JOURNAL OF PURE AND APPLIED MICROBIOLOGY, June 2015. Vol. **9**(2), p. 1211-1221

Does Integrated Nutrient Management, Enhance Agricultural Productivity?

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(Received: 10 February 2015; accepted: 06 March 2015)

Nowadays the global food demands of a growing human population and need for an eco-friendly strategy for sustainable soil-plant-microbes-environmental system, require significant attention when addressing the issue of enhancing agricultural productivity. One possible way to enhance crop productivity by chemical fertilization, but due to injudicious uses of chemical input in agricultural system detonated the soil, food, environmental and human health, chemical fertilization also increasing their prices 21st century. However, it is not possible to supply all the nutrient requirements of crops through organic manures. So by taking into consideration the above facts, integrated nutrient management (INM) has been developed. Here we discuss the role of INM in resolving these concerns, which has been proposed as a promising strategy for addressing these challenges. INM has multifaceted potential for the improvement of plant performance and resource efficiency while also enabling the protection of the environment and resource quality. Lower inputs of chemical fertilizer and therefore lower human and environmental costs (such as intensity of land use, N use, reactive N losses and GHG emissions) were achieved under advanced INM practices without any negative effect on crop yields. A comprehensive literature research revealed that INM increases crop yields by 8-150% as compared with conventional practices, increases water and nutrients use efficiency and the economic returns to farmers, while improving grain quality and soil health and sustainability. Strong and convincing evidence indicates that INM practice could be an innovative and environment friendly practice for sustainable agriculture worldwide.

Key words: Crop productivity; Soil quality; Sustainability; Microbes; Organic manures.

The growing population and consumption, and reduction in available land and other productive units are placing unprecedented pressure on the current agriculture and natural resources to meet the increasing food demand. Providing food for human under sustainable systems having a significant challenge in the developing world and is highly critical for alleviating poverty. To circumvent this challenge, farmers tended to overuse certain inputs such as chemical, agricultural inputs, which in turn have already started deteriorating soil-plant-microbes environmental system. To meet the world's future food security and sustainability needs, food production must grow substantially while agriculture's environmental impact must decrease dramatically at the same time[1]. Global food production must increase by 70% by 2050 to fulfil the increasing demand[2]. In order to meet this challenging target, an average annual increase in cereal production of 43 million metric tonnes per year is required[3].

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Soil-plant-microbes system play a key role in maintaining soil fertility and crop productivity. Most of the agricultural soils suffering from declining fertility status, their physical and chemical properties are deteriorating and the vital nutrients for plant growth are slowly being depleted. By some estimates, the annual cost of environmental degradation in some countries ranges from 4-17% of gross national product. Three-quarters of the area degraded and eroded by inappropriate agricultural practices, overgrazing and deforestation is in the developing world. Nowadays, the most important challenge facing humanity is to conserve/sustain natural resources, including soil, air and water, for increasing food production while protecting the environment. As the population rises that increases stress on natural resources, making it difficult to maintain food security. Long-term food security requires a balance between enhancing crop production while maintaining soil health and environmental sustainability. In India, effective nutrient management has played a major role in accomplishing the enormous increase in food grain production from 52 MT in 1951-52 to 230 MT during 2007-08. However, application of imbalanced and/or excessive nutrients led to declining nutrient-use efficiency, making fertilizer consumption uneconomical and producing adverse effects on the environment[4] and groundwater quality[5] causing health hazards and climate change. On the other hand, nutrient mining has occurred in many soils due to lack of affordable fertilizer sources[5].

Agricultural practices that improve soil quality and agricultural sustainability have received much attention by researchers and farmers under both developed and developing countries. The role of organic manures in plant nutrition is now attracting the attention of agriculturists and soil scientists throughout the world. Chemical fertilization, no doubt has enhanced the crop productivity, but to larger extent they have contributed to soil deterioration. Organic manures are a vital resource not only for supplying plant nutrients, but also for the replenishing organic matter content of most agricultural soils. This would further emphasize the need to use organic manures alone or in conjunction with chemical fertilization to maintain soil fertility for the sustainable crop production. However, neither inorganic fertilizers, nor organic manures alone can sustain productivity. So judicious uses of organic manures and inorganic fertilizers are essential to safeguard soil health and augment productivity and input use efficiency. Integration of different sources of nutrients has a promising strategy for soil health management and sustained productivity.

Integrated nutrient management (INM) involves the use of manures, chemical fertilizers and biological agent achieve sustainable crop production and improved soil health. INM is the best approach for better utilization of available resources and to produce crops with less expenditure. In soils of India, NPS deficiencies are principal yield-limiting factors in crop production. INM, which entails the maintenance of soil fertility to an optimum level for crop productivity to obtain the maximum benefit from all possible sources of plant nutrients organics as well as inorganic in an integrated manner[4, 5], is essential to address the twin concerns of nutrient excess and nutrient depletion. INM is also beneficial for marginal farmers who cannot afford to supply all crop nutrients through costly chemical fertilization[6, 7, 8]. This review article examines the concepts, objectives, procedures and principles of INM and its effect on soil. Most of the INM research work carried out with dominant crop rotations of major field crops grown in the subtropical north-western states of India, sustainable production of prominent cropping systems, enhancing nutritional quality of products, improving soil health, and minimizing environmental pollution.

Concept of INM

Primarily INM refers to combining old and modern methods of nutrient management into ecologically sound and economically optimal farming system that uses the benefits from all possible sources of organic, inorganic and biological components-substances in a judicious, efficient and integrated manner[9]. It optimizes all aspects of nutrient cycling, including macro- and micronutrient inputs and outputs, with the aims of synchronizing nutrient demand by the crop and its release into the environment (Fig. 1). Under INM practices, the losses through leaching, runoff, volatilization, emissions and immobilization are minimized, while high nutrient-use efficiency is achieved[10].

Moreover, it also aims to optimize the soil conditions by improving its physical, chemical, biological and hydrological properties to enhance farm productivity and minimize land degradation[11]. There is now a greater awareness that INM can't only increase crop productivity, but also simultaneously and almost imperceptibly preserve soil resources. Its practices use farmyard manures, farm wastes, soil amendments, crop residues, natural and chemical fertilizers, green manures, cover crops, intercropping, crop rotations, fallows, conservation tillage, irrigation and drainage to conserve available water and to boost plant nutrients[12]. This strategy also includes new techniques, such as deep placement of fertilizers and the use of inhibitors or urea coatings that have been developed to minimize nutrient losses and improve plant uptake[11]. Such practices encourage farmers to focus on long-term planning and have greater consideration of environmental impacts, rather than only focusing on yield-scaled profit.

INM method based on inputs and outputs; matching the quantity with the demand of the crop, and synchronizing in term of time with crop growth (Adapted from Gruhn[13]).

A complete set of INM strategy is comprised of several key steps which are as follows; (i) determine soil nutrient availability and nutrient deficiency in crop plants. While soil sampling and laboratory determinations are usually used for assessing soil nutrient availabilities, there are two general ways to detect nutrient deficiencies. First, visual clues can provide indications of specific nutrient deficiencies through plant symptom analysis diagnosis. Second, where symptoms are not visible, post-harvest tissue and soil samples can be analyzed in a laboratory and compared with a reference sample from a healthy plant; (ii) systematically appraise the constraints and opportunities in the current soil fertility management practices, and how these relate to nutrient diagnosis, such as the insufficient or excessive use of N fertilizers; (iii) determine the farming practices and technologies that balance the nutrients which are necessary under different climates and soil types. The soil nutrient budgets for a given area and time can be calculated by the difference between the nutrient input and output as suggested by Fig. 1. Once these factors are understood, then appropriate INM technologies can be selected; and, (iv) assess the productivity and sustainability of INM practices. INM methods require locally appropriate technologies and farmers' participatory involvement in the testing and analysis. The overall INM management strategy described above focuses on optimizing fertilization rates and timing. Based on the soil nutrient supply capacity, a basal fertilization of NPK requirements can be recommended[14].

The main principles of INM

Below are the main principles of INM, which include the following: (a) using all possible sources of nutrients to optimize their input as mentioned earlier, the overall objective of INM is to maximize the use of soil nutrients to improve crop productivity and resource- use efficiency; (b) matching the soil nutrient supply with crop demand spatially and temporally. INM requires the nutrient application amount and timing to be in accordance with the crop nutrient requirements, which is essential to achieve maximum yields and improve the nutrient-use[15]. N fertilizers applied during periods of crop demand in small quantities and with frequent application can potentially reduce N losses, while increasing the crop yield and qualit[16]; (c) reducing N losses, while improving the crop yield. Excessive applications of N fertilizer can result in increased leaching of nitrates into groundwater and more emission losses to the atmosphere. The principle of INM is to control the N losses and their harmful environmental effects while achieving high crop productivity[13]. The fate of N in field is an integrated consequence of crop N uptake, immobilization and residues in the soil, and N losses to the environment, such as ammonia volatilization, NO_X emissions, denitrification, N leaching and runoff[17].

In addition, INM favors organic regimes of fertilization, which have tremendous potential for the sustainable development of agriculture along with more direct environmental benefits. Using organic manure together with other management practices, such as incorporation of crop residues and the development of conservation tillage (no-tillage or reduced-tillage practices), also reduce GHG emissions, improve the soil quality and increase C-sequestration, accompanying high crop yield[18, 19].

Components of INM

Major components of integrated nutrient management are (i) integration of soil fertility restoring crops like green manures, legumes, etc.; (ii) recycling of crop residues; (iii) use of organic manures like FYM, compost, vermicompost, biogas, slurry, poultry manure, Biological composts, Press mud cakes, Phospho-compost (iv) utilization of biological agent; (v) efficient genotypes; (vi) balanced use of fertilizer nutrients as per the requirement and target yields.

Organic nutrient sources

Organic sources of plant nutrients include growing of legumes in the cropping system, green manures, crop residues, organic manures (FYM, compost, vermicompost, biogas slurry, phosphor-compost, bio-compost, press mud, oil cakes, wellgrow manure etc.) and biofertilizers. Available information shows that organic manures in addition to fertilizers sustain high crop yields over long periods as compared to application of only fertilizers as observed in many long term studies[20]. The results indicate scope for substituting more than 25% of the RDF with organic sources in intensive cropping systems. Under ideal conditions green manures and grain legumes when integrated into the cropping system has the potential to meet more than 50% of the N requirement of the immediate rice crop. Further addition of organic manures as partial substitutes or supplementary and enhance soil and plant health. Biofertilizers (N-fixing, mineral solubilization, cellulolytic microorganisms) facilitate economizing fertilizer nutrient use through utilizing BNF systems, solubilising less mobile nutrients from the fixed components and recycling of nutrients from crop residues. Integration of such systems makes the production system more stable and sustainable[21, 22, 23].

Legumes and green manures

Grain and fodder legumes and green manures can fix atmospheric N to the extent of 50-500 kg N ha^{-1} before the plant starts flowering (about 40-60 days growth) except by soybean. The residues of legumes after harvest of grain contain 25-100 kg N ha^{-1} which is released at a steady rate when incorporated because of optimum lignin content. GM accumulates 100-200 kg N ha^{-1} in about 50 days period, of which 60-80% is fixed from the atmosphere[24] and can meet 60-120 kg ha^{-1} of the N requirement of rice. Besides N, the crop mobilizes less available soil P and K which can be recycled into the system. A 60 day GM was reported to accumulate 20 kg P_2O_5 and 125 kg K_2O ha^{-1} in their biomass, which gets released upon decomposition and is less prone to soil fixation because of organic environment. The deep rooted grain legumes also have the potential to recycle sub soil nutrients to the benefit of the following cereal crops in the cropping system. GM under many situations can meet entire N demand of a crop more efficiently than urea[24]. The GM crops had C: N ratio of 14-15 at 30 days and 18-19 at 60 days, and mineralize in 15 days 41-43% of biomass N of a 30 day old crop while a 45 day old GM crop took 30 days to mineralize same amount of biomass N. A 60 day old GM crop when incorporated released 20-30% of biomass N after 15 days and 26-30% in 30 days. The biomass N release rates depend on plant characteristics like lignin content, see: N ratio, N content, age of the residue, *etc.* Multi-location trials in rice-wheat and rice-rice system indicated that GM crops can on an average supply 50% N requirement of rice, with considerable impacts on SOC, NPK status of soils besides improving soil physical conditions.

Fertilizer uses the scenario of India

India is the 3rd largest producer and consumer of fertilizers in the world, after China and USA. It accounts for 12.2% of the world's production of nitrogenous (N) and phosphatic (P) nutrients and 12.6% of the world's consumption of NPK. However, India's annual consumption of chemical fertilizers in nutrient terms (NPK), has increased from 0.7 lakh MT in 1951-52 to 277.39 lakh MT 2011-12, while per hectare consumption of chemical fertilizers, which was less than 1 kg in 1951-52 has risen to a level of 141.30 kg (estimated) in 2011-12[25].

Impact of injudicious uses of chemical fertilizers

Intensive agriculture, while increasing food production, has caused second generation problems in respect of nutrient imbalance. Some, such problems include, (i) greater mining of soil nutrients to the extent of 10 MT every year, depleting soil fertility (ii) emerging deficiencies of secondary and micronutrients (iii) decline of the water table and its quality of water (iv) decreasing organic carbon content (v) and overall deterioration in soil health.

Soil quality and agricultural productivity

The potential of soil for producing crops is mainly determined by the environment that the soil provides for root growth and roots need air, water, nutrients and adequate space to develop. Soil attributes, such as the capacity to store water, soil reaction, depth, texture and density determine how well roots develop. Changes in these soils attribute directly affect the health of the plant. For example, bulk density, a measure of the compactness of a soil, it affects agricultural productivity. When the bulk density of soil increased beyond the critical level, it becomes more difficult for roots to penetrate the soil, thereby impeding root growth. Heavy farm equipment, erosion and the loss of soil organic matter can lead to increases in bulk density. These changes in soil quality affect the health and productivity of the plant and can lead to lower yields and/or higher costs of production (Tables 1, 2 and 3).

Effect of INM on soil physical properties

Soil physical properties are closely related with SOC and OM, thus, any soil management practice that enhances soil organic matter has direct bearing on soil physical properties and microbial biomass, for this,

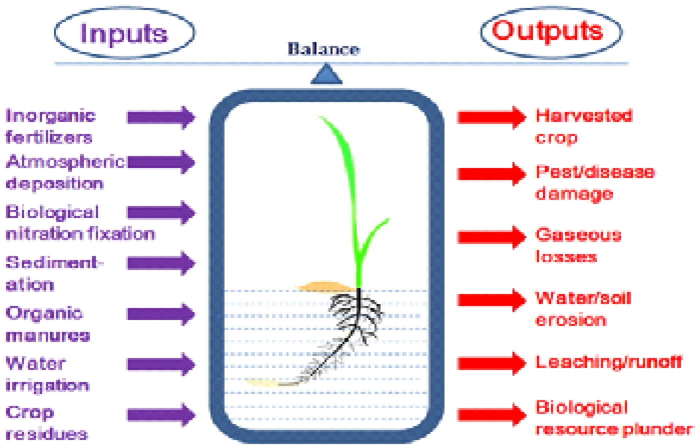

Fig. 1. The nutrient budgets between inputs and outputs, and the principles of INM method.

Table 1. Integrated impact of nutrient management on soil physical properties

Crops	Response to integrated nutrient management	References
Soybean	Significantly decreased in bulk density	29
Maize	Significantly improved total porosity, HC, soil moisture content	44
Wheat	RDF + FYM @ 5 ton ha^{-1} significantly reduced BD	38
Maize	BD, PD reduced and pore space %, significantly increased	45
Cotton-Wheat	Significantly improved in BD, total porosity, WSA, MWD	46
French bean	Integrated treatments improved BD, WHC	47
Pea-Wheat	Soil moisture conserves, significantly increased WSA, MWD	48
Soybean	BD significantly lowered with the application of FYM	29
Tomato	Soil temperature, BD significantly reduced	49
Maize–Mustard	Significantly increased WSA, WHC, and decreased BD	26
Wheat-Soybean	Significantly reduced BD, increased MWD, SOC	31
Rice–Wheat	Increased MWD, total porosity, WHC	50

combined use of organic and inorganic nutrient sources might be the right proposition for these soils, primarily for the improvement of soil physical health. Significant improvement in the soil physical conditions of the soil was observed by many researchers under integrated application of organic manure and inorganic fertilizers. The addition of NPK fertilizers along with organic manure, lime and biofertilizers increased SOC, WSA, moisture-retention capacity, and infiltration rate of the soil while reducing bulk density[26]. Incorporation of organic either in the form of crop residue, organic manure or amendment has a significant effect on BD of agricultural soils[27], soil aggregation[11], soil structure, soil moisture-retention capacity[28] and infiltration rate[27]. The SOC, BD, WHC, WSA and fertility status of the soil improved by the integration of organics with inorganic[29], organic carbon and microbial biomass carbon increased in the treatments receiving an application of organic manures (particularly FYM), green manure and biofertilizers in conjunction with inorganic fertilizers (Table 1). Build up of organic carbon in soil was relatively higher in macro-aggregates compared to micro-aggregates[30, 31, 32].

Effect of INM on soil fertility

Most of the agricultural soil fertility deteriorated day by day due to the imbalanced use of mineral fertilization, a significant improvement in soil fertility status was reported by many of the researchers[31, 32, 33]. SOC of the

Table 2. Integrated impact of nutrient management on soil fertility and crop productivity

Crops	Response to integrated nutrient management	References
Wheat-Maize	Significantly increased SOC and TN, enzymatic activities	51
Maize	RDF + VC enhance NPK availability and microbial activity	45
Pea–French bean	FYM level improved SOC, microbial colonization	32
Wheat–Corn	Enhance SOC availability by FYM and MSWC	52
Chilli	Highest available NPK and micronutrients, higher yield with INM	53
Wheat	Increase the availability of OC, NPK	33
Rice-Rice	Significantly increased in NUE and SOM	54
Rice-Barley	Significant improvement in enzymatic activity	55
Rice	Enhance available NPK in post harvest soil	56
Maize	Revealed that highest grain yield was recorded with 3/4th RDF + VC	39
Green gram	Available NPK and humic substances were higher with INM	57
Cotton	INM significantly increased NPK uptake and sustain soil fertility	58
Maize	VC + RDF enhances 100 seed weight, grain yield	45
Pea-Wheat	Significantly higher yield with manure and NP	48
Cereal-Legume	GM with mineral fertilizer ensures higher crop productivity, soil fertility	59

Table 3. Integrated impact mineral fertilization and biofertilizer on crop performance and soil health

Crop	Response of biofertilizers with mineral fertilization	References
Apple	Biofertilizers play a significant role in the crop production, help to build up the lost micro flora and improve the crop yield and soil health	60
Corn	Bioinoculants with ½ RDF obtained a significant result in terms of ear length, ear weight and grain yield of corn	61
Lentil	FYM and biofertilizer improve the soil health	62
Soybean	RDF with biofertilizers resulted improve productivity, soil fertility and nutrient balance	63
Review	Results indicate that liquid biofertilizer enhance and restoring soil health	64
Sunflower	Significantly higher grain and biological yield with biofertilizer –N fertilization-FYM	65
Wheat	Significant response of biofertilizers on growth and crop productivity	66
Mungbean	Significantly enhanced crop productivity and soil fertility status with bioinoculants and mineral fertilization	67

soil improved by the application of organic manure with RDF, this combination significantly influenced crop growth, development and productivity[33, 34, 35]. Most of the research results clearly demonstrated that INM enhances the yield potential of crops over and above achievable yield with recommended fertilizers (Table 2), and results in better synchrony of crop N needs due to (a) slower mineralization of organics; (b) reduced N losses via denitrification and nitrate leaching; (c) enhanced nutrient use efficiency and recovery by crops, and (d) improvements in soil health and productivity, and hence could sustain high crop yields in various cropping systems ensuring long-term sustainability of the system[36, 37].

Judicious application of mineral fertilizers and organic manure along with biofertilizers and micronutrients gave highest available NPK in soil as compared to other treatment combinations[33, 34, 37]. According to Kusro[38] stated that the organic carbon, mineralisable nitrogen and NH_4^+-N showed statistically significant increase over control (Table 2). Incorporation of FYM, GM and BGA, through an inorganic source in the treatment increased organic carbon, mineralisable N, NH_4^+-N and reduced the bulk density[39, 40].

Impact of biofertilizer on crop productivity

Biofertilizer is a substance which contains living microorganism which, when applied to seed, plant surfaces, or soil, colonizes the rhizosphere or the interior of the plant and promotes growth by increasing the supply or availability of primary nutrients to the host plant (Table 3). Very often microorganisms are not as efficient in natural surroundings as one would expect them to be and therefore artificially multiplied cultures of efficient selected microorganisms play a vital role in accelerating the microbial processes in soil. Use of biofertilizers is one of the important components of INM, as they are cost effective and renewable source of plant nutrients to supplement the chemical fertilizers for sustainable agriculture. Several microorganisms and their association with crop plants are being exploited in the production of biofertilizers (Table 3). A number of microorganisms are considered as beneficial for agriculture and used as biofertilizers viz. *Rhizobium, Azotobacter, Azospirillum, Cyanobacteria, Azolla*, Phosphate and potassium solubilizing microorganisms[21, 22, 23, 41]. Silicate solubilizing bacteria, plant growth promoting rhizobacteria and these are also available as liquid biofertilizers[41, 42, 43].

Strategies for further development of INM

The number of advantages that INM practices can bring to farmers and the environmental benefits are remarkable. By reviewing numerous research reports, here we have synthesized some strategies and recent opportunities that can be accessed and further enhanced by modification and adjustments in the adoption of site-specific INM practices. Future strategic development of INM under following points (i) combination of soil and plant analysis (ii) fine-tuned to the local environmental conditions (iii) mechanization due to serious labor shortage (iv) conservation tillage and rainwater-harvesting technologies (v) recycling of organic nutrient flows (vi) new technological innovations, and (vii) appropriate policy interventions.

CONCLUSION

The practice of INM includes all possible sources of plant nutrients to optimize nutrient inputs, spatial and temporal matching of the soil nutrient supply with crop demand and reducing N losses while improving crop yield. Interaction of agricultural inputs leads to increases in crop productivity while substantially reducing N losses and GHG emissions, judicious application of mineral and organic fertilization with higher resource-use efficiency, enhance the soil-plant-microbes-environmental sustainability. Balanced use of organic manures will be of fundamental importance for crop productivity and environmental concerns, which should be a priority for INM practices, provides a “win–win” opportunity to simultaneously increase crop productivity and agricultural sustainability.

ACKNOWLEDGEMENTS

The author thankful to Head, Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University. LKJ is thankful to University Grants Commission (UGC, New Delhi), Government of

India (GOI) for Doctoral Fellowship.

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