Integrated Nutrient Management: A roadmap for improving the soil sustainability and crop productivity - A review

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ABSTRACT

The excessive of chemical fertilizers with minimal organic inputs in modern agriculture are resulted in nutrient deficiencies and environmental problems. The inorganic chemical fertilizers cannot sustain plant nutrition in highly intensive agricultural systems.Sustainableyieldandcrop performancearedifficulttoimprovewithoutbalanced application ofnutrientmanagement practices. The integrated nutrient management (INM) strategies involved the application of vermi-compost, green manure, cover crops, crop residues, vermi-compost and farmyard manure. Since organic manure cannot synchronized the concentrated requirement of plant nutrients as per crop demands, hence balanced integration of organic and inorganic fertilizers helps to improve the crop productivity and economic returns to famers. Therefore, INM strategy has come up as field specific approach in modern era. The INM strategy build-up the organic matter which improve the crop performance and efficient management of water and nutrients. However, optimizing the timing, rate, source and methods of nutrient application is helpful in achieving the higher apparent recovery efficiency and crop production synchronization with crop demands.

Keywords: Crop yield, fertilizers, nutrient management and soil fertility

1. INTRODUCTION

The most serious problem being faced by agriculture in current scenario is excessive chemical fertilizers and groundwater depletion. To meet the increasing population demand, intensive farming using highly resistant cultivated varieties and indiscriminate use of fertilizers had been practiced [1]. Food and Agricultural Organization reported that inorganic fertilizers contribute to increase in the world's agricultural food production. The Unbalanced use of chemical fertilizers without soil testing, conventional farming practices with flooded irrigation practices and reduced or less persistent use of organic manures in appropriate quantity in the past three decades had induced the stagnation crop yield, deteriorating the crop quality, negative nutrients balance in soil, organic carbon depletion and soil health degradation [2] and [3]. It is not possible to meet the increase nutritional demand of population growth without balanced nutrients management strategies

[4]. Increasing in population growth have put a lot of burden on farming community to increase the agricultural production. Most of the Indian soils are deficient in N element [5]. The judicious use of chemical N-fertilizer such as urea cannot sustain soil productivity in highly intensive agricultural systems which can lead to reduction in growth performance and yield-related parameters [6]. Relying applying chemical fertilizer, especially nitrogenous fertilizers cannot sustain soil quality which can lead to degrading soil recuperative and crop productivity [7]. The fertilizer prices increase year after year and the indiscriminate use of nitrogenous fertilizers can lead to N losses, reduces the N use efficiency and further results in an increase in total expenditure on crops [8]. The widespread application of inorganic N-fertilizers and the limited use of organic and bio-fertilizers in modernagriculture are resulting in loss of organic carbon (%) and multi-nutrient deficiencies. India consumes 16 % out of the total N-fertilizer consumed globally [9]. High fertilizer consumption in developing countries is due to knowledge gap between farmers and scientist, high population pressure and availability of highly subsidized N fertilizers. The trends of N consumption have increased substantially in India which can lead to nitrate contamination of surface and groundwater [10].

Need for Integrated Nutrient Management: There is significantly challenging task of developing countries to meet the agricultural food demands with increasing population growth. Now a days, farmers apply excessive use of hazardous chemical inputs such as fertilizers which leads to environmental deterioration to meet the challenges of modern era. The soil microbe system plays vital impacts on improving the soil quality and agricultural sustainability. The unbalanced use of inorganic fertilizers results adverse effects on groundwater quality which causes air contamination and ultimately causing nitrate leaching hazards. Also, with increase in population growth, it is most difficult criteria to improve the food security of nation. In India, nutrient management strategy played a significant role in increasing food grain production from 52 MT in 1951 to 252 MT during 2015. Currently,agricultural specialists suggest farmers to change their perspective and adopt an integratednutrientmanagement (INM) strategytoreplaceaportionofchemicalfertilizer withmoresustainable, more efficient and eco-friendly sources of nutrients. It also reduces exploitation of resources and improve soil carbon stocks [11]. Manuresareeco-friendlyalternativetochemicalfertilizers which helps in improving the soilhealthwithoutanyenvironmentalpollution[12].It can help in sustaining the crop yield while reducing the soil and water pollution [13]. The conjoint application of organic, bio and chemical fertilizers helps to increment the agricultural production and soil sustainability, whereas sole application of chemical fertilizer degrades the soil fertility status. The INM greatly improve soilhealth andbiological activity than sole application of chemical fertilizers. It is now possible to optimizing the nutrients management strategies to account the variations in the nutrient supplying capacity of soil through variable rates and timings of fertilizer application [14].

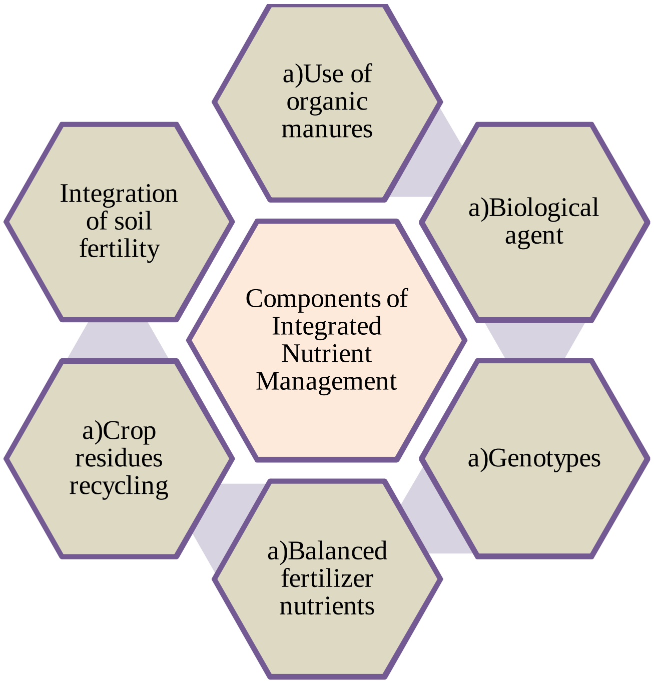
The INM can improve the microbial and slow persistent decomposition of biological matter which helped in conversion of organic N to plant available form and hence can improve the soil fertility along with fruit yield [15]. Nutrient management strategy such as split application of fertilizers, applying organic manure in their integrated combined application have proven to be very effective in increasing nutrient use efficiency, crop yield and reducing nutrient losses such as leaching, denitrification, etc [16].

2.CONCEPT OF INTEGRATED NUTRIENT MANAGEMENT

For optimal soil fertility and crop production, nutrients play a significant role in improving the soil structure. The right timing, rate and source of nutrients application influences the higher apparent recovery of added nutrients e.g., ammonium nitrate source of N-fertilizer is best for upland crops besides amide and ammonium sources of N-fertilizer are considered best for lowland rice crop. The split and balanced application of nitrogen and potassium fertilizer is best preferred than basal application whereas for phosphorus, basal placement is generally adopted method due to less fixation. The developed countries using nutrient management stewardship strategy such as the application of phosphorus-based fertilizer/manure, most cereal growing areas will overcome the problem of low phosphorous availability [17]. The phosphorus availability is affected by soil *p*H and maximum when soil *p*H between 5.5 and 7.5 whereas soil *p*H < 5.5 *i.e.* acidic soil causes dissolution of aluminium and iron minerals which precipitates with solution phosphorus but in soil *p*H > 7.5, basic soil cause excessive calcium present in soil solution which precipitates with phosphorus decrease the availability of phosphorus content. Integrated nutrient supply not only improves the physical, chemical and biological soil properties but also improves the availability concentration of applied and native soil nutrients. The water degradation and environmental sustainability can be improved by adopting carbon sequestration and checking the losses of nutrient to water bodies and atmosphere. The slow and controlled release fertilizers are best nutrient fertilizers which synchronizes the demand of nutrient as per crop demands both in space and time and sufficient nutrient supply from the labile soil.

3. COMPONENTS OF INTEGRATED NUTRIENT MANAGEMENT

The various components of integrated nutrient management are:



4. IMPLEMENTATION OF INTEGRATED NUTRIENT MANAGEMENT

Testing methodologies to assess nutrient deficiencies in plant and soil samples are:

a) Deficiency or toxicity symptom evaluation - The general appearance of crop can provide indications of certain nutritional toxicity or deficiencies syndromes e.g., N deficient plants appear pale yellow, stunted and less vegetative growth than healthy plants

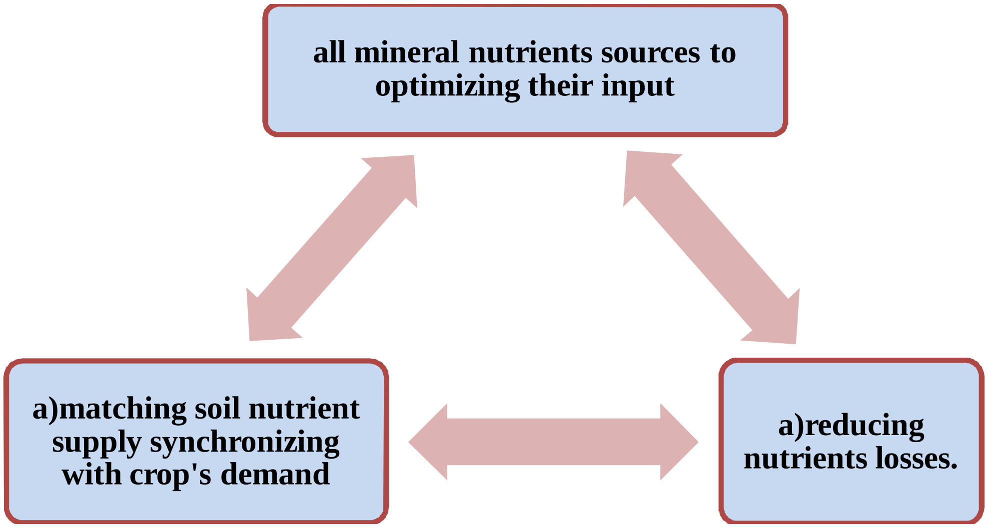
b) Plant tissue analysis and soil analysis - where signs or syndrome of leaves are not clearly visible, tissue and soil samples can be examined in a laboratory after harvesting and compared with a reference plant sample from a healthy plant.

c) Scientific examination of different constraints and opportunities in modern strategy for managing soil fertility and how they connect to the diagnosis of nutrients, for e.g. excessive or inadequate application of fertilisers.

d) Evaluation of faming system's productivity and soil sustainability - The balanced application of nutrients required by crop is influenced by soil type, climatic conditions, tillage practices, nutrient management approach and *In-situ* straw management technologies. Once these physical, chemical and biological factors are understood, so that optimal INM technologies can be used.

e) Environment friendly INM strategy research and development - The field specific need for locally available resources means that farmer participate in the soil and water analysis adopted the INM practices.

BASIC PRINCIPLES OF INTEGRATED NUTRIENT MANAGEMENT INCLUDES:



The timing and levels of nutrient application in accordance with the leaf's nutrient requirements, is necessary to achieve maximum yields and improve nutrient-use efficiency [18]. The N-fertilizers with most frequently applying can potentially reduce the environmental pollution but increases yield and quality of crop. Li et al. [19] reported that nitrogen fate is an integrated consequence of nitrogen uptake, immobilization, nitrogen losses like volatilization, denitrification, leaching and runoff.

5. IMPACT OF INTEGRATED NUTRIENT MANAGEMENT

5.1 Effects on Soil Fertility

The ability of soil to continue functioning as critical living system within land-use boundaries is known as soil health. It is due to soil containing biological components that plays a key role in ecosystem function [20]. Plants are often unable to grow in poor soil structural condition which consequently limit their capacity to explore the soil depth for water and nutrients [21]. The main components of integrated nutrient management are farmyard manure (FYM), vermicompost, crop residues, bio-fertilizer, green manure and chemical fertilizer which help to improve soil properties in cropping system. The physico properties such as soil structure, aeration, porosity, infiltration rate and water holding capacity indirectly improves the health status of soil. Kumar et al [22] studied that soil sustainability and crop productivity by applying chemical or synthetic fertilizers have negatively effect on bio-geochemical cycles [9]. Also, usage of inorganic fertilizer caused denitrification, leaching and run-off, especially nitrogen (N) and phosphorus (P) which results in environmental and global warmth. The different sources of nutrients such as manure, bio-fertilizers, soil, irrigation water, and atmosphere can change the crop productivity. The nutrients removal by crops from the surface soil exceeded their restoration through fertilizers; manures causing unbalanced nutrients in soil were also reported by Gangwar and Prasad [23]. Kumar et al. [24] studied that organic manures in combination with fertilizers can enhance crop performance, productivity and profitability to famers. The decrease in soil *p*H with the conjoint application of N fertilizer with FYM may be attributed to the release of carbon dioxide and the production of organic acid during the mineralization and decomposition of FYM [25]. Rajneesh et al. [26] revealed that an increase in the level of N fertilizer can decrease the soil *p*H due to the release of H^+ ions and hydrolysis of inorganic urea. The decrease in surface soil *p*H has a positive influence on the availability of different nutrients, notable Zn, Mn, Fe and P [27]. The lower EC values under organic amendment (FYM) could be attributed to increased soil water holding capacity because of improved soil aggregation [28]. Soil organic carbon (SOC) is the most imperative indicator of agricultural sustainability and soil health.The greater SOC with FYM may be attributed to FYM’s slower rate of decomposition (less and persistent mineralization rate) because of polyphenol as well as lignin content. An improvement in SOC content might be due to the improvement of root anatomy and increased plant residue with the increased nutrient application through manure and chemical fertilizers [29]. The INM treatments have higher available N as compared to sole inorganic N fertilizer due to the improvement of SOC and slow mineralization of available N in surface soil [30] and [31]. The FYM with inorganic N fertilizer have higher available P content than inorganic N fertilizer which might be due to soil organic matter (SOM) coating the sesquioxides (Al-P and Fe-P), rendering them inactive and reducing the P fixing capacity of surface soil resulting in improvement of P in soil [32]. The increase in available K of surface soil with combined application of N fertilizer with FYM may be attributed to improve the water holding capacity (WHC) and slow mineralization of nutrients. The study revealed that FYM can significantly increase the available K content in INM plots as compared to inorganic N fertilizer plots [33]. The INM treatments have higher available micronutrients as compared to sole inorganic N fertilizer due to increasing soil microbial activity during mineralization and decomposition of organic matter which improved the DTPA-extractable Zn, Cu, Fe and Mn content in surface soil by preventing leaching, fixation and precipitation [34].

5.2 Effects on Environmental Benefits

Organic farming was shown to be successful strategy for improving soil sustainability, environmental quality and maintaining soil ecosystem services [35] and [36]. Efficient use of on-farm inputs, crop residues, and limited use of off-farm inputs sustained the soil fertility, nutrients and environmental quality in organic farming. The extensive integration of organic leftovers in organic farming lead to accumulation of high soil organic matter in organically amended soils which supports productivity of an agroecosystem [37]. Bhattacharya et al. [38] reported that organic carbon in soil increase under long-term legume-based crop rotation in organically managed soils. In addition to organic practices, i.e., incorporation of compost and manures, crop rotation, bio-fertilizers and cover crops not only improve soil organic matter but also improve physico-chemical and biological properties of soil [39] and [40]. Numerous studies have evaluated that permanent additive of organic manures, green manures, crop residues and bio-fertilizers in cropping system improved soil physical properties, *i.e*., bulk density, water-holding capacity (WHC), aggregate stability and hydraulic conductivity; chemical properties i.e. *p*H range (0.3-0.9), electric conductivity (0.2-0.5 dS m^{-1}), organic carbon (32%), available N (47%), available P (90%), available K (50%) and biological properties, i.e., microbial biomass carbon (132%) dehydrogenase activity (347%) and phosphatase activity (203%) relative to control treatments [41] and [42]. Significant physico-chemical properties and variation in micro-environment as a result of organic residue have shown positive effects on DTPA-extractable Fe, Cu, Zn, and Mn content in soil [43]. Dhaliwal et al. [2] observed significant apparent recovery of DTPA-extractable micronutrients with the addition of organics, crop residues, and bio-fertilizers in soils with alternate drying and wetting conditions. The integrated application of FYM, green manures and bio-fertilizers and subsequent microbial degradation of amendments significantly improved soil organic carbon (SOC), available N, P, S and DTPA extractable micronutrients. The integrated incorporation of organic manures with crop residues and bio-fertilizers results to improve the nutrient availability and crop productivity [44]. Significant improvement in crop productivity and DTPA-extractable micronutrients were observed through several researchers when 25% to 50% of the recommended dose of nitrogen was substituted through different organics, *i.e.*, wheat straw, FYM and green manures in rice followed by wheat crop each year [32]. Walia and Dhaliwal [34] reported a positive correlation of Fe, Mn, Zn with the SOC in soil. Further, organic matter affects growth and yields either by directly supplying nutrients or indirectly by modifying soil physical properties such as stability of aggregates, porosity and available water capacity that can improve the root environment and stimulate plant growth. Organic matter not only increases the water holding capacity of the soil but also proportionates water available for plant growth and improves physical properties of soil [39].

5.3 Effects on Crop Productivity

The crop yield is influenced by many parameters, besides its most important parameter for attaining net profit for the farmers. It is combined effect of metabolic and physiological parameters. It helps us to understand the several factors that limit the adaptability of crop.

The yield was increased in INM plots because the application of organic manure can supplement the N fertilizer to crop for developing plant growth that reflects on the resultant crop productivity [45]. A higher source generatesa more efficient sink, which increases yield and dry matter production. The rate of photosynthesis is measured by chlorophyll content which serves as an indicator of biomass accumulation. The higher nutrient availability through microbial activity enhancement with conversions of some of the nutrients from unavailable to available forms which improve the physical, chemical and biochemical conditions for better nutrient translocation and nutrient assimilation. Babhulkar et al. [46]; Singh et al. [47] and Kumar et al. [48] studied that significant positive correlation observed between available nutrients and crop yield. The microbial and slow decomposition of FYM, crop residues and continuous slow release of nutrients throughout the growth stage of crop coupled with higher nutrient assimilation. Singh et al [49] provide conducive situation for higher yield performance of different field crops. The optimal soil physical conditions are important prerequisite for sustaining fertility management. The soil aggregates breakdown, platy soil structure, root restrict growth and consequently limit their capacity to explore the soil profile for water and nutrients [21]. Soil organic matter affects growth and yield, either directly by supplying nutrients or indirectly by modifying soil properties that results the rhizosphere environment and better plant growth. The INM strategies of sustainable crop production plays a significant role through reducing chemical fertilizers. Kamboj et al. [50] studied that integrated N management practice with FYM improve growth, quality and yield of chillias compare to sole use of inorganic N-fertilizers. The addition of organic manure, lime and bio-fertilizers enhanced soil organic carbon, moisture retention capacity and infiltration rate [51]. Bio-fertilizers sustained fertilizer nutrient use through biological nitrogen fixation, which further solubilize fewer mobile nutrients and leading to sustainable agriculture system [52].

6. CONCLUSION AND FUTURE PROSPECTS

The integrated nutrient management emphasis on the balance between organic and inorganic inputs in current context of global agricultural challenges, such as soil degradation and environmental sustainability. The INM integrates scientific concepts such as nutrient cycling, soil microbe interaction, and the environmental implications of fertilizer use. It improves the microbial decomposition of organic matter which helped in conversion of organic N to plant available form and hence can improve the soil fertility along with fruit yield. The conjoint integration of organic, bio-fertilizers and chemical fertilizers improves the productivity and agricultural sustainability, whereas sole application of chemical fertilizer degrades the soil fertility. The nutrient management techniques such as split application of fertilizers, the use of organic manure and their combined application have proven to be very effective in increasing nutrient use efficiency, crop yield and reducing nutrient losses such as leaching, denitrification, etc. The fertilizer prices increase year after year and the indiscriminate use of nitrogenous fertilizers can lead to N losses, reduces the N use efficiency and further results in anincreaseintotalexpenditure on crops Therefore, integrated nutrient management is eco-friendly approach which helps to improve the soil fertility, crop productivity and environmental sustainability.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that no generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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