farmers and get required information about the need to incorporate amount of organic and inorganic fertilizers, nutrients balance available in soil, targeted outputs, labor and cash requirements, anticipated benefits, so that extensions and farmers can easily take decision leading to popularization of IPNS and contribute to sustainable food production system;
- Most of the countries in the region have developed IPNS modules for major crops and cropping systems for different agro-ecological zones. To influence farmers to practice the holistic approach of IPNS, now it is imperative that researchers and extensions focus on site-specific diagnoses of constraints, assess the need and available resources at farm and villages level, develop design and conduct test on innovative plant nutrition system on 'Reference Farms or Pilot Farms' and showcase these farms to the farmers. The positive results from these farms should subsequently be extended through farming community with the support from community level farmers' organizations and in close coordination with extensions. These activities should be conducted and established at village level so that farmers will have easy access to innovative IPNS technology. To move ahead with these activities at village level, strong coordination and cooperation of decision makers, researchers and extensions is of utmost importance to realize the intended objectives of IPNS approach;

- The country papers revealed that to implement the program of IPNS approach successfully, adequate level of financial as well as human resources are required. South Asian countries comprise of least developed and developing countries, where there is financial resource gap to execute the IPNS program. It is crucial to seek financial as well as human resources from regional and international organizations through projects and programs relevant to IPNS. Further, the region also needs to seek cooperation and support from national, regional and international research organizations to address the aspects of IPNS;

- In South Asia, agriculture sector provides 43% of the total employment which is one of the key sectors that our region will not afford to slow down the momentum of agriculture development. The region faces the challenge of food security for present and future populations, to generate incomes to farmers living in rural communities, to conserve natural resources and protect the environment. It is important that agriculture production in the region be intensified under the umbrella of sustainable development. One important factor in sustainable food production in agricultural system is the maintenance and enhancement of soil fertility through an appropriate replacement of plant nutrients removed by the harvest of produce. IPNS is the holistic approach where implementation of this approach will contribute to solve the issues of soil fertility and maintain soil productivity. As the region gear towards implementation of IPNS approach, strong political commitment, coordinated policy decision, continued research innovations, robust extension services and most important of all actors – the farmers positive motivation will definitely pave way to successful adoption of IPNS approach at farm, village and catchment levels on large scale to reap the wide range of benefits associated with the implementation of the approach.

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Chapter 2

Integrated Plant Nutrition System Modules for Major Crops and Cropping Systems in India

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Introduction

Maintaining food and nutritional security without deteriorating natural resource base and environmental quality is the major challenge in 21st century. Soil is one of the vital resources for agricultural development and sustaining life on the earth. About 52% of the Indian population (1.27 billion) depends on agriculture for their livelihood. 86% farmers are marginal and small category. Agriculture contributes only 14% of GDP, but share of workers is 52%. Agriculture contributes 14.1% earning of total exports.

India presently supports 18% of the world's human and 15% livestock population with only 2.4% of the land mass and 4.0% of the world's water resources. With increase in population from 361 million in 1951 to 1.21 billion in 2011, there is tremendous demographic pressure on finite land resources. This has resulted in sharp decrease in per capita availability of agriculture land in India from 0.48 ha in 1951 to 0.13 in 2011, and projected to decrease to 0.08 in 2035. The net sown area is 141 m ha with 140% cropping intensity. 60% of cultivated area is rainfed as only 40% of area is under irrigation. India is 1st in Jute, Millets, Chickpea, Pigeon, Pea, Castor, Spices, banana, mango, papaya, pomegranate, sapota, aonla and guava production; 2nd in Rice, Wheat, Groundnuts, Sugarcane, Fruits & Vegetables, Potato, Onion, lemon, brinjal, Cabbage and cauliflower; 4th in Soybean; 5th in Sorghum & Maize and 6th in Safflower.

Soil Health Issues

Deterioration of soil health is considered as one of the main reasons of declining nutrient use efficiencies vis-à-vis stagnation of agricultural productivity in tropical region without the exception of India. Post green revolution, sharp increase in the use of high analysis chemical fertilizers like urea, Diammonium phosphate (DAP) to meet the nutrient demand of High Yield Varieties (HYV) and decrease in use of organic manure due to shifting of animal based farming to mechanized agriculture resulted in multi-nutrient deficiencies particularly micro and secondary nutrient and deterioration of soil physical and biological health over the years. Climate change impact on soil has further aggravated the situation.The major soil health issues in India are as under:

Low response to applied fertilizer

The Nutrient deficiency in India is in the order of: 95, 94, 48, 25, 41, 20, 14, 8 and 6% for N, P, K, S, Zn, B, Fe, Mn and Cu respectively. The limiting nutrients do not allow the full expression of other nutrients, lower the fertilizer response and crop productivity. Although fertilizer consumption has been increasing at a fast rate in South Asia since 1970s, the yield response to fertilizer is declining at a similar pace. In India, with a kilogram of NPK about 13.4 kg of additional food grains was obtained in 1970 while the same amount of NPK produced only 2.7 kg of food grains in 2015. While only 54 kg NPK fertilizer nutrients were required per ha during 1970 to maintain the yield level around 2.0 t ha, over five times fertilizer nutrients (280 kg) is being required presently to sustain the same yield level, which is a matter of concern (Chaudhari *et al*, 2015).

Imbalance fertilizer use

Indian soils are working with negative nutrient balance to the tune of 12-14 million tonnes per year and the negative balance is likely to increase in future even after using the full potential of fertilizer industry. Fertilizer use efficiency has been affected as the balance of nutrient application including micro and secondary nutrients is not maintained. In Indian agriculture, nutrient ratio is 6.0:2.5:1.0 during

2017-18 whereas, the ideal ratio for better nutrient use efficiency is considered to be 4:2:1 for nitrogen, phosphorus and potash. Single or multiple nutrient deficiencies (usually NPK, sulphur, boron and zinc) is the general scenario in most of the intensified cropping systems in south Asia mainly due to inadequate and imbalanced fertilizer applications and low addition of organic manure. Phosphorus and potassium depletions were found mostly in rice-rice, rice-vegetable, rice- potato and other cereal based cropping sequences. Deficiencies of secondary macronutrients (calcium, magnesium and sulphur) have seen occurring in acid sandy soils that are low in organic matter. Among the micronutrients, boron deficiency in cauliflower, papaya, mustard and wheat, molybdenum deficiency in cabbage and tomato, and zinc deficiency in rice, maize, tomato and onion are commonly seen in most South Asian soils. Copper can be limiting on some organic soils where as high pH can limit the availability of iron, manganese and zinc. It is, therefore, important to note that improving efficiency of fertilizer use is urgent rather than applying more fertilizer in Indian agriculture.

The consumption of fertilizers in India in terms of NPK has increased substantially from a mere 16.7 million tonnes in 2000-01 in the pre-green revolution period to more than 26.6 million tonnes in 2017-18. As per the International Fertilizer Association, India ranked second in total world fertilizer consumption in 2016. The all-India average consumption of fertilizers has increased from 69.84 kg per hectare in 1991-92 to 134 kg per hectare in 2017-18. There is, however, wide inter-state variability in consumption of fertilizers, with states like Punjab, Haryana and Andhra Pradesh having per hectare consumption of over 200 kg and other states, like Odisha, Kerala, Madhya Pradesh, Jharkhand, Chhattisgarh and Rajasthan, reporting less than 100 kg per hectare consumption. The crop-wise fertilizer consumption (NPK) in India is highly skewed with four crops namely rice, wheat, sugarcane and cotton consume 70% of the total fertilizers used in agriculture.

Declining soil organic matter

Organic matter of soil has profound influence in fertility maintenance by exerting major impacts on soil physico-chemical and biological properties. The soil physical properties most commonly influenced by Soil Organic Matter (SOM) include bulk density, aggregate stability and moisture retention. The chemical properties of soil that are mainly influenced by SOM include nutrient availability, exchange capacity, reaction with meals and contaminants and its capacity to act as proton buffer. It contributes 25-90% of the Cation Exchange Capacity (CEC) of surface layers of mineral soils depending on the nature and content of organic matter. The soil biological properties or processes influenced by SOM include mineralization, microbial biomass and enzyme activities (Sharma and Adhya 2016).

Most of the soils in India are suffering from the loss of organic matter mainly due to continuous removal of crop biomass, continuous use of chemical fertilizers without commensurate applications of compost and other organic fertilizers and climate change impacts on soil properties. A number of studies in India have shown that Soil Organic Carbon (SOC) is the most important parameter for soil quality index formulation indicating that soils with relatively higher organic matter content are better in performing functions that are critical for crop production and environmental conservation. Indeed, an increase of SOC stock by 1 Mg C ha^{-1}in the root zone can raise the crop yield by 15-33 kg ha-1 for wheat (Benbi and Chand, 2007), 160 for kg ha-1 for rice, 170 kg ha^{-1} for pearl millet, 13 kg ha^{-1} for ha-1for groundnut, 18 kg ha^{-1} for lentil 90 kg ha^{-1} for sorghum, 101 kg ha^{-1} for finger millet and 145 kg ha^{-1} for soybean, (Srinivasarao *et al*, 2013). Therefore, greater SOC content can result in higher food grain production in the country.

SOC is the main source of energy for soil biota to flourish for which addition of organic manure is a must. Crop residues returned to the soil provide substrate to soil organisms, which help in SOM turnover. It is estimated that burning of one tone of rice straw accounts for loss of 5.5 kg Nitrogen, 2.3 kg phosphorus, 25 kg potassium and 1.2 kg sulphur besides, organic carbon. In India, an estimated 500-550 (Tg) of crop residues are produces annually. After accounting for multiple competitive uses about 141 Tg are surplus most of which are burnt in situ. The crop residues on an average contain 45% C and assuming a humification rate 10% the incorporation of surplus crop residues can result in C sequestration of 6.3 Tg C annually (NAAS, 2012).

Low nutrient use efficiency

The nutrient use efficiencies in this region are also low ranging from 30-50% (N)'15-20% (P), 60-70%(K), 8-10%(S) and 1-2% (micronutrients). While the unutilized nitrogen are subjected to leaching and denitrification/volatilization loss polluting groundwater and atmosphere respectively, considerable amount of P & K nutrients are lost through the process of soil erosion. It has been estimated that over 5.3 billion tonnes of soil is lost annually through water erosion with a loss of ~8 mt of plant nutrients (NPK).

Land degradation

It has been estimated that around 120.4 million ha (36.5% of the total geographical area) of the country is affected by various kinds of land degradation (NAAS, 2010) comprising of water erosion (82.6 million ha), wind erosion (12.0 million ha), chemical degradation (24.8 million ha) and physical degradation (1.0 million ha). Out of total degraded area, 104.2 million ha is arable land. Erosion induced loss in crop production in rainfed areas under major cereal, oilseed and pulse crops has been estimated as 13.4 million tonnes (~16%), which in economic terms is equivalent to Rs. 162.8 billion (Sharda, *et al*. 2010). Similarly, the crop production loss due to salinity and alkalinity at the national level has been estimated to be 5.66 and 11.18 million tonnes, respectively.

Fertilizer Management Strategy

Nutrient management in India over time has specific syndrome which can be summarized by abuse of nitrogen, disuse of potassium, overuse of phosphorus coupled with low or no addition of organic manure and micro & secondary nutrients. It suggests inherent flaws in nutrient management practices adopted by farmers that probably promotes imbalance in nutrient applications. Soil analysis and site specific crop response trials should be the basis for fertilizer applications and not the blanket recommendation. Accordingly, AICRP (STCR) has developed fertilizer prescription equations for several crops based on soil test-fertilizer requirement calibration to maximize crop yield and profit per rupee investment on fertilizer (Dey, 2015). Based on this, the Govt. of India has launched a National Mission on Soil Health Card (SHC) to provide soil tested based fertilizer recommendation to all the farmers in the country.

IPNS Approaches for Food Security

Judicious and intensive use of soil resource is inevitable to satisfy human needs. Only a healthy soil can support healthy plant growth to provide nutritious produce to keep us healthy. From agricultural point of view, soil health is the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant, animal and human health. A healthy soil would ensure proper retention and release of water and nutrients, promote and sustain root growth, maintain soil biotic habitat, respond to management, resist degradation and act as a buffer for environmental pollution (Brevik and Sauer 2015). The United Nations Millennium Development Task Force on hunger has made Soil Health Enhancement as one of the five recommendations for increasing agricultural productivity and fight hunger. Accordingly, Integrated Nutrient Management (INM) hold merit for higher crop productivity in the country. Integrated plant nutrition system (IPNS) strategies are now recognized to be the only practicable, efficient, economically feasible and environmentally benign way of managing nutrients in cropping systems that is the golden mean between purely organic and chemical farming for achieving the twin goals of sustainability of production and environmental protection. Even in case of problem soils, integrated use of chemical fertilizers, organic manures including green manure and recycling of crop residues, assumes greater significance of improve efficiency of chemical fertilizers in alkali soils, especially during post reclamation period.

The concept of INM first originated in late 80's or beginning of 90's due to wide spread multi-nutrient deficiencies and deterioration of soil physical and biological health resulted from imbalanced use of chemical fertilizers coupled with low addition of organic matter. This concept has evolved as *integrated plant nutrition systems* the basic principle is the maintenance of soil fertility, sustaining productivity and improving farmer's profitability through the judicious and efficient use of synthetic (mineral) fertilizers, organic manures and bio-fertilizer and growing of legumes in the cropping systems. The basic objectives of IPNS are to reduce the inorganic fertilizer requirement, to restore organic matter in soil, to enhance nutrient use efficiency and to maintain soil quality in terms of physical, chemical and biological properties. The most popular and widely used IPNS technologies based on locally available resources for major crops and cropping under different agro-climatic region of the country are as under (table 1):

Table 1: IPNS technologies for major crops and cropping under different agro-climatic region of the country

Western Himalayan Region	
Cropping System	**IPNS package**
Rice – Wheat	Rice : 40 kg N + FYM/Green Manure @ 15 t/ha + 20 kg Zinc sulphate (in Zn deficient soils) Wheat : 120 kg N + 80 kg P_2O_5 (through SSP) + 40 kg K_2O
Maize – Wheat	Maize : 60 kg N + 30 kg P_2O_5(through SSP) + 20 kg K_2O + 10 t FYM + fresh Eupatorium/ Lantana Mulch @ 10t/ha Wheat : 80 kg N + 30 kg P_2O_5 (through SSP) + 15 kg K_2O
Eastern Himalayan Region	
Rice – Rice	Rice : 20 kg N + 20 kg P_2O_5 + 15 kg K_2O +FYM/GM @ 10t/ha + Azolla @ 10t/ha + 20 kg Zinc Sulphate once in 3 years + 5 kg borax + 1 kg ammonium molybdate + 5 kg copper sulphate Rice : 60 kg N + 40 kg P_2O_5 25 kg K_2O + Azolla @ 10t/ha
Rice- wheat	Rice : 40 kg N + 20 kg P_2O_5 + 40 kg K_2O + FYM@5t/ha/GM + Azolla @ 10t/ha + 20 kg Zinc Sulphate once in 3 years + 5 kg borax + 1 kg ammonium molybdate + 5 kg copper sulphate Rice : 50 kg N + 20 kg P_2O_5 + FYM @ 5t/ha

Rice – Mustard	Rice : 40 kg N + 30 kg P_2O_5 (through SSP) + 40 kg K_2O + FYM/GM @ 10t/ha + Azolla @ 10t/ha + 20 kg Zinc Sulphate once in 3 years + 5 kg borax + 1 kg ammonium molybdate + 5 kg copper Sulphate Mustard : 20 kg N + 10 kg P_2O_5 (through SSP) + 25 kg K_2O
Rice – Potato	Rice : 40 kg N + 20 kg P_2O_5 + 15 kg K_2O + Azolla/GM @ 10t/ha + 20 kg Zinc Sulphate once in 3 years + 5 kg borax + 1 kg ammonium molybdate + 5 kg copper sulphate Potato : 50 kg N + 50 kg P_2O_5 + 30 kg K_2O + FYM@ 10t/ha + seed treatment with *Azotobacter* and PSB
Lower Gangetic plain	
Rice – Rice	Rice : 60 kg N + 40 kg P_2O_5 + 30 kg K_2O + FYM/GM @ 10t/ha + 20 kg Zinc Sulphate Rice : 90 kg N + 80 kg P_2O_5 + 60 kg K_2O + Azolla @ 10t/ ha
Rice – Wheat	Rice : 40 kg N + 45 kg P_2O_5 + 30 kg K_2O + FYM/GM @ 10t/ha + Azolla @ 10t/ha/BGA @ 10 kg/ha + kg Zinc Sulphate Wheat: 90 kg N + 45 P_2O_5 + 45 kg K_2O
Jute – Rice – Potato	Jute : 30 kg N + FYM @ 5t/ha Rice : 30 kg N + 30 kg P_2O_5 + 30 kg K_2O + Azolla @ 10t/ha/BGA@ 10 kg/ha + 20 kg Zinc Sulphate Potato : 150 kg N + 40 kg P_2O_5 + 100 kg K_2O + FYM@ 5t/ha + seed treatment with *Azotobacter* and PSB
Middle Gangetic plain	
Rice – Wheat	Rice : 50 kg N + 30 kg P_2O_5 + 20 kg K_2O + Green Manure (greengram/stover) 20 kg Zinc Sulphat (in calcareous soils) Wheat: 90 kg N + 60 P_2O_5 + 30 kg K_2O + FYM@ 10t/ha **OR** Rice : 75 kg N + 45 kg P_2O_5 + 30 kg K_2O + BGA @ 15 kg/ha + FYM @ 10 t/ha + 20kg Zinc Sulphate (in calcareous soils) Wheat : 100 kg N + 65 kg P_2O_5 + 30 kg K_2O
Maize – Wheat	Maize : 90 kg N + 60 P_2O_5 (through SSP) + 30 kg K_2O + GM + 16 kg borax (in calcareous soil) Wheat : 90 kg N + 60 kg P_2O_5 + 30 kg K_2O + FYM@ 10t/ha
Groundnut-Pigeonpea intercropping	100% RDF + lime @2 t/ha + FYM@2 t/ha + Soil water conservation measure (furrows between groundnut and pigeon pea rows)
Upper Gangetic plain	
Rice – Wheat	Rice : 90 kg N + 30 kg K_2O + FYM/GM (Sesbania/ Leucaena Lopping) @ 10t/ha Wheat : 90 kg N + 60 kg P_2O_5 (through SSP) + 30 kg K_2O

Maize – Wheat/ Mustard	Maize : 50 kg N + 20 kg K_2O + FYM @ 10t/ha Wheat : 120 kg N + 60 kg P_2O_5 (through SSP) + 40 kg K_2O Mustard : 60 kg N + 40 kg P_2O_5 (through SSP) + 30 kg K_2O
Sugarcane – Potato	Sugarcane(Autumn planting) : 100 kg N + 45 kg P_2O_5 + 30 + Sulphitation pressmud/ GM + Incorporation of Potato foliage. Potato (Intercropping): 135 kg N + 20 kg P_2O_5 + 60 kg K_2O + FYM 2 10 t/ha + seed treatment with Azotabacter and PSB * (In case of ratoon crop, incorporate sugarcane frash along with only 75 kg N)
Sugarcane – Wheat	Sugarcane(Autumn planting) : 135 kg N + 45 kg P_2O_5 + 30 t (FYM/ Sulphitation pressmud) /GM (Sesbania /Sunhemp/cowpea @ 10 t/ha Wheat (Intercropping) : 80 kg N + 40 kg P_2O_5 + 40 kg K_2O *(In case of ratoon crop, incorporates sugarcane frash along with only 75 kg N)
Trans Gangetic Plain	
Rice/ Maize/Bajra – wheat	Rice: 60 kg N + 30 kg K_2O + FYM/poultry manure/GM @ 10 t/ha Maize: 70 kg N + FYM/GM (Sesbania/ cowpea) @ 10t/ha Bajra: 60 kg N + 30 kg P_2O_5 FYM @ 10 t/ha Wheat: 150 kg N + 30 kg P_2O_5 (through SSP) + 30 kg K_2O + *Azotobactor/Azospirillium* + PSB
Cotton–wheat	Cotton: 120 kg N Wheat: 150 kg N + 30 kg P_2O_5 (through SSP) + 30 kg K_2O + *Azotobactor/Azospirillium* + PSB
Eastern Plateau & Hills	
Rice –Winter Maize/Wheat/Pulses	Rice : 30 kg N + 15 kg P_2O_5 (through SSP) + 15 kg K_2O + FYM/GM @ 10t/ha + 15 kg BGA Winter Maize : 100 kg N + 45 kg P_2O_5 (through SSP) + 20 kg K_2O Wheat : 90 kg N + 45 kg P_2O_5 (through SSP) + 30 kg K_2O Pulses : 10 kg N + 20 kg P_2O_5 (through SSP) + FYM @ 2.5t/ha + Rhizobium + 500 g PSB
Central Plateau & Hills	
Rice-Wheat/Mustard	Rice : 75 kg N + FYM/Green Manure @ 5t/ha Wheat : 90 kg N + 45 kg P_2O_5 + 30 kg K_2O Mustard: 30 kg N + 15 kg P_2O_5 + 10 kg K_2O FYM @ 10 t/ha.
Soybean - Wheat	Soybean : 10 kg N+ 25 kg P_2O_5 (through Boronated SSP) + 4t FYM+ Rhizobium + 25 kg Zinc Sulphate in alternate years Wheat : 90 kg N + 45 kg P_2O_5 (through SSP)

Rice – Gram	Rice : 25 kg N+ 15 kg P_2O_5 + pulse crop residue Incorporation + BGA @ 10 kg/ha/Azolla @ 10t/ha Gram : 10 kg N+ 20 kg P_2O_5 + Rhizobium + 5t FYM + 500 PSB
Soybean-Chickpea (Rainfed system)	100% RDF + 2 t/ha FYM to soybean and 50% RDF to chickpea
Western Plateau & Hills	
Soybean – wheat	Soybean : 10 kg N + 25 kg P_2O_5 (through SSP)+ 4 t FYM + Rhizobium + 25 kg Zinc Sulphate in alternate year Wheat: 90 kg N + 45 kg P_2O_5 (through SSP)
Cotton – Fallow/Pigeon pea/wheat	Cotton : : 50 kg N + 25 kg P_2O_5 + 25 kg K_2O + seed treatment with *Azotobacter* + 4 t FYM / in situ Green manuring (cowpea) followed by mulching with subabul loppings . Pigeon pea : : 10 kg N + 20 kg P_2O_5 (through SSP) + 10 kg K_2O + FYM @ 2.5 t/ha + Rhizobium + 500 g PSB Wheat : : 90 kg N + 30 kg P_2O_5 (through SSP) + 30 kg K_2O + *Azotobactor* / *Azospirillium* + PSB
Green gram-Safflower (Rainfed)	Incorporation of green gram stalk before sowing of safflower along with 75% RDF of safflower + Soil moisture conservation measure (Summer ploughing and inter-culture with blade hoe)
Fallow-sunflower (Rainfed)	100% RDF+FYM @ 2 t/ha +Soil moisture conservation measure (Opening furrow after every 6 rows)
Southern plateau and Hills , East Coast Plains and Ghats and West Coast Plains Regions	
Rice-Rice	Rice: 75 kg N +15 kg. P_2O_5 + 15 kg. K_2O+ FYM/Green Manure @ 5t/ha Rice: 90 kg N + 60 kg P_2O_5 + 40 kg K_2O + 40 kg. K_2O+Azolla @ 10 t /ha BGA @ 10 kg / ha + 20 kg Zinc Sulphates
Rice – Pulses	Rice: 25 kg N+ 15 kg K_2O + pulse crop residue incorporation + BGA @ 10 kg /ha/Azolla @ 10 t/ha Pulses: 10 kg N + 20 kg P_2O_5 + 10 kg K_2O + Rhizobium + 2.5 T FYM + 500 g PSB
Fallow-Sunflower (Rainfed)	Sunflower:100% RDF+FYM @ 2 t/ha +Soil moisture conservation measure (Opening furrow after every 2 rows)
Castor monocropping (Rainfed)	Cowpea incorporation after first picking and 75% RDF of castor

Gujarat Plains & Hills Regions	
Groundnut/ wheat/ Mustard	Groundnut : 15 kg N + 30 kg P_2O_5 (through SSP) +45 kg K_2O + Gypsum @ 250 kg / ha in furrow + 25 kg Zinc Sulphate + 1 kg Boron Wheat: 70 kg N + 30 kg P_2O_5 (through SSP) + 20 kg K_2O + Azotobactor/Azospirillium + PSB Mustard : 30 kg N + 15 kg P_2O_5 (through SSP) + 10 kg K_2O + FYM @ 10 t/ ha
Cotton – Castor	Cotton : 50 kg N + 25 kg P_2O_5 + 25 kg K_2O + seed treatment with *Azotobacter* + 4 t FYM Castor (irrigated) : 25 kg N + 50 kg P_2O_5 (through SSP)+ 1 t castor seed cake/FYM @ 5t/ha + seed treatment with Azospirillium and PSB @ 5 kg/ha
Western Dry Regions	
Kharif Pulses – Fallow	Pulses : 10 kg N + 20 kg P_2O_5 +10 kg K_2O + Rhizobium + 2.5 t FYM
Pearmri millet – mustard	Pearl mrimillet : 25 kg N + 20 kg P_2O_5 (through SSP)+ 10 kg K_2O + *Azotobacter/ Azospirillium* Mustard : 45 kg N + 20 kg P_2O_5 (through SSP)+ 15 kg K_2O + FYM @ 5 t/ha
Fallow-Mustard (Rainfed)	Green manuring with Sesbania and FYM @ 2 t/ha + 75% RDF
Maize-Raya (Rainfed)	100% RDF + S @ 20 kg/ha + Soil moisture conservation Measures (summer ploughing + maize residue application on surface)

Source: Sharma and Biswas (2004).

Liming @3-4 q/ ha in furrows at the time of sowing for soils having pH<5.5

Policy/Research –Extension/Farmer Linkages

The ICAR is addressing soil health and fertility related problems in the country through ICAR-Indian Institute of Soil Science (IISS), All India Coordinated Research projects on Soil Test Crop Response-STCR (25 centres), Micro- and Secondary Nutrients and Pollutant Elements in Soils and Plants-MSPE (22 centres), Long Term Fertilizer Experiments-LTFE (18 centres) and All India Network Project on Soil Biodiversity-Bio-fertilizers-SBB (18 centres). ICAR is providing technical backstopping to following Government programmes/schemes which were being implemented by different Ministries/Departments to address soil health issues and promoting IPNS:

- A National Mission on Soil Health Card has been launched to provide soil tested based fertilizer recommendation to all the farmers in the country based on the twelve soil parameters;
- The Government under the component of soil health management of National Mission on Sustainable Agriculture (NMSA) is promoting soil test based balanced and integrated nutrient management in the country through setting up/strengthening of soil testing laboratories, establishment of bio-fertilizer and compost unit, use of micronutrients, trainings and demonstrations;
- A number of value added fertilizer materials fortified with secondary and micronutrients have been enlisted in Fertilizer Control Order (FCO) to promote balanced and efficient use of fertilizers;
- Customized fertilizers specific to crop, soil and area specific are also promoted;
- The Govt. of India took a historical policy decision of introduction of Nutrient Based Subsidy (NBS) on N, P, K and Sulphur containing fertilizers. Additional subsidy for fertilizers fortified with zinc and boron was paid at the rate of Rs. 500 and Rs. 300 per tonne respectively. It helps well in ensuring efficient use of plant nutrients including secondary and micronutrients;
- The Department of Fertilizers, Ministry of Chemicals & Fertilizers has declared subsidy on city compost @ Rs. 1500 per tonne to serve twin objectives of supporting government's Swachh Bharat Abhiyan and providing manures to farmers;
- The government is implementing National Biogas and Manure Management Programme aiming at setting-up of Family Type Biogas Plants at rural and semi-urban/households level for recycling of rural wastes linking sanitary toilets with biogas plants (http://mnre.gov.in/schemes/decentralized-systems/schems-2/);
- The Government under "Pradhan Mantri Krishi Sinchayee Yojana is promoting micro irrigation/fertigation;

- Under Watershed Management Programme, the major activities taken up include soil and water conservation, rain water harvesting and storage;
- The Government is also implementing programme under National Mission for Sustainable Agriculture (NMSA) for reclamation of Problem soils (*viz*., saline, alkali and acid soils).

Challenges of Soil Fertility Management

It is indeed a real challenge to manage soil resource for achieving food, nutritional, environmental and livelihood security, conserving this vital natural resource base for future generations without any deterioration. The overall strategy for increasing crop yields and sustaining them at a high level must include an integrated approach for managing soil health along with other complementary measures which have a major impact on soil quality, plant growth, crop productivity and agricultural sustainability.

The real challenge for implementation of IPNS is low availability of organic manure. Shifting of animal based farming to mechanized agriculture, use of crop residues for other purposes, use of cowdung cake for cooking and crop residue burning are some of the reasons of low availability of biomass for compost preparation hindering adoption of IPNS technology by the farming community. If farmers have to buy even 1 tonne compost from outside, it will require Rs. 8000/- (@ Rs. 8/- per kg) which is not affordable by the resource poor farmers.

Besides, timely supply of fertilizers in adequate quantity is another limitations hindering IPNS technology in the country. Many a times, the farmers either do not have sufficient money or get affordable credit facilities to pay for the recommended doses of fertilizers. Bio-fertilizers which is cheap and eco-friendly fertilizers do not have organized market like chemical fertilizers. We recommend practice of green manuring but the availability of quality seeds is also a problem.

Conclusion

Improving and maintaining soil fertility for enhancing and sustaining agricultural production is of utmost importance for India's food and nutritional security. Though India is a food surplus nation at present, it will require about 4-5 million tones additional food grains each year to cater the food grain requirement of teeming millions of population. Sustaining such a rate of agricultural growth would require use of both chemical fertilizers and organics in an integrated manner. The results from several long term fertilizer studies conducted in different agro-ecological regions of India involving diversified cropping systems and soil types have shown that imbalance fertilizer use, particularly N alone, had a deleterious effect on soil productivity and health, mainly resulting from damaging effects from imbalance of P, K, S and micronutrients. Integrating organic manure with fertilizers doses not only sustained high productivity but also maintained fertility in most of the intensive cropping systems and soil types. The environmental effects of crop production are related to the amounts of plant nutrients required to produce a defined amount of grain. Integrated nutrient management is environmentally beneficial due to enhanced efficiency of applied fertilizers and increase yield resulting in higher producer profits. Location-specific integrated nutrient management interventions need to be adopted. Region-specific amalgamated technological prescriptions for IPNS strategies refined with targeted policy analysis are required for effective implementation and obtaining positive outcomes within a finite time horizon. This will provide a strong foundation for pragmatic policy formulation on use of IPNS and combating climate change. Last and not the least, INM technology must be developed in farmers' participatory research mode using cluster approach with due consideration of farmers' resource availability and conditions, farm innovations and indigenous technology knowhow.

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Chapter 3

Integrated Plant Nutrition System Modules for Major Crops and Cropping Systems in Pakistan

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Introduction

Agriculture is the backbone of Pakistan's economy, contributing 18.5% to Gross Domestic Product (GDP), providing productive employment to 38.5% national labour force (Pakistan Economic Survey, 2018-2019), and accounts for about 60% of foreign exchange earnings. Agriculture sector provides food and livelihoods to approximately 68% rural population of the country. Out of the total geographical area of 80 million hectare (mha), approximately 22 mha area is cultivated (Ahmad, 2009), 17 mha and 5 mha out of 22 mha are irrigated and rain-fed, respectively (Qureshi et al., 2010; Kahlown and Majeed, 2004).

The farming systems in Pakistan can be broadly classified into three categories (1) Irrigated plains, fall along major river banks in the Central-Eastern, and dominated by the cultivation of wheat, rice, and cotton; (2) Rainfed plains (subtropics) in the North-western region cultivated with wheat and pulses; and (3) Nomadic systems in the south-western region consist mostly of rangeland for animal production (Byerlee and Husain, 1993; Afzal and Naqvi, 2004). The livestock production system dominated by cattle and buffalo, closely linked with integrated crop production system (Afzal and Naqvi, 2004). Primarily in irrigated areas rice-wheat, cotton-wheat, wheat-maize, sugarcane-wheat and mixed cropping whereas wheat, pulses and oilseeds major cropping system in rain-fed areas. Major cropping patterns are shown in Figure 1.

Wheat, rice, maize, cotton and sugarcane are major crops of Pakistan. In general, the average crops yield of these crops are relatively low as compared to crop productivity in progressive farmers and agriculture research setups. An estimated 53%-82% average yield is obtained when compared to those achieved in agriculturally developed countries (Kamal *et al.*, 2012), and so suggest the potential for increasing crop yield (Aslam, 2016).

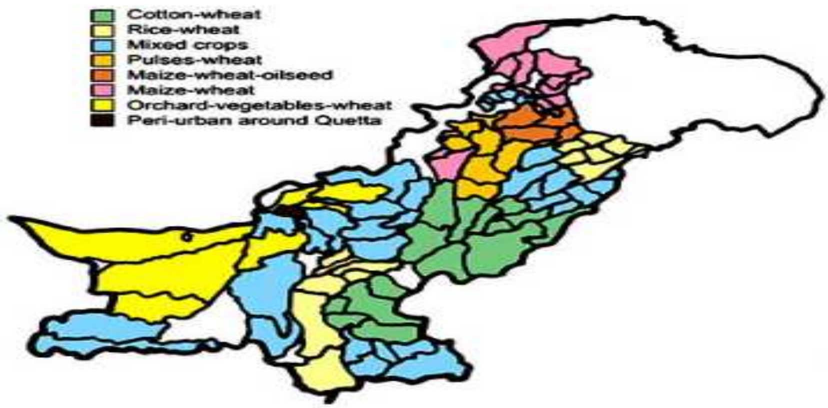

Figure 1. Crop production regions of Pakistan (NFDC, 2003)

Yield Response of Major Crops

Wheat

Wheat is the major staple food, accounts for 8.9% of value added and contributes 1% to GDP of Pakistan. Wheat yield shows marginal increase (0.5%) of 25,195 million tons (mt) against 25,076 mt over last year, the area under wheat cultivation declined to 8,740 (000' ha) against 8,797 (000'ha) last year showing declined by 0.6%. Such declines in cultivation could be triggered by land allocation to oilseed and other competitive crop during this period. However, it has been observed increase in production due to better crop yield and healthy grain formation.

Rice

Rice is the second most important staple food and cash crop accounts for 3% of the value addition in agriculture sector and 0.6% share in GDP. During 2018-19, it was recorded that though area decreased by 3.1%, the production cross the target of 7 mt by producing 7,202 (000't), however less than 7,450 (000't) of previous year. The decrease in production can be ascribed to decline in cultivation area, dry weather and shortage of water.

Maize

Maize is the third important crop after wheat and rice. It contributes 2.6% to value addition in agriculture sector and 0.5% to GDP. Area under maize cultivation increased by 5.4% from 1,251 (000′ ha) last year to 1,318 (000′ ha), and so production also enhanced due to shift from cotton and sugarcane, availability of improved variety seed as well as better economic returns.

Cotton

Cotton is considered as life line of economy of Pakistan contributing 0.8 percent share to GDP and contributes 4.5 percent in agriculture value addition. During 2018-19, cotton production remained moderate at 9.861 million bales, a decrease of 17.5 percent over the last year's production of 11.946 million bales, and 31.5 percent against the target of 14.4 million bales. The decrease in performance can be ascribed to shrinkage in the cultivated area on account of less economic incentive to the farmers by 12.1 percent to 2,373 thousand hectares compared to last year's area of 2,700 thousand hectare (Pakistan Economic Survey, 2018-19)

Oilseeds

During 2018-19 (July-March), 2,421 mt edible oil valued Rs. 192.203 billion (US$ 1.455 billion) was imported. Local production of edible oil during 2018-19 (July-Match) recorded at 0.5 mt.

Natural Resource Degradation

Pakistan is primarily an arid to semi-arid country representing diversity in temperature and precipitation. The eastern area of the southern half received precipitation through the southwest monsoon (June-September), while Northern and western area of the other southern half get rain through western disturbance in winter (Dec.-March). The average annual rainfall is about 250 mm (Kahlown and Majeed, 2004).

Pakistan is confronting serious challenges of environmental pollution, land degradation and air pollution. The environmental degradation cost heavily to the country by more than Rs. 365 billion per annum including Rs. 112 billion by inadequate water supply, sanitation and hygiene situation, Rs. 70 billion by agricultural soil degradation, Rs. 67 billion by indoor pollution, Rs. 67 billion by urban air pollution, and Rs. 6 billion by land degradation and deforestation. The environmental degradation may shoot up the total cost beyond Rs. 450 billion.

These challenges are posing serious threats to the water security, food security, and energy security of Pakistan. The increased frequency and severity of extreme events such as floods, droughts and cyclones, high rainfall events and subsequent sedimentation of water reservoirs, rapid recession of Hindu Kush, Karakoram, Himalayan (HKH) glaciers, and increased incidence of high altitude snow avalanches and glacial lakes outburst flood in valleys, reduced agricultural activities in arid and semi-arid regions due to increase heat and water stress, abundance of insects, pests and pathogens attack (Grasshopper attack in recent history), reduced livestock productivity and numbers due to heat and decrease feeds particularly in high altitude areas, increased intrusion of sea water affecting delta, mangroves and demising breeding site for fish and prawn are posing few of the serious threats Pakistan faces as global community of nations.

It is increasingly realized to take serious and consistent efforts to mitigation and adaptation to climate change. Pakistan is experiencing high rural to urban migration turning cities into overpopulated and its infrastructure inefficient and inadequate, and resulting in air pollution due to increasing traffic etc. It is estimated that the proportion of urban population shoot up from 22.4 % in 1960 to 39.7% in 2018, it is further expected to increase by up to 50% in 2050. The concentration of particulate matter in the air is 2-3.5 times higher than safe limits. Smog and haze frequency is continuously increasing in the cities.

Fertilizers Production, Demand and Import Scenario

South Asia is the second largest fertilizer consuming region in the world, using 19.8% N, 3.6% P and 4.9% K fertilizers. The agriculture sector is fast growing in Pakistan and according to FAO Global Fertilizer Outlook (2018), Pakistan needs for the N and P fertilizers may increase by 4 % and 3% respectively (World Fertilizers Trends and Outlook, 2018). Fertilizer import scenario shows that the import of N, P fertilizer reduced by 46% and 9% respectively, while that of K fertilizer increased by 10%. On overall, it has been observed that due to increase in domestic production the import of fertilizer reduced by 47% in the last ten (Figure 3).

Domestic fertilizer production during 2018-19 shoot up by 2.6% during same period last year, this increase could be attributed to increased production of urea fertilizers due to functioning of two fertilizer plants (Agrotech and Fatima fertilizers). The total fertilizer off take (000′ N/tons) increases during last 19 years (2000-19). Most of the fertilizers requirements (70-80%) were met by domestic fertilizer production (Figure 2).

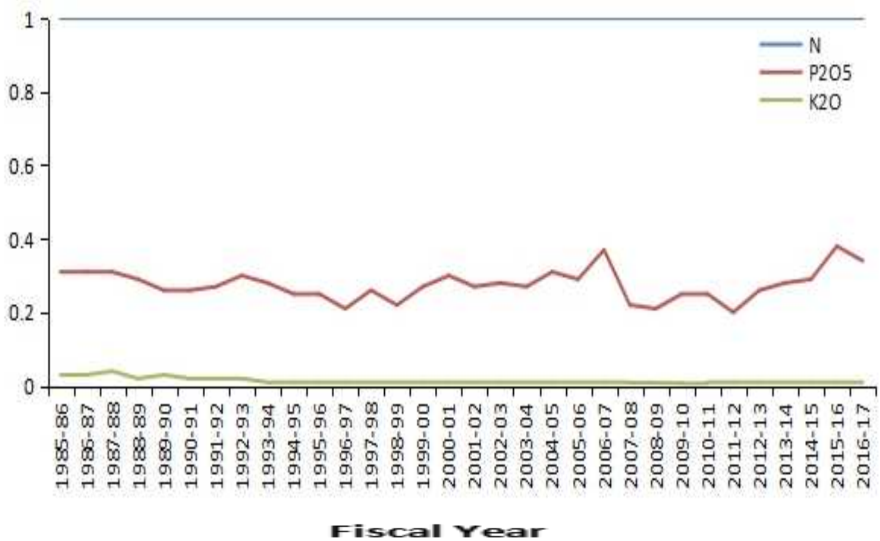

Figure 2. Fertilizer Off take in relative terms (MNFS&R, 2018)

In case of urea, domestic production (2,923 mt) along with opening stock (115 mt) and imported (105) stands to be 3,143 mt against total demand/off take of 3,033 mt leaving a closing balance of 135 thousand tones (tt) for next season, top up by the import of 100 mt. The DAP availability was 1,762 mt included 729 tt opening stock, 6,79 tt imported and domestic production of 354 tt against total demand/off take of 1164 mt, leaving a balance of 599 tt for next season (Table 1).

Table 1. Fertilizer Supply Demand Situation (000' T)

Description	Rabi (Oct-Mar) 2018-19		Kharif (Apr-Sep) 2019	
	Urea	DAP	Urea	DAP
Opening stock	**115**	**729**	135	599
Imported supplies	**105**	**679**	100	18
Domestic Production	**2,923**	**354**	3,217	360
Total Availability	**3,143**	**1,762**	3,452	977
Off take/Demand	3,033	1,164	2,942	865
Write on/off	25	1	0	0
Closing stock	135	599	510	112

Source: National Fertilizer Development Center

As noted, the total off take of fertilizer nutrients decreased by 7.3% (Figure 3), due to high farm gate prices. Consequently, Government provided different type of subsidies during current FY 2018-19 by implementation of uniform tax rate for all type of fertilizers, and operational two fertilizer plants, located at Sui Northern Gas Pipelines (SNGPL) network, by providing Rs. 916/bag of urea subsidy for using LNG.

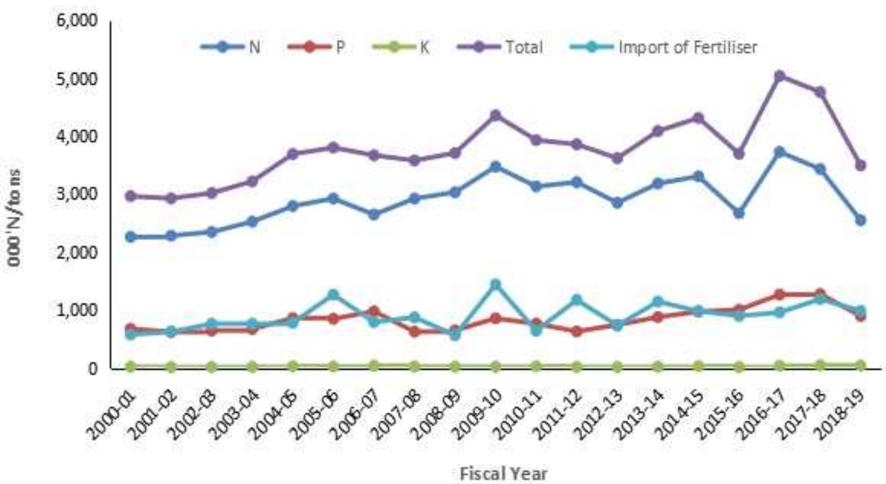

Figure 3. Fertilizer Off take (Agri. Statistics, 2000-18)

A tremendous increase in total food crop production by the factor of 6.5 in Pakistan between 1961 and 2016 can be ascribed to adoption of improved varieties, increase land under irrigation and fertilizer inputs. The increase in irrigated land from 10.8 mha in 1961 to 20.2 mha in 2015 by as much as 187% also resulted in increased use of fertilizer, the fertilizer use between 1961 and 2002 increase from 41.7 thousand tone to 2.34 million tons for N and 42.1 thousand tons to 2.96 million tons for total use of chemical fertilizer (FAO, 2018). It is estimated that the N fertilizer application rates have increased much faster than for P or K, considered both P and K as expensive (Solaiman and Ahmed, 2006). Since the majority of agricultural soils in Pakistan are deficient in all three macro-nutrients, the addition of N has increased yields but the imbalance use of fertilizer in terms of NP ratio as 4.15:1 against desirable 2:1 promoted yield gaps which triggers rural poverty whereby farmers due to low purchasing power, cannot afford the combination of nutrients that would allow them to increase their yields. To narrow down this NP ratio in 2015, the government decided to remedy the lag in Phosphorus fertilizer use by providing a subsidy of 190 million USD on P fertilizers (FAO, 2016) aimed at closing yield gaps through balance nutrients management.

Closing global yield gaps through better nutrient and water management would go a long way to meet food security goals (Mueller *et al.*, 2013), within a multi-pronged approach (e.g., reducing waste, changing diets, expanding agriculture). In fact, closing yield gaps on irrigated and rain-fed land alone could boost globally available calories by 80%). It is therefore seen that recycling high-nutrients organic wastes can not only help reduce yield gaps by meeting crop nutrient needs (van Noordwijk and Brussaard, 2014), but also improve application of combine nutrients which could not otherwise be possible in current economics of farmers (Akram *et al*. 2018).

Potential of Bio-supply for Use in Crop Production System

In Pakistan an estimated 50% of animal excreta is collected, half of that is used as fuel, leaving the other half for likely to be return to crop production. Consequently, huge amount of organic waste remained non utilized and present potential source to meet crop nutrients needs in Pakistan (Akram *et al*., 2018).

Akram *et al,*. (2018) calculated crop need for N, P and K based on fertilizer recommendations as 3.1 million tons (Mt), and each 1.1 Mt for N, P and K respectively (Table 2). Synthetic fertilizer meets 99 % of N, 31% of P, and 2% of K needs costing approximately 2.8 billion USD (Table 2; Figure 4). It was further reported that surpluses of N and K only occur at the national scale (synthetic fertilizer + total bio-supply recycling) concurrent with 26% gap between supply and crop P needs.

Table 2. 2010, National scale availability and current use of bio-supply

	Crop Need		**Synthetic Fertilizer use**	
	Mt	**Billion US $**	**Mt**	**Billion US $**
Nitrogen	3.1	1.7	3.1	1.7
Phosphorus	1.1	3.6	0.3	1.1
Potassium	1.1	1.8	0.03	0.04
Sum	5.3	7.1	3.4	2.8

Mt=Million tons

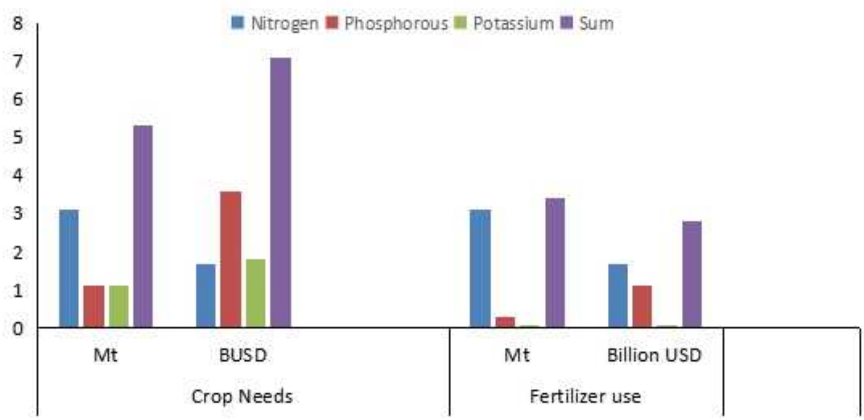

Figure 4. National scale crop nutrient need and use of synthetic fertilizers in 2010 in Pakistan

(Akram et al. 2018)

There were 4.4 million tons of available bio-supply as animal manure and human excreta, with a total NPK fertilizer value of 5.9 billion US $ (Table 3). It is estimated that if 3.3 Mt of not recycled bio-supply is also recycled it could meet N and P by 43% and 57% respectively (Table 4), and could substantially reduced expenditure on purchase of synthetic fertilizers in the country (Akram *et al.*, 2018) which is currently more skewed towards N fertilizers.

Table 3. 2010, National scale availability and current use of bio-supply

	Available		Recycled, 2010		Not recycled, 2010	
	Mt	**Billion US $**	**Mt**	**Billion US $**	**Mt**	**Billion US $**
Nitrogen	1.8	0.97	0.45	0.24	1.4	0.7
Phosphorous	0.46	1.52	0.12	0.38	0.34	1.1
Potassium	2.2	3.45	0.54	0.86	1.6	2.6
Sum	4.4	5.93	1.11	1.48	3.3	4.4

Mt=Million tons; Akram et al. (2018)

Table 4. Gap to meet crop needs at the national scale: (1) 2010 synthetic fertilizer use + 25% bio-supply recycling (2) 100% recycling of bio-supply and no synthetic fertilizers use

	2010			100 % Recycling		
	%	**Mt**	**Billion US $**	**%**	**Mt**	**Billion US $**
Nitrogen	0	0	0	43	1.36	0.73
Phosphorous	58	0.62	2.07	57	0.62	2.04
Potassium	52	0.59	0.94	0	0	0
Sum		1.22	3.01		1.98	2.77

Mt=Million tons; Akram et al. (2018)

In Pakistan it is estimated that about 21-32% of the total farms apply integrated fertilizer such as mineral fertilizers as well as organic fertilizer in the form of manure, while most of the farms (29-46%) rely on mineral fertilizers and very few farm (1-5%) uses depends on manures as source of their fertilizer (Figure 5).

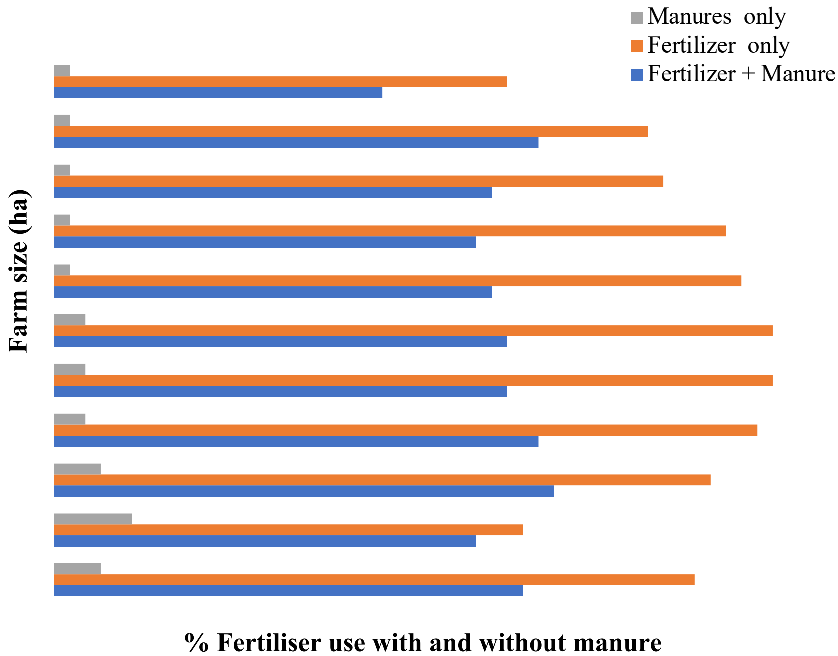

Figure 5. Relative proportions of farms using fertilizer with and without manures (Agri. Stat., 2016)

Government Policies to address Soil Health

Comprehensive strategy encompassing mitigation, rehabilitation, and better land-use planning will adopted in order to protect land resources. The strategy includes action such as: establishment of groundwater regulation system to monitor and regulate water and salt balance of aquifers, reduction in drainage surplus through precision irrigation, strengthening and expansion of soil testing laboratory for issuance of soil health cards to farmers to provide updated information on nutrients balance, improved watershed and rangeland management, soil conservation program through technical, biological, chemical and social measures, promotion of remote sensing and Geographic Information System tools for identification, assessment and monitoring of degraded lands, and improved coordination and capacity building of the stakeholders. Legislation are going to be introduced against uncheck spread of housing schemes on fertile lands. Under the land reform program, additional land will be reclaimed and irrigated for allotment to landless, agri-graduates, women haris and tenants. A land consolidation program is going to be initiated to create viable units of modern agriculture.

The Prime Minister's Agriculture Emergency Program (2019-23) initiated by the present government to enhance agriculture productivity. The program focus on Productivity Enhancement of Wheat, Rice, Sugarcane and oil seeds, enhancing command Area of Small and Mini in Barani Area and water conservation in Barani Areas of Khyber Pakhtun khwa and lining of watercourses. The Government is committed to increase forest covered area in Pakistan through Ten Billion Tree Tsunami Program (TBTTP) with investment cost of Rs. 110 billion. For this purpose 2nd December, 2018 was commemorated as "Plant for Pakistan Day". In order to combat deforestation, Sustainable Land Management Program II (SLMP II) is being implemented since 2015 with the help of UNDP, GEF and ADP. REDD++ program aimed at reducing GHG emission as a results of deforestation and forest degradation. The Watershed Management and Soil Conservation program aimed at bringing fragile land in Gilgit Baltistan, Baluchistan under permanent plantation.

Integrated Plant Nutrition System Approach

Integrated Plant Nutrition System (IPNS) aimed at the maintenance and possibly increase of soil fertility for sustaining increased crop productivity through optimizing of all possible sources, organic and inorganic, of plant nutrients needed for crop growth and quality in an integrated manner appropriate to each cropping systems and farming situation within its ecological social and economic possibilities. The Integrated Plant Nutrient (IPN) Management involved collective use of organic and inorganic fertilizers not only to increase mutual efficiency but also help in substitution of costly chemical fertilizers.

Approaches

- Raise soil productivity and food production, so that food security is ensured at local level;
- Enhance resilience of the land to erosion and degradation;
- Enhance soil and agro-biodiversity;
- Enhance soil capacity to sequestrate carbon and mitigate the effect of climate change; and
- Ensure prosperity and healthy environment for the future generation.

Components and Technology

The main components of integrated plant nutrient management are (i) soil (ii) balance and efficient use of mineral fertilizers (iii) organic fertilizer sources (iv) green manures (v) biofertilizers, and (vi) industrial waste and city garbage. These are briefly discussed in the follow up sections with their relevance to Pakistan conditions.

Soil: Soil supplies all the known essential plant nutrients. However, crop intensification and cultivation of soils over the years triggers the problem of nutrients mining particularly those essential for plant growth. Most of the soils in Pakistan have poor status of available plant nutrients and cannot supply optimum level for crop productivity. Soil fertility is depleting due to mining of essential plant nutrients. However, through good tilt and physical condition of soil, the nutrient availability can be improved.

Chemical fertilizers: Balance and adequate use of chemical fertilizers is very important component of technology.

Farmyard Manure (FYM): The FYM consists of materials collected from animal droppings, beddings, and domestic sweep. The fertilizer value of animal manures has been recognized since ancient times. Based on number of animals, the estimated contribution is shown (Table 5), it may be stated that about 50 percent of animal dropping is not collected. While about 50 % of the collected is used as fuel. Thus, nutrients recycled to crops are about 1/4th of the total droppings (Table 5)

Table 5. Livestock Population, Production of Manure, and Nutrient Potential of Manure in Pakistan

Animal	No.	Droppings	Urine	Manure moisture	Total DM	Total N/ yr	Total P_2O_5/yr	Total K_2O/yr
	Mh	(mt/yr)		(%)	(mt/yr)	('000 t)	('000 t)	('000 t)
Cattle	23.77	208.3	103.6	79	43.7	1 159	477	1 242
Buffalo	26.15	267.0	134.2	79	56.1	1 492	611	1 600
Goat	59.15	33.1	21.5	65	11.6	595	204	512
Sheep	24.46	17.7	9.3	65	6.2	252	80	217
Poultry	357.18	8.1	0.0	54	3.7	120	68	31
Others	4.84	21.0	6.0	60	8.4	143	47	149
Total	495.55	555.2	274.6		129.7	3761	1213	3049

Sources: Livestock Census, 1996; modified/estimated (2005); Hussain, 1996; Mh=million heads

Green manures (GM)

The GM with N-fixing leguminous crops improves soil and enhances availability of other nutrients.

The prominent cropping systems in Pakistan are:

i. Rice-wheat   ii. Cotton-wheat

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

iv. Oilseed-pulses-wheat

The three of the four cropping systems i.e. (i) rice-wheat, (ii) cotton-wheat and (iii) mixed cropping are very exhaustive with cropping intensity of over 150 percent. The use of only nitrogenous and phosphatic fertilizers is causing potash, sulphur and micronutrients deficiency restricting the yield potential. The sandwiching of green manuring crops in these tight cropping patterns is considered not only an excellent source of nitrogen (N), but the intervention improves physical condition of soil and availability of other nutrients. The studies have shown that the contribution of green manure legumes was quite high at low level of N application through fertilizers and dropped with increase in rates. The studies of pre-rice green manuring of three years showed a significant impact on yield of next wheat crop and reducing its N requirements. Major green manure crops are dhaincha/jantar (*Sesbania aculeatea*) and guar

(*Cyamopsis tetragonolaba*). However, trials on sun hemp (*Crotalaria juncea*) and tropical jantar (*Sesbania rostrata*) have also been conducted. The N contribution from all these sources have been quantified from 70 to 100 kg/ha. In wheat-cotton system, there is generally no time for GM except to try relay cropping. The farmers are also not prepared to sacrifice main crop.

Crop residues and residues based humic substances

A huge quantity of crop residues such as wheat straw, cotton sticks, sugarcane trash/tops and rice husk, etc., are available. But due to some economic compulsions such as need for animal fodder and fuel, the crop residues are partially recycled in the soil, or burned to clear field for next crop otherwise these may contribute in improving organic matter in the soil and thus keep it productive. Khan *et al.* (2017) reported that application of humic substances (HSs) derived from crop residues and coal increased grain yield by 21% and 11% over control with application of HSs at the rate of 50 mg/kg.

Filter cake and silage

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

Sewage sludge, city garbage, industrial wastewater

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

Biofertilizers

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

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

The Pakistan Agriculture Research Council (PARC), National Institute of Biotechnology and Genetic Engineering (NIBGE) and Provincial Agricultural Research Institutes are carrying out work on biological fertilization. All these institutions are isolating strains of rhizospheric bacteria, which have potential for mobilizing atmospheric N, both on legumes and non-legumes. In greenhouse, field and laboratory studies, effective microorganisms, in combination with NPK, green manure and FYM, have been shown to give yield responses of 18.3 percent in rice and 39 percent in wheat. Significant responses have also been reported in maize, peas and potatoes. NARC in collaboration with Engro Chemical Pakistan

Limited (ECPL) commercialized rhizobium specific for chickpea in the name of Biozot. One packet of 500 gms was sold at Rs.50 to farmers. The project continued for three years (1996 to 1998) covering an area of one thousand acre each year.

At NIBGE, isolates were tested for their ability to produce indole acetic acid (IAA) in the rhizosphere and it was found that certain *Pseudomonas* spp. were most active. IAA, like 2:4D, can produce nodule-like excrescence on wheat roots and has been shown to mobilize atmospheric N thereby. Thus the prospects of providing partial N nutrition of wheat by inoculation of soil with isolates of *Pseudomonas* appear promising. NIBGE based on its facilities including different capacity fermenters has already marketed its bio-fertilizer for rice under the name biopower. This product has been used over 10 000 acres of rice growing areas, and response of farmers has been excellent.

NIBGE has also been carrying out experimentation with *Azolla* for rice nutrition. An earlier problem, that *Azolla* would not survive the summer temperatures of Pakistan, has been overcome and there are now several heat-tolerant strains available. *Azolla* has been combined with N fertilizer and rice rhizospheric diazotrophic bacteria in field trials, from which it was found that an *Azolla* cover with 30 kg/ha N gave maximum rice yield, although biological nitrogen fixation (BNF) assisted in providing N to the rice plants. At PARC, another important biological fertilization study is being conducted on microorganisms, which solubilize soil P. It has been found that strains of *Aspergillus niger* and *Penicillium* spp. have some solubilizing properties, not only in soil but also of P from rock phosphate.

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

IPNS based Fertilizer Recommendations

Wheat

The Integrated Plant Nutrient Management (IPNM) show that biological and grain yield of wheat increase (Table 6). The NPK application with biozote about 27% increase in grain yield against 24% where biozote was not applied. Besides yield, plant nutrients concentration was also affected with IPNM (Table 7). Based on the results of the study it can be concluded that under field conditions soils are less developed, coarse textured and poor in nutrient for supporting plants growth, IPNM can be a potential source for enhancing crop productivity and boosting the crops production.

Table 6. Effect of Integrated Nutrient Management on Biological and Grain yield of wheat

Treatments (kg ha^{-1})	BY		GY		% Increase in GY	
	+ Bioz	- Bioz	+ Bioz	- Bioz	+ Bio	- Bioz
$N:P_2O_5$ (120:60)	9220	10260	2980	3130	-	-
$N:P_2O_5:K_2O$ (120:60:100)	11120	10170	3800	3880	27	24
$N:P_2O_5:K_2O$ and Zn (120:60:100 and 5)	11170	9250	3540	3360	19	7
$N:P_2O_5$: K_2O:Zn and B (120:60:100:5 and 2)	10340	9640	3710	3600	24	15
$N:P_2O_5:K_2O$:Zn:B and HA(120:60:100:5:2 and 20)	10460	9140	3470	3540	16	13

GY= Grain yield; BY=Biological Yield; Bioz=Bozote; Source: Unpublished Annual Technical Report (2014-15, NR010)

Table 7. Nutrient Composition of wheat in response to Integrated Nutrient Management

Treatments (kg ha^{-1})	K	P	Zn	Cu	Mn	Fe
	(%)		(mg kg^{-1})			
+ Bioz						
$N:P_2O_5$ (120:60)	2.21	0.22	29.56	81.80	10.80	387.13
$N:P_2O_5:K_2O$ (120:60:100)	1.60	0.19	23.36	56.13	07.87	509.33
$N:P_2O_5:K_2O$ and Zn (120:60:100 and 5)	2.01	0.29	43.82	76.27	10.87	719.47
$N:P_2O_5$: K_2O:Zn and B (120:60:100:5 and 2)	1.85	0.22	27.82	71.73	14.00	590.33
$N:P_2O_5:K_2O$:Zn:B and HA (120:60:100:5:2 and 20)	2.03	0.23	28.49	72.87	15.07	433.80

	- Bioz					
$N:P_2O_5$ (120:60)	1.92	0.23	24.07	5.53	55.13	212.40
$N:P_2O_5:K_2O$ (120:60:100)	1.90	0.22	24.00	5.93	40.13	230.73
$N:P_2O_5:K_2O$ and Zn (120:60:100 and 5)	2.02	0.23	22.53	5.93	32.60	169.33
$N:P_2O_5$: K_2O: Zn and B (120:60:100:5 and 2)	1.94	0.23	22.20	6.87	40.00	266.27
$N:P_2O_5:K_2O$: Zn:B and HA (120:60:100:5:2 and 20)	2.08	0.24	23.40	6.33	34.33	226.93

Bioz=Bozote; Source: Unpublished Annual Technical Report (2014-15, NR010)

The Integrated Nutrients Management increased soil organic matter (SOM). Mehmood *et al.,* (2013) reported that after 5 years of following the cotton-wheat rotation in the Aridisol, SOM content in the surface soil (0–15 cm) was significantly increased by BNM, INM and BNM+GM treatments in comparison with the FFU treatment in both Awagat and Shahpur soils (Table 8).

Table 8. Effect of Nutrients Management and Crop Residues Management on Soil, Organic Matter Contents (%) after 5 years

	Awaget						**Shahpur**					
	0-15 cm			**15-30 cm**			**0-15 cm**			**15-30 cm**		
Treatments	**CRR**	**CRI**	**Mean**	**CRR**	**CRI**	**Mean**	**CRR**	**CRI**	**Mean**	**CRR**	**CRI**	**Mean**
FFU	0.62	0.66	0.64	0.42	0.45	0.44	0.81	0.87	0.84	0.53	0.58	0.56
BNM	0.64	0.69	0.67	0.45	0.49	0.47	0.84	0.90	0.87	0.57	0.61	0.59
INM	0.67	0.70	0.70	0.48	0.54	0.51	0.87	0.92	0.90	0.60	0.66	0.63
BNM+GM	0.66	0.68	0.68	0.44	0.50	0.47	0.84	0.90	0.87	0.58	0.64	0.61
Mean	0.65	0.67	0.67	0.45	0.50		0.84	0.90	0.87		0.57	0.62

T1 – Farmers' fertilizer use (FFU), i.e., 110 kg N ha-1 in cotton and 80 kg N + 60 kg P2O5 ha-1 in wheat; T2 – Balanced nutrient management (BNM), i.e., 170 kg N + 60 kg P2O5 + 5 kg Zn + 1 kg B ha-l in cotton and 140 kg N + 100 kg P2O5 + 5 kg Zn + 1 kg B ha-lin wheat; T3 – Integrated nutrient management (INM), same as BNM, except that 75% N was applied as fertilizer and 25% N as FYM; T4 – same as BNM, except that wheat was substituted by *Berseem* green manure during years 2 and 4 of the experiment (BNM+GM).

Source: Mehmood et al. (2013)

The K uptake by Wheat across all treatments show that the lowest total K uptake by wheat was obtained under FFU and the highest uptake occurred under INM treatment. Potassium uptake with BNM+GM during year 1, 3 and 4 was almost equal to BNM treatment uptake. As the experiment progressed, K uptake under FFU treatment generally got sustained/reduced at both field sites (Rafique *et al.*, 2012)

Pulses

The IPNM including application of NPK with or without bio-fertiliser (+/- biozote) and humic acid (HA) to lentil shows that NPK in presence of biozote increased lentil yield by 13.6% and 12.8% in presence of HA. The maximum increase of 17.4%-17.9% was obtained when NPK coupled with Zn and B along with biozote (Table 9). The integration of inorganic fertilizers with organic fertilizer (Humic Acid) and biofertilizer has become imperative for sustained crop production and maintenance of soil health.

Table 9. Effect of Integrated Plant Nutrients on the yield of Lentil

	Grain yield		Increase in yield	
Treatment (kg ha^{-1})	**+Bioz**	**-Bioz**	**+Bioz**	**-Bioz**
	(kg ha^{-1})		**(%)**	
Control (No fertilizer)	989	966	-	-
N: P_2O_5 (25: 80)	1055	1000	6.7	3.4
N: P_2O_5 :K_2O (25: 80:75)	1123	1100	13.6	13.8
N: P_2O_5 : K_2O and Zn (25: 80:75 and 5)	1161	1100	17.4	13.8
N: P_2O_5 : K_2O and B (5: 80:75: 5 and2)	1165	1122	17.9	16.1
N: P_2O_5 : K_2O and HA (5:80:75:5:2 and 25)	1115	1077	12.8	11.5

Bioz=Bozote; Source: Unpublished Annual Technical Report (2014-15, NR010)

Potato

The IPNM included recommended fertilizer application with humic acid (HA) on the yield of potato. Results show that tuber yield increased with application of HA, it was observed that maximum yield of 23.46 t ha^{-1} was recorded with application of HA@40 kg ha^{-1} and the corresponding fertilizer reduction rate @ 75% of recommended rate (Table 10). The minimum tuber yield was recorded in the control treatments where recommended dose of NPK was used. The applied HA increased the yield about 26% vis-à-vis controls on overall basis. The yield increase with different fertilizer treatments ranged from 10-22% and these results show that soil application of plant derived HA was more effective as compare to foliar feeding in potato crop to realize potential yield. Besides tuber yield, the integrated plant nutrients also increased macro and micronutrients concentration in potato.

Table 10. Effect of Humic Acid on Potato Tuber Yield under Field conditions

	Yield (kg/ha)	%Increase over control
Full dose (NPK)	18.86[c]	
75% NPK+CDHA	21.02[b]	11
75% NPK+PDHA	21.16[b]	12
75% NPK+CDHA+MN	22.41[a]	19
75% NPK+PDHA+MN	23.04[a]	22
75% NPK+CDHA (Foliar)	20.79[b]	10

RP= Recommended Practice; PDHA= Coal derived Humic acid; CDHA=Coal derived Humic acid; MN=Micronutrients; FS= foliar spray; Khan et al. (2017)

Besides tuber yield, the integrated plant nutrients also increased macro and micronutrients concentration in potato.

Limitations of IPNS

Package of technology

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

Low availability of FYM

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

Limitations in use of green manuring

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

Limitation in use of crop residues

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

Limitation in use of biofertilizers

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

Conclusion

There was a large amount, worth 4.4 billion USD, of non-utilized bio-supply across Pakistan which could have complemented or replaced synthetic fertilizer use with largest bio-supply monetary values of 4.97 billion USD were associated with P and K. Recycling organic waste has been shown to increase yields and is compatible with other sustainable nutrient management practices.

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

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Chapter 4

Integrated Plant Nutrition System Modules for Major Crops and Cropping Systems in Bangladesh

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Introduction

Bangladesh is a lower middle-income country in South Asia. It is bordered by India on all sides except for a small border with Myanmar to the far southeast and by the Bay of Bengal to the south. Bangladesh is the 8th most populous country in the world with 165 million people in the country with population density of 1,118 person/km^2 and its area is 147,570 km^2.

Bangladesh is predominantly an agricultural country. Agriculture remains the most important sector of Bangladesh economy, contributing 14.75 percent to the national GDP and providing employment for 63 percent of the population (Bangladesh Economic Review, 2017). It is therefore important to have a profitable, sustainable and environment-friendly agricultural system in order to ensure long-term food security for people. The land area of Bangladesh is about 14.8 million hectares, of which net cropped land is 8.2 million ha and cropping intensity is 191% (Salahin, *et al.*, 2017). Rice is the staple food in the everyday diet of Bangladeshis. The production of rice, which can be harvested 2 or even 3 times a year, reached 34.7 million metric tons in 2016-17 (Bangladesh Economic Review, 2017). The production of wheat reached about 1.4 million metric tons in 2016-17. Both crops play an important role in achieving self-sufficiency in food production. The production of Maize was 3.6 million metric tonne in 2019 (Bangladesh Bureau of Statistics (BBS), 2019). According to preliminary estimate of BBS, in Financial Year 2016-17, food grains production stood at around 38.81 million metric tonnes. Jute, often called the "golden fibre" of Bengal, is the main export-earner for Bangladeshi agriculture, as Bangladesh remains the world's second-largest producer of jute (after India) and the world's largest exporter of fiber. Tea is grown in the northeast. Bangladesh stands in global production positions of (FAOSTAT, 2017): Rice – 4th, Vegetable- 3rd, Potato – 8th, Mango – 8th, Guava – 8th, Tea – 4th and Fruits – 28th.

Natural Resource Degradation

Bangladesh faces a number of environmental problems due to its geographical location and setting, high density of population, poor socio-economic development, inefficient resource management and institutional framework. A study on Bangladesh state of environmental has been able to identify five environmental issues on a priority basis as points of national concern. The identified key issues include land degradation (with impact on ecology and quality of life), water pollution and scarcity (impact on ecology and quality of life), air pollution (impact on environment and health), biodiversity (impact on ecology, development and quality of life) and natural disaster (impact on environment, development and quality of life).

Land degradation

The rapid population growth coupled with poverty, lack of proper land use and other driving forces, have led to over-exploitation of natural resources in Bangladesh. Land degradation varies according to regions, seasons and years due to the diverse nature of the driving forces and their subsequent causes. Land degradation in the flood plains is chiefly attributable to improper use of fertilizer and pesticides (Ali *et al*., 1997). In the coastal areas it is partly due to the nature of shrimp culture, which requires letting in saline water into emboldened shrimp beds. (Hossain and Majumder, 2018). Erosion of top soils in the hilly districts has increased (Khan *et al*., 2008). Excessive irrigation of agricultural lands may also contribute to soil degradation. Estimation of land degradation in Bangladesh has been presented in Table 1.

Table 1. Land degradation in Bangladesh

Types of land Degradation	Extent of land degradation	References
Soil erosion (Hilly areas)	1.7 Mha	SRDI, 2010 (GIS map)
Soil salinization	1.06 Mha	Ahsan, 2010
Soil acidification	3.96 Mha	SRDI, 2010 (GIS map)
Water-logging	2.6 Mha	Khan, 2011
Soil fertility depletion - Phosphorus deficiency - Potassium deficiency - Sulphur deficiency - Zinc deficiency - Boron deficiency	3.71 Mha 2.72 Mha 3.31 Mha 2.76 Mha 2.49 Mha	SRDI, 2010 (GIS map) SRDI, 2010 (GIS map) SRDI, 2010 (GIS map) SRDI, 2010 (GIS map) SRDI, 2010 (GIS map)
Arsenic contamination	3.0 Mha	Duxbury *et al*. 2007

Source: SRDI (Soil Resources Development Institute) (2010)

Table 2. Estimation of nutrient depletion in major cropping pattern

Major cropping pattern	Total yield ($t\ ha^{-1}\ yr^{-1}$)	Nutrient add			Nutrient uptake			Nutrient balance		
		N	P	K	N	P	K	N	P	K
		kg ha^{-1}								
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	+2	-105
Mustard-Boro-T. Aman	9.5	378	73	183	404	95	326	-26	-22	143
Potato-T. Aus-T. Aman	38	386	67	220	430	53	435	-44	+14	-215
Potato-Jute-T. Aman	36	380	70	240	385	55	496	-5	+15	-256
Mustard-Jute-T. Aman	7.5	340	70	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	190	55	150	210	60	320	-20	-5	-170

Source: (Nahar, *et al*.,2015)

Water pollution and scarcity

The seasonal/regional availability and the quality of surface and ground water highly influence the environmental as well as the economic growth and development of Bangladesh. Spatial and seasonal availability of surface and groundwater is highly responsive to the monsoon climate and physiographic of the country. Upstream withdrawal for consumptive and non-consumptive uses also influences availability. The surface water quality is affected by untreated industrial effluents, municipal waste water and run off from the surface of the agricultural lands treated with pesticides and chemical fertilizers. Pollution problems in the rivers close to the industrial areas are exceedingly high. For example: The dissolved oxygen (DO) level in the Buriganga has been found to be very low, and hence toxic. The level of arsenic contents in the ground water is of major concern in Bangladesh (Duxbury *et al*., 2007).

Biodiversity

Biodiversity in Bangladesh is significant. Rivers and inland water bodies support over 200 indigenous fish species and 150 species of birds. The marine water bodies harbour about 442 species of fish and 36 species of shrimps as well as significant number of crabs and turtles. The Sundarbans, one of the largest mangrove forests in the world, supports 300 species of plants, 400 species of fish and over 200 species of birds (DOE, 2015). It also serves as the feeding area of migratory birds during winter.

However, like other sectors of Bangladesh ecology, the diverse biological resources are also threatened by human intervention through destruction and degradation of land, denuded forest and aquatic habitats. The threat is most visible in the fisheries and forestry sectors. Forest areas already small to the proportion of the total land area, is being depleted by the combined pressure from timber extraction, encroachment by expanded agricultural activities and by the land grabbers. The forest area like Madhupur, which used to be the home of many species of flora and fauna, has thinned out significantly in recent years. Shrimp culture, owing to the method, has an adverse effect on soil condition, vegetation and crop production in the coastal area. These are mainly due to intrusion of saline water into the shrimp beds and deposition of suspended silt that comes along with the saline water (Ahsan, 2010). Overfishing under conditions of population pressures has depleted the fish resources.

Natural disasters

Bangladesh is widely known as a land of natural disasters. Between 1980 and 2018, it experienced more than two hundred natural disasters. The geographical location, land characteristics, multiplicity of rivers and the monsoon climate render Bangladesh highly vulnerable to natural hazards. The coastal morphology of Bangladesh influences the impact of natural hazards on the area. Bangladesh suffers from floods, cyclones, storm surge, river bank erosion, earthquake, drought, salinity intrusion, fire and tsunami. Cyclones and floods particularly caused massive damages. Cyclones occurred in 1970, 1991, 2007 and 2009 and killed 364,000, 136,000, 3,363 and 190 respectively (ADRC, 2019).

Soil Fertility Management

Organic Manure

Organic manures are composed of residues and wastes from plant and animal life. They contain much carbon and relatively small amount of plant foods, which have been time-tested materials for improving the fertility and productivity of soils. Organic manures, which are bulky in nature but supply the plant nutrients in small quantities are called bulky organic manure e.g. farmyard manure (FYM), poultry manure (PM), cattle dung (CD), compost, green manure (GM) etc. whereas those contain higher percentage of major plant nutrients like N, P and K are concentrated organic manures e.g. oil-cakes, blood meal, bone meal, fish meal etc.

Soil Fertility

In total there are 30 agro-ecological zones (AEZ) sub divided into 88 sub units and 536 units (Fig. 1) distributed throughout the country. The overall scenario of soil fertility status of most of the AEZs of Bangladesh is deficient in nitrogen, phosphorous, potassium, sulphur, zinc and boron. Successful crop production in different AEZs is therefore, depends on balanced doses of fertilizer with judicious application, so that sustainable crop production is possible keeping the soil health in good condition.

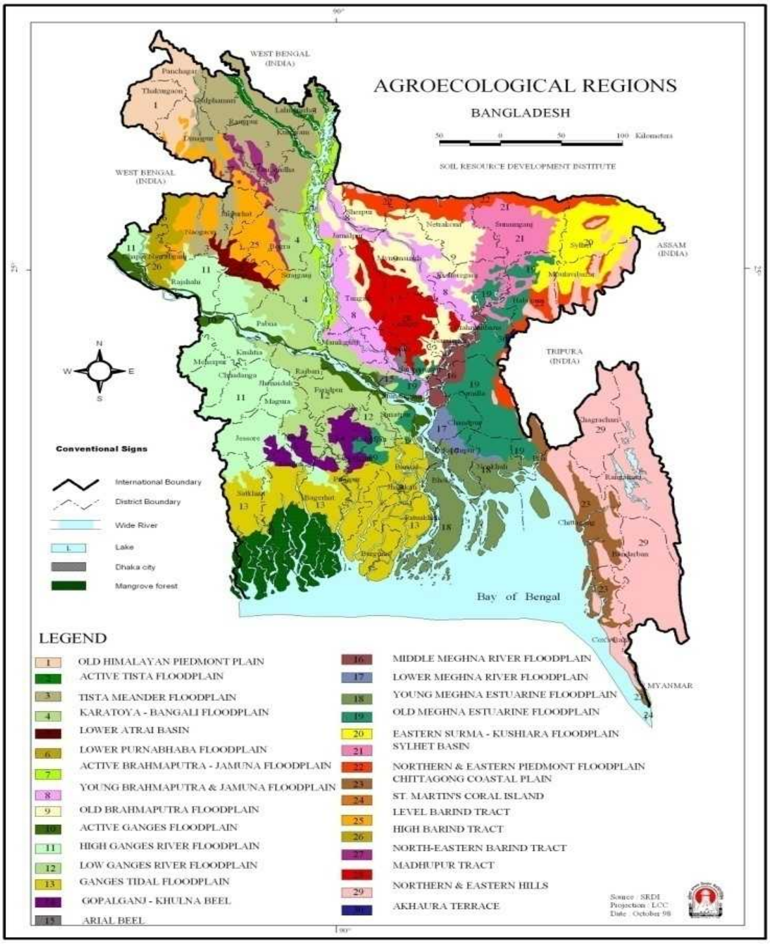

Fig. 1. Agro-Ecological Zones of Bangladesh

Nutrients flow and balance in farming system

The continuous recycling of nutrients into and out of the soil is known as the nutrient cycle, which involves complex biological and chemical interactions. A simplified version of this cycle of plant growth, based on Smaling (1993), and Rijpma and Jahiruddin (2004), is shown in Fig. 2.

Fig. 2. The Plant Nutrient Balance System

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

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

Soil Nutrients

Due to continuous and intensive cultivation, the nutrient supplying capacity of the soils is getting limited, as nutrient losses through crop removals, leaching, erosion and run-off. To enhance the soil nutrient supply, greater emphasis should be given to the following points:

- Appropriate soil management and conservation practices to reduce losses of nutrients;
- Amelioration of infertile soils through mobilizing of unavailable nutrients;
- Improvement of soil physical conditions to ensure maximum possible efficiency of applied nutrients;
- Introduction of a legume crop in the cropping system, since the major portion of the nitrogen requirement of legume will be met through fixation of atmospheric nitrogen, soil nitrogen will therefore be conserved and will be available to the accompanying non-legume crop or the succeeding crop;
- Other practices, like inoculation with phosphate dissolving micro-organisms which have shown promise in mobilizing unavailable soil phosphorus and making it available to the plants.

Mineral fertilizers

The fertilizer use efficiency can be increased by adopting the following (BARC, 2018):

- The scheduling of fertilizer recommendation based on the cropping system taking into account various components like the effect of the previous crop and its fertilization on the basis of fertilizer requirements of the succeeding crops/intercrop; contribution of legumes in the cropping system for nitrogen management; residual effect of applied fertilizers particularly of phosphorus;

- Identification of crops and soils where specific fertilizer material would be most efficient;
- Minimizing nutrient losses through appropriate time and methods of application;
- Correcting deficiencies of secondary and micronutrients;
- Improving all other production factors like water management, weeds, pests and disease control, etc.

Organic Resources

Application of organic materials to soils and their effect on improving their physical properties are well known. Increasing water-holding capacity and water content, aeration and permeability, soil aggregation and rooting depth, plant nutrient holding capacity, decreasing soil crusting and water/nutrient losses through surface runoff and protecting agricultural soil from erosion are just examples. The contribution of properly prepared organic manures and wastes to the nutritional requirements of crops and correcting their micronutrient deficits is another important and well-established advantage.

The organic resources available in many farms include:

- Cattle-shed wastes like dung, urine and litter (FYM);
- Crop-wastes/residues like sugarcane trash, stubbles, weeds, straws and spoilt fodder;
- Poultry-litter;
- Sheep and goat-droppings;
- By-products of agriculture-based industries such as: oilcakes, wastes from fruit and vegetable processing, press-mud from sugar factories, saw dust, rice husk and bran, cotton-dust from textile industries.

Biological Sources

There are two modes of nitrogen fixation: one is the recycling of nitrogen fixed by selected leguminous plants (*Sesbania* sp.) and their incorporation in the soil as green manures thus making the nutrients in it, particularly nitrogen available to the succeeding crop; the other is the nitrogen fixation through some symbiotic and non-symbiotic micro-organisms and making it available to the associated field crop.

Green manuring

Raising of quick growing leguminous plants and burying them after 45 to 60 days has been practiced to improve soil fertility. A leguminous green manure crop contributes about 30 to 40 kg N/ha for the succeeding crop.

Rhizobium inoculants

Rhizobium bacteria can fix atmospheric nitrogen in the nodule of legume crop. A legume in the cropping system, if suitably inoculated and supplied with 25-30 kg P_20_5/ha can meet about 80 per cent of their own needs of N through fixation. Additionally, it may show a residual effect to the extent of 20-25 kg N/ha on succeeding crop. When grown in inter cropping system they may also provide some nitrogen to the main crop.

Blue Green Algae and Azolla

Blue Green Algae (BGA) and Azolla are used in water logged rice fields for nitrogen fixation. If 12-15 tons of Azolla biomass per hectare is incorporated, 30-40 kg N/ha may be reduced for rice. BGA can add 20-30 kg N/ha for rice crop.

Other Micro-organisms

Azotobacter, *Azospirillum*, Mycorrhizae, etc. are also gaining importance. However, much more is yet to be known about them before their use can be advocated to the farmers.

Fertilizer demand-supply situation

The expansion of modern agricultural farming practices like use of High Yielding Variety (HYV) together with intensified cultivation is needed to ensure food for all, which led to an increasing demand for fertilizers. Therefore, it is necessary to ensure timely supply of fertilizers to meet the nutritional demand of these varieties. The use of chemical fertilizer is on the rise with the increasing demand for food production in the country. Farmers of Bangladesh use mainly single or straight fertilizers (Table 3). Among them-Urea-49.75%, TSP-13.93%, DAP-11.94%, MoP-17.31% of the total fertilizer use. Gypsum, ammonium sulphate, zinc sulphate, boric acid, magnesium sulphate and potassium sulphate account for the rest.

Table 3. Use of chemical fertilizers in Bangladesh during the last five years (in '000'metric ton)

Year	*Urea*	*TSP*	*DAP*	*MoP*	*Gypsum*	*Zinc sulphate*	*Ammonium sulphate*	*Others (NPKS, SOP, $MgSO_4$)*	*Total*
2014-15	2700	725	675	700	130	50	20	200	5200
2015-16	2800	750	700	750	130	50	20	200	5400
2016-17	2500	750	700	700	150	50	20	200	5070
2017-18	2500	650	850	850	150	50	20	200	5270
2018-19 (Proposed)	2550	700	900	850	150	50	20	200	5420

Source: BFA (Bangladesh Fertilizer Association 2019)

Domestic production of fertilizers

In Bangladesh, urea, TSP and DAP are produced in the local industries, which can partly meet the total demand of the country. At present there are six urea, one TSP and one DAP 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 2600,000 tons of urea, 12,000 tons of ammonium sulphate, 65,000 tons of TSP and 50,000 tons of DAP. About 60,000 phosphogypsum is produced as a byproduct from

TSP factory. There are more than 50 small zinc sulphate manufacturing factories in the country. These factories can produce 10-12 thousand tonnes granular monohydrate and crystalline heptahydrate zinc sulphate

Fertilizer import

Additional requirements of urea and TSP are met from import. All MoP and DAP are imported.

Table 4. Fertilizer use, domestic production and import situation in 2017-18 (in '000'metric ton)

Types of Fertilizer	*Total use*	*Actual production capacity*	*Domestic production*	*Import*
Urea	2500	2600	784	1716
Ammonium sulphate	20	12	-	12
DAP	850	50	-	850
TSP	650	65	10	640
MoP	850	-	-	850

Source: BFA (Bangladesh Fertilizer Association 2019)

Fertilizer pricing and subsidy

In Bangladesh, price of fertilizer is an administered price for the last twenty years. During this period, the costs of major fertilizer import were higher than the selling price. Bangladesh government provide subsidy in urea, TSP, MoP and DAP. No subsidy provided to micronutrient containing fertilizer and organic fertilizer (Alam, 2018). Bangladesh government provide subsidy of 15,835 Tk./MT in urea, 16,000 Tk./MT in TSP, 25,000 Tk./MT in DAP and 16,000 Tk./MT in MoP. On an average, Bangladesh government provide 44.44 to 53.33% subsidy in imported fertilizer.

Strategy to address Soil Health

Bangladesh government has several schemes to address soil health:

Promote soil analysis facility

Government encourages farmers to test soil. There are about 25 static laboratories and 10 mobile vans for testing soil at cheaper rate.

Upgrade fertilizer recommendation guide

Bangladesh Agricultural Research Council (BARC) published Fertilizer Recommendation Guide in the year 2018 upgrading information of fertilizer recommendation of different crops.

Use of upazila (sub district) Nirdeshika for fertilizer recommendation

Soil Resources Development Institute (SRDI) develops upazila (sub district) Nirdeshika where fertilizer recommendations based on soil fertility are provided at block level.

Promoting soil test based fertilizer recommendation

Government encourages farmer to promote soil taste based fertilizer recommendation instead of package fertilizer recommendation through field demonstration.

Implementing Integrated Crop Management (ICM) project for improving soil fertility

Department of Agriculture first implemented Sustaining Soil Fertility Project (SSFP) during 1995-2005. then implemented Integrated Nutrient Management (INM) project. Now implementing Integrated Crop Management (ICM) project, where the main objective is to restore soil fertility and crop productivity.

Make separate policy for organic agriculture

Bangladesh Government made separate policy for organic agriculture, where use of all chemical inputs is restricted, only organic inputs can be used. Use of organic fertilizer improves soil fertility.

Promoting organic fertilizer license

Government already provide license to 80 small and large private companies to sale organic fertilizer.

Subsidizing price of chemical fertilizer

To reach the price of chemical fertilizer in farmers hand, government provide subsidy in chemical fertilizer. About 44.44 to 53.33% subsidies are provided in imported urea, TSP, MoP and DAP.

Promote N-P-K-S mixed fertilizer

Farmers of Bangladesh are using more urea, as it is cheap and its response is fast than TSP, MoP. As a result, P and K are depleted more than N. Promoting N-P-K-S mixed fertilizer, balanced fertilizer are applied and N-P-K balance are improved.

Agricultural credit for agricultural input

Different banks provide agricultural credit for purchasing agricultural input like fertilizer, organic manure at low interest.

Integrated Plant Nutrition System Approach

Integrated Plant Nutrition System 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 are used according to the local ecological conditions, land use systems and the individual farmer's social and economical conditions. For this, the cropping pattern and whole of farming system should be considered rather than a single crop and the individual field. Before establishing the need for mineral fertilizers, it should be assessed what is available and what is the plan nutrient value of FYM, crop residues, compost and other organic material. Before preparing a balanced fertilizer plan, proper crop rotation, crop diversification, and the use of the green manure like dhaincha (sesbania) and the use of BNF should be taken into consideration. The elements of IPNS are from natural (soil supply, water supply, deposition by rain or dust), organic (crop residues, green manure, nitrogen fixation, organic manure, organic waste) and mineral (inorganic fertilizers).

Integrated Plant Nutrition System Modules for Major Crops and Cropping Systems

Computation of IPNS

First an assessment should be made of the possible plant nutrient and organic matter sources available within the farming system. Then, it should be assessed what are the approximate plant nutrients, nutrient content and nutrient release. Some assessment of the soil fertility status in the field can be made, using the information available with the farmers from the field and possible soil sample test 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 without fertilizer.

Together with the farmer, a realistic yield target should be set, taking into account the resources, possible risks, etc. Then, the question remains how best to complement the shortfall between targeted plant nutrients 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.

IPNS technology for major crops and cropping systems

Cowdung, poultry manure and vermicompost are widely used organic fertilizer in Bangladesh.

Cowdung

Cowdung is widely used organic manure which is comparatively cheap and available in Bangladesh. About 30 million cow present in Bangladesh producing about 0.45 million tons cowdung (fresh weight basis) every day. In dry weight basis, total 131 million tones of cowdung produced every year in Bangladesh. Cowdung contains about 1.0% N, 0.3% P and 0.45% K. Considering mineralization; 1 ton cowdung supplies 5 kg N, 1.5 kg P and 2.3 kg K.

Poultry manure

Poultry manure (PM) is a product of poultry dropping and litter, which contains high value of plant nutrients when the dropping boards are cleaned every morning and the birds bedded with straw changing every fortnight intervals. This is rich organic manure since liquid and solid excreta are exerted together resulting in no urine loss. The dropping and litter are preserved in suitable pit or enclosure, and should be protected from water and sunlight. About 250 million poultry bird produces 37.5 thousand metric tonne poultry manure (fresh weight basis) every day. The droppings (fresh) contain on an average 1.6% N, 1.8% P_2O_5 and 0.8% K_2O. Poultry manure can be used for successful crop production of vegetable fruits and cereal crops.

Vermicompost

Vermicompost refers to organic manure produced by earthworms. It is a mixture of worm castings (faecal excretions), organic material including humus, live earthworms, their cocoons and other organisms. Vermicompost is one of the best ways to dispose the wastes because of its capacity to reducing the wastes as well as to remediate and amend the soil. The potential of some epigeic earthworm to recycle organic waste materials into value-added products is well documented. The end product, the vermicompost is considered as an outstanding product, since it is homogenous, desirable aesthetics, reduced levels of contaminants and tends to hold more nutrients over a longer period without impacting the environment. Vermicomposting is gaining popularity in rural Bangladesh as the technology is simple, viable and cost effective. More than ten thousand vermicompost producing industries of both small and large are running in the country.

Some of the popular IPNS based fertilizer recommendations for different crops and cropping systems are presented in Tables 5 and 6.

Table 5. IPNS based fertilizer recommendation for different crops (Land type: Medium High Land; Soil fertility: High; Rainfed/Irrigated: Irrigated)

Crop	Yield target (t ha^{-1})	Inorganic fertilizer (kg ha^{-1})						Organic fertilizer (kg ha^{-1})		
		Urea	TSP	MoP	Gypsum	Zinc sulphate	Boric acid	Cowdung	Vermi compost	Poultry manure
Boro rice	4.0-5.0	130	30	44	35	1.5	-	5000		
T.Aman rice	3.5-4.0	120	25	36	28	3	-	4000		
Wheat	4.5-5.0	155	100	120	40	3	1	4000		
Maize	8-9	285	180	150	90	5.5	2	5000		
Potato	25-30	150	160	240	80	12	1		5000	
Cauliflower	30-40	220	150	160	100	12	7		5000	
Cabbage	70--80	300	160	180	100	12	7		8000	
Brinjal	30-40	250	180	250	80	12	7	5000		
Tomato	75-80	280	220	240	80	12	7	5000		
Chilli	10-15	180	200	160	80	12	-			4000
Carrot	25-30	170	150	175	80	10	-			4000
Radish	30-40	270	160	160	80	12	-	5000		
Indian spinach	30-35	280	80	75	80	12	-			4000
Onion	10-12	260	160	130	60	15	-	4000		

Source: BARC (Bangladesh Agricultural Research Council 2018)

For cereal crops (rice, wheat, maize) cowdung application is better as it is the cheapest source of organic manure pricing 1 taka/kg and price of cereal crops are always low compared to vegetables. For vegetable production, costly organic manure like vermicompost (price: 10 taka/kg) and poultry manure (price: 3 taka/kg) along with cowdung can be used. Vermicompost and poultry manure supplies more nitrogen, phosphorus and potassium compared to cowdung and thereby required less quantity of chemical fertilizer.

Table 6. IPNS based fertilizer recommendation for different cropping systems (Land type: Medium High Land; Soil fertility: High; Rainfed/Irrigated: Irrigated)

Cropping System	Yield target (t ha^{-1})	Inorganic fertilizer (kg ha^{-1})						Organic fertilizer (kg ha^{-1})		
		Urea	TSP	MoP	Gypsum	Zinc sulphate	Boric acid	Cowdung	Vermicompost	Poultry manure
Wheat-	3.0-4.0	155	100	120	40	3	1	4000		
Mungbean-	1.2-1.8	40	-	-	-	-	-	-		
T. Aman	3.5-4.5	120	25	36	28	3	-	4000		
Mustard-	1.7-1.9	150	80	100	40	3	1	3000		
Mungbean-	1.2-1.8	40	-	-	-	-	-	-		
T.Aman	3.5-4.5	120	25	36	28	3	-	4000		
Potato-	25-30	150	160	240	80	12	1		5000	
Mungbean-	1.2-1.8	40	-	-	-	-	-	-		
T.Aman	3.5-4.5	120	25	36	28	3	-	4000		
Potato-	25-30	150	160	240	80	12	1			4000
T. Aus-	3.0-3.5	100	20	32	24	-	-	-		
T.Aman	3.5-4.0	120	25	36	28	3	-	4000		

Source: BARC (Bangladesh Agricultural Research Council 2018)

More than 300 cropping patterns exist in Bangladesh, among these patterns above mentioned four are the major cropping patterns. Cropping pattern with a legume crop like mugbean required less quantity of chemical fertilizer as some of the requirements of the pattern are supplied by biomass of mungbean when incorporated in the soil. Organic manure should be applied twice a year (rabi and kharif-2 season) and it will supply nutrient for the whole cropping cycle. Vegetable crop pattern like Potato-Mungbean-T.Aman required more organic manure with high nutritional value (example vermicompost and poultry manure). Considering cost-benefit, low cost organic manure like cowdung can be applied in cereal based cropping patterns (Wheat-Mungbean-T. Aman and Mustard-Mungbean-T. Aman).

Policy/Research-Extension/Farmer Linkages

The following points are crucial to strengthen policy/research-extension/farmers linkages and effectively implement IPNS technology:

- Strengthened public-private sector linkages in research and technology transfer to improve farmer knowledge on IPNS concept;
- Strengthened the role of fertilizer dealer to support IPNS technology transfer to farmers;
- Extend financial service providers facilities to improve farmers' loan provisions about IPNS technology;
- Build strong linkages with national and international agriculture research centers to upgrade research programs on soil-fertilizer-crop research;
- Public and private sector linkages with NGOs about fertilizer and soil fertility;
- Strengthened public and private sector risk mitigation systems for fertilizer quality to prevent fertilizer adulteration.

Soil Fertility Management for Food Security

Bangladesh has been mostly successful in attaining food security notwithstanding some deficiency in nutritional target. Sustainable agriculture system must be built on an approach that will explore connection between farming and other aspects of social, economic and ecological environment. Organic farming along with use of crop residues, compost, and animal waste has been popularized but need more effort. Considering the increasing demand for food production, it is an essential task to use agricultural inputs judiciously. Fertilizer is one of the critical inputs required for increasing crop production. The expansion of modern agricultural practices together with intensified cultivation had 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 and excessive mining of plant nutrients resulting in the decline of soil fertility on the one hand and reduction in the potential yield on the other. Emphases are given for the production of bio-fertilizers and facilitating their increased use. Rebalancing of fertilizer subsidy to encourage balanced use of fertilizers had given some results. It is, therefore, important to adopt pragmatic measure to encourage farmers using balanced fertilizers to maintain soil fertility.

Challenges of Soil Fertility Management

The major challenges of soil fertility management are listed below:

Geographical and climatic condition of Bangladesh

Bangladesh is a subtropical country prevailing hot and humid weather around the year (Alam *et al.*, 2014). Due to high temperature and high rainfall, organic matter rapidly decomposes. As a result, soil fertility decline.

Effect of climate change and global warming

Due to rise in temperature, soil organic matter is decomposing more rapidly which cause deficit in soil plant nutrient.

Soil erosion and salinazation

Soils are degraded due to increase soil erosion in hilly areas. As a result plant nutrient are eroded. More salinization occurred in coastal area due to intrusion of saline water in crop field. Due to high osmotic pressure, crops are unable to uptake nutrients and thereby die.

Soil Pollution and acidification

Soil adjacent to industrial area often exposed to discharge of effluents from industries. These effluents contain toxic heavy metal, which pollute soil. Due to high use of nitrogenous fertilizer like urea, DAP and ammonium sulphate, soil acidity is increasing. On the other hand, liming is not properly done and as a result, soils becomes more acidic and nutrient availability decreases.

Soil Compactness and nutrients balance

Due to puddling, a hard pan formed in most of rice soils, which restricts root to penetrate for uptake of required nutrient. Farmers in Bangladesh applying more urea than TSP and MoP. As a result more P and K are depleted than N and thereby creating imbalance of N-P-K balance.

Water logging

Water logging areas of Bangladesh are increasing. Due to submergence, micro-nutrient deficiency occurred resulting in decline of soil fertility.

High cropping intensity

In Bangladesh, average cropping intensity stood 191%, this indicates more than two crops in a year in a same piece of land. As a result more nutrienst are depleted from soil.

Less application of organic fertilizer

Price of organic fertilizers is comparatively high as it is not subsidized. Farmers use less or no organic fertilizer in the soil, which result in decline of soil fertility.

Lack of incorporating legume crop in the pattern

Soil fertility will improve, if legume crops incorporated in the pattern. In Bangladesh, there are more than 100 cropping pattern, of them only 18 are legume based. As a result, most soils are deficit in plant nutrients.

Potential and Constrains of IPNS technology

Potential

The following points are some of the potential measures to strengthen IPNS program:

Promote effective and environmentally sound management of plant nutrients

- The balance and efficient use of plant nutrients from both organic and inorganic sources should be emphasized, at the community levels. Use of local sources of organic matter and other soil amendments should be promoted. Success cases of integrated plant nutrient system should be analyzed, documented and disseminated to the farmers;
- Innovative approaches to support and promote IPNS should be pursued.

Improve database, research, monitoring and extension for effective adoption

- Participatory forms of design, testing and extension of improved IPNS strategies that build upon local institutions and social organizations, including trained farmer groups, should be promoted;
- Further research should be undertaken on location specific appropriate IPNS system for different crops, cropping patterns by integrating inorganic fertilizers, organic manures, green manures, crop residues etc., which would be agronomically, economically suitable and environmentally sound;
- A comprehensive data base needs to be developed for all mineral and organic sources of nutrients, including their amount, composition, processing techniques, economic value and their availability;
- The impact of micro and macro economic policies on IPNS should be evaluated;

- A network of benchmark sites on representative farmers' fields in major farming systems should be developed to monitor the stocks and especially the flow of plant nutrients.

Support complementary measures to lower the costs of fertilizers, recycle urban wastes, secure land tenure and increase production capacity

- Ways and means should be sought to lower fertilizers price at farm gate and to reduce the farmers' perception of the risk in the use of fertilizers;
- Recycling of pollution free organic urban waste into the wider peri-urban agricultural sector should be promoted, as this waste constitutes a significant source of plant nutrients;
- Investment in production capacity of mineral and organic fertilizer industries should be increased;
- NGOs involvement is also required for effective simulation of the use of plant nutrient inputs, with appropriate monitoring by the government for effective, equitable and pollution-free distribution of these inputs.

Constraints

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

- Farmers often have inadequate knowledge and funds, which led them to wrong purchase and application of fertilizers, even though most of the farmers are aware of fertilizers, but do not use it in balanced proportion;
- Linkage and interactions among researchers, extension services and NGOs personnel are weak;
- Degradation of lands due to intensive cropping and /over exploitation because of the enormous pressure from the ever increasing population;
- Risk of water deficit at drought prone period is considered the most important deterrent to fertilizer use;

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

Conclusion

Bangladesh is one of the most densely populated countries in world with very low per capita cultivable land. It has to produce huge quantity of food from small piece of land to feed large number of population. Hence, it is very important to restore soil fertility and increase crop productivity. Chemical fertilizer alone cannot restore soil fertility and provide sustainable crop production without the use of organic fertilizers. On the other hand, it is not possible to increase crop production by applying only organic manures. Therefore, integration of organic manure with chemical fertilizer can improve soil fertility and sustain crop productivity. Department of Agriculture has introduced IPNS approach many years ago. Lack of knowledge about balanced fertilization, no subsidy on organic manure in contrast to highly subsidized chemical fertilizer, lack of attempt to recycle organic waste are the major constrains to promote IPNS technologies in Bangladesh. Adequate training about imbalance fertilizer and IPNS approach, subsidy in organic manure and promote composting technology to convert organic waste to manure can strengthen implementation of IPNS technologies in the country. IPNS approach can enhance food production and ultimately gear towards achieving food and nutrition security in Bangladesh.

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Chapter 5

Integrated Plant Nutrition System Modules for Major Crops and Cropping Systems in Bhutan

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Introduction

Bhutan is a small landlocked mountainous country located in the southern slopes of Eastern Himalayas. The country has a total geographical area of 38,394 km^2 with a population of 727,145 people (NSB, 2018). The forest cover of the country is about 70.46%, arable land 2.93%, meadow land 4.10%, shrub 10.81%, snow cover land 7.44% and bare areas 3.20% of the total geographic area. Out of the total arable land, 27.86 % is wetland, 61.90% is dry land, 10.24% is under horticulture (LCAR, 2010). It is estimated that 57.2% of the population is engaged in Agriculture Sector (LFSR, 2016). In 2017, agriculture sector contributed about 15.17% of the total Gross Domestic Product of the country (NSB, 2018). Rice, maize, potato, apple and citrus are the major cereal horticulture crops cultivated in Bhutan.

Bhutan is an agriculture-based society and most of the farmers are small and marginal. Farming is mainly subsistence based on traditional knowledge with relatively low amount of agriculture inputs. Farm households are scattered in remote villages and each village comprises of a dozen to hundred households on average. The average cultivated agriculture land holdings are 2.22 acres per household (PHCB, 2017). Farming in Bhutan is difficult and labor demanding because of small land holding sizes on steep slopes with limited prospect for any farm mechanization (Dorji, 2008). Majority of the Bhutanese farmers continue to practice self-sufficient, integrated agricultural production system growing a variety of crops under different farming practices for food security (Katwal, 2013).

Although agriculture is one of the most important sectors of the Bhutanese economy, it faces lot of challenges basically less public investment, loss of agriculture land for other development, lack of infrastructure such as irrigation and post harvest storage, labor shortages, rural urban migration, human wildlife conflict and lack of credit opportunities (MoAF, 2014). Despite such challenges, agricultural practices have changed tremendously over the years. With road connectivity and better communication facilities in the country, there is an increasing tendency of farmers opting for cash crops like apples, oranges, areca nut, cardamom, ginger, chilies and vegetables (NSB, 2018). Improved technologies are disseminated such as high yielding crop varieties, plant protection chemicals, inorganic fertilizers (Dorji, 2008), farm mechanization, construction of irrigation channel to increase food productions.

Natural Resource Degradation

Land Degradation

Bhutan lies in the foothills of the Eastern Himalayas and because of its rugged topography and altitude the land resources are at risk from the various types of land degradation that occur in Bhutan (Dorji *et al*. 2006). Different types of land degradation which are common in Bhutan are illustrated below:

- *In situ Degradation*- The common in-situ land degradation in Bhutan is hard crust formation especially on top soil that severely limits permeability and subsoil hardening. Both tend to make soils more liable to erosion (Dorji *et al*. 2006).
- *Degradation involving removal of soil* - Wind erosion is extensive in Bhutan especially when the fields are kept bare. Although it is difficult to quantify, the erosion is assessed as being quite substantial and contributing to lowering the soil fertility by removing the fertile topsoil (SSU, 2005).
- *Degradation Involving removal of soil and weathered rock by water*- Splash erosion is quite extensive in Bhutan especially in the pre-monsoon season between meadow preparation and emergence of crop seedlings, and after harvest of the crops when the fields are

kept bare. With bare field, the heavy rain showers cause splash erosion which leads to sheet erosion and sheet erosion to rill erosion removing the fertile topsoil (Dorji *et al*. 2006).

Land Degradation Mitigation

Different land management campaigns such as establishment of hedgerow, bench terracing, stone bunds, check dams, basin making, water source protection, plantation of fruit trees, orchard establishment and legume cropping has been implemented in land degradation prone areas. In the 11th Five Year Plan (FYP), 4,530 acres of agriculture land was developed, 7,321 acres of land was put under sustainable land management and 120 acres of fallow land was bought under cultivation (DoA, 2019)

Climate Change

Climate change in Bhutan largely endangers the agrarian population that depends on subsistence agriculture for their daily livelihood; the farming society is the most susceptible group as farm productions are highly reliant on climate change. Already recurrent landslides and extended dry periods and unprecedented heavy monsoon rain affecting agriculture are visible. The main cash crops of the farmers such as rice, potatoes, chilies, apples and oranges are highly sensitive to water and temperature variations. Dry land crops such as wheat, buckwheat, maize and barley are entirely dependent on rainfall thus making it even more vulnerable to climate risks (MoAF, 2014).

To combat climate change, Bhutan embarked on National Adaptation Programme of Action (NAPA). The project focused on lowering the threats posed by glacial lake through artificial lowering of the lake's water level, addressing the risks posed by climate induced threats like floods, landslides through building national and local capacities for effective actions and building the resilience of the agriculture and forest systems in Bhutan.

Water Pollution

The water pollution is becoming a concern in Bhutan due to increasing urbanization, intensification of agriculture and livestock, population growth, industrial upsurge, prevalence of natural casualties and other activities (Dorji, 2016). The capital city alone in 2011 produced about 60 tones of solid waste daily which was about 21,900 tones in a year. The Royal Government of Bhutan approved water flagship program to be implemented within 12th FYP. The program aims to embark on construction of new water supply schemes, rehabilitation of existing water supply schemes, water source protection and water quality testing and surveillance.

Biodiversity

Bhutan has rich biological diversity due to its geographical location and landscape in the Eastern Himalayas. Bhutan has extensive range of ecological zones and has one of the highest species density in the world. It has an area of 16,396.4 km2 (51.40%) of the country under protected areas, 24 globally threatened species and 182 species of butterflies categorized as rare and threatened (NEC, 2016).

Gender and Agriculture

The agriculture sector employed higher proportion of women (62.8%) than men (32.6%) (LFSR, 2016), this is basically due to community anticipation, inheritance pattern as woman are responsible for house and farm chores and less metropolitan sector skills add to the fact that mostly woman are engaged in agriculture sector. Besides formwork, women are engaged in providing care activities such as housekeeping, food preparation, fetching water and wood. Investing in improving smallholder agriculture would help women more than it would in most other areas of investment. If the investment is carefully targeted, the gender benefit can be considerable (MoAF, 2014).

Soil Fertility Management

As in any other farming system, soil fertility is basic to the productivity and sustainability of farming in Bhutan. Conventionally, soil fertility management (SFM) has been based mostly on the use of animal manures through either tethering of animals in fields or the use of farmyard-manure. The traditional labor exhaustive soil fertility management systems are based on the integrated use of the forest as a resource of fodder and leaf litter, livestock for dung, and crops as supply of crop residues (Norbu & Floyd, 2001). The sustainability of the traditional SFM system is very much reliant on the domestic labor accessibility and farm animal number and management system. Farm labor deficiency, less farm animal size and increasing distance to forests for leaf litters are becoming more evident threatening the sustainability of the SFM system.

The use of chemical fertilizers has changed the SFM practice to a certain level. The current SFM practice therefore involves Integrated Plant Nutrition Systems (IPNS) modules using some chemical fertilizers along with the organic sources of plant nutrients. The use of chemical fertilizers has increased largely with the socio-economic development. However, total quantity of chemical fertilizer use is low compared to the global level, but households are increasingly depending on these fertilizers (Norbu & Floyd, 2001) particularly on commercial crops such as potato, apple and maize. Under the current SFM system, in general, farmers apply about 5 to 7 tons of Farm Yard Manure (FYM) per hectare of cropped land which corresponds to 1.38% Nitrogen, 0.29% Phosphorus, 1.97% Potassium and 2.35% Calcium (nutrient calculation from 50% dry matter of FYM) (RNRRC Bajo & SSF&PNM Project, 2001) equivalent to 41 kg N/ha, 9 kg P/ha, 59 kg K/ha and 71 kg Ca/ha of cropped land. The amount of nutrients added through FYM alone is insufficient to ensure high yields and therefore inorganic fertilizer supplement is necessary (Dorji, 2008). The national averages (Table 1) of the yields of various crops are still very low as compared to those from many other countries.

Table 1: Productions of major crops, 2017

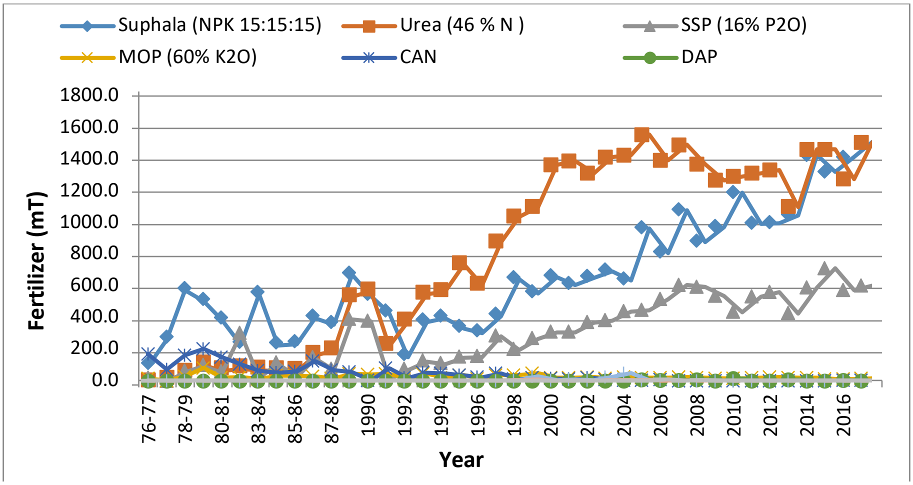
Crop	Harvested area (ha)	Production(MT)	Yield
Rice	20,788.34	86,385	4.155 t/ha
Maize	26,726.43	94,052	3.519 t/ha
Wheat	2,128.30	3,833	1.801 t/ha
Potato	5,189.80	57,223	11.02 t/ha
Apple	2,58,215	8,039	31 kg/tree
Citrus	8,64,608[1]	28,017	32 kg/tree

Source: MoAF 2017

Chemical Fertilizer

Bhutan started importing chemical fertilizers since 1960s and its use has been an important component of agricultural development strategy as inputs to increase crop yields and production. The fertilizer import statistics indicate an increasing tendency mainly due to their increased availability with the improvement in road network and better distribution systems; efficient promotion of their use through district extension programmes; and their efficiency to provide substantial and cost effective yield increases. Currently, no one including private companies is allowed to import chemical fertilizers and there is only one agency; National Seed Centre (NSC) authorized to import chemical fertilizers. The centre has trained network of Agriculture Sales and Service Representatives (ASSRs) across the country who are authorized to sell fertilizers directly to the farmers/clients. The NSC fix the rate of the chemical fertilizer and the ASSRs sell the chemical fertilizer at the same rate across the country. The Government provides transportation subsidy from the NSC fertilizer store to the ASSR sale point in all districts.

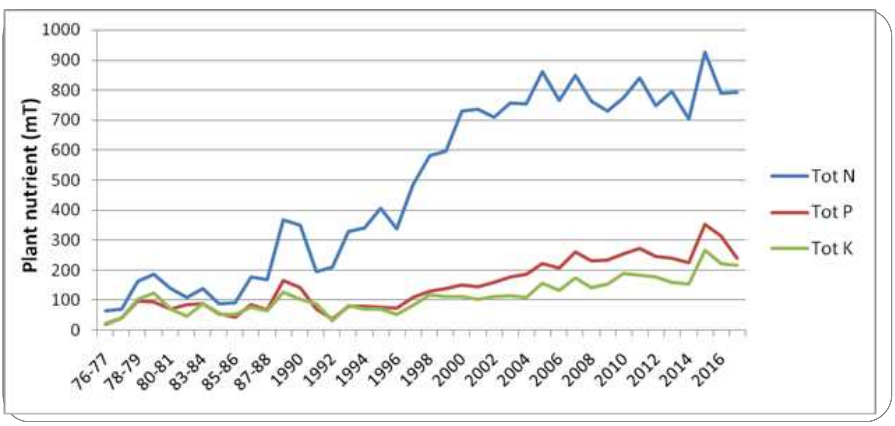
The import of chemical fertilizers increased from about 250 MT in 1960s to 2,998 metric tones in 2006 (Dorji, 2008). In 2017, highest amount of chemical fertilizer totaling to 3,634.8 metric tones was distributed which corresponds to about 45.03 kg of fertilizer per hectare of cropped land. Currently, farmers mostly prefer urea (46% N), suphala (15-15-15) and single super phosphate (16% P2O5). Fertilizers are generally applied more in cash crops such as potatoes and apple which are exported outside country. Within the four regions in the country, fertilizer distribution is highest in the west central region (30%) followed by western and eastern region (27%) and then by east central (16%).



Source: National Seed Centre, 2018

Figure 1: Type and quantity of chemical fertilizer distribution by calendar year (1977-2017)

According to Dorji (2008), about 50% of the in-country fertilizers are applied in potatoes, 25% in apples, 9% in paddy and 13% of fertilizers are applied in other crops like maize, wheat and buckwheat. The fertilizer nutrient based consumption pattern is illustrated in figure 2. The ratio between N and P, K was 3:1:1 in early 1990 to 7:1:1 in 2005 (Dorji, 2008). The NPK ratio at the national level is recorded at 3.8:1.4:1 for the year 2017-2018. The gap between N, P and K has narrowed due to use of compound fertilizer such as suphala in the country.



Source: NSSC, 2019 (soil fertility strategy-unpublished)

Figure 2: Distribution of plant nutrient (N, P2O5, K2O) by year

Soil Nutrient Status

In total 1,891 samples from across twenty districts were analyzed and compiled to know the current soil fertility status. The available data provide information on the general trend of soil fertility. The overall soil nutrient statuses of the soils are as follows:

- Although almost all soils had low pH. However, most of the soils are above pH level 5.5 where nutrients are moderately available to plants;
- The nitrogen levels are low to medium but the total organic carbon levels and organic matter are adequate with most of the soils having rating above low level;
- Almost half of all samples had low phosphorous (P), potassium (K) and exchangeable basses. According to Norbu & Floyd (2001), low available P is of greatest concern as soil parent materials are generally K rich. Decreasing the use of FYM and/or absence or inadequate P fertilizers application could deteriorate the soil P status;
- More than half of the samples had cation exchange capacity (CEC) rating above low range. It is good indication for agriculture/horticultural crop production since the soils with good CEC rating is considered fertile;
- C: N ratio is medium to low range which is within moderate to good ratings for nitrogen mineralization usually good for agriculture;
- The Base Saturation percent (BS%) is within very low to low in most soils across country;
- The soil nutrient for different land types shows that the dry land soils have a higher soil nutrient status rating.

Farming System in Bhutan

Based on altitude, Bhutan is classified into six agro-ecological zones (AEZ) as shown in Table 2. These AEZ divisions define the country's eco-floristic zones and agricultural ecosystems; each zone has comparatively different flora cover and agricultural practices. The AEZ divisions are wet sub-tropical, humid sub-tropical, dry sub-tropical, warm temperate, cool temperate and alpine. They do not associate directly with the division into physiographic regions (the Southern Foothills, Inner Himalayas, and High Himalayas) although the division is similar.

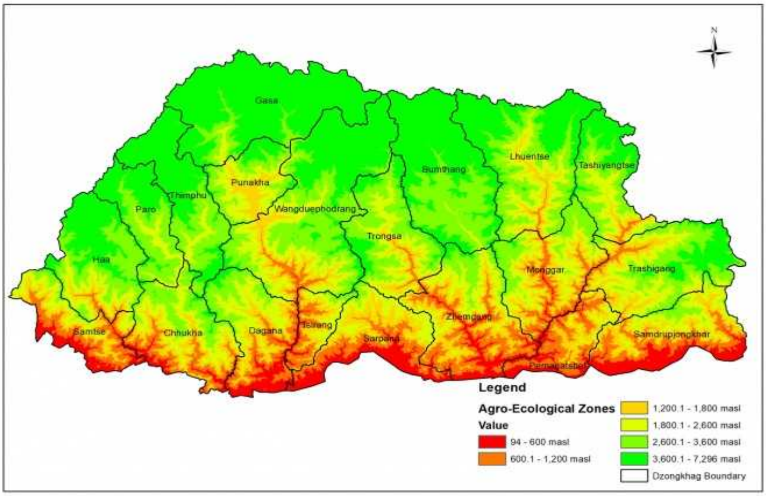


Figure 3: Six Agro-Ecological Zones of Bhutan

Table 2: Major agro-ecological zones farming practice of Bhutan

Agro-Ecological Zone	*Altitude (meters)*	*Temperature (degree Celsius)*			*Rain fall (mm per year)*	*Major crops grown*
		Monthly Maximum	Monthly Mean	Annual Mean		
Alpine	3,600-7,296	12.0	-0.9	5.5	<650	Wheat, Potato, Buckwheat, Mustard, Barley, Vegetables
Cool Temperate	2,600-3,600	22.3	0.1	9.9	650-850	Vegetable, Potato, Buckwheat
Warm temperate	1800-2600	26.3	0.1	12.5	850-1,200	Rice, Wheat, Potato, Vegetables, Apple
Dry Sub-Tropical	1200-1800	28.7	3.0	17.2	850-1,200	Mustard, Pulses, vegetables
Humid Sub-Tropical	600-1200	33	4.6	19.5	1,200-2,500	Rice, vegetable, pulses, Citrus
Wet-Subtropical	94-600	34.6	11.6	23.6	2,500-5,500	Rice, Vegetable, Citrus

Source: MoAF, 2017.

Bhutan is mountainous country with arable land on sloppy area which inherently exhibit low soil fertility due to high erosion prospective, restricted soil depth, and poor parent material. In spite of low fertility problem, farmers produce rationally good crop yields with negligible inputs of chemical fertilizers as source of plant nutrient. Obtaining good crop yields with non-significant chemical fertilizer inputs is only possible due to the continuous flow of plant nutrients from the forest to other parts of the production system (Roder *et al*. 2003).

Besides chemical fertilizer and forest as source of nutrient, most of the farmers apply farm yard manure, chicken manure, bio-slurry, green manure, legumes and compost as source of nutrient to improve soil fertility and crop production. Recently, few domestic production houses have been established for production of vermi-compost which is being used extensively in our farming system. National Organic Program has approved few selective bio/organic-fertilizers which are being imported from India for our farming communities.

Soil Fertility Management Strategy

Soil is important to the productivity and sustainability of the farming in Bhutan. Without healthy and fertile soil even high yielding crop varieties may not give a good harvest. The National Soil Services Center (NSSC) is responsible for all soil and land related issues and vigorously promoting and creating awareness on soil health and soil fertility through numerous farmers' training across the country. Through such trainings, farmers are aware of the importance of soil health and soil fertility. The NSSC also provides free soil testing services to all communities and accordingly recommend correct soil amendments to improve soil health and soil fertility. Improving soil fertility and soil health is one of the top priorities of the Ministry of Agriculture & Forests (MoAF). Accordingly some of the action taken to improve soil fertility and soil health are explained below:

National Action Program (NAP) to Combat Land Degradation, 2013

The overall goal of NAP is to prevent and mitigate land degradation and its impacts through systems and practices of sustainable land management that protects and maintains the economic, ecological and aesthetic values of our landscapes.

National Adaptation Programme of Action (NAPA), 2012

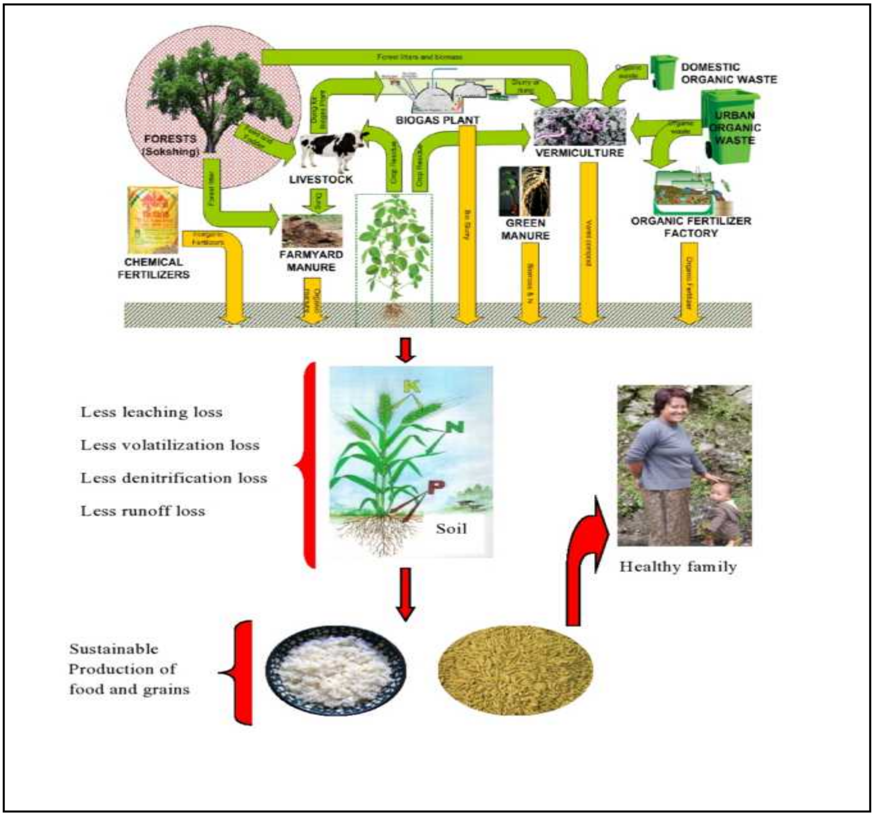
Under this programme some of the agriculture vulnerabilities like loss of soil fertility due to erosion of top soil and runoff, loss of fields due to flash floods and loss of soil nutrients were included for management.

Agriculture Land Development (ALD) guidelines, 2017

Under ALD guidelines, some of the agriculture focused area includes standardized and effective in addressing issues that confront sustainable agriculture production, such as land degradation, and low inherent soil fertility.

Integrated Plant Nutrition System Approach

The basic concepts of Integrated Plant Nutrition System (IPNS) is the preservation or modification of soil fertility and supply of plant nutrients to an optimum level for sustaining increased crop productivity through optimization of benefits from all possible sources of plant nutrients in an integrated manner (Roy, 1986). In other words, IPNS is basically reducing the use of chemical fertilizer and simultaneously using other organic nutrient sources to improve soil structure, fertility, soil microbes and water retention and at the same time increase productivity. The IPNS approach adopted by Bhutanese farmers is illustrated figure 4:



Source: SFU, NSSC, 2019 (Soil fertility Strategy, unpublished)

Figure 4: IPNS approach adopted by Bhutanese farmers.

IPNS is the integral part of Bhutanese farming and National Soil Services Center (NSSC) has been vigorously promoting IPNS. A Guide to Fertilizer Recommendation for Major Crops Version 2 was prepared in 2013 for important crops with additional information on the unit cost of nutrient, soil texture classes and soil fertility status. The fertilizer guide aims to educate farmers and extension agriculture officials on the use of balance nutrient and recommended rate of fertilizers for agriculture and horticulture crops. The guide books have been distributed in all districts.

Capacity development of farmers on IPNS

Several farmers' training on importance of soil fertility and soil health management were conducted across the country. The farmers' trainings were designed to disseminate IPNS related subjects to farmers through lectures, field demonstration and associated interactions. The mode of delivery was interactive and participatory rather than instructional so as to maintain the attention and interest of farmer participants. Adequate knowledge on IPNS was disseminated to the farmers and extension staffs.

One of the major activities that the NSSC has been promoting is Farmer-Extension Use Fertilizer Trial (FEFUT) as IPNS approach. It is on-farm trial on balance use of plant nutrient through combination of chemical fertilizers and organic manures especially FYM. The main objective of conducting FEFUT trials is to enable extension agents (EAs) to implement participatory technology development with farmers so that the farmers would be able to develop locally appropriate IPNS recommendations from field tested IPNS approaches. It is also to show the difference in crop yields between the IPNS soil fertility management and farmers' practices and ultimately to determine the potential in these areas to improve crop production economically through use of balanced fertilizers and locally available organic manures. The FEFUT trials on important assorted crops have shown a major difference in yields. With promotion of IPNS approach, farmers have registered increase in crop yields (Dorji, 2008).

Table 3: Crop yield comparison between IPNS technology and farmers' soil fertility management practice

Crop	*Yield (t/ha)*		*Difference*
	IPNS Technology	*Farmers' SFM*	
Rice	6.20	5.10	**+1.10**
Wheat	9.88	4.94	**+4.94**
Potato	15.91	10.92	**+4.99**
Onion	13.10	11.36	**+1.74**

Source: NSSC (Report on FEFUT)

IPNS Modules for Major Crops and Cropping Systems

Rice based cropping system

Rice is one of the most important food crops in Bhutan and is the staple food in the country. The domestic production meets only about half of the national annual requirement. To keep pace with the increasing population, rice production should further be increased. However, declining soil fertility coupled with shortages of irrigation water and household labor are the three most constraining factors. Generally the wetland soil nutrient status is low across the entire rice growing region. Traditional soil fertility management is primarily farmyard manure (FYM) or tethering cattle, crop residues, forest litters, fodder residues, green manure especially peas, beans and mineral fertilizers are the major sources of plant nutrients for rice production (Bajgai, 2006). NSSC have been promoting IPNS approaches in rice to improve soil fertility and increase crop yield. The IPNS approaches for rice based cropping systems are presented in table 4:

Table 4: IPNS approach for rice based cropping system

Cropping system	*IPNS approach*
Rice	Pre-sowing green manure such as Dhaincha (*Sesbania aculeate*) in the month of march-april and ploughed back in the field during flowering stage within 45-60 days. The green manure increase biomass, micro-organism and their activity in the soil. It also increases farm production and quality of the crops and at the same time suppresses weeds. Use of dhaincha increased yield by 2.1 ton/ha as compared to control.
Rice-Legumes	In higher altitude, leguminous plant like peas and beans are planted right after paddy harvest to replenish the nutrient loss from soil. Farmers usually plow back the green leguminous plant during flowering time before the seed setting. In this way they are benefiting two things, increase in bio-mass and nitrogen fixation in soil.
Rice	Green manuring of rice with Dhaincha (*Sesbania aculeate*) with 70:30:50 kg/ha increases rice yield by 2.52 ton/ha as compare to control (table 5)
Rice	Use of chemical fertilizer NPK (60:30:20) kg/ha and FYM (8.63 t/ha) increased yield by 1.10 ton/ha when compared to traditional soil fertility management control.

Table 5: Comparison of paddy yield between Dhaincha and other treatments

Treatments	*Mean yield (t/ha)*	
	Grain	*Straw*
Control	4.45	29.50
FYM alone (7.5 t/ha)	5.93	32.70
FYM 7.5 t/ha with 80:25:55 NPK kg/ha	6.92	33.84
Dhaincha alone	6.55	29.00
Dhaincha with 70:30:50 NPK kg/ha	6.97	28.21

Source: ARDC-Bajo (PPT Presentation-unpublished)

Maize cropping system

Most of the maize is cultivated in the dry lands and to a small extent in wetland especially in the south. The cultivation ranges from less than 300 m up to 3000 m owing to its versatile capacity to adapt to different environments (RNRRC Bajo, 2008). Maize plays a critical role in the household food security as it is a staple food especially for six eastern districts (Katwal, 2013). One of the constraints for low maize yield is poor soil fertility and drought. The most important means of fertilization of maize crop is through the use of Farm Yard Manure (FYM) or solely through tethering cattle. There is a need to explore and identify suitable soil fertility management options to further enhance the productivity of maize production system. After the introductions of chemical fertilizers, maize growing farmers have been using chemical fertilizer especially urea as top dress to maize. The average Urea application from the East districts in 2002 was 157.16 kg/ha (Dema *et al*. 2012).

The IPNS approaches for Maize based cropping systems are summarized in table 6.

Table 6: IPNS approach for maize based cropping system

Cropping system	*IPNS approach*
Maize	Use of chemical fertilizer NPK (99:69:39) kg/ha and FYM (7.41 t/ha) has shown promising yield in eastern part of Bhutan (Dema *et al*. 2012).
Legumes-Maize	Leguminous plant like peas is planted before maize plantation. The seeds are harvested and the bio-mass are ploughed back to the soil. In this way they are benefiting two things, increase in bio-mass and nitrogen fixation in soil.
Maize-potato-vegetables	Basically farmers practiced crop rotation by growing different crops in progression on a same field to avoid soil nutrient depletion and weed control.
Maize	Incorporation of Dhaincha (*Sesbania aculeate*) in the maize field has shown increase in biomass, soil fertility and less weeds.

Potato cropping system

Potato is one of important components in food security. The potato in Bhutan directly contributes to food security through consumption or as cash crop. It is also important cash crop to the households above 2500 msl. Potato has acted as an agent in transforming the survival farming to market oriented agricultural farming. The national area under potato is estimated at 5,189.80 ha with a total production of 57,223 MT (MoAF, 2017). In eastern Dzongkhag, potato is intercrop with maize. The most important means of organic manure of potato crop is through the use of Farm Yard Manure (FYM) or solely through tethering cattle. As per the long term studies, the average FYM application rate for three villages in Eastern districts was about 24.2 to 20 tons per ha for 2002 and 2008 respectively (Dema *et al*. 2012). Since potato is one of the main cash crops, farmers usually apply chemical fertilizers along with FYM/compost. In some potato growing areas, farmers apply more chemical fertilizers than required with a notion that applying more chemical fertilizer results in more yield and subsequently more economic benefits. The NSSC through farmers' training have been creating awareness on the use of recommended rate of fertilizer to improve soil health and increase crop yield. The IPNS approaches for potato based cropping systems are summarized in table 7.

Table 7: IPNS approach for potato based cropping system

Cropping system	*IPNS approach*
Potato	Use of chemical fertilizer NPK (99:79:79) kg/ha and FYM (6.2 t/ha) increased yield by 4.99 ton/ha (table 4).
Potato-Turnip-buckwheat	Leguminous plant like peas is planted before maize plantation. The seeds are harvested and the bio-mass are ploughed back to the soil. In this way they are benefiting two things, increase in bio-mass and nitrogen fixation in soil.
Potato-Turnip-buckwheat	Crop rotations are being practiced by growing different crops which are suitable as per the altitude to avoid soil nutrient depletion and weed control.
Potato	Balanced used of chemical fertilizer recommended for major potatoes growing areas in Bhutan. The nutrient management guideline was formulated based on soil result and various trials.

Besides above IPNS approaches, Bhutanese farmers use locally available or produced organic manures such as compost, leaf litter, bio-slurry, chicken manure, vermin-compost in vegetables.

IPNS approach for food security

Bhutan is an agriculture-based country and agriculture is one of the core growth areas of Bhutanese economy providing employment to 57.2% of the total population (LFSR, 2016). However, Bhutan is not food self-sufficient; it imports 53.3% rice, and 14% maize and vegetables. In order to meet the food self sufficiency, Bhutan has to increase its crop production. Although numerous improved high yielding varieties has been introduced, still production is low as compared to other countries. Bhutanese farmers use less chemical fertilizers (45.03 kg/ha) and organic manures which cause depletion of nutrients resulting into poor soil health and fertility. To address this issue, there is a need for a significant increase in balance and recommended use of plant nutrients for agriculture and also focuses should be given more on organic and biological fertilization. Maintaining good soil health through IPNS and increasing crop productivity through sustainable soil management and conservation can be important factor in achieving food security.

Scope of Research

With exception to NSSC as centre for excellence in soil and land related matters, research centers in the country lacked soil division and thus not much focus was given to soil research. Considering the importance of soil, recently soil unit was instituted in all research centers in the Country. NSSC as national focal point of soil unit in research centers, the programs and activities of soil research are expected to be geared towards meeting the nutrient requirements of identified commodities for optimum crop productivity and at a same time maintaining soil health. Research on new technologies like intercropping with leguminous crop, nitrogen fixation and large scale production of organic manures are expected to be accessible to the farmers for implementation (DoA, 2019).

Policy/Research – Extension/Farmer Linkages

Strengthening research, extension and renewable natural resource policy linkages are one of the priority areas of Ministry of Agriculture and Forests. To address these linkages, Research Outreach Programme (ROP) has been strengthened and streamlined for conducting farm research trials, encapsulate research findings and disseminate to farmers or extension institutions. Meetings, workshops and forums amongst different stakeholders have been strengthened basically to identify core research needs, planning and implementation. Better linkages and communication amongst different agencies such as research, extension and central programs have helped disseminating research results in a manner and form that are useful to farmers, policy makers and other stakeholders (CoRRB, 2011).

Challenges of Soil Fertility Management

Although Bhutan is agriculture based society, farming is not easy due to rugged and steep terrain. According to soil survey report (SSU, 2005) approximately 31% of agriculture occurs on land with >50% slope often with unstable geology, which is being repeatedly affected by physical land degradation resulting into low soil nutrient content and low crop yield. Demographic pressure and constraints of land availability have also contributed to the decline in soil fertility (SSU, 2005). With increasing populations, the traditional techniques for renewing soil fertility, such as slash-and-burn and long-term fallowing are not as feasible as they once were. The need for subsistence production is such that land can no longer be taken out of production for substantial periods to allow for natural nutrient replenishment. Further, animal manures and crop residues are usually not sufficient to supplement the nutrients loss. Other traditional soil fertility management techniques also generally fall short of the nutrient requirements of today's intensive agricultural practices (SFU, 2005).

Adequate knowledge on IPNS approach was disseminated to the farmers and extension staffs. Based on field experiments and soil analysis, a guide to fertilizer recommendation was developed and circulated to all districts. Despite several interventions to improve soil fertility and promote IPNS, only 37% of the farmers use chemical fertilizer in 19% of the cultivated land (ARDC-Yusipang, 2019). There are several reasons for low rate of adoption of chemical fertilizer such as high price, inputs not easily available in remote villages and soil hardening due to use of chemical fertilizer.

Conclusion

Bhutan remains a predominantly agriculture-based society, with the majority of the population relying on agriculture for their livelihoods. Although, Bhutan has only 2.93% arable land, approximately 57.2% of the populations depends on agriculture. Most of the country's arable land is cultivated by small farm holdings for food production and livestock rearing. Bhutan is not food self-sufficient and imports 53.3% of rice and 14% maize and vegetables. With increasing population there is a huge pressure on agriculture sector to increase food production. Farming is not easy in Bhutan as it is constrained by factors associated with the rugged and steep terrain. Under such conditions, IPNS can be one of the means to increase crop production. Farming system has always adopted IPNS for good management of soils, ensuring judicious use of chemical fertilizer in combination with organic manures. With environmental protection as one of the guiding principles of the country's development programs, IPNS plays an important role directly or indirectly to enhance crop productivity and food security, environment sustainability and human health. To achieve food security, managing soils in a sustainable manner will be a challenge with fragmented land holding, steep slopes and land degradation problems. Proper research is required to avoid further degradation of soils, especially loss of top soils through erosion, explore introduction of effective micro-organisms technology, production of appropriate inoculants of nitrogen-fixing bacteria, introduction and promotion of integrated plant nutrient systems approach in research and extension, integrated use of chemical fertilizer and locally available organic manures besides FYM. The soil fertility management is a priority area and accordingly, Department of Agriculture plans to develop soil fertility management strategy in 12 FYP.

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Chapter 6

Integrated Plant Nutrition System Modules for Major Crops and Cropping Systems in Nepal

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Introduction

Agriculture remains Nepal's principal economic activity employing around 66 percent of the total population. The agriculture sector alone contributes 33 percent to the Gross Domestic Product. The current food production is not sufficient to meet the food requirement of the growing population, which is at a rate of 2.25 percent indicating serious food insecurity (MOAC, 2005). Therefore, agriculture is a priority sector and there is a strong need to appraise the potentiality and at the same time subsistence farming has to be changed to commercial agriculture to uplift the economic status of the poor people.

Unavailability of appropriate technology, rain water erosion in the hills and mountains, poor irrigation infrastructure and network as well as frequent droughts, nutrient mining, and increasing cropping intensities without judicious fertilizer application have been the major technical problems that prevail in Terai region of the country. There are also social constraints like small land holding, subsistence farming and poverty prevailing in the country. Root causes of low production and productivity in general are inadequate supply of basic agriculture production inputs, such as improved seeds, chemical fertilizers, improved breeds and animal feeds, inadequate irrigation, poor coordination between agriculture and irrigation, and decline in pasture lands due to the expansion of community forests. The potential arable land is already under cultivation and there is not much scope to expand. The alternative option would be to cultivate the forest land and the marginal land which are already at the state of degradation.

Table 1. Land Systems by Physiographic Regions of Nepal

S.N.	Physiographic Regions/ Elevations	Land Forms	Climate
1	High Himal Region (>4000 m.)	Alluvial, colluvial and morainal depositional surfaces. Steep to very sloping mountainous terrain.	Alpine and Tundra
2	High Mountain Region (2200 - 4000 m.)	Past glaciated mountainous terrain below upper altitudinal limit of arable agriculture.	Warm to Cool temperate
3	Middle Mountain Region (500–3000 m.)	Ancient lake and river terraces (Tarselevated plains) (erosional). Moderate to steep mountainous terrain. Steep and straight mountainous terrain.	Warm temperate
4	Siwalik Region (120-2000 m.).	Active and recent alluvial plains Fans, Aprons and ancient river terraces (Tars). Depositional basin (Duns). Moderate to steep to very steep hill and mountainous terrain.	Sub-tropical
5	Terai Region (60-330 m)	Active and recent alluvial plains (depositional). Alluvial fan apron complex (erosional). Sub-tropical	Tropical/Sub-tropical

Source: CBS 1994

Soil types of Nepal vary according to physiography zones. Terai soil usually developed with alluvial deposit having fine texture with good water holding capacity. Siwaliks dominated with sandy texture consisting pebbles. Sivaliks soils are poorly developed and prone to erosion, and cannot retain high-intensity precipitation. Middle Mountain soil types are varying from medium to light textured coarse-grained sand, which is also prone to erosion. The upper region also consists of hard rocks in many places.

Natural Resource Degradation

Land and forest are main sources of livelihood for large proportion of population. Poverty is linked to degradation of natural resources and loss of biodiversity. Large numbers of families have small farms and more than two third of population of Nepal owned less than half hectare of land (APP 1995). Since these groups of people depend on forests for fuel and other forest products for survival of their day to day life. Poor farmers expand cultivation into highlands that are not suitable for agriculture for increasing production, leading to soil erosion, land degradation, declining productivity of farmland and sedimentation of downstream areas. On the other hands, high population growth rate of the country led to increase demand of fuel wood, timber for construction materials, land to grow more food and fodder for livestock. Forests were cleared and converted to agriculture lands and this process is ongoing.

We rarely noticed natural caused fire in Nepal. Forty percent forest fire in mid-hills occurred by accident whereas sixty percent fire started purposely (Karkee, 1991). Accidental causes of fire include carelessness with cigarettes and matches, clearing land for cultivation, smoldering charcoal left by charcoal burners, fires set to smoke out wild bees while collecting honey. Fires are also set intensely in forest for killing trees that later collected as dead wood for firewood, to induce new grass growth for grazing and also for hunting. Overgrazing by livestock affects the species composition and productivity of the grassland vegetation. Undesired or unpalatable plant population may increase due to overgrazing, which will have direct bearing on wildlife population and its diversity. The loss of grass cover reduces insect populations, which in turn changes the bird life.

Rivers in Nepal have damaged more than 400,000 hectares of productive agricultural lands (LRMP, 1986). The Shiwalik hills and middle mountainous regions are highly vulnerable to soil erosion. The extent and severity of damages have increased continuously due to frequent changing nature of mountain-rivers. Farmlands near river banks are washed away by flooding, crops are ruined and widths of rivers widen every year during monsoon. Nepal's rivers carry around 336 million tonnes of soil per year to the main river systems entering to India (Brown, 1981). The bed level of Terai's rivers has been rising by 35-45 cm annually (Dent, 1984).

Gender Issues

Nepal is committed to provide women and men equal access to agricultural training and other opportunities. Female participation in farmers' field schools (FFS) is higher in mid-hill compare to the Terai communities. The important role of women in agriculture in Nepal requires to be reflected in the soil management program. Majority of agricultural trainers are male and very little training on gender issues were given to the trainers. Gradually, women participation in the farmers' field school has increased over the years. A set of tailor made "gender sensitization tools" was developed, which is being used to motivate women and men to discuss, reflect and review their roles and responsibilities for achieving equality.

Survey on Sustainable Soil Management (SSM) in mid-hill districts has revealed that 80% of women were found to have benefited from improved practices of sustainable soil management. The beneficiaries include ethnic group and other castes; however, Dalit communities have not yet been significantly involved in SSM activities.

Soil Fertility and Nutrient Management Strategy

Chemical fertilizer import policy

Various sources of plant nutrients in the Nepalese farming system have been identified (Carson, 1992) and among them chemical fertilizer is becoming gradually a major source as its import data indicates an increasing trend (Figure 1).

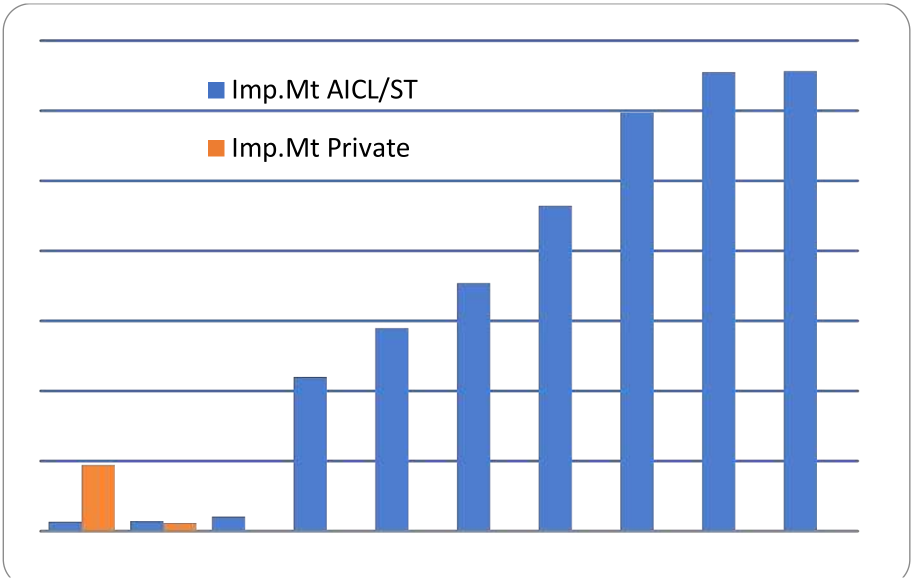


Figure 1, Fertilizer import by government and privet sectors

(Source: Agriculture Diary 2017)

Prior to the introduction of mineral fertilizer into Nepal in 1952, crop production mainly depended on farmyard manure (Pandey & Joshy, 2000). With the increasing demand of fertilizer, Agriculture Input Corporation (AIC) the sole authority responsible for procuring, storing and distributing fertilizers all over the country was instituted and the price of fertilizers was uniform (Jaisy & Manadhar, 2004). Since fertilizer import by AIC could not meet the demand, His Majesty Government (HMG) of Nepal deregularized fertilizer import policy in 1996/1997. This deregularization has resulted in both positive as well as negative effects. Positive effects are that agriculture input corporation and private importers were treated equally leading to free and healthy competition in the market. Free and timely available of fertilizer, free and fair competition reduces the prices of fertilizer and the burden to the government was minimized. On the other hand, there are negative effects such as quality deterioration, price hiking and unhealthy market competition and uncertainty in availability. The government had put subsidy in transportation of the fertilizers for twenty six very remote districts to support the food security (Sherchan and Karki, 2005).

International donors fund for import of chemical fertilizers was also established to commensurate the demand and ensure the continuous supply. Till now there are limited choices for farmers. Urea consists of 50 percent of total fertilizer demand followed by Di-ammonium Phosphate (DAP), Mutate of Potash (MoP) and few others. Mixed or multiple nutrients containing fertilizers would give much more benefit compared with straight fertilizers, provided the market price is affordable to farmers (Sherchan and Karki, 2005).

The total N, P, and K consumption is around 35 kg/ha and Agriculture Perspective Plan (APP) has target to increased this to 131 kg/ha. The statistics show around 75 percent of the total imported fertilizer is consumed in Terai (accessible area) and only 25 percent by the hills and mountains areas. There had been constant complain on the quality and supply of fertilizers in the market after the de-regulation of fertilizers policy.

Fertilizer Inspectors in various districts are monitoring the quality of fertilizer; they carry out fertilizer quality test in various laboratories to control and maintain its quality. The supply of chemical fertilizers on time is still not guarantee, which hinder its use on right time and the majority of farmers cannot afford to buy fertilizers. Frequent changes of fertilizers types lose confidence amongst poor farmers.

Soil Fertility Status

A total of 25,000 soil samples were collected from all over the country and analyzed by five regional and one central laboratories under the Department of Agriculture. The soil analysis result revealed that the organic matter is low in 58.5 percent soil samples and soil is acidic in 63 percent soil samples (Table 2). Organic matter depletion, acidification, erosion vulnerability, siltation, degradation of forest and marginal land, cropping intensification, mono cropping system for long period, unbalance and inadequate use of manure and fertilizer, low quality manure and fertilizer use, desertification, environmental pollution, red soil problems are the reasons for poor soil fertility status.

Table 2: Soil Fertility Status of Nepal

Organic Matter Status			*Phosphorus Status*			*Potassium Status*			*pH status*		
Rank(%)			Rank(%)			Rank(%)			Rank(%)		
Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
58.5	33	8.5	29	23	48	29	32	39	63	27	10

Source: Green Field Journal of Agriculture 2004

Hill farmers depend primarily on organic manure, either compost prepared from locally available organic materials or farmyard manure. Large amounts of organic manure are applied to kitchen gardens at the time of land preparation. In addition, farmers also use wood ash, cattle urine, leguminous crops, mulch and recycled weeds as part of soil fertility maintenance.

Nutrient flow and balance in farming system

The source of plant nutrients are mainly from forest and livestock. External sources of plant nutrient particularly the chemical fertilizers depend on imports from outside. However, purchasing capacity of farmers and availability on right time is the major challenge. A limited study conducted to estimate the nutrient balance showed mixed results. Ghani and Brown (1997) reported that the balance of plant nutrients N, P, K and S were estimated after the harvest of the early rice, the main season rice, the maize and the wheat. The early rice showed negative balance of K and S. At two sites N was negative, but P was found to be positive balance in all the tested sites. After the maize harvest, the N balance was found to be positive around 60 percent of the tested sites, but P, K and S were largely negative. After the wheat harvest N, P, K and S were found strongly in negative balance. It is surprising to note that despite adequate K in the Nepalese soils the balance is negative.

However, Karki (2004) reported that reserve soil K in intensive farming areas is declining. Regmi *et al.* (2002) reported that application of 40 kg/ha potash under rice-rice and wheat rotation cannot maintain K balance in soils. Pandey *et al.* (1998) reported results of a three years experiment on rice and wheat rotation in a low land rain-fed condition that three major nutrients N, P and K found in negative balance after rice harvest. Application of 50 kg/ha nitrogen, 30 kg/ha phosphorus and 30 kg/ha potash were also found negative in balance. The result also indicated that farmyard manure at a rate of 10 t/ha is not enough to maintain nutrient balance under rice and wheat rotation system. Pilbeam *et al.* (2000) estimated nitrogen balance in positive referring to the nutrient management system of the middle mountain region and negative balance of the vegetables cultivation in the majority of study site except at few locations. They have emphasized use of bacterial fertilizers for maintaining productivity and soil health. However, there is lack of proper study to quantify the nutrients contribution from various sources and losses through the system.

Soil nutrients loss in the hill slopes

Water erosion is the main causes of land degradation in hills, which covers 86 percent land of Nepal and it leads to 32 tones/ha soil loss every year (Shresth *et al* 2005). It is well identified that more than 50 percent of soil losses occur during the earlier monsoon period, nutrient losses such as Nitrate-N and K found high in leachate (Gardner *et al.*, 2000). Nitrogen loss occurred in between pre-monsoon and main monsoon where as K loss occurs in the early monsoon. Erosion and runoff in hills are leading to a serious problem in nutrient loss in Nepal. It is estimated that erosion and run-off of 1 mm top soil remove 10 kg of nitrogen, 7 kg P and 15 kg of potassium from one hectare of land (Carson 1992). Experiment on maize and millet cropping pattern showed a soil loss of 33.2 to 36.7 mt /ha in 1998/1999. However, it was reduced by 60 % in maize and millet planted in line against the slope.

Soil loss annually in conventional and reduced till was estimated 16.6 and 11.1 Mg/ha respectively (Ateraya, *et al.*, 2006). Annual loss of nutrient in sediment loss were 188 kg organic carbon,18.8 kg nitrogen.1 kg phosphorus and 3.8 kg potash per hectare in conventional till and 126 kg organic carbon,11.8 kg nitrogen,1 kg phosphorus and 2.4 kg potash in reduced till (Ateraya, *et al.*,2006). According to Tripathi 2019, Soil loss through erosion from agricultural land in Nepalese hills varied from 2 to 105 t/ha/year. In terms of nutrients loss, a 5 t/ha soil loss is equivalent to a loss of 75 kg/ha of Organic Matter (OM), 3.8 kg/ha of Nitrogen (N), 10 kg/ha of potassium (K) and 5 kg/ha of phosphorus (P) in the mid hills of Nepal.

Acid soil improvement

Soil Management data (Annual progress Report 2017) shows nearly 60 percent of Nepal soils are acidic and need to amelioration. Acidic condition hinders the availability of many essential nutrients to crops. Karki and Dacayo (1990) recommended 6-9 t/ha of lime on various soils. Tripathi (2001) recommended 2 t/ha applied for maize and wheat that would increase up to 35 percent yield over non limed plot. He further recommended applying lime in combination with compost or organic manure.

Bacterial fertilizers, Biological Nitrogen Fixation (BNF) and Organic Manure

Significant achievements have been obtained in BNF research and its associated fields to improve the productivity of legume crops in Nepal. The productivity of the major summer and winter legumes crops such as soybean and lentil have been increased through effective inoculums in the farmers' fields (Subedi K, 2000). The effective Rhizobium strains for soybean, black gram, cowpea, lentil, chickpea, peanut, mungbean clover, desmodium, stylosanthees, astragtalus, ipil-ipil, medicago and vetch are being maintained at Soil Science Divisions. Technologies for the preparation and application procedures have been well standardized. Rhizobium culture for different leguminous crops is on high demand. Since government agencies have not been able to meet the demand, private sectors are encouraged to do this job (Sherchan and Karki, 2005). Field research conducted on various cropping systems indicated that integrated use of organic and inorganic sources of plant nutrients is the most sustainable nutrient management.

Emerging micronutrients problems in soils

Micronutrients such as zinc, boron and molybdenum deficiency is increasing at different ecological belts at varying intensity (Karki *et* *al.*, 2004). Zinc is a problem in the Terai belt on rice crop. Farmers are now applying zinc sulphate at a rate of 25 kg/ha without proper extension advice. In the hills where vegetables are being grown during off season and normal season, boron and molybdenum are deficient. There is lack of proper recommendation to farmers as well.

Livestock rearing and its role in soil fertility management

Livestock provides draft power and manure to agriculture, income, nutritional and other byproducts. An estimation in 2017/2018 shows that the population of animal species such as cattle, buffalo, goats and sheep were nearly 7.3 million, 5.1 million, 11.1 million and 0.8 million respectively (Agriculture diary 2017). These figures indicate an increasing trend of livestock population. Sherchand and Pariyar (2005) reported that 60 percent of livestock's feeds come from low quality crop residues and 40 percent from the forest. The estimated feed balance also indicates 34.7 percent feed deficit on Total Digestible Nutrients (TDN) basis (Sherchand and Pariyar, 2005). The indigenous system of livestock rearing and access to the forest resources have been broken down due to pressure on the land. In higher altitude areas during winter, folks of sheep and goat are brought down to the valleys and in situ manuring is done by leaving the animals overnight in the cultivable field. Composting forest litters with animal excreta is another advantage related to livestock production.

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

SALT technology one of the suitable techniques to reduce run off and soil loss in the hills of Nepal. It also provides fodder and biomass for various purposes (Sherchan and Karki, 2005). On the edge of terraces, farmers grow fodder trees and other plant species for fodder, fuel and timber. There is a need to blend farmers' local knowledge and the SALT together. Currently, the promotional activities have been constrained by unavailability of seedlings and saplings and open grazing systems (Maskey, 2001). During pre-monsoon period soil is exposed and identification of suitable cover crops to conserve soils and nutrients loss is recommended. In addition, study on nutrient flow in watershed base on the biophysical feature and hydrological behavior needs to be taken up. Agri-silvipastoral approach is a successful approach under the leached hold forestry programme (Pariyar, 2002). Various types of fodder species, nitrogen fixing legumes and trees can be established and the fodder and other need of the rural household can be met

Fertilizers recommendations

Joshy and Deo (1976) developed a comprehensive recommendation on economic use of fertilizers for various crops in 1975. Fertilizer recommendations for the major crops of Nepal on the basis of crop responses and soil analysis are given in table 3. Since then, no further systematic work has been carried out in Nepal. We can expect quite different response level due to change in cropping systems, increasing intensity and change in soil fertility status. The current recommendation should tie up with the farmer's knowledge and it should be most practical from farmer's perspective. Site specific fertilizer recommendation has been made for the important crops, but farmers deviate and they still use their own rate of fertilizer without consulting with agriculture technician. This indicates that farmers do have their own economic judgment which we overlooked. Dissemination of information on chemical fertilizers handling would be an important area for promotion of effective use of fertilizers.

Table 3: Fertilizer recommendation of major crops

Crops and Variety	Optimum dose (kg/ha)			Organic Fertilizer t/ha	Expected Yield kg/ha
	N	P_2O_5	K_2O		
Rice Improved	100	30	30	10	3811
Rice Local	40	20	30	6	2541
Wheat (Improved)	100	40	30	10	3287
Maize (Improved)	120	50	40	10	3359
Barley(Improved)	60	30	30	10	2479
Sugarcane (Improved)	120	60	60	16	65300
Jute (Improved)	60	30	40	10	3231

Source: Maskey 2000.

Inclusion of legumes in crop rotation

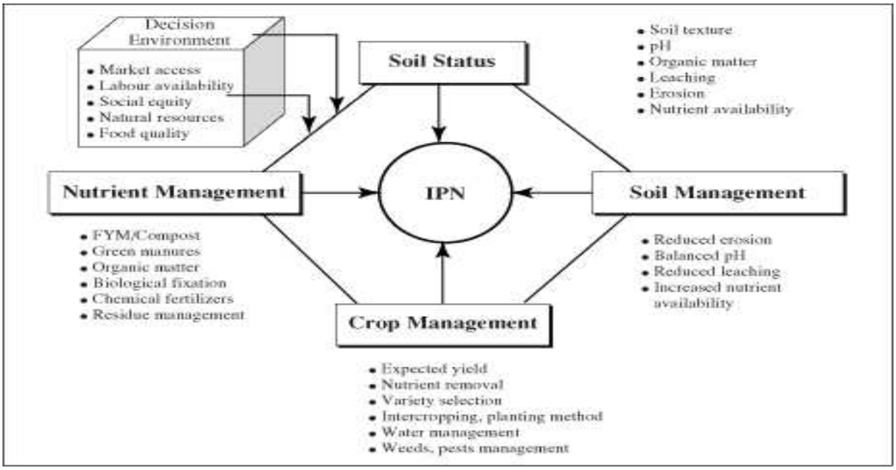
Both in the hills and Terai regions of Nepal, legumes are one of the important sources of protein and covers around 326,055 ha area with total production of 378,196 mt (MoAC, 2016). However, N-fixing capacity of these legume crops varieties is low. The priority work should be to develop improved productive varieties and improve the N-fixing capacity by developing appropriate strains (Sherchan and Karki 2005). Currently, Soil Science Division has identified effective strains of most legume crops.

Integrated Plant Nutrition System

The Sustainable Soil Management Programme (SSMP) was initiated in 1999 with the objective "to improve the livelihoods in Nepal's middle hills small holder farmers by fostering sustainable soil management (SSM) practices in the bari (rainfed)-dominated hill farming systems and their diffusion through a locally based extension system"

The programme was implemented in the country; where 85% of the population live in rural areas and derive their livelihood at least partly from farming that takes place on very small fields; 40% of the farms count less than 0.5 ha, and 47% of the farms count 0.5-2 ha. Agriculture in Nepal's mid hills is characterized by low fertility soils and limited access of the farming community to knowledge on improved and sustainable farming practices

An integrated nutrient model developed quite some time ago as shown below Figure 2 was a successful programme, but it has not been popularized or has not been well adopted by large number of farmers. There should be a follow up study to see the impact on soil fertility management and to look on how best we can promote to wider areas.



Source: Regmi *et al, 2004*

Figure 2. Integrated plant nutrient model in the Nepalese farming system

Some modules of IPNS formulated by SSMP have been already tested on different cropping system but popularity has not been gained at the farmers' level. Therefore, follow up study has to be conducted to see impacts of different module on Rice-Rice, Rice -Wheat, Maize -Millet, Maize-Cauliflower systems. Considering the above model, SSMP has developed nutrient balance calculator of following crops and cropping systems in bari (up-land) and khet (low-land) of mid-hills of Nepal:

Maize –Wheat System in bari lands

Maize/ Millet System

Rice –Wheat System, good water control

Rice –Wheat System, limited water control

Maize –Vegetable System

Example of determination of the amount of fertilizers to the crops in both conventional approach and IPNS approach as below:

Conventional approach

- Test the soil sample;
- Find out Soil test rating: Low, Medium, High;
- Find the recommendation dose for the crop.

Determine the amount of nutrients as follows:

Soil test rating	*Nutrient*
Low	Full dose of the recommendation
Medium	Half dose of the recommendation
High	One fourth of the recommendation

IPNS approach

Test the soil sample:

- Find out Soil test value;
- Determine the amount of nutrient provided by the soil to the crop (from the IPNS calculator)-A;
- Estimate the targeted yield of the crop;
- Determine the amount of nutrients required to meet the targeted yield (from the IPNS calculator)-B;
- Subtract A from the B. i.e. B-A;
- Result/outcome of B-A is the soil nutrient (both chemical and organic) required to produce targeted yield.

Development of IPNS approach

Weber *et al* (1999, 2000), has developed IPNS approach on the following basis:

- Various research provided base-line information for IPNS;
- Complementary uses of organic and inorganic fertilizer were particularly important;
- A working group developed a concept for the promotion of IPNS;
- This was taken into practical field-testing by Department of Agriculture, NARC and SSMP in 2001 and 2002.

Implementation of Farmers Field School (FFS) on IPNS

The first FFS on IPNS were implemented in 2001 and wider testing was initiated in 2002.

IPNS implemented in 2001 as below:

- Technical working group was formed and FFS approach has been approved for IPNS promotion;
- Implementing guidelines and norms were approved;
- IPNS trainings were conducted;
- Publication and distribution of IPNS related documents by SSMP and NARC.

FFS implemented in 2002 as under:

- A total of 33 FFS were implemented in 2002;
- A review workshop among all facilitators and resource persons from all districts was organized at the national level in December 2002;
- Publication and distribution of IPNS related documents by STSS, SSMP and NARC.

IPNS Extension activities flow

Training of trainers and facilitator

↓

IPNS Farmers Field School ⟷

↓

Farmer to farmer training

- Acknowledgement of indigenous knowledge and experiences of farmers.
- Participatory technology development and transfer.

Source: INM Introduction Book

Conclusion

Nepal is land locked agricultural country employing more than 66 % of population in agriculture and contributing 33% to Gross Domestic Product. Landform and climate vary with agro-ecological zones having benefit to grow variable crops or plenty of opportunity to diversify agriculture. Natural resources degradation mainly land, soil and forest directly relate with poor socio-economic condition, which ultimately determine the sustainability of the system. There is a policy to guide nutrient management activities in the country, but it is difficult to implement as there are constraint in terms of financial as well as human resources. Soil fertility status of the country is declining because of soil acidity, depletion of organic matter and also deficit of certain micro-nutrient such as zinc, boron and molybdenum. Taking current soil fertility status into consideration, soil fertility management is important priority area of the country. Various soil fertility management programs were launched by government to sustain the soil system.

Looking into the imbalance use of organic and inorganic fertilizer, government has given emphasis on integrated plant nutrient management system approach to improve the productivity of crops and maintain soil health. Though, different nutrient balance calculators of cropping systems were developed, it is not implemented at farmers level due to limited use in farmers field school. Therefore, adoption of integrated plant nutrient management system must be given priority in order to sustain the soil and to obtain sustainable production.

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Chapter 7

Integrated Plant Nutrition Systems Modules for Major Crops and Cropping Systems in Sri Lanka

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Introduction

The Democratic Socialist Republic of Sri Lanka is an island which is situated in the Indian Ocean and it lies between latitude 5^0 55′N and 9^0 50′ N and longitude 74^0 42′E and 81^0 53′E. The total land area is 65,610 km^2 and the population is about 20 million (AgStat, 2015) and annual growth rate is 1.2%. Sri Lanka is located in the tropical belt and it is divided into three major climate zones with influence by northeast and southwest monsoons during the months of October to January and April to July, respectively. The three major climatic zones are, Wet, Intermediate and Dry zones which receive average rainfall of >5000-2500 mm, 2500-175 0mm and 1750-900 mm respectively. These three major regions further have been identified low country (0-300m) mid country (300 – 900m) and Up country (>900mm) based on elevation. Three major agro-climatic regions, wet, intermediate and dry zone, are further sub divided into 24 agro-ecological regions. According to the modern scheme of climatic zonation, the wet zone of Sri Lanka falls within the humid tropics and the dry zone within the seasonally dry tropics. There are two main cropping seasons namely "maha" (northeast monsoon) - wet season from September to February and "yala" (southwest monsoon) - dry season from March to August. Due to availability of water, the "maha" is considered as the major cropping season.

The agricultural production system in Sri Lanka has two sectors such as plantation sector and food crops sector. Plantation sector consists of perennial crops such as tea, coconut, rubber and coffee and they are called export crops which are mainly grown for export. The food crop sector consists of rice which is the major staple food, fruits, vegetables, legumes and other field crops, root and tuber crops and spices. The Agriculture sector plays a dominant role in the Sri Lankan economy, contributing to nearly 13.4% of Gross National Product (GDP) and employment opportunities in the agriculture sector is estimated to be 28.5% (AgStat, 2015).

Natural Resource Degradation

Natural resources in Sri Lanka consist of land, biodiversity, forests, minerals and water resources. The demand of a rapidly expanding population in the country has put tremendous pressure on the islands natural resources which in turn have resulted in a high level of environmental degradation. Land degradation, deforestation, coastal degradation, water, and air pollution are main natural resource degradations.

Land Degradation

The major land use sectors in the country are agriculture (paddy, tea, rubber, coconut and other perennials, non-perennial crops), close canopy and sparse forests, home gardens and others. Out of total land area, about 22% represents home gardens, 11% plantation crops, 14% paddy and 33.8% other food crops. Spatial differences of land use can be observed in Sri Lanka; in the dry zone only 30 % of land is utilized. In the wet zone more than 80% of land is utilized. Forest covers around 9% of land area of the wet zone.

Land degradation is one of the most critical problems affecting the future economic development in Sri Lanka. Inadequate attention paid to soil erosion leads to serious environmental problems such as siltation of reservoirs, pollution of surface and ground water bodies, landslides and threats to biodiversity. Reduction of organic matter and plant nutrients leading to fertility decline, salinization caused by improper water management, soil compaction, landslides and deforestation are the issues in the country.

Soil erosion is the major factor responsible for land degradation in Sri Lanka, where more than 33% of the land is exposed to erosion (Nayakekorala, 1998). Severe erosion takes place in the hilly slopes of lands which are under vegetables, potatoes, tobacco, tea nursery and chena cultivations. Soil erosion is also considered as a threat to agricultural production in the rain fed farming areas in the dry zone. Soil erosion leads to sedimentation of reservoirs, downstream floods, loss of soil fertility, soil compaction and it is a serious threat to agricultural production.

Table 1. Soil erosion rates under different land uses without any soil conservation measures

AEZ	Land Use	Soil Loss (t/ha/yr)
Mid Country Wet Zone	Seedling Tea Mixed home garden	40 0.05
Mid Country Intermediate Zone	Tobacco Vegetables	70 18.4
Low Country Dry Zone	Sorghum/Pigen Pea Cotton	21 22

Source: IUCN (2016)

Erosion rates are high in the Mid Country Intermediate zone with soil loss of 70t/ha/yr could be reduced to 0.24t/ha/yr with soil conservation practices. The least soil loss is from the mixed home garden with a rate of 0.05t/ha/yr where the canopies at different heights intercept rain drops effectively. Most of the agricultural lands show highest soil loss rates than tolerable soil losses.

Table 2. Sedimentation of selected catchments in the mid country Wet Zone

Sub Catchment	Area (km2)	Land use	Sediment Yield t/h/yr
Above Peradeniya	1,160	Tea, Grassland	4.2
Above polgolla	1,300	Tea, Townships	3.4
Nilambeoya	61	Tea, Home garden	0.6
Victoria	1,800	Tea	3.4
Mahaoya	476	Vegetables	9.4
Umaoya	99	Vegetables	10.6

Source: IUCN (2016)

Salinization

Salinity is a conspicuous problem. In addition to problems in the low-lying coastal areas of the country, inland salinity has been developing in areas with major irrigation schemes. Poor water management practices and methods of drainage adopted by farmers aggravate the situation. Continuous application of only chemical fertilizer is also caused for the inland salinity. The area under saline soils is gradually increasing and is estimated to be about 15,000 ha. Little has been done to address the problem. The present recommendations for overcoming the salinity relate problem is to apply organic manure and cultivation of salt-tolerant varieties.

Deforestation

Generally, forest degradation occurs with increasing population, road construction, timber production, agricultural development, irrigation, hydropower generation and forest cleaning by private businessmen. The extensive deforestation leads to raise in average surface temperature and greenhouse gas emissions. Forest cover was depleted substantially during the last century in contrast to the minimal deforestation at present. Further, the government of Sri Lanka has adopted the target to increase forests cover to 32% by 2030.

Soil Fertility Status

Soil Fertility Decline

Fertility decline may take place due to reduction of soil depth, depletion of soil nutrients and organic matter. The removal of most fertile top soil can reduce the yields of crop drastically. It is shown that removal of the first five centimeter of top soil reduces the yield from 40% to 50% in many crops (Mapa, 2003).

Depletion of soil organic matter

Soil organic matter content is one of the key parameters influencing soil fertility. Most of the soils in many part of the country are low in organic matter leading to low cation exchange capacity and nutrient retention in the soil. Due to prevailing high temperature of the country, decomposition rate of the organic matter is high which result in low retention of the organic matter in soil. Therefore, it is important to apply organic manure in every season.

Table: 3. Soil organic matter content in different cropping systems

Cropping System	AEZ	District	Organic matter content %
Rice	LCDZ	Anuradhapura	1.8
Rice	LCWZ	Gampaha	4.0
Rice	LCIZ	Kurunegala	1.0
Rice-Veg Rice-Rice	UCIZ	Badulla	2.7 1.8
Vegetable	UCWZ	NuwaraEliya	7.7
Rice - Veg	MCWZ	Kandy	1.7
Rice - Veg	MCIZ	Matale	3.5

DOA Unpublished Data 2016, 2017

The increase inorganic matter content was much prominent in the intensively vegetable growing areas in the up country wet and intermediate zones and low country wet zone area. Lower temperature in those areas could be the cause to build up the organic matter. High rate and continuous application of organic manure in intensive vegetable growing areas also resulted in accumulate of organic matter in this soil.

Decline of plant nutrients

Depletion of plant nutrients in soil is mainly due to leaching and high runoff. Wijewardena (1996) reported low available phosphorous in rice soils of the Low Country Wet Zone. Presently, due to indiscriminate use of chemical fertilizers, rice growing soils in Low Country Wet Zone and Low Country Dry Zone also accumulate soil P as well as K.

Table 4. Soil characteristics of the paddy cultivated soils

Characteristic	Uncultivated soil (Jungle)	LCWZ Rice-Rice	LCDZ Rice-Rice	LCIZ Rice-Rice	MCWZ Rice-veg	MCIZ Rice-Rice	UCIZ Rice - Veg	UCWZ Rice-Veg
pH	5.5	4.5	7.1	5.7	4.9	6.2	6.3	5.5
EC	0.058	0.120	0.110	0.029	0.082	0.077	0.124	0.144
P	2.0	16.3	10.4	8.7	28.8	9.9	163.6	69.8
K	164	102.9	68.1	79.3	190.3	121.4	359	375.1
OM	1.9	4.0	1.8	1.0	1.7	3.5	2.7	

DOA Unpublished Data, 2017

Excessive build-up of Nutrients

Vegetable growing farmers apply high doses of the inorganic fertilizer mixtures containing N, P and K or straight fertilizers (Wijewardena and Yapa, 1999). Potato and vegetable growers, particularly in the up-country, apply different kinds of foliar fertilizers during the growing period at 6-7 days intervals at a high rate of 12 l/year/ha (Rezania 1992). The application of organic manure particularly poultry manure in potato cultivation has increased considerably in up country of Sri Lanka. Therefore, excessive build-up of P and K has been observed in many intensive vegetable-growing soils. The condition is caused by indiscriminate use of organic and chemical fertilizers. Build-up of phosphorus in some potato and exotic vegetable growing soils in the up-country area, particularly in Up Country Wet Zone and Up-Country Intermediate Zone has been reported. Similarly, occurrence of high available P due to the use of high rates of deep litter as well as chemical fertilizers was observed in leafy vegetable-growing soils in the LCWZ.

Soil analysis data in different areas shows that more than 50 % sites contain high available P in potato and vegetables growing areas in up country wet zone (UCWZ) and vegetable and potato in rotation with rice in the up-country intermediate zone (UCIZ). Field crops on rain fed uplands receive inadequate fertilizer phosphorus and potassium. As a result, soils are relatively low in available P and exchangeable K. About 84% of the rice-growing soils in the UCIZ have exchangeable K content of less than 100 mg/kg. However, more than 50% of soils in rice vegetable cropping system contain between 160-400mg/kg exchangeable potassium. It has been observed that there is an increasing exchangeable K in these soils where vegetables are grown.

According to the results of recent studies conducted by the DOA, plant nutrients build up in intensive vegetable – vegetable, vegetable -rice and vegetable-potato cropping systems are more than the rice-rice cropping system. Although, Wijewardena (1996) and Kumaragamage *et al* (1999) reported low available P content in LCWZ soils, results of the studies conducted by DOA recently showed that nutrient contents in vegetable growing soils in LCWZ and LCDZ are high, when compared to the rice growing soils. Wijewardena and Yapa (1999) reported low exchangeable K in vegetables and tuber crops growing soils in LCWZ. Wijewardena (1995) reported soils in the up-country contain reasonable quantity of exchangeable K. Recent studies conducted by DOA also show high exchangeable K contents in intensive vegetable growing soils in up-country wet and intermediate zones. Wijewardena(1996) and Wijewardena (1999) reported P build up in potato and exotic vegetable growing soils in the up-country wet zone and intermediate zones. Studies conducted by DOA recently also show the accumulation of P and K in the intensive vegetable growing soils in similar areas.

Micronutrient Deficiencies

Rice-growing soils particularly in the dry and intermediate zones are deficient in Zn and Cu. Citrus-growing soils in the Uva region are deficient in available Zn and Cu content. Boron deficiency in papaya is widespread in Sri Lanka. However, recent studies conducted by DOA showed that most of the agricultural soils contain appreciable amount of micronutrients except Zn and Cu for several locations. Further, farmers use high amounts of micronutrient containing fertilizers without any recommendations. However, studies of micronutrient response on vegetables conducted in several locations showed that there were no any responses (*DOA, unpublished Data*).

Soil Fertility Management

Plantation and food crop sectors are major categories in agriculture sector in the country. Since 1950 Sri Lanka started to use inorganic fertilizers such as urea, Triple Super Phosphate and Muriate of Potash to enhance the crop yields. N. P. K containing fertilizer mixtures were used earlier in the country and at present use of inorganic fertilizer are widespread in agriculture. However, in 1990, Department of Agriculture recommended use of N, P, K straight fertilizers as inorganic fertilizers instead of fertilizer mixtures and it benefits farmers to make necessary adjustments in fertilizer application for optimum yield. Further, DOA formulated blanket recommendations for all food crops and advises to use organic fertilizers with recommended inorganic fertilizers.

Fertilizer use

Due to N, P and K straight fertilizers has been recommended as the inorganic fertilizers, relatively large amount of urea, TSP and MOP fertilizers are imported annually compared to other fertilizers (AgStat, 2016). At present, Urea is the most dominant form of nitrogen fertilizer used in Sri Lanka. It accounts to almost 59 percent of the total fertilizers used in the country (AgStat, 2016). Muriate of Potash (MOP) could be the second most dominant fertilizer used in the country. Triple Superphosphate (TSP) is the most dominant phosphorus fertilizer used for short-duration crops such as rice, vegetables and other crops.

Small quantity of sulphate of ammonia, kieserite, commercial Epsom salt, zinc sulphate, diammonium phosphate, and single super phosphate are imported. Department of Agriculture (DOA) has recommended zinc sulphate only for rice, while micronutrient containing fertilizers has not been recommended for any other food crops. However, there are more than hundreds types of new fertilizer that are available in the market. In addition, magnesium fertilizer which is available locally as calcium magnesium limestone (dolomite) is often used as a soil ameliorant for acid soils. It is mainly used for potato, vegetables and other horticultural crops.

Special fertilizers used in Sri Lanka are NPK formulations with trace elements, micronutrient mixtures, and fertilizer mixtures for hydroponics, fertigation mixtures and fertilizer with growth promoting substances and micronutrient containing fertilizers and liquid fertilizers. Most of these fertilizers are comparatively high value fertilizers imported in small quantities.

Liquid fertilizers

Liquid fertilizer are either organic fertilizers or fertilizers containing both organic and chemical fertilizer. Even though the DOA has not recommended liquid fertilizers, some farmers are using them for crops such as vegetables, onion, potatoes, floricultural crops etc. By application of foliar fertilizers, farmers expect to obtain attractive product, which can fetch high prices in the market rather than to increase their yield. Similarly, many farmers in the country use foliar fertilizers due to influence of fertilizer companies.

In 2015, 357,937 liters of liquid fertilizer mixtures and 9,558 metric tonnes of granular fertilizer mixtures were imported to the country (Agstat 2016). Prior to 2013, there was no proper method for import of those new fertilizers to the country. However, in 2013 the Department of Agriculture has commenced a programme to test efficacy and quality of new special fertilizer products that are being imported into the country.

Table 5. Major Fertilizer consumption by crop sectors (metric ton) in 2015

Year	Urea	TSP	MOP	Others
	Metric ton			
Paddy	224,814	56,054	65,210	325
Tea	90,138	370	42,275	79,244
Rubber	3,208	173	2,475	5,399
Coconut	16,664	3,602	23,145	13,516
OFC	32,422	9,549	7,611	3,757
Vegetable	10,464	10,297	12,528	32,614
Potato	1,396	5,176	5,318	9,881
Fruit	7,229	4,390	8,471	3,183
Export Agric. Crops)	5,558	670	3,434	7,588
Others	39,348	11,114	12,116	8944

Source: AgStat-2016

Rice crop used almost 70% of fertilizers import to Sri Lanka and 20% were used by tea sector and remaining 10% were used by other crops.

Table 6. Amount of Fertilizer Import to the Sri Lanka

Year	Amount (metric ton)
2011	859,470
2012	743,477
2013	953,912
2014	1,063,722
2015	1,251,814

Source: Agstat, 2016

Locally produced fertilizer

Sri Lanka depends on imports of chemical fertilizer to meet the requirement. However, rock phosphate deposit at eppawala was discovered in 1971 and there are two forms of rock phosphate fertilizers being produced in Sri Lanka, namely Eppawala Rock Phosphate and High grade Eppawala rock phosphate (HERP). HERP could be considered as an improvement, which is processed by crushing pure apatite only. R phosphate fertilizers are not presently being imported to the country. With the increased demand for plantation crops and also with enhanced promotional efforts, the local supply of ERP had reached the highest level. Eppawala rock phosphate is used for perennial crops, such as tea, rubber, coconut, fruit crops etc. Dolomite is mined and crushed by private firms in the Central Province of Sri Lanka. It is regularly used as a liming material for tea and food crops in wet zone areas in the country when soil pH is lower than 5.

Use of organic fertilizer

The most dominant cropping system in Sri Lanka is the rice-rice cropping system and the most commonly generated organic manure in rice-rice cropping system is rice straw. Amarasiri and Wickramasinge (1988) studied the K contribution from rice straw to flooded rice. They showed that N content of rice straw may range from 0.66–0.84% while K content ranged from 1.30–2.03% and straw could replace nearly 1/3 of the N and the total supply of K in inorganic fertilizer terms. Presently, farmers apply rice straw for rice cultivation and it could be applied in combination with recommended chemical fertilizers. The straw must be incorporated into the soil two to three weeks before land preparation or three to four weeks before rice planting. Use of animal wastes for rice cultivation is very limited, since the cost of transporting animal manure is too high to permit its application for rice. Use of green manure in rice cultivation is not widespread. Nijamudeen *et al* (2003) showed the importance of black gram as an in-situ green manure with maize crop. They showed that incorporation of the in-situ grown black gram could increase the soil available P and exchangeable K content compared to the no black gram treatment.

Intensive vegetable growing areas in the country use cattle and poultry manure with chemical fertilizers. Poultry manure is generally used at the rate of 10 to 15 ton/ha per crop. Application of cattle manure is in the range of 20 to 30 ton/ha per crop. Further, Ministry of Agriculture has been promoting to increase the organic fertilizer production and its use. The national government policy is to implement balance use of organic and chemical fertilizers or integrated plant nutrition system (IPNS) at the field level, but the adoption of IPNS is low.

Soil Test-based Fertilizer Recommendation

In 1993, the Department of Agriculture introduced a programme to provide farmers with soil test based fertilizer recommendations and it is still continuing. Soil Test Based fertilizer recommendation prevents the excessive application of inorganic fertilizers. In 2017, Department of Agriculture established twenty soil testing laboratories in twenty districts in addition to existing twelve laboratories to promote the soil testing programme in the country. In addition, tea, coconut and rubber sectors have their own soil testing laboratories run by their respective research institutions such as Coconut Research Institute, Rubber Research Institute and Tea Research Institute. Further, Department of Agriculture provided the soil and plant testing kits to the extension officers and recently the Department is conducting soil test crop response studies.

Table 7. Crop yield and estimated fertilizer use efficiency with blanket recommendation and soil test based fertilizer recommendation

Crop	Location	Blanket application of recommended level of fertilizer			Soil test based recommended level of fertilizer		
		Fertilizer quantity (kg/ha)	Yield obtained t/ha	Fertilizer use efficiency kg/kg	Fertilizer quantity (kg/ha)	Yield obtained t/ha	Fertilizer use efficiency kg/kg
Rice	Bathalagoda	340	5.9	17.0	300	5.48	18.0
Rice	Bombwela	265	3.56	13.4	120	2.97	20.4
Beans	Gannoruwa	640	10.88	17.0	390	10.25	26.2
Bitter gourd		570	7.24	12.7	335	6.78	20.2
Beans		640	20.84	32.5	390	19.28	49.4
Cabbage	Bandarawela	750	61.29	08.1	500	83.87	12.2
Bitter gourd	Makandura	620	4.30	06.9	455	3.80	8.3

Source: DOA Unpublished data

Nitrogen fertilizers lost from paddy fields pollutes the environment and accumulates the NH_3, NO_2, N_2 and N_2O in the atmosphere, which in turn contribute to global warming. It also contaminates the ground water with NO_3 and washed N fertilizer from runoff water, hence N fertilizer management is also needed especially in paddy cultivation.

Losses of N from rice fields can be minimize by using slow release N fertilizer such as granular urea nano urea, use of more splits for top dressings. Department of Agriculture recommended granular urea as the slow release N fertilizer and N applied only as top dressing (No basal application) and use of nitrogen responsive rice varieties. N fertilizer should be applied only when the plants need it, to minimize N losses. DOA Leaf Colour Chart (LCC) is used for the N application in paddy cultivation (Sirisena *et al*, 2003).

Fertilizer Pricing and Subsidy

One of the largest subsidies given in Sri Lanka is the fertilizer subsidy worth about Rs. 15 billion each year, which is given to farmers, especially the rice cultivating farmers. However, in 2015 Government changed the fertilizer subsidy into a cash transfer system considering the damage caused by chemical fertilizers to human lives and to the soil. According to the Fertilizer Cash Grant Programme, the government provide Rs.25,000 allowances to farmers who cultivate paddy lands below two hectares for two seasons. Upon the repeated requests made by farmers, the government had taken measures to reintroduce the fertilizer subsidy programme. Only three types of fertilizers, urea, TSP and MOP were considered under fertilizer subsidy programme.

Soil Fertility Management Strategy

The Government of Sri Lanka stipulated national policies for the agricultural sector to solve many problems. Implementation of technically sound, environmentally viable, environmentally friendly and society acceptable programmes to promote sustainable agricultural development with efficient and effective utilization of resources; promotion of good agricultural practices such as integrated plant nutrition management and integrated pest management practices for sustainable agricultural development; promotion of production and utilization of organic and bio fertilizers and gradually reduce the chemical fertilizer through integrated plant nutrition system.

The government also ensures timely availability of chemical fertilizer in sufficient quantities while providing soil and plant testing facilities for their rational use through site specific fertilizer application. Promotion of application of straight fertilizers, promotion of manufacturing fertilizers using locally available raw materials, taking appropriate actions to prevent the misuse of fertilizer subsidy are also included in the national policies.

Adhere to the National Land Use Policy in allocating land for cultivation purposes, promotion of maximum use of degraded, barren and infertile lands to ensure higher productivity and idle lands to be used for crop/forest cultivation and animal husbandry. Promotion of land conservation within watershed areas, promotion of mixed cropping and inter cropping to ensure efficient use of land; encourage the use of efficient water management and moisture retention techniques to achieve high productivity in agriculture and enforcement of implementation of the provisions of the soil conservation act to ensure proper soil conservation are also implemented by the government.

Integrated Plant Nutrition System Approach

Farmers in the country especially intensive vegetable growing areas and other highland cropping areas use heavy doses of fertilizers. Due to this unbalanced use of fertilizer and continuous and intensive cultivation, nutrient supply capacity in soils has decreased considerably leading to decline in crop yields and soil fertility. Therefore, it is important to maintain the soil fertility in long term and reduce soil degradation in agricultural land. In order to improve soil fertility, it is important to follow environmentally-friendly plant nutrition management practices under Integrated Plant Nutrition System. This approach advocates the balanced use of organic and inorganic fertilizer for sustainable crop production. When adding fertilizer, it is important to assess and take into account the contribution of different sources such as soil, water, organic manure, rain to the nutrient pool. IPNS practices incorporate chemical, organic and bio fertilizers to the soil for restoring soil health and carbon storage in soils. IPNS is a holistic approach to provide required plant nutrients from different sources such as inorganic and organic sources to maintain and sustain soil fertility.

Studies conducted in relation to plant nutrition management had shown that in many cropping systems the integrated nutrient supply and management through judicious use of organic and chemical fertilizers would lead to sustainable crop production and overall improvement of soil as highlighted in Tables 8 and 9. Hence, the use of this technology is advantageous, as it helps to improve fertilizer use efficiency, improvement of long-term soil fertility (Wijewardena and Yapa, 1999; Dissanayake, 2000).

Table 8. Rice yield with different fertilizer management practices

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

Source: Dissanayaka 2000

Table 9. Effect of organic and chemical fertilizers on crop yield

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

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

Best Practices of Integrated Plant Nutrition System in Sri Lanka are balanced use of inorganic fertilizers and manures soil test-based or site specific fertilizer application, cropping pattern with green manure, mix cropping, crop rotation and in situ green manuring etc. Further, correction of pH with liming use of appropriate pest, disease and weed management practices are also used. Different agronomic practices such as mulching, contour planting and zero tillage are also practiced. Mulching helps to conserve moisture, improves soil fertility and reduce weed growth. In tea plantation, pruning materials are also added as mulch. In Sri Lanka, many soil conservation methods such as contour planting in vegetable farms in hill slopes are used.

At present Sri Lanka use available green manures, all possible crop residues, available animal manures and compost in combination with recommended NPK inorganic fertilizers. In addition, farmers use soil amendments, such as charcoal paddy husk with recommended NPK fertilizers for rice cultivation. For rice cultivation every season 2-4t/ha organic manure application should be practiced.

There are many advantages of the use of IPNS such as enhancement of availability of applied nutrients as well as native soil nutrients; provides balance nutrition to crops; match the nutrient demand of the crop with nutrient supply from nature and applied sources; improve and sustain chemical, biological and physical properties of the soil; minimize the deterioration of the soil, water, and ecosystem by promoting carbon sequestration; reducing nutrient losses and increase the fertilizer use efficiency.

Table 10. Recommended IPNS Practices in different cropping systems in Sri Lanka

Cropping system	IPNS Practice
Rice- Rice	• Recommended NPK fertilizer with supplementary rice straw recycling (total weight of rice straw of previous crop). • Use of cow dung/poultry manure/ green manure at the rate of 2t/ha. • Use of charred rice husk. • Use of leaf color chart for N management. • Cultivation of Sandwich crop. • Application of ZnSO4 in once a year.
Rice –Fallow	• Recommended NPK fertilizer with rice straw (4-5t/ha), green manure (2-3t/ha) and cow dung (5t/ha) or poultry dung (3t/ha). • Charred rice husk can be applied at the rate of 625kg/ha.
Rice –Other Field crops	• Rice straw is added as mulch for chili, onion and vegetables crops. • Addition of organic manure (cow dung, poultry manure and goat dung) is practiced with recommended chemical fertilizer of NPK.
Vegetable – Vegetable	• Use combination of recommended NPK fertilizer as inorganic fertilizer with organic manure as cattle manure or compost (10t/ha). Poultry manure also can apply at the rate of 5t/h. • Lime the soil pH is below 5. • Practiced soil test based chemical fertilizer (P and K). • Recycle crop residue if disease free. • Crop rotation is practiced.
Other Field crops – Food crops	• Practice combine use of mineral fertilizer and organic manure.

Source: Integrated plant nutrition system (IPNS) Training Manual. FADINAP/PRUDD/RDS/CAP/001046-B

Table 11. IPNS Based Fertilizer Recommendation for different crops

Crop	Urea	MOP	TSP/Rock Phosphate	Lime/ Dolomite/ Charcoal	Compost /Cattle Manure	Poultry Manure
	kg/ha					
Rice – Wet Zone				If pH is less than 5.0 add 2t/ha dolomite or lime	2 t/ha	2 t/ha
Irrigated	140	50	35 as TSP			
Rain fed	100	110	55 as TSP			
Rice–Dry/Intermediate zone						
Irrigated	225	60	55 as TSP			
Rain fed	175	50	35 as TSP			
OFC Chili (Irrigated)	320	100	100 as TSP	If pH is less than 5.0 add 2t/ha dolomite or lime	10-15t/ha	3-4t/ha
Vegetable				If pH is less than 5.0 add 2t/ha dolomite or lime		
Potato-Nuwara ELiya and Badulla districts	330	170	270 as TSP		10 t/ha	5t/ha
Cabbage-Nuwara Eliya	330	150	270 as TSP		10 t/ha	5 t/ha
Tomato – all areas	195	130	325 as TSP		10 t/ha	5 t/ha
			g/plant			
Fruits						
*Banana			100 Rock Phosphate in wet zone 80 TSP in dry/intermediate zone		5-10 kg/clump	3-5 kg/clumps
Wet zone	110	190				
Dry & intermediate zone	120	250				
**Papaya						
Wet zone				5kg/plant dolomite	5-10 kg/plant	4-5 kg/plant
Basal	55	95	80 RP			
2 months after planting	55	95	80 RP			
3 months interval	55	95	80 RP			
Dry and Intermediate zone						
Basal	60	130	40 TSP			
2 months after planting	60	130	40			
2 months after planting	60	130	40			
3 months interval	60	130	40			
***Pineapple				2-5t/ha dolomite		
1 months after planting	10	15	10 RP			
3 months interval	10	15	10 RP			

Source: DOA recommendation of Rice, Horticultural crops and OFC.

* Application of organic manure at 4 month intervals with chemical fertilizer.

** Organic manure application- Cattle manure or poultry manure or compost (every 3-4 months).

*** Apply plant residue or animal manure. For rice apply ZnSO4 at the rate 5kg/ha in once year.

Challenges of practicing IPNS

Although IPNS provides number of benefits, there are also many challenges to practice IPNS in the country. Low availability and competitive use of organic manure sources and high transportation cost, scarcity of labor for agriculture are the main challenges of practicing IPNS in the country.

Generally, IPNS is a long term approach for effective crop productivity, but farmers in the country expect immediate and quick economic benefits, therefore they are not in favor of practicing IPNS technologies. Another challenge of practicing IPNS is application of organic manure, which is very expensive and labour intensive and it is also not available in required quantity. In addition, lack of knowledge of farmers on IPNS technologies and inadequate linkage and interaction among researchers, extension officers and farmers are another challenges. Therefore, government and other relevant organizations should encourage the farmers by providing suitable facilities, conducting large scale demonstrations, training and awareness programmes.

Conclusion

Sri Lanka is an agricultural country with diverse agro-climatic region. Rice is the major crop in the country and it consumed highest proportion of fertilizer. Agricultural soils generally in low country wet zone area are acidic and due to prevailing high temperature, soils are low in organic matter content. Declining of soil nutrients due to imbalance and indiscriminate use of fertilizers are the main challenges in soil fertility management. Therefore, it is important to introduce sound nutrient management programme like integrated plant nutrition management in the country. Government of Sri Lanka had adopted a subsidy scheme of fertilizers and also promotes balance use of available organic and inorganic fertilizers. The Department of Agriculture had also developed a national policy for the promotion of Integrated Plant Nutrition System in Sri Lanka.

Inadequate knowledge of balanced use of nutrients among farmers, poor linkages between researchers and extension officers are major challenges to implement IPNS in the country. However, soil test based fertilizer recommendation is popularized among farmers and it was successful. Hence, the Ministry of Agriculture and Department of Agriculture have introduced 20 districts level new soil testing laboratories in the country. The Department of Agriculture is actively promoting and encouraging farmers to adopt IPNS approach and strongly recommend using organic manure such as cattle manure, compost, poultry manure etc. with recommended NPK fertilizer for different food crops production. It is also imperative that the relevant organizations should carry out research continuously to develop most appropriate technologies with effective fertilizer recommendations for different crops and cropping systems in different agro-ecological zones.

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Chapter 8

Integrated Plant Nutrition System Modules for Major Crops and Cropping Systems in Maldives

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Introduction

Maldives forms the major chunk and biodiversity rich central portion of the Lakshadweep-Maldives-Chagos Archipelago in the Indian Ocean. A chain of 26 atolls with over 1,200 islands, spread across a range of 1,600km north to south. Its submarine mountain range boasts of one of the most spectacular coral reef gardens around the globe, home to hundreds of species with varying size and color, forming a unique combination of flora and fauna (Sujanapal, 2016).

Vegetation and physical features of the island ecosystem varies between islands from North to South, and also depends where the island is situated within the atoll, since the exterior islands are more subjected to oceanic currents than the interior islands. Though these tiny islands are subjected to harsh climatic and environmental conditions, healthy growth of trees is observed in all the islands. The characteristic of the foreshore area does affect the vegetation of the islands. A typical island can be seen from a distance highlighted by its tall coconut trees. In most of the islands they cultivate a wide variety of crops in their homesteads, such as chilly, almond, drumstick tree, banana, cucumber, mango, taro etc. majority of which were introduced from other countries. In addition to this, large amounts of ornamentals and planting material for avenue gardening is imported every year. Hence, the Maldivian flora is composed of a large number of exotic species (Sujanapal, 2016). Despite suitable tropical conditions for plant growth observed across the country all throughout the year, other factors such as salinity, soil alkalinity, and harsh salty winds inhibit the healthy growth of certain food crops.

With over 1,190 islands which are barely 1.5 meters above sea level divided and sorted into 26 atolls arranged in a double chain in a North-South direction, Maldives is the world's most geographically dispersed island nation. Poor transportation has made the movement of people and goods around the country very difficult. Establishing a sustainable supply chain was almost impossible. Therefore, some crops became exclusive to some areas and not all had the access to these food sources. The easier option was fish and products from the coconut palm. Being unable to achieve balanced diet severe cases of malnutrition followed, giving rise to high mortality rates, especially among infants.

Agriculture

Agriculture and fisheries in the Maldives has evolved over the past 50 years. Contemplating the scarcity of good agricultural land, farmers moved on from the cereal crops to ones which can be grown easily and provide a reasonable yield over small plots of land. The main crops grown were finger millet *(Eleusine coracana)*, sorghum *(Sorghum vulgare)*, common millet *(Panicum maliaceum)*, foxtail millet *(Setaria italic)*, maize *(Zea mays)* etc. different products made from the coconut palm *(Cocos nucifera)*, bread fruit *(Artocarpus altilis)* Taro *(Colocasia esculenta)*, sweet potato *(Ipomoea batatas)*, cassava *(manihot esculenta)* and other related root crops were mostly popular in the southern islands where land and climate are both suitable. But as land is scarce and its demand grew, high yielding and high value crops replaced most of the field crops (Adheel, 2017).

Contribution to Gross Domestic Product (GDP)

The 2004 tsunami has highlighted the need to promote economic diversification in the Maldives to increase its independence from being completely reliant on its two key sectors, namely tourism and fisheries, which currently make up almost half of the GDP. Agriculture's share in the GDP was around 7 per cent in 1984, which declined to 3.6 per cent in 1995 and then further to 2.0 per cent in 2009, and it only engages about three per cent of the labor force although it is estimated that 9,000 farmers are supporting a large group of rural families. According to the GDP outlook compiled by the national bureau of statistics, in 2018 contribution of agriculture to the GDP has dropped to 1.1% (National Bureau of Statistics, 2019).

Fifty-four per cent of that labor force is comprised of women. Recently, there has been an increasing trend of employment of cheap foreign labor in the agriculture sector, slowly replacing local women. Therefore, capacity-building of rural women in leadership and organization skills is an important step towards their empowerment (Ministry of Environment and Energy, 2014).

Soil

In the Maldives, soils are made up of coral material, coral rock and sand and in general, they are of poor quality, very saline and with low water-holding capacity due to high porosity. The brown soil only is up to 40 cm in depth, and followed by a transition zone on top of the limestone, thus preventing the penetration of almost everything. In the wetlands, the depth of the clay may be deeper due to accumulation of materials over a long time (Liebregts, 2008). The pH might be more acidic in the wetlands due to the humus, but generally soils are alkaline with pH values between 8.0 and 8.8. In order to cultivate these harsh soils, import of animal manure and compost in large quantities has been on the rise (Liebregts, 2008).

Agricultural Land Use

In the Maldives agricultural activities are carried out mainly on the larger islands. In terms of land availability and soil fertility, the southern islands hold an edge over the northern islands. Down south of the country most of the inhabited islands are quite large in comparison to the northern islands, thus have more available area for agricultural activities.

The land is managed by the council which is based on each island. The amount of land to be allocated for agriculture will be decided by the island councils, and the final land use plan of the island will be approved by the Ministry of Housing and Infrastructure. Alterations can be brought about every now and then but will require approval from the main government. Usually in an average inhabited island, the amount of land given to a single farmer could vary from a range between 3000 – 10,000 square feet. In rare cases farming plots over 20,000 may have been given out as well.

Agriculture in the Maldives is not limited to inhabited islands only. There are commercial scale producers also on the uninhabited islands which are leased by the government on a long term basis, for the sole purpose of carrying out agricultural activities. Some of the larger islands could measure around 200 hectares, while some of the smallest could be around 5 hectares. Scheduled monitoring and performance evaluation trips are carried out by the Ministry of Fisheries and Agriculture to ensure the contracted works are carried out on the islands accordingly.

Natural Resource Degradation

Today, global warming is a major issue all over the world. It affects many aspects of life: agriculture, plant and animal biodiversity, the environment and socio-economic well-being. One effect of global warming is climate change, and it is possible to mitigate the effects by good agricultural management.

The Maldives' hot climate is ideal for vegetation growth, but there are limiting factors such as salinity and high calcareous soils. In some island with the removal of the "green boundary" cultivated crops suddenly die from exposure to the salty wind, which does not differentiate species, native or naturalized in the Maldives. Land clearing has become a common norm for development purposes (Ministry of Environment and Energy, 2014). Removal of the tall coconut palms in large numbers to be transported to newly built tourist resorts exposes lower growing plants, crops and even houses to high winds causing severe damages.

Clearly, climate change and sea-level rise, accompanied by saltwater intrusion of groundwater, will pose a severe threat to the existing limited agriculture practiced by the rural farming communities in the country. The probable impacts include intensification of productivity loss, drought, varying monsoon patterns with less rainfall, stronger winds, shifting crop cycles and more pests (Ministry of Environment and Energy, 2014).

Our livelihoods depend even more on surrounding reef and the sea than on the land. With the ever changing global temperatures, and especially more frequent *el nino's* has been catastrophic to our marine ecosystem. Coral bleaching, habitat loss of reef fishes, algal blooms and sudden mass death of fish are now more frequently encountered. Thus, the fishermen need to venture further away from their islands in search of better fishing grounds, burning more fuel and having to stay away from their family for longer periods of time. After the 2004 tsunami, fresh water lenses of most of the islands remained more saline for a prolonged period of time. As a result there was severe vegetation loss in some areas of the country which were later re-established by the government with the help of international donor agencies.

Air pollution

While most of the islands are relatively air pollution-free, air quality in Malé is on the decline as more and more people move to the city. Already 40 per cent of all Maldivians 150,000 people are crammed into an area of just 3.6 square miles. Almost every other person has rides a motorbike. During busy hours a beeline of car can jam the narrow streets, while numerous motorbikes weave their way through, the sorry pedestrians are filtered on to the dangerous roads through the ever growing parked motorbikes on the side of the streets. It is not only wheeled vehicles emitting the unhealthy pollutants. The country's large ferry network connects Malé to neighbouring atolls, and the boats mostly run on heavily polluting diesel engines. As the capital builds upward to accommodate new arrivals, construction dust is also playing a role. And the smoke from the open burning of waste on nearby waste management Island is the main source of air pollution in the country.

Temperature

Throughout the year, temperature remains almost same in the Maldives. However, daily temperature ranges from around 31 degrees Celsius in daytime to 23° Celsius in night time. The highest temperature ever recorded in the Maldives was 36.8°C, recorded on 19 May 1991 at Kadhdhoo Meteorological Office. Likewise, the minimum temperature ever recorded in the Maldives was 17.2°C, recorded at the National Meteorological Centre on 11th April 1978 (Adheel, 2017).

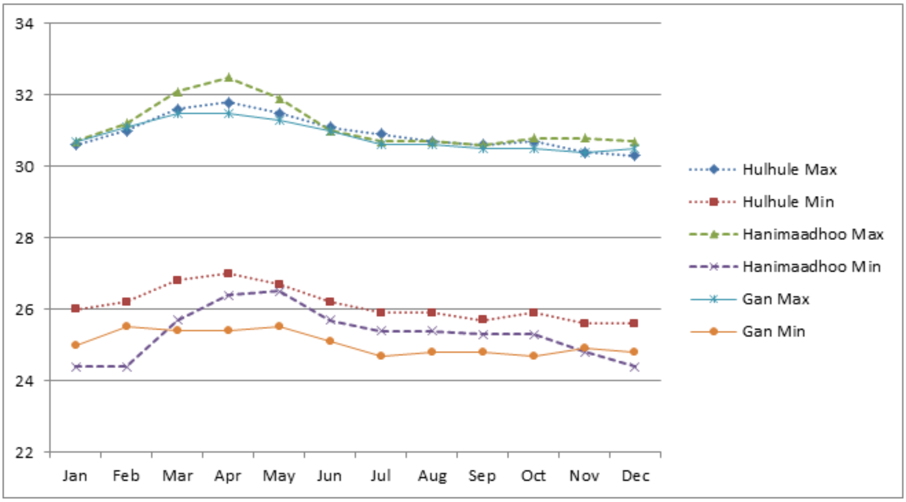

Figure 1. Average temperature data from MET service since the year 2000

Integrated Plant Nutrition System Approach

Maldivian islands are composed of high calcareous soils, which are low on organic matter and are also highly porous. Thus soil application of nutrients is highly expensive, as the soil cannot retain the majority of the applied nutrients for a decent amount of time; frequent applications of fertilizers are required. The increased application rates pose a threat to the environment and even to the marine ecosystems due to run off and leaching into the ground water. To tackle this issue, the ministry of agriculture had introduced different models of hydroponics over the past decade to properly manage and provide plant nutrients in an environmentally friendly way. The introduction of drip irrigation system, coco peat, and fertigation methods has been more effective to manage plant nutrients.

Figure 2. Drip feed demonstration in Agriculture Centre 2019

Even through this systems reduction on the synthetic fertilizers reliance cannot be reduced as yet, since healthy crop production is be maintained which sustains livelihood in some of the more isolated areas of the country. Some of the larger islands do practice cover cropping, green manuring and other soil nourishing practices like on site compost production, but in general most of the farmers are more reliant on the imported compost and manure.

Figure 3. On field composting done in Gn. Fuvahmulah island 2017

Soil Fertility Status

In the recent past, no soil fertility tests have been officially carried out by the Ministry of Fisheries and Agriculture in any registered farm in the Maldives. This is largely due to the high expense, lack of resources, facilities and expertise in the related field. In the current situation, advice and guidance from the Agriculture Ministry is provided based on experience and best practices adopted by other similar island nations. But the effort has been continuous on capacity building and acquiring necessary funds to carry out such activities.

There are few islands which follow cultural practices in the Maldives. Most of the farmers being subsistence growers, all year round cultivation is not carried out on most of the average sized islands. The demand for specific fruits and vegetables like watermelons and cucumbers rise during the Ramadan period. Most subsistence growers target this period of the year to make some quick good money. But on the islands where the livelihood depends on agriculture, the level of agriculture is quite intensive in terms of production, usage of fertilizers and pesticides.

Table 1. Pesticide and fertilizer import

Type	Qty	2013	2014	2015	2016	2017	TOTAL
Fungicide	**Ltrs**	3964.15	554.5	10707.6	9750.42	4940.47	**31291.99**
	Kgs	17526.3	22641.95	51323.84	33713.9	50124.87	**186334.4**
Herbicide	**Ltrs**	116	814.4	1638.8	3062	1	**5972.71**
	Kgs	42	0	0	2	11	**55**
Insecticide	**Ltrs**	104160.3	284326.4	180186.5	189938.4	213074.5	**1066610**
	Kgs	45564.18	62771.23	26170.13	42220.87	54009.44	**253956.1**
Fertilizer	**Ltrs**	4491.76	4467.75	85068.89	271844.7	113669	**52204.85**
	Kgs	1550167	1875967	3164016	2671159	4678498	**3606622**

Source: Ministry of Fisheries Marine Resources and Agriculture.

Statistics of Manure and Compost Import

Traditionally farmers have always been incorporating large amounts of organic material in the soil prior to cultivation. Soils in Maldives being highly alkaline (usually between 7 and 8.5) the importance of spreading compost and animal manure has always been emphasized. This helps in lowering the soil PH thus reducing the stress on inorganic fertilizer applications. It is often difficult to convince farmers on the effects of such technical implications related to plant nutrient uptake.

Based on feedback from farmers and field officers, reduction in soil fertility has been observed in the most intensive agricultural areas around the country. In some cases the increased and inappropriate use of synthetic fertilizers is quite staggering. Continuous and extensive use of animal manure and synthetic fertilizers and agrochemicals has resulted in contamination of ground water bodies in most of those islands. The effects on our fragile coral reef ecosystems, which our livelihoods depend on, are also at question due to inappropriate agricultural waste disposal methods (Liebregts, 2008).

Modern and traditional methods of returning the nutrients back to the soil are continuously practiced during awareness and training programs. Also information is disseminated through extension material and officers all year round.

Table 2. Import of Manure and Compost

Year 2013	Year 2014	Year 2016	Year 2017	Year 2018	Year 2019
7041 Tons	6947 Tons	8723 Tons	6866 Tons	8767 Tons	6351 Tons

Source: Maldives Customs Services, 2019)

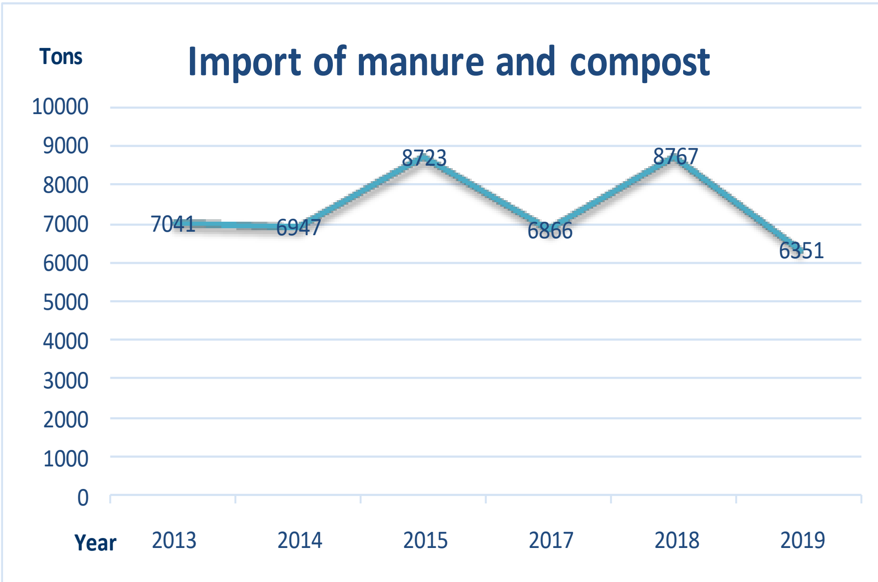

Figure 4 Import of Manure and Compost

Soil Fertility Management

Continuous trials on crop management and soil fertility management is carried out by the Ministry, in Hanimaadhoo Agriculture Centre located up north of the country. Once again data on crop production and performance are taken, while no data on soil fertility is taken due to lack of resources and expertise.

Nevertheless to ensure the soil does not get "exhausted", crop rotation practices are carried out. A fallow period of around 2 years is usually provided after a full year of cultivation. It has been observed that when cultivation begins after the resting period that was provided for the selected plots, it required fewer amounts of external inputs into the soil, for the plants to have a healthy growing cycle.

Figure 5. Composting site
Maldives complete blog. Site: Soneva Fushi resort.

Figure 6. A typical farmland.
Photo: Dr. agr. Volker Kleinhenz

In order to improve soil structure and texture, soil conditioners are prepared in the Centre. This usually comprise of main compostable plant material available from the site and goat manure which comes from the goat farm in the Centre.

In addition to these activities government had mandated composting to the environment ministry through solid waste management. The islands in which the project has now been implemented, production of compost has gradually increased, and in some cases have produced more than enough for the island and have started generating income from it.

Challenges

Addition of compost is no doubt one of the best and easiest ways to maintain soil health and prolong sustainable crop production. It has always been difficult to convince farmers to take up the practice of composting or even to have a cover crop. Main reason behind this reluctance is due to the small parcels of land each farmer has access. Main policy of an island council is to provide maximum farming land to the maximum number of people to reduce conflict. By doing so, the area of land leased to a farmer is insufficient to produce a good harvest and earn a good income. The farmer has to carry out their composting in the same area of land which is roughly 3000 sqf in most cases. Which is why they are not very encouraged to do it. (Liebregts, 2008)

In the past years the then, Ministry of Fisheries and Agriculture had tried to conduct large scale composting programs in some of the bigger islands. But due to the overlapping of mandates with the Ministry of Environment and Energy, Agriculture Ministry found it difficult to proceed with the program. Large scale composting was mandated under the waste management program to the Environment Ministry. But the use of compost produced from MSW (Municipal Soil Waste) management in agriculture is not generally a recommended practice, as there is a concern of high metal content in the compost. Metals and excess nutrients can move through the soil profile into groundwater. Municipal solid waste compost has also been reported to have high salt concentrations, which can inhibit plant growth and negatively affect soil structure. Its safe use in agriculture can be ensured with source separation (or triage of MSW to be composted) as well as the development and implementation of comprehensive industry standards.

IPNS Approach

Integrated plant nutrition system involves the balanced supply of chemical, organic, and biological forms of plant nutrient sources with the aim of improving the productivity, sustainability, and stability of production in an environmentally safe and economically and socially viable manner (Altieri, 1995).

In the Maldives, farmers are very dependent on synthetic fertilizers. Sustainable land use practices are usually neglected in order to maximize the amount of income generated from the small plots of land allocated for farming. It has proved to be a challenge to convince farmers to adopt methods that are both less hazardous to the environment but at the same time provide a good yield which they are happy.

Lack of infrastructure and technical expertise to check biotic and abiotic factors of our soil have been a major drawback in better understanding the soil requirement. In nutrient application, farmers often use customized versions which are random and do not comply with the regulations provided by the ministry. These contradictions are seldom accounted for and never get recorded while managing farm data. Thus, no one can really tell how much fertilizer applications have been carried out in a given period of time. Often the data recorded by field officer is the data provided by the farmer and no cross check referencing is available to verify the information.

Despite the gloomy situation of IPNS in the past, there are some crops like papaya, breadfruit banana, taro, cassava, coconut and mango which are often cultivated in a more balanced manner for both farmer and the environment. It is not common to use tons of inorganic fertilizers on such crops in a production cycle. Perhaps the approach of people towards these crops as more home gardening crops than cash crops has resulted in these continued cultivation practices. Some of these crops like papaya, mango, banana and coconut are now proving to be major cash crops, but the practices have changed only very slightly. Most of these crops are grown in backyards and are fertilized by homemade compost and imported manure.

With the initiation of large scale composting through the island waste management system, there has been a positive response from the local communities including farmers towards the management of organic waste and producing compost which has great value as a soil additive to improve their crop health and yield. At the same time they have experienced the reduction in weeds (which were often carried in with the imported compost and manure) thus reducing the cost of weed management. Improving the soil health by incorporating more organic matter into the soil, overall crop performance has improved for most of the farmers thus slightly promoting the belief in the importance of an integrated nutrient management system.

Challenges in up scaling IPNS

- Difficulty in information dissemination due to geographical distribution;
- Lack of accessibility to crop varieties that perform better in our environment;
- Lack of field officers in major agricultural islands to provide expert knowledge;
- Lack of priority for IPNS at national level;

- Lack of man power to conduct supervision and monitoring;
- Lack of resources, expertise for sampling and testing;
- Lack of good agricultural land;
- Lack of good fresh water sources;
- Lack of technology transfer, research and development.

Potential for future IPNS development

In most of the islands in Maldives, developing an integrated plant nutrition system where both farmers and environment will benefit, prove to be a major challenge. No plant grows without nitrogen, and few crops grow economically without added inputs of this plant nutrient. Many farmers' and tree growers cannot afford to buy nitrogen fertilizers, so yields suffer. In Maldives, the most common nitrogen fertilizers are Urea and Ammonium Sulphate. Farmers have been experiencing reduction in plant response to these fertilizers. Thus, it has triggered an increase in application rate. The highly soluble urea does not remain in highly porous soils and gets leached away easily with irrigation and even rain. With the weak physical and chemical composition of our soil, conversion of nitrogen into plant available forms could get affected. This could lead to the assumption that more and more fertilizer is required disregarding the importance of the biological health composition of the soil (Liebregts, 2008).

Solutions could include:

- A possible substitute could be the use of slow release fertilizers;
- Using focused feeding methods rather than broadcasting;
- Improving the physical and biological composition of the soil, by incorporation of organic matter thus improving the uptake of available nutrients in the soil;
- Using suitable irrigation methods, like drip feeding and incorporating moisture retaining organic materials like coco peat which are readily available from all the islands;
- Due to our highly calcareous sandy soils, it has often been advised to use soil less media for crop production where ever

possible. This would increase the efficiency of nutrient application and reduce the cost greatly for the farmers (Liebregts, 2008);

- Use live fencing around the farms by planting Nitrogen Fixing Trees (NFT). Mutually beneficial relationship with root microorganisms in legumes able to transform atmospheric nitrogen into a form usable to the trees, which in return provide carbohydrates to the microorganisms (Adheel, 2017). Such a built-in, living nitrogen fertilizer factory often allows NFT to grow more rapidly with fewer inputs in nitrogen-poor soils than most non-nitrogen fixing trees. This nitrogen can be used not only for the NFT's growth but as a green manure for other crops and trees (FAO, 1987). Nitrogen rich foliage material from these trees can then be utilized in preparing compost (FAO, 1987);
- As reported in the (Hameed, 2002), Five sea grass species belonging to four genera have been recorded in Maldives, namely; *Thalassia hemprichii, Syringodium isoetifolium, Cymnodoea rotundata, Thallassodendron ciliatum* and *Cymnodocea* sp, the first being the most dominant species found in Maldives. All of the species can be used to prepare compost since they are high in beneficial nutrients for plant growth. Currently, the dead and dried sea weeds remain on the beach and decay away or in some islands are burned as unusable waste.

Conclusion

To achieve the goal of sustainability in the field of agriculture, IPNS can play a key role in the Maldives. But more work need to be done in different sectors of agriculture to achieve sustainability; from capacity building to infrastructure development and securing of funds need to be addressed at the earliest.

With collaborative work with our neighboring countries that have advanced knowledge in the field of agriculture and IPNS, could provide Maldives a better platform to launch its efforts in preparing a proper agricultural framework with IPNS at its core. At the same time capacity building to provide better information and guidance to farmers is also vital.

Improving soil structure physically and biologically is highly important to sustain plant growth. Crop production practices and programs should be conducted by promoting this as the main idea. It is often said in agriculture, our job is to feed the soil, and in return the soil will feed our crop. Farmers who had started off without sufficient knowledge about the complex issues that affect soil plant health, fails to grasp the importance of regulating, maintain and adapting to certain changes that occur naturally, and are altered physically during crop production. To prolong the longevity and productivity of our soils, our practices need to change.

With the ever growing population in the south Asia region, food demand and prices are expected to rise in near future. Maldives being a country very much dependent on import, should focus more on increasing domestic production.

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Chapter 9

Integrated Plant Nutrition System Modules for Major Crops and Cropping Systems in Afghanistan

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Introduction

Afghanistan is a land locked country in Central Asia with a total area of about 652,000 km^2. It is bordered by Turkmenistan, Uzbekistan and Tajikistan on the North, China in the North-East, Pakistan on the Eastern and Southern parts and Iran on the Western side. It is characterized by its rugged terrain and the elevation varies from 150 to 8,000 meters with an average elevation of 1,100 m above the sea level. About three quarters of the territory consist of mountains and hills, while low lands include river valleys in the northern part and desert regions in the Southern and Southeast part.

Agriculture is the backbone of economy of the country and it contributed 28% of the Gross Domestic Product (GDP). It provides 59% of overall employment in the country and the total value of licit export from Afghanistan was US$ 385.5 million in 2010/2011.The major export items were carpets and rugs, dried fruits, medicinal plants, wool, fresh fruits, skin and other items. Hence, the importance of agriculture sector in the national economy and export earnings is obvious. Overall performance of agriculture in Afghanistan is very much dependent on cereal production, which accounted for over three-fourth (77%) of the agricultural GDP at 2010 /11 market prices. Corresponding shares of horticulture and livestock sub-sector in agriculture GDP were 9% and 14 %.

Natural Resource Degradation

Natural resources support livelihoods and offer diversified growth options. There is almost 30.2 million hectares of the rangeland which constitutes 47 % of the land area in the country. About 1.8 million hectares of the natural forest and rangeland provide up to 80% of fodder for livestock and fruits, nuts and medicinal plants contribute 34 % of agriculture GDP, 7 % of the national GDP and 50 % of Afghanistan's export earnings.

The forests trees in the mountains are cut heavily and in unprofessionally manner for use within the country as well as for smuggling into other countries. This makes the soil of the mountains susceptible to wind and water erosion. National Natural Resource Management Strategy 2017-2021 is a comprehensive program that aims to increase management effectiveness, bring investments, and improve economic benefits for the local communities heavily dependent on natural resources. The people living in the remote areas indiscriminately cut the plants and bushes for cooking and heating of their houses. This causes severe loss of bio-diversity and land degradation. Further, overgrazing of the rangeland and pasture has destroyed many palatable species of the plants and there is great loss of biodiversity.

Afghanistan is vulnerable to climate change because of its location in the dry areas of the world, which causes the shortage of water, reduction of rainfall and higher rates of evapo-transpiration resulting in hotter and drier climatic conditions. Further, climate change with incaresed temperatures induce early melting of snow causing floods, soil erosion, land degradation and sometimes even landslide. Evapo-transpiration rates are relatively low in the Hindu Kush because of sever and long winters varying between 1300 mm and 1500 mm in the Northern plains and reach values of up to 1800 mm in the Southern and South-western plains.

Agriculture

The cultivable area in the country has been estimated at 8 million ha, which is 12 % of the total area of the country. The total irrigated area is 5.3 million ha, but the functional irrigated is 2.5-2.6 million hectares. Wheat is one of the most important cereal crops grown in Afghanistan, which is cultivated under both irrigated and rain-fed environments and it covers a total of 2.3 million ha in the country. Before the war of 1979, cereals were grown on about 87 percent of all cultivated land; out of this wheat was planted on 57 percent of the cultivated land. Per capita consumption of wheat is 175-200 kg (SAC 1989).

Afghanistan was almost self-sufficient in 1976-77, the average yield increased from 832 kg/ha to 1131 kg/ha in 1978. The increase in yield was mainly owing to introduction of high yielding improved varieties and improved agro-techniques. With the introduction of improved wheat varieties and the use of proper inputs, the average yield was raised to 2500 kg/ha. According to growth habit of all three types of wheat grown in Afghanistan by the farmers, cold-resistant winter wheat variety is grown in high elevations and covers 10 percent of the wheat area, 90 % is covered by facultative type wheat grown during the fall and small acreage are under spring wheat cultivation (Manan and Wassimi, 2019).

The climate in the country varies greatly from place to place resulting in variation in sowing time for example when the wheat crop is harvested in low eastern part of the country, wheat is sown in high elevation of Salangs and Bamyan. This benefits the wheat shuttle breeding program in the country.The F1 generation progenies produced in low elevation will be able to sow in the higher elevation and it will become F2 generation and harvested in the same year. Similarly, sowing of wheat in low and warm areas will make F3 generation and this process will be continued till we get a line to be put in varietal trial.

The source of water for irrigation is canals which irrigates 84 percent of the total irrigated area, Karezes , springs and shallow wells irrigates the remaining 16 %. The climatic condition of Afghanistan is arid and semi-arid with an average precipitation of 250 mm per year. The rainfall distribution is not good as more than 80 % of the rain fall during winter and early spring, when there is less need for irrigation of the crops. During the summer when the temperature rise high, there is more need for irrigation but there is no rain and very less water in the rivers which is not enough for irrigation of the crops.

Overall irrigation efficiency is only 25-30 for both modern and traditional irrigation schemes due to the following point:

- High conveyance losses in traditional schemes with earth canals;
- High operation losses in modern schemes with lined conveyance canals;
- High on farm distribution losses (over-irrigation, poorly leveled land) in both traditional and modern schemes (Mumtaz, 2000).

Agricultural production capacity and food security in Afghanistan were greatly damaged by prolonged war and several years of continued drought which destroyed the agriculture infrastructures. Rebuilding agriculture is crucial for Afghanistan to return to free war status and progress beyond that level. More than 80 % of Afghan families depend upon agriculture for their livelihoods, re-establishing viable livelihoods for the people of Afghanistan are one of the high priority.

The aridity index of the country is as follows:

Very dry	15.35 %	Dry	53.39%
Semi-dry	22 %	Semi-humid	9 %
Humid	0.26 %		

This reveals that almost 15 % of the country falls under very dry and more than 75 % of the area locates under arid and semi-dry conditions. Agriculture activities could not be done without irrigation. The following land tenure is practiced in Afghanistan:

1- Own cultivator

Having legal right to land as farmers own property

2- Share-cropper

The arrangement, under which a person cultivates others land in return for a fixed part of production.

3- Renting

This is an arrangement with the owner, through which the cultivator pays a fixed amount of grain or money, for the use of land.

4- Grow or Rehan

It is a form of money lending, where a piece of land is cultivated by the lender for an agreed fixed amount. There is no interest charged but lender can frequently get his investment back in the form of produce in 1-3 year. Some of the arrangements are of long term but the property is never transferred.

5- Mortgaging

This is an arrangement where money lenders (local credit sources) take the land as security against loan, given to the land owner.

It is estimated that 60.5 % of all agricultural land was owner operated and most of Afghan farmers are small landholders. However, Swedish Committee for Afghanistan (SCA), the agricultural survey (1988) estimated that 80% of all farmers in Afghanistan cultivated their own land before 1979.

Seed Production System

In Afghanistan seed regulation, seed policy and seed law are present and implemented. According to the seed law the breeder seeds are produced by the Agricultural Research Institute of Afghanistan (ARIA) in over 19 agricultural research stations, which is located in different part of the country. The basic seed is given to the Improved Seed Enterprise (ISE) for the production of foundation seeds in their farms. The foundation seed is distributed to the 140 Village Based Seed Enterprises (VBSEs), which are located in different parts of the country for the production of certified seed. Certified seed after the processing, cleaning, treating and bagging are sold to the farmers for planting. The Seed Certification Department is carrying out field inspection and laboratory testing for the quality of the seed produced.

Soil Fertility Management

During 1974 because of the presence of natural gas in the northern part of country, the Kud Barq fertilizer factory was built by Russia in Mazari-e-sharif with the annual production of 105,000 MT. Currently, this factory produces only one-third of its production capacity because of the aging factory and lack of proper maintenance. This quantity of fertilizer is not enough to meet the needs of the farmers. Therefore, urea is imported mostly from Pakistan and small quantity from Tajikistan, Iran and Uzbekistan.

In 1970 Fertilizer Company was established in the country to import good quality chemical fertilizers and agrochemicals. Later, this Company stopped operation and now merchants can import fertilizer directly but the quality is somehow compromising. The use of fertilizers is still relatively low in Afghanistan, but it will increase substantially in the future as the farmers are made aware of strategies to increase agricultural production. The common basic calcareous soil with 8.2 pH and high $CaCO_3$ fixes phosphorus and other micro nutrients in the soil, making them unavailable for uptake by the plants. Research at Darul Aman, Herat, and Balkh stations have shown that 80 and 160 kg/ha of P_2O_5 significantly increased yields of consecutive wheat crops because of the phosphorus carryover from the previous years (Agriculture Research Development, 1971)

The results of the fertilizer rate trials on wheat crop in major provinces of the country reported in Table -1.

Table 1. Fertilizer Recommendation on Wheat Crop in Major Provinces

No	Fertilizer kg/ha $N - P_2O_5$	NGR	R	KDR	R	BLK	R	HRT	R	GZN	R	LGN	R	NST	R	KNR	R	TKR	R	Overall Mean	R
1	N_0P_0 (0-0)	2798	8	3155	9	4001	9	1926	9	5900	9	1918	9	1711	9	3540	8	4192	8	3238	9
2	N_0P_1 (0-46)	2667	9	3166	8	4548	7	2607	6	6096	7	2452	7	2428	8	3078	9	4138	9	3464	8
3	N_0P_2 (0-92)	2692	7	3341	7	5049	6	2679	5	6047	8	2067	8	2561	7	4548	4	4250	7	3693	7
4	N_1P0 (57-0)	3910	6	3384	6	4318	8	2317	8	7202	2	3236	6	2719	6	3728	7	5625	6	4049	6
5	N_1P_1 (57-46)	4337	4	3951	4	6097	4	3754	4	6466	6	4076	5	3333	4	4312	5	6344	4	4741	4
6	N_1p_2 (57-92)	4734	3	4374	2	6543	3	3871	3	6972	4	4086	4	3346	3	5040	3	6363	3	5037	3
7	N_2p_0 (115-0)	4055	5	3644	5	5116	5	2399	7	6765	5	4139	3	2916	5	3748	6	5663	5	4272	5
8	N_2P_1 (115-46)	5032	2	4216	3	7175	2	4307	2	7175	3	5343	2	3350	2	5461	1	7225	1	5476	2
9	N_2P_2 (115-92)	5191	1	4559	1	7957	1	4400	1	7577	1	5589	1	3710	1	5226	2	7158	2	5707	1

NGR (Nangarhar) ,KDR (Kandahar) ,BLK(Balkh),HRT (Herat),GZN (Ghazni),LGN (Laghman),NST(Nooristan),KNR (Kunar),TKR (Takhar)
Source : (Wassimi, 1999)

The above table shows that treatment 8 and 9 are producing high yields in improved wheat variety. If the farmers can afford to apply N_2P_2 they will get more yields. If they cannot afford to use high dose they can use N_2P_1 which produced the second highest yield. For the local varieties half of that amount, 25 kg urea and 10 kg super phosphate/0.20 ha is the recommended. Application of more fertilizer than the recommended amount on local varieties shows no response. In dryland areas the amount of 12 kg urea and 5 kg phosphorous per 0.20 ha is the optimum doses to be used.

All of the phosphorus fertilizer should be applied during the sowing of the wheat. Compare to broadcast application, the band application of phosphorus increases its availability and early access to the young wheat plants. Early access to fertilizer produces more vigorous plants, and thus wheat competes better with weeds. Also, banding of phosphorus can improve survival of wheat in areas where winter kill is a problem.

Status of Nitrogen

Nitrogen fertilizer or urea can be split into two applications. Apply half at sowing time and the remaining half during the first irrigation in the spring. Delay of urea application will delay the maturity of the wheat after the first spring irrigation. Nitrogen is needed badly for crop production because of low organic matter content in the soil, so nitrogen is applied by the farmers. Researchers have concluded that the required ratio of N to P is (1: 2). The research conducted by FAO revealed that there is more need for Nitrogen application compare to Phosphorus in Afghan soils because there is no carryover for the next crop. Except alfalfa crop, nitrogen is applied to all crops because there is no nitrogen fixation by the nodules.

Status of Phosphorus

Phosphorus is applied during soil preparation and before the planting of the crops which will help to fix more phosporous in the soil. All Phosphorous fertilizer is imported to Afghanistan. DAP from United States and Australia is typically exported to Pakistan, where it is re-packaged and exported to Afghanistan.

Status of Potassium

At present the farmers are not using potassium and micronutrients in crops, the minerals present in the soil releases sufficient potassium to the crops. Moreover, the availability of K fertilizer is more in the country and it is present in sufficient quantity in Afghan soil.

Organic matter

Afghan soils are very low in organic matter because animal dung is used for cooking and warming of the houses, and only the ash after burning are used as fertilizer. Less than 1 % of the animal dung is used for agriculture. Very less green manure and composts are used for strengthening of the soil (Manan and Wassimi, 2019).

Integrated Plant Nutrition System Approach

In Afghanistan the amount of land owned by the farmers varies from province to province from 0.2 hectares up to one hectare under irrigation condition to more than a hectare under rain-fed situation. Pulse crops (food and feed) which are an important crop for supporting the soil fertility are estimated to be planted in 40,000-50,000 hectares of land and this is the only option for the farmers to increase their soil fertility and crop productivity. The use of animal manure is less, because the farmers are using the animal manure for cooking and warming of their houses. The green manure and compost are rarely used by the farmers. However, some of the farmers in some part of the country are harvesting and collecting wild relatives of legume called (Boya) and *Pegnumharmala* from the deserts and burying it under the bush of cucumber, water melon and melon when it is fresh to improve the organic matter of the soil.

The concept of Integrated Plant Nutrition System (IPNS) is new and the farmers have no knowledge about the soil health and sustainability of the soil fertility. Agricultural Research and Institute of Afghanistan (ARIA) and Extension Department of Ministry of Agriculture, Irrigation and Livestock (MAIL) are not well informed with the concept of the IPNS and soil health. There is a need to develop IPNS strategies to implement the IPNS concept in the farming systems. Dissemination of IPNS technologies through awareness programs and carrying out field trials with farmers in participatory way will have to be strengthened to adopt IPNS program in farming communities. The objectives and importance of IPNS is to reduce the use of the inorganic fertilizers and make use of organic matter in the soil to enhance fertilizer use efficiency and at a same time maintain soil physical, chemical and biological properties. We need to build farmers' capacity through policy intervention and make the conditions favorable for practicing IPNS concept. Research-extension-farmer linkages should be strengthened for implementation of IPNS program in the farming systems.

Fertilizer recommendations for major cereal crops and vegetables

Wheat

250 kg Urea and 125 kg phosphorus per hectares. Research results have shown that potassium and other micronutrients are not now limiting factors in wheat production in Afghanistan. The research finding revealed that using micro-nutrients gives no benefit on wheat yield improvement in Afghanistan

Maize

75kg urea and 100 kg DAP/ha.1/2 Urea + all DAP at planting time and ½ urea after thinning.

Onion

185 kg Urea, 80 kg DAP and 30 kg potassium sulphate per ha.
½ Urea +DAP + K^2O during planting.
½ Urea after one month.

Potato

250 kg Urea and 250 kg DAP and 10 tons of organic matter is recommended per ha.

All the organic matter is applied during the land preparation and ½ Urea +all DAP at planting time. ½ Urea after 40 days during earthling.

Tomato

125- 150 Urea and 150 – 175 kg/ha plus organic matter.
½ Urea +DAP and organic matter during planting time
½ Urea after one transplanting.

Major cropping systems used by the farmers are as follows:

Wheat – rice –wheat | Wheat - maize –wheat

Wheat –legumes- wheat | Wheat- clover –wheat

Major Agricultural constraint

- Lack of qualified personnel in agriculture sector;
- Insecurity because of prolonged war;
- Frequent presence of drought;
- Lack of water for irrigation as river water were not used efficiently and more than 30 % of surface water such as Karezes and springs are dried up;
- Lack of good quality fertilizer;
- Lack of quality seed;
- Presence of landmines;
- Displacement of the farmers;
- Lack of feed for the livestock;
- Pest and diseases incidences;
- Poppy production replacing licit crops.

Afghanistan is the world's top grower of opium and the crop accounts for hundreds of thousands of jobs. A total of 263,000 hectares is under the cultivation of opium in Afghanistan. This year is still the second largest scored crop for Afghanistan since the UNODC began systematic monitoring in 1994. Most poppy production in Afghanistan is in the Talban –controlled southern part. Poppy crop competes with wheat crop as both are planted in the same season during fall and poppy reduces the area under wheat coverage, which is the major cause of food security in Afghanistan.

Conclusion

Sustainable soil fertility management is very important to increase the crop productivity per unit area of the land and to reduce the percentage of malnutrition in the country. The population of Afghanistan is rapidly increasing and others natural calamities like drought, climate change impacts and war has lead to import of wheat and rice in huge quantity. Currently, Afghanistan Government is importing 1- 2 million tons of wheat annually. The famers are using Urea and Phosphate fertilizers only to maintain soil health without using organic manure, which is likely to deteriorate soil health more in the future. Afghanistan soil are very poor in organic matter content which is less than 1 %, as the available sources of organic matter are used as fuel for heating and cooking purposes. The farmers are using more of chemical fertilizers and they are not aware of the importance of organic matter use in soil to maintain sustainable soil health. Further, the farmers are not aware of the use of green manure and how to prepare good compost to apply in their fields before planting especially for their vegetable crops. The available weeds instead of using it for making composts are used as source of feed for animals during the summer and they also dry weeds mixed with straw for feeding the animals during the winter. As a result, the soil in the country is deteriorating year by year.

Given the overall scenario of soil fertility management in the country, government should prepare policy framework and soil management strategy to sustainably management the soil. Policy support is also required for research and development which in turn will be able to build capacity of the extension personnel and farmers. Huge effort is required from policy-makers, researchers and extension personnel to build the capacity of the farmers through awareness program, IPNS field demonstrations, providing subsidies for fertilizers and organic manure etc. It is of paramount importance to develop IPNS based inorganic and organic fertilizer recommendations for major crops and cropping systems of Afganistan by Research Institutes. Government should create enabling environment for the farmers to implement the recommendations in the field to increase crop productivity and sustainably maintain soil productivity.

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Report of the SAARC Agriculture Centre/IRRI/ Horticultural Crop Research and Development Institute (HORDI), Department of Agriculture, Sri Lanka on "Developing Country Specific Integrated Plant Nutrition System Modules for Major Crops and Cropping Systems in South Asia"

(21-23 August 2019, Oak Ray Regency Hotel, Kandy, Sri Lanka)

Opening of the Session

The SAARC Agriculture Centre (SAC), Dhaka, Horticultural Crop Research and Development Institute (HORDI), Department of Agriculture, Government of Sri Lanka and International Rice Research Institute, New Delhi, India jointly organized the Regional Expert Consultation Meeting on "Developing Country Specific Integrated Plant Nutrition System Modules for Major Crops and Cropping Systems in South Asia" at Oak Ray Regency Hotel, Kandy, Sri Lanka during 21-23 August, 2019. The meeting was attended by the National Focal Experts of 7 SAARC Member States, experts from Department of Agriculture, Tea and Rubber Research Institutes, University of Peradeniya, International Rice Research Institute. Welcome addresses were delivered by Ms Jayantha Ilangakoon, Additional Director General, Department of Agriculture; Dr. W.M.G. Samarasinghe, Director, Horticulture Crop Research and Development Institute; Dr. Punyawardana, SAARC Governing Board Member, Sri Lanka and Mr. Kinzang Gyeltshen, Senior Program Specialist (Natural Resource Management), SAARC Agriculture Centre, Dhaka, Bangladesh.

The regional expert consultation meeting was organized with the objectives to:

- ❖ Study the alarming rate of natural resources degradation;
- ❖ Mapping of organic and inorganic plant nutrient resources;
- ❖ Develop country specific integrated plant nutrition systems (IPNS) modules for major crops and cropping system based on resource availability and climate suitability;
- ❖ Assess the status of implementation of IPNS approach and its issues and challenges.

Paper Presented

A total of 7 country papers on "Developing Country Specific Integrated Plant Nutrition System Modules for Major Crops and Cropping Systems" were presented at the regional consultation meeting covering Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka. Afghanistan expert could not present the country paper, but included in this publication. Another four technical papers covering crucial aspects of food crops, plantation crops, soil microbiology and information and communication technology (ICT) tools for nutrients management were also presented by the acknowledged experts from SAARC region in these special fields.

Recommendations

The following recommendations were emerged during the regional expert consultation meeting 21-23 August, 2019 at Kandy, Sri Lanka:

Policy

- ❖ Develop policy and create ideal environment to encourage manufacture of bio-fertilizers and to ensure quality control;
- ❖ Develop strategies and seek fund to purchase inputs for improving soil health e.g. Kisan Credit Card;
- ❖ Develop policy interventions and strategies to combat water pollution due to injudicious use of inorganic and organic fertilizers;
- ❖ Re-visit land ownership issues to ensure that the cultivators own and care for the land to maintain soil fertility in long run (Maldives);
- ❖ Each country should have action plan and vision statements to gradually replace the inorganic fertilizers with the organic;
- ❖ Develop policy recommendations and policy briefs about IPNS approach.

Strategy

- ❖ Inventory existing and explore new sources of organic materials including city compost, seaweeds, human excreta (preparation and usage as grade A, B and C sewage sludge, city garbage, industrial wastewater etc);
- ❖ Encourage liquid fertilizers where feasible and affordable by the farmers;
- ❖ Encourage use of various soil amendments for improving soil physical condition and to tackle other soil problems e.g. acidity, alkalinity;
- ❖ Encourage to develop and use ICT based tools or applications to enable extension and farmers to get information easily about soils, nutrient balance, balanced fertilization, additional nutrients requirement, cost and resource need to take decisions and adopt IPNS recommendations;
- ❖ Include good agricultural practices and introduce new responsive varieties to supplement IPNS approach for maximum benefit;
- ❖ Encourage strategies to increase nutrient use efficiencies e.g. neem coating urea, USG, slow release fertilizers etc;
- ❖ Strengthen soil, plant and (fertilizer) testing facilities, explore in-situ testing tools;
- ❖ Encourage and explore use of locally available sources of nutrients to decrease fertilizer imports;
- ❖ Encourage involvement of women and youth in IPNS approach of agriculture farming.

Enabling environment & regulations

- ❖ Develop and set guidelines for manufacturing and marketing of liquid fertilizers;
- ❖ Develop legal instruments and mechanisms for generating and recycling organic matter/ green manures in-situ/urban waste/ biofertilizers etc;

- Provide sufficient funding for continuous research innovations to develop, revise and adapt IPNS approach to changing environment including climate change;
- Government should provide fund for procurement of modern tools and strongly support using it in soil fertility management;
- Ensure close coordination and cooperation among various stakeholders and departments (researchers, extension workers, farmers, private sector, policy makers, fertilizer industries etc.) to ensure maximum adoption of IPNS approach and for wider benefits.

Capacity development

- Strategically sensitize and strengthen extension services system and farmers on IPNS approach and its modules;
- Conduct skill development programs for extensions and farmers;
- Increased adoption of 'farmers participatory research' for better result and effective implementation of IPNS approach;
- Develop appropriate tools and brochures for field demonstrations and training.

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REGIONAL EXPERT CONSULTAION MEETING PHOTO


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