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# Integrated Nutrient Management for Improving and Sustaining Crop Productivity

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## Abstract

Sustainable agricultural production uses the natural resources to generate increased output and income, especially for low-income groups, without depleting the natural resource base. In this context, integrated nutrient management (INM) integrates the use of all natural and man-made sources of plant nutrients in an efficient and environmentally benign manner to increase crop productivity without sacrificing soil productivity for future generations. Sufficient and balanced application of organic manures and inorganic fertilizers is a major component of INM in crop production. INM maintains soils as storehouses of plant nutrients that are essential for growth and productivity of crops. The integrated use of organic manures, chemical fertilizers and biofertilizers in different crops and cropping systems was found responsible not only for increasing crop productivity, nutrient use efficiency and soil fertility but also for sustaining crop productivity at high level.

## Introduction

Of late almost every agricultural, social and political person has linked farming with environmental issues. This has happened as a result of sudden realization by the scientific community of the west that there are limits to growth of human population, consumption and exploitation of resources of the world and of the evil effects of the modern high energy technology. Serious concern was voiced in the U.N. Conference on Environment in 1972 at Stockholm about ecological crisis, protection of natural environment of the globe and restoration of ecological balance in every possible way. Agriculturists were pretty familiar with such fields and used to talk about ecological requirements of crops, agro-ecosystem, carrying capacity and sustainability. But no action was taken to save the civilization from the possible extinction in the immediate future (Stoate *et al*., 2001). Despite the continued development of new and improved modern varieties, greater use of chemical fertilizers and high technologies yield growth began to slow in the latter part of the 20$^{th}$ century. The world's annual cereal yield growth rate has declined from an average of 2.2% in the 1970s to 1.1% in the 1990s. Wheat yields in Asia grew at an average annual rate of 4.3% during the 1970s; but in the 1990s, wheat yields dropped to the far slower growth rate of only 0.7% year$^{-1}$ (FAO, 1998). After rapid growth of almost 2.4% year$^{-1}$ during 1980s, Asian rice yield growth fell to 1.5 % year$^{-1}$ in the 1990s (Gruhn *et al*., 2000). This global slowdown has raised concerns that yield growth may have reached a plateau or begun to decline in many of the world's most fertile areas.

The world population is estimated to rise to 9-10 billion by 2050. The proportion of land devoted to agriculture is generally more than one-third of the land in most countries and there is no scope to increase the availability of agricultural land further. On the other hand, there is increasing pressure on land to build new homes, public institutions (schools, colleges, health centers, community halls etc.), roadways, railways and others to accommodate the growing population and that may decrease the availability of agricultural land in future. Coupled with this are increasing concerns over climate change and access to adequate water supplies. This means that global food security is heavily dependent upon technological advances in order to avoid Malthusians scenario of poverty and famine due to overpopulation (Hole *et al*., 2005). The effective maintenance of water quality, waste management, soil moisture retention with reduction of runoff, water infiltration, erosion control, carbon sequestration are all dependant on sustainable agricultural systems. Harsh climatic conditions contribute to soil erosion in several parts of tropical Asia and Sub-Saharan Africa. Rapid water evaporation and inadequate and highly variable rainfall deprive crops of the water necessary for growth. High atmospheric temperature, strong light, and heat retentive sandy soils can combine to make the local environment too hot for proper crop growth. Powerful dry wind gusts may also damage crops through both lodging (which causes crops to fall over and die before harvest) and evaporation (Lawson and Sivakumar, 1991). These harsh climatic factors have reduced soil fertility by enhancing soil and water erosion.

Increased and sustainable food production is a must for food security of the growing population. It cannot be compromised. What we have to do is to search for possible ways of increasing food production in a sustainable manner without deteriorating the soil quality. Modem large-scale conventional agriculture with intensive monoculture often results in unacceptable soil erosion, runoff and in associated losses of plant nutrients. Further, the highly productive fertilizer and seed technologies introduced over the past four decades are now reaching almost a point of diminishing returns (Dawe *et al*., 2000). Possibilities of expanding low-cost irrigation (Ghosh *et al*., 2001) and converting marginal lands into productive arable land (Das *et al*., 2000; Karforma *et al*., 2012) as option for yield improvement are now becoming more and more limited. Similarly the genetically engineered, yield-increasing plants may not expect to be major factors in increasing food production in near future (Sanginga *et al*., 2003). This necessitates the search for a sustainable system that can maintain crop productivity at higher level without deteriorating the ecosystem (Dobermann and White, 1999; Biswas *et al*., 2006; Ghosh 2015).

## Effective Soil Management

Balanced and adequate plant nutrition may be an option with great potential. Both the over- and under application of fertilizer and the poor management of resources have damaged the environment. In many Asian and African countries, population pressure, land constraints, adverse climatic conditions, and high productive technology have often reduced soil fertility (Chianu and Tsujii, 2005; Biswas *et al*., 2006; Ghosh 2015). We are in deep concern about the long-term sustainability of agricultural productivity. As agriculture is a soil-based industry that extracts nutrients from the soil, effective and efficient approaches that slow down the nutrients removal and return the nutrients to the soil are required to maintain and increase crop yields and sustain agricultural productivity for the long term. The overall strategy for increasing crop yields and sustaining them at a high level must include an integrated approach of soil nutrients management, along with production measures (Ghosh *et al*., 2001; Baishya *et al*., 2010a). An integrated approach recognizes that soils are the storehouse of most of the plant nutrients essential for plant growth and that the way in which nutrients are managed must have a major impact on plant growth, soil fertility, and agricultural sustainability (Madari *et al*., 2005; Karforma *et al*., 2012; Mondal *et al*., 2016).

For better understanding the processes of retaining soil fertility, we have to know the role of plant nutrients in creating conducive ecosystem for the crop growth. The capacity of a soil to be productive depends not only on its plant nutrient content, but also on its physical, biological, and chemical characteristics. Its texture, depth, organic matter content, acidity and water-retention capacity influence the fertility and productivity. Some soils, because of their favourable texture and depth can store and make available large amount of water and nutrients to plants and become inherently productive (Gruhn *et al*., 2000); while other soils having poor water and nutrient holding capacity and very low organic matter content are virtually fragile and unproductive (Kumar *et al*., 2012; Borah *et al*., 2016). Thus, the soils differ in their quality due to the differences of these attributes among them. The soil management practices can largely improve or degrade the natural quality of soils (Madari *et al.*, 2005; Lee *et al.*, 2008; Baishya *et al.*, 2010a). Millions of hectares of land are subjected to degradation through erosion, compaction, salinization, acidification and pollution by heavy metals due to mismanagement (Aggarwal *et al.*, 2000; Swarup *et al.*, 2000). The process of reclaiming degraded soils is very expensive and time consuming. It is also very difficult to recover some heavily degraded soils. Contrary to the above, good soil management practices can check soil degradation. Good soil management includes use of cover crops, legumes, soil conservation measures, residue management, organic manures and judicious use of chemical fertilizers and farm machinery (Ghosh *et al.*, 2001; Biswas *et al.*, 2006). Soil organic matter (SOM) is most important for the proper management of soil fertility (Green *et al.*, 2005; Ghosh *et al.*, 2001). SOM acts as storehouse of plant nutrients in soil. It helps the plants grow by improving bulk density, soil acidity, nutrient holding capacity, water holding capacity and drought-resistance (Huang *et al.*, 2009; Ghosh, 2015). It permits better aeration, enhances the absorption and release of nutrients, and makes the soil less susceptible to leaching and erosion (Hati *et al.*, 2007; Wang *et al.*, 2013). A given quantity of mixture of nutrients is required for proper growth and development of crop plants. It varied greatly in accordance with growth and productivity of the crop. The higher the growth and productivity, the greater will be the nutrient requirement. A shortage of one or more nutrients can check or inhibit crop growth. On the other hand, excess nutrients particularly applied through chemical fertilizers, can be wasteful, costly and in some cases, toxic to the crop and harmful to the environment. Effective and efficient management of the soil is, thus, essential for maintaining soil fertility and sustaining high crop yields (Green *et al.*, 2005; van Diepeningena *et al.*, 2006). Soil should be managed in such a way that plant nutrients must be available in suitable form in correct quantity and proportion at the right time to achieve healthy crop growth and high productivity (Sanginga *et al.*, 2003; Baishya *et al.*, 2010b; Kumar *et al.*, 2012; Shafi *et al.*, 2012).

## Nutrient Recycling

The nutrient availability in soil changes over time. The continuous recycling of nutrients into and out of the soil is known as the nutrient cycle (Gruhn *et al.*, 2000). The cycle 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 inputs are inorganic fertilizers; organic manures, biofertilizers, plant residues, cover crops, nitrogen generated by legumes and atmospheric nitrogen deposition. Nutrients are exported from the soil through harvested crops and crop residues, through leaching, atmospheric volatilization, and erosion. The difference between the volume of inputs and outputs constitutes the nutrient balance (Ghosh *et al.*, 2001). Positive nutrient balance (when nutrient addition to the soil exceeds the nutrient removal from the soil) in the soils indicates the improvement in the soil fertility status. Negative balance shows that soils are being mined and under such situation nutrients must be replenished to maintain crop productivity and soil fertility for the future (Ghosh *et al.*, 2009). Highly weathered soils, being inherently low in nutrient reserves, must have a regular nutrient supply to facilitate intensive cultivation for increased food production. Intensive land use and high yields on soils of low inherent fertility can be achieved only by raising the nutrient levels through the integrated use of inorganic fertilizers, organic manures, nutrient recycling and biofertilizers (Chand *et al.*, 2006; Kaur *et al.*, 2008). Many small land holders and resource-poor farmers cannot afford the expense of costly fertilizers. Policy makers must ensure a dependable and timely supply of chemical fertilizers at affordable prices. Over-dependence on synthetic fertilizers and other agricultural chemicals must be avoided because the energy and economic costs of using them are prohibitive for the small land holders of the tropics. A combination of organic manures and chemical fertilizers along with biofertilizers is, therefore, a useful strategy to minimize dependence on synthetic fertilizers, enhance soil physic-chemical characteristics and improve its quality (Jiang *et al.*, 2006; Kumar *et al.*, 2011). The rate of application of inorganic fertilizers can also be reduced by minimizing losses and increasing the recycling of nutrients (Lal, 2006; Shafi *et al*., 2009). Losses of nutrients can be controlled through conservation tillage, nutrient recycling, split application, fertilizer placement, and slow-release formulations (Parmer and Sharma, 2002; Gopinath *et al*., 2008). There are some advantages in substituting biological nitrogen fixation for inorganic fertilizers (Kumar *et al*., 2012). However, the economics of growing nitrogen versus buying nitrogen have to be carefully evaluated in terms of land scarcity and efficiency of nitrogen availability (Baishya *et al*., 2013).

## Integrated Nutrient Management (INM)

Sustainable agricultural production incorporates the idea that natural resources should be used to generate increased output and incomes, especially for low-income groups, without depleting the natural resource base. In this context, integrated nutrient management (INM) maintains soils as storehouses of plant nutrients that are essential for growth and productivity of crops (Stephen, 2001; Prasad *et al*., 2002; Ghosh *et al*., 2009). INM's goal is to integrate the use of all natural and man-made sources of plant nutrients, so that crop productivity increases in an efficient and environmentally benign manner, without sacrificing soil productivity of future generations (Place *et al*., 2003; Islam *et al*., 2013). INM relies on a number of factors, including appropriate nutrient application and conservation and the transfer of knowledge about INM practices to farmers and researchers. Sufficient and balanced application of organic and inorganic fertilizers is a major component of INM. Classical field experiments at the Rothamsted Experimental Station in England have provided a wealth of INM related information on crops grown continuously and in rotation under a variety of soil fertility amendments. A number of lessons can be learned about appropriate and balanced fertilization from these experiments. Continuously wheat cropping without applied nutrients typically produces low yield (1.2 t $ha^{-1}$). Short fallow rotations of one to three years have little effect on yields. The application of organic and inorganic fertilizers can increase wheat yield up to 6-7 t $ha^{-1}$. The highest wheat yield (9.4 t $ha^{-1}$) was obtained by applying farmyard manure along with inorganic fertilizers to top-up nitrogen availability in wheat grown in rotation (Anonymous, 1991).

Shifting cultivation from the no-external input agriculture (slash and burn) to intensified agricultural systems led to high soil organic carbon and nutrient depletion in Eastern and Southern Africa particularly in farming systems with reduced fallow period or continuous cropping without or with little inputs (Stephen, 2001). He noticed great loss of carbon (0.69 t $ha^{-1}$ $year^{-1}$) and nutrients from the surface soil layer and pointed out that the losses could be replenished by addition of organic manures, wastes materials, residues, plant litter, soil amendments, legume integration and integrated use of inorganic and organic inputs in the production system. Sustainable resource management is the critical agricultural research and development challenge in sub-Saharan Africa. The knowledge on soil management combined with crop improvement at farmers' level helped the intensification of cereal–grain legume based cropping systems in the dry savanna of West Africa in a sustainable and environmentally positive manner. Two sustainable farming systems (maize-nodulating soybean and millet–dual purpose cowpea) that greatly enhance the productivity and sustainability of integrated livestock systems have been developed and implemented in the dry savanna of Nigeria (Sanginga *et al*., 2003). Improvement of the cropping systems in the dry savanna has been driven by adoption of nodulating soybean varieties (TG x 1448-2E) and dual purpose cowpea. Increased production of nodulating soybean has been stimulated by increased demand from industries and home utilization. Economic analysis of these systems shows an increase of 50–70% in the gross incomes of adopting farmers compared to those still following the current practices of continuous maize cultivation. Further, increase in legume areas of 10% and yield of 20% in Nigeria have translated into additional fixed nitrogen valued annually at US$ 44 million. The increase in land-use productivity and spread of the improved crops make excellent prospects for additional economic and environmental benefits from a very large recommendation domain across West Africa. Place *et al*. (2003) reviewed the organic nutrient management practices and their integration with mineral fertilizers in Sub-Saharan Africa with a view to understanding the potential impacts on a range of input markets and noticed a number of different organic nutrient management practices to be technically and financially beneficial, but they differ considerably as to their effectiveness and resource requirements. Similar discrepancy in response of rice yield and soil fertility to long-term organic amendments and chemical fertilization in paddy soils cultivated from infertile upland in subtropical China was also noticed by Liu *et al.* (2011).

African smallholder experiences with integrated soil fertility management practices found growing and stimulated by profitable commercially oriented agricultural opportunities (Place *et al.*, 2003). Chianu and Tsujii (2005) studied the INM practices among farmers in the sub-Saharan Africa (northern Nigeria) in details and revealed that only a partial integration was occurring with limited impact on soil fertility among the various components of INM available in the farming systems. The major constraints include: the harsh savanna environment, lack of supportive institutions and labour, high fertilizer prices and inadequate availability of organic manure. Strip cropping of improved sorghum and dual-purpose cowpea and integrated fertility management using neem foliage and half of the recommended fertilizer rate show great potential in increasing crop productivity and restoring soil fertility in the sub-Saharan Africa (Sanginga *et al.*, 2003). Long-term (1990–2006) INM practice in rice at subtropical hilly region in south central China indicated that integrated use of organic manures and chemical fertilizers benefited the conservation of soil organic C and soil N in addition to high rice yield, but it had less impact on soil P (Wang *et al.*, 2013). They noticed that integrated use of organic manures and 67% recommended dose of chemical fertilizers could improve soil quality and save 33% recommended dose of costly chemical fertilizers without decreasing crop productivity under subtropical hilly region in south central China.

Prasad *et al.* (2002) observed that green manuring with *Sesbania* and *Crotalaria* 10 t ha$^{-1}$ to rice increased grain yield of rice by 1.60 and 1.10 t ha$^{-1}$ and pod yield of succeeding groundnut by 0.25 and 0.16 t ha$^{-1}$, respectively over no green manure; and integrated use of 120:26:37 kg NPK ha$^{-1}$ with green manures recorded the highest grain of rice; whereas, maximum pod yield of groundnut was obtained by residual effect of green manure applied to rice and use of 30:26:33 kg NPK ha$^{-1}$ in combination with gypsum applied to groundnut crop. Green manuring with *Sesbania* along with 25% recommended dose of N (30 kg N ha$^{-1}$) also proved to be superior to other organic (Dhaincha, sunnhemp, FYM and BGA) inorganic combinations in producing high rice yield in addition to saving 75% of costly chemical N fertilizer (90 kg N ha$^{-1}$) and improving soil quality by increasing organic C, N, P and K contents and decreased the bulk density of the soil (Premi, 2003). Combined application of FYM 20 t with 60 kg N, 90 kg $P_2O_5$, 60 kg $K_2O$ and 5 kg Zn ha$^{-1}$ was found promising in increasing wheat yield by 58-88% over the farmer's practice and 18-28% over the recommended dose of NPK (Ali *et al.*, 2007). They noticed decrease in bulk density and increase in water holding capacity, organic matter, soil P and soil Zn over a period of time with INM and concluded that the crop productivity of eroded land could be restored and soil fertility status be improved with INM practices. Integrated use of organics (farm yard manure, piggery manure, poultry manure, green manures and crop residues) with chemical fertilizers in prominent cropping systems (rice–wheat, rice–mustard, rice–rapeseed, soybean–wheat, soybean–rapeseed, groundnut–wheat, and groundnut–sunflower) of the subtropical north western India enhanced the yield potential of crops over and above achievable yield with recommended fertilizers, made better synchrony of crop N needs due to slower mineralization of organics and reduced N losses (denitrification and nitrate leaching), enhanced nutrient use efficiency and recovery by crops, improved soil health and might sustain productivity of various cropping systems (Aulakh, 2010).

Sharma *et al.* (2005) noticed that application of gliricidia loppings and higher N levels in sorghum-castor cropping system maintained higher soil quality index of dryland semi-arid tropical soils in southern India than sorghum stover and no residue treatments. Available N, K, S, microbial biomass carbon (MBC) and hydraulic conductivity (HC) were found to be the key indicators of regulating soil quality index. They opined that conventional tillage with gliricidia loppings and 90 kg N $ha^{-1}$ was most promising for maintaining high soil quality index and sustainability of crop yields at high levels under sorghum–castor cropping system. The results indicate that primary tillage along with organic residue and nitrogen application are needed to maintain the yield and soil quality of *Alfisols*. Another long term INM studies in sorghum-wheat cropping system also showed high sustainability yield index with super optimal (150% RDF) fertilizer dose (0.436), 100% RDF + FYM (0.432) and 100% RDF + sulphur (0.421), but the highest soil quality index was obtained with 100% RDF + FYM (2.45), followed by only FYM (2.16) and 150% RDF (2.15) in sorghum-wheat system (Katkar *et al*., 2012). They recommended use of 100% RDF + FYM for improving soil quality index and maintaining yield sustainability at higher level under sorghum-wheat cropping system in central India. INM studies in rainfed fodder maize-rapeseed cropping system showed that integrated use of 50% RDN through organic manures (FYM or mustard cake) and 50% RDF through chemical fertilizers along with biofertilizer (*Azotobacter*) increased crop productivity, enhanced soil fertility, nutrient balance and paid high economic return from this cropping system in terai region of Indian sub-tropics (Karforma *et al*., 2016).

Studies on integrated nutrient and crop residue management in cotton–wheat cropping system on coarse loamy and fine silty alkaline-calcareous soils conducted by Rafique *et al*. (2012abc) revealed that balance nutrient management (BNM) increased 18-24% yield in cotton and 24-37% in wheat in different soils over farmers' fertilizer practice (FFP), INM increased yield by 3 –5% over balance nutrient management (BNM) and residue recycling increased yield further by 2 –7% in cotton and 2 –10% in wheat. They recorded minimum yield of both the crops with with (BNM). They observed INM practices and crop residue recycling resulted in positive SOM, N ($NO_3$-N) and P balance in coarse loamy and fine silty alkaline-calcareous soils; but negative K balance in both the soils. FFP recorded the lowest N, P and K uptake by cotton and wheat, while, INM resulted in highest N, P and K uptake by both the crops and N, P and K uptakes enhanced further by crop residue recycling. They concluded that INM could produce high crop yield, improve SOM and NP balance; but had negative K balance, possibly because of high K removal by both the crops.

INM practices in potato showed that 75% NPK through chemical fertilizers and 25% N through FYM increased tuber yield and net profit from potato (Baishya *et al*., 2010a) and improved fertility status of rainfed soils of north eastern hill region of India (Baishya *et al*., 2010b). The tuber yield decreased by 9.1, 12.6 and 25.6% respectively due to replacement of 50, 75 and 100% N through FYM when compared to that of 25% N replacement through FYM (Baishya *et al*., 2013). However, Kumar *et al*. (2011) noticed that 50% NPK through chemical fertilizers and 50% N through organic manures (FYM, poultry manure or vermicompost) in addition to seed treatment with biofertilizer (*Azotobacter* + PSB) produced higher tuber yield, better tuber keeping quality, greater nutrient uptake and paid higher returns compared to other treatments. Seed treatment with biofertilizer might enhance the availability of N from FYM that led to increase potato productivity. Integrated use of 50% N as organic manures and 50% NPK as chemical fertilizers along with biofertilizer seed treatment seemed to be promising not only for increasing tuber yield, nutrient uptake and profit (Kumar *et al*., 2013); but also for improving soil quality (increasing total organic C, microbial biomass C, available N, P, and K contents in soil) and sustainability (Kumar *et al*., 2012).

Investigating the effect of INM on vegetable based cropping system in Bangladesh, Islam et al. (2013) observed that poultry manure 2.5 t $ha^{-1}$ + chemical fertilizers increased the yield of cabbage and brinjal; while, household waste 5 t $ha^{-1}$ + chemical fertilizers increased yield of red amaranth. This treatment also enhanced the N, P, K, and S uptake by the crops. INM and organic manuring also improved the bulk density, organic carbon, and NPK availability in soil after two-crop cycles. Substitution of 25% NPK through FYM and 75% NPK through chemical fertilizers along with 5 kg Zn $ha^{-1}$ and PSB + *Azotobactor* increased grain yield, nutrient (N, P, K, S and Zn) uptake by wheat and improved available N, P, K, S and Zn in soil over other treatments (Sharma *et al.* (2013). They opined that integrated use of organic manure and chemical fertilizers along with biofertilizers and micronutrients was necessary for increasing wheat yield, improving crop quality and soil fertility.

Study on integrated nutrient management in rainfed upland rice in Arunachal Pradesh, India revealed that integrated use of 75 % recommended dose of nitrogen (RDN) through farm yard manure (FYM)/ vermicompost (VC) and 25 % recommended dose of fertilizer (RDF) through chemical fertilizers improved the growth parameters and yield components over other treatments and led to higher grain yield by 89.6 % over control and by 29.9–35.6 % over other treatments. The growth parameters showed strong and positive correlations with grain yield. Use of 75 % RDN through FYM/VC and 25 % RDF through chemical fertilizer seems to be conducive for improving growth and productivity of rainfed upland rice in the hill region of northeastern India (Borah *et al.*, 2016). Another study conducted in West Bengal showed that use of 75% RDF + 25% RDN through MOC + biofertilizer or 50% RDF + 50% RDN through MOC in hybrid rice increased growth, productivity and profit from hybrid rice (Mondal *et al.*, 2015). Further they noticed that integrated use of 50% RDF + 50% RDN through MOC or 75% RDF + 25% RDN through MOC + biofertilizer not only increased hybrid rice productivity and PFPN but also improved soil fertility for sustainabile crop productivity (Mondal *et al.*, 2016).

## Conclusion

It is very clear from the above information that INM is beneficial almost in all fields of agriculture, whether it is dry region or humid region, upland or lowland, rainfed or irrigated land, mono cropping or multiple cropping, food crops or commercial crops, fruits or vegetables, spices or narcotics. In every field INM not only increases the crop productivity, crop quality and profitability but also improves or maintains soil fertility, soil quality and sustainability. Therefore, balanced and efficient use of plant nutrients from organic and inorganic and biological sources, at the farm and community levels, should be emphasized; because, balanced application of plant nutrients not only conserves nutrients in the soil, but also makes nutrient uptake more efficient. The use of local sources of organic matter and other soil amendments should be promoted to cut down the cost of crop production. Innovative approaches to support and promote integrated plant nutrient management should be pursued. The security of access to land is essential for intensification and successful promotion of integrated plant nutrient management systems. The recycling of pollutant-free organic urban waste into the agricultural sector should be promoted, considering that such waste constitutes an increasingly untapped source of plant nutrients.

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