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Integrated Nutrient Management: Concept, Constraints, and Advantages for A Sustainable Agriculture

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ABSTRACT

Achieving the zero-hunger aim, filling nutritional requirement gaps, and ensuring food security for the ever- increasing population of the world are the key challenges that are faced by the agricultural planners around the world. Agronomic management, especially fertilizer nutrient supply, to fulfill crop requirement as well as limiting the costs on inputs is of atmost importance, Integrated nutrient management (INM) is one such agronomic management practice. The use of a simple strategy of employing a minimum effective dose of sufficient and balanced quantities of organic and inorganic fertilizers in combination with certain microbes, is known as the INM. Combining chemical fertilizers with organic manure is becoming a very beneficial approach, not only for assuring higher yield output but also for sustaining productivity, improving soil health and ensuring environmental benefits. The organic component in integrated nutrient management serves as source of energy, organic carbon, and accessible nitrogen for the growth of soil microorganisms. It also improves other soil physical and chemical qualities of soil. Achieving environmental benefits is a key component of INM which is fulfilled via combining the harmonious properties of both sources (organic, inorganic) and creating a combination that can be used for reducing the indiscriminative use of chemical fertilizers, maintaining a balance between fertilizer inputs and crop nutrient requirements, enhancing soil fertility, optimizing yield, maximizing profitability, and reducing pollution. Integrated nutrient management is a tool that can provide cost-effective option via which plant nutrient requirement can be fulfilled, along with reduction in total input costs, creation of favorable soil physiochemical conditions and a healthy environment, removal of production constraints, balancing of soil nutrient budgets, and pollution control via recycling of agriculture wastes

Keywords: Integrated Nutrient Management, Crop residue, Fertilizers, Crop nutrient requirement

INTRODUCTION

The main challenge that agriculture planners and farmers will be facing in the coming years is the increasing hunger and poverty due to population explosion and diminishing natural resources. The answer to this is to develop a strategic plan that promotes successful farming and empowers farmers to achieve agricultural growth, alleviate poverty, and maintain good returns on their investment. As a result, the key challenge in the coming years will be to answer the following question. Is agriculture capable of meeting all of the world's food needs, when the population is predicted to exceed 7.5 billion soon? Because of the growing scarcity of land and water, most agriculture plans rely on the use of chemical fertilizers and the development of new high-yielding crop varieties. However, both components are extremely costly, resulting in increased pressure and responsibility for financial investments, as well as an increase in total expenditures. Despite an increase in fertilizer application, current and succeeding crops absorb a portion of applied fertilizers and soil native nutrients, especially in the intensive agriculture, where two to three crops are taken up annually. The use of inorganic fertilizers is not a economically viable option for many impoverished farmers in many parts of the world. Since ancient times farmers have recognized that applying organic manure can restore soil health; as a result, they have applied farmyard manure on a regular basis. The practice of applying organic manures after harvesting has been linked to improved soil health and improved physical, chemical, and biological properties, particularly in marginal soils that already have low organic matter, low native nutrient content, and low productivity (Adeoye *et al.* 2011; Siavoshi *et al.* 2011; Rahmann *et al.* 2017; Selim *et al.* 2017; Selim, 2018). Furthermore, organic practices produces food, which, despite its higher cost, is favored by many people health benefits. Organic fertilizers have a stronger lasting influence on succeeding crops than inorganic fertilizers, which are quickly lost to underground and surface waters due to water leaching and runoff.

Farmers and agriculture experts have recently been urged to replace a portion of inorganic fertilizers with cheaper, more sustainable, efficient, and eco-friendly nutrients derived from natural resources by adopting principals of INM. Organic waste, crop residue recycling via INM can also be a valuable and acceptable option for many agriculture planners and farmers to overcome traditional methods of organic waste disposal, with or without the slight risk to plants, groundwater or ecological pollution, and human health, in order to make the best use of available natural resources. The key goal in INM is to find the most effective and homogeneous combination that can lead to good fertilizer management, sufficient and balanced use of fertilizer quantity and quality, and direct uptake by plants for higher yield without jeopardizing soil native nutrients or polluting the environment. It is finally possible to reach such a goal by employing an integrated strategy, which is defined as a well-balanced mix of organic, inorganic, and bioorganic microorganisms used in various operations. Integrated nutrient management can match crop nutrient requirements and ease nutrient deficit limits without causing harm to the environment or goods. Mismanagement, on the other hand, inevitably results in soil degradation, nutrient shortage, and rapid soil runoff (Selim, 2018).

Furthermore, there are numerous advantages to employing integrated nutrient management. Integrated nutrient management has the potential to be the driving force behind efforts to turn marginal lands into productive ones, thus achieving the strategy target of increasing cultivated land. Despite the fact that many researchers and specialists have been surprised by the results of INM practices, farmers still require significant efforts and additional assistance from a variety of departments, including scientific researchers, extension specialists, government sectors, and non-governmental organizations, to identify suitable INM strategies fitting their requirement and budget, and delineate the specifics of its components. For example, training programs aimed at increasing the basic knowledge of plant nutrient requirements for the optimum level of yield production may be needed. Farmers also need to know which forms of plant nutrients can be combined with one another to achieve optimum nutrient-use efficiency, as well as how these supplies can be integrated to achieve the best production levels while maintaining acceptable economic returns and environmental benefits. To summarize, INM is a tool that can provide good and cost-effective options for providing plants with sufficient amounts of most macro- and micronutrients, as well as reduce the dose of chemical fertilizers, create favorable soil physicochemical conditions and a healthy environment, eliminate constraints, maintain the soil nutrient balance in the long run to achieve sustainable crop productivity.

The concept of Integrated Nutrient Management (INM)

Fertilizers are typically divided into two types, according to the source. The first is an organic (natural) source, whereas the second is an inorganic source (mineral or synthetic or manmade). Integrated nutrient management (INM) is an agronomic practice that aims to combine the beneficial properties of both sources in order to reduce the use of chemical fertilizers and achieve a balance between fertilizer inputs and crop nutrient requirement options that can maintain soil fertility, restore soil health, and provide continuous nutrient supply to plants in order to achieve an optimal level of yield (Fig. 1). Integrated nutrient management is an approach that combines ancient and new fertilizer and nutrient management techniques. Harmony in nutrient properties, a balance between crop nutrient

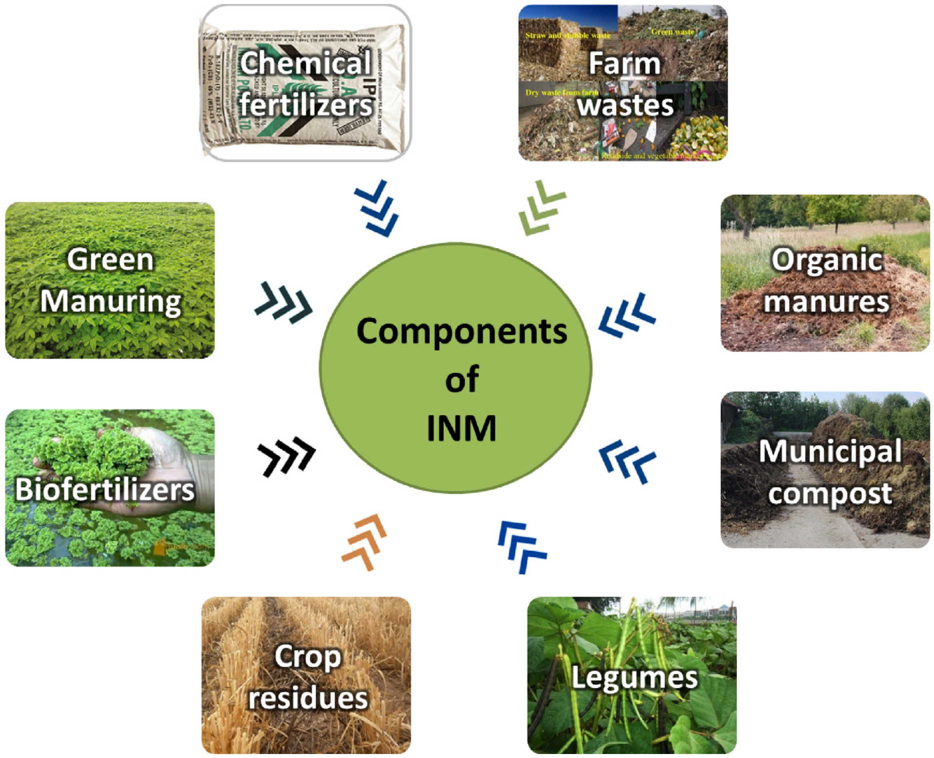

Fig. 1. Components of integrated nutrient management

demands, what kind of nutrient is available in general in soil and in the farmer's hand, and which materials can be safely used to increase nutrient-use efficiency are all factors that influence INM.

It is also a process and a way of securely disposing of organic wastes, as well as an effective method of recycling wastes into high-quality compost (Selim *et al*. 2017; Roy *et al*. 2006). The major components of the INM concept include raising farmer knowledge of the importance of INM practices, urging them to abandon their overuse of chemical fertilizers, and pushing them to concentrate on a long-term plan for sustainable agriculture. Rather than focusing just on the profit that may be made, producers must pay more attention to environmental consequences and creating safe food. It's important to note that many buyers value food safety above all else, regardless of price, and that following such measures can boost a farmer's profits.

The main objective of integrated nutrient management is to maintain economic yield for a long time with minimal impact on native soil fertility and pollution, as well as to raise farmer awareness of eco-friendly techniques (organic farming system) for producing healthy, contaminant-free food while ensuring adequate financial returns.

Main constraints in INM

Soil erosion, nutrient mining, structural deterioration, and loss of fertility are the main causes of irreversible plant output reductions and significant damage to sustainable agriculture. Maintaining soil health and restoring soil productivity is critical to solving the problem of low soil productivity. Serious efforts have been undertaken to promote more productive use of integrated nutrient management, which is a necessary component of the organic farming system. Significant attention must be paid to determining soil nutrient balance, including nutrients taken by the current crop, as well as the requirements of the following crop. Because rapid depletion of soil fertility and decline in soil organic matter is expected, continuous assessment of present soil fertility is required to evaluate nutrient loss through crop absorption, erosion, and leaching (Tirol-Padre *et al*. 2007; Yu *et al*. 2014). In addition, there are various roadblocks to the integrated nutrient management's progress. To begin with, some impoverished farmers have difficulty collecting organic manure due to the difficulty in obtaining FYM and biofertilizers, as well as a lack of knowledge, poor advisory services, and abilities in recycling organic wastes to generate high-quality compost.

Biotic or abiotic pressures are ranked second, poor tillage is placed third, and lack of equipment is ranked fourth in the list of constraints. A constraint is also the lack of extension services and non-governmental organizations to assist farmers and direct their attention to the importance of using integrated nutrient management and its benefits in preserving soil properties, soil nutrient balance, environmental impacts, and their role in increasing profitability

Advantages of INM

Preparing the soil to produce at its maximum capacity is an important goal and a complex process that requires the cooperation of many factors, many of which rely on more than one to achieve the best results, such as soil nutrient content, which must be in an appropriate and accurate quantity as well as in an easy and available form for plant absorption at the right time of plant requirement (Fig. 2). As a result, a good nutrient management package is a technique to achieve appropriate development and yield levels for most crops in various agro-ecological zones, with or without minimal environmental risk (eco-friendly strategy) (Selim *et al*. 2017; Selim, 2018; Zhang *et al*. 2012; Parkinson *et al*. 2004). This can alternatively be characterized as a system that includes a number of the following benefits.

1. Soil nutrient can be improved, and fertilizer solubility and availability can be increased.
2. Make use of the harmonious behavior of nutrient supply by matching them to the crop's needs.
3. Advance and maintain soil characteristics' physiochemical and biological functions.
4. Reduce the pace of soil degeneration, water pollution, and ecosystem degradation through increasing carbon sequestration and reducing nutrient losses to ground and surface water forms, as well as pollution.
5. Increase the farmer's returns by lowering total production expenses (increasing profitability)
6. Improve crop ability to withstand both biotic and abiotic stresses.
7. An successful technique of farming methods for ensuring healthy food while also addressing many soil and environmental issues, particularly in areas with high population increase.

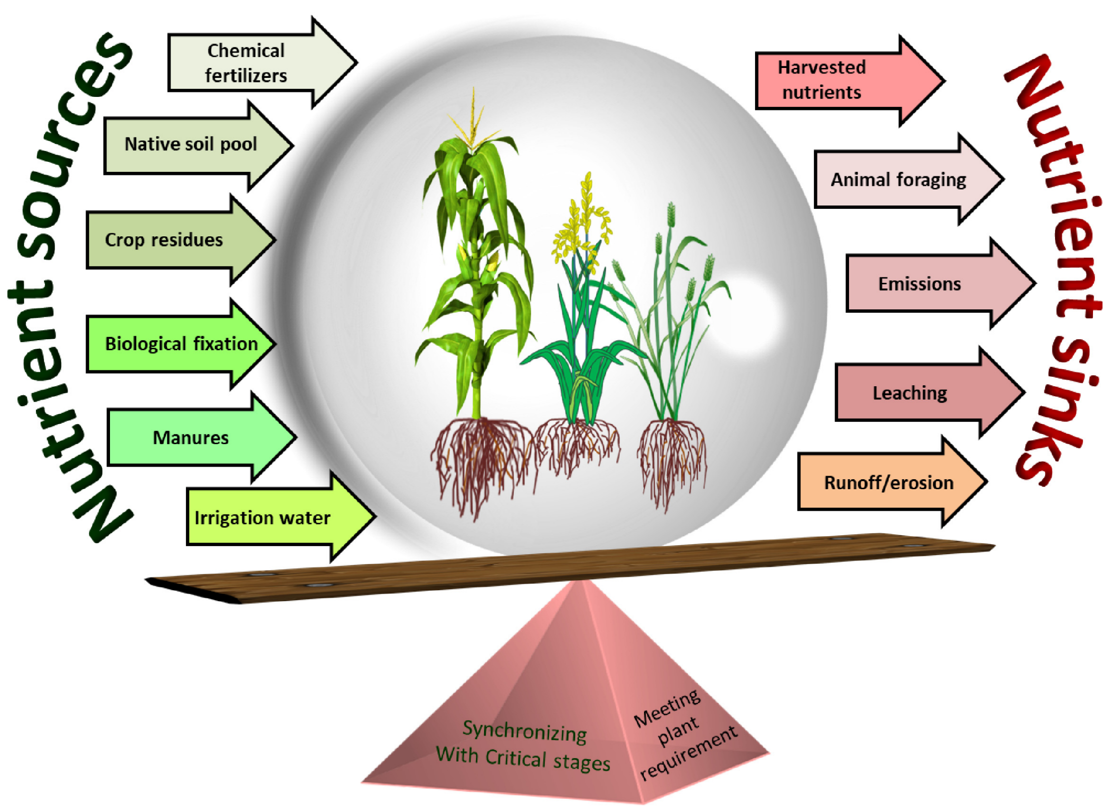

Fig. 2. Balancing the nutrient sources and sinks for meeting plant requirement and synchronizing plant availability in integrated nutrient management

8. Additional benefits can be obtained; it not only keeps total expenditures at a reasonable level while increasing crop yield, but it is also simple to use by farmers; as a result, it is regarded as one of the most promising strategies for future demands.
9. Changes in farmer understanding of climate change from season to season, which have more ecological implications in order to produce safe food rather than reaching bigger yields in order to make more money

INM effects on soil fertility and productivity

Most important studies on the effect of macronutrient application (NPK) are primarily concerned with determining the rate of application, time of application, varietal responses, and the impact of its integration with a variety of agronomic methods. The majority researchers concluded that applying the prescribed amount of inorganic fertilizers is more necessary than ignoring it in order to maintain a profitable production, particularly in low-fertile soils (Wu and Ma 2015; Roy *et al*. 2001; Ramachandrappa *et al*. 2014) (Fig. 3).

Researchers have also observed that the use of inorganic fertilizers might sometimes result in a longer growing period, as well as a delay in flowering and physiological maturity of 1-2 weeks (Tenywa *et al*. 1999) as well as a reduction in yield quantity and quality. Above all, unbalanced and prolonged use of inorganic fertilizers can cause micronutrient deficiencies, which can be a major stumbling block to soil productivity, stability, and sustainability (Yadav and Meena, 2009; Hossein and Ghooshchi, 2013; Bhattacharyya *et al*. 2005). As a result, INM has emerged as one of the most important practices that can be used to replace traditional approaches, reducing nutrient losses and their negative impacts on the environment while retaining higher crop yields and revenues (Gruhn *et al* 2000). The selection of a combination that can provide multiple nutrients to plants in suitable amounts at intervals agreeable to the plant requirements plays a critical role in enhancing nutrient-use efficiency (Wu and Ma, 2015; Cassman *et al*. 2002). Furthermore, it is not only the most effective method for preventing nutrient insufficiency, but it is also closely linked to socioeconomic issues, particularly for poor farmers who are unable to make big investments in soil fertility maintenance.

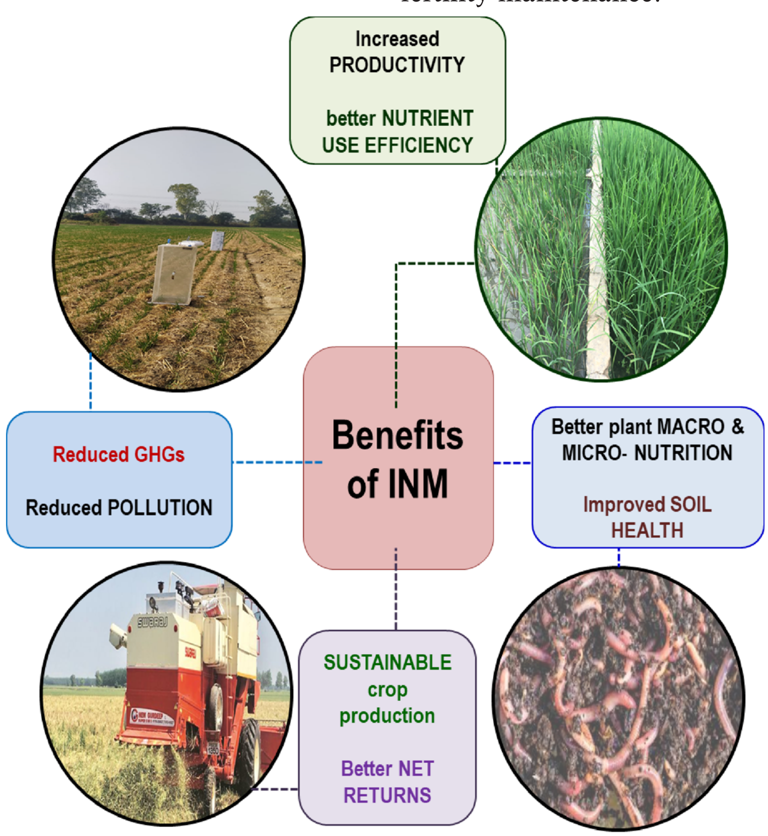

Fig. 3. Benefits of integrated nutrient management

Because of the slow release of nutrients over time and the added value in soil organic matter content, the combination of organic and inorganic fertilizers can be considered a scheme that has a greater residual effect on subsequent crops than sole application of inorganic fertilizers (Chukwuka, 2009, Ogunwale *et al*. 2002). Further-more, the majority of recent literature demonstrated that the role of integrated nutrient management of organic and inorganic fertilizers on growth and production, including the application of FYM, green manures, and biofertilizers, has gotten a lot of attention (Ryan *et al*. 2012; Mgonja *et al*. 2013).

Similarly, Hemalatha and Chellamuthu (2013) discovered that continuous application of inorganic fertilizers alone diminishes soil organic carbon levels due to low dry matter generation and reduced crop residue return to the soil in a long-term field experiment. Keeping these considerations in mind, excess or lack of essential nutrients (N, P, K, S, Ca, and Mg) and micronutrients are commonly referred to as "limiting factors" because each one can limit plant growth and cause serious problems in most of the accumulation processes, making the use of integrated nutrient management an important factor and a primary reason for sustainable agriculture. Finally, farmers and researchers must consider the role of soil microorganisms in nutrient conversions, solubility, availability, and release from the soil root zone to plant roots, as well as absorption and increasing nutrient-use efficiency, which can be achieved by using the INM system (Garai *et al.* 2014; Marimuthu *et al*. 2014; Bairwa *et al*. 2013). A decrease in water and nutrient losses by leaching, runoff, volatilization, emissions, and immobilization (Zhang *et al*. 2012) was also noted, owing to an increase in soil organic matter content and improvements in soil physical and hydrological parameters.

Relevance of INM to environment and food security

The agricultural production for major food crops has been increasing since the early 1990s, although the trend for global food production needs to increase to above 4 billion metric tonnes by 2050 to meet rapidly expanding population needs (FAO, 2009). Further increase in agricultural production, have been linked to negative effects on climate change, water shortages, land degradation, erosion, and soil nutrient balance, as well as depletion of soil organic carbon and subsequent soil runoff (Bruinsma, 2009; Brisson *et al*. 2010). The massive change in ecosystem mostly attributable to the widespread use of synthetic fertilizers and pesticides, particularly in the intensive agriculture system (Zhang *et al*. 2012, Peng *et al*. 2010). As a result of their long-term use in some developing nations, chemical fertilizers, notably nitrogen, phosphorus, and potassium (NPK), are an important factor and primary source of environmental contamination and land erosion (Mueller *et al*. 2012; Davidson *et al*. 2014).

According to some recent studies, intensive use of synthetic fertilizers and pesticides did not result in a significant increase in yield; this could be due to a number of factors, including high nutrient losses due to leaching, runoff, volatilization, releases and immobilization, or low nutrient-use efficiency. As a result, changes are essential in devising an agriculture strategy plan to find a way to produce higher yield production for long-term periods, encourages natural resource conservation, ecological impacts, and global climate change mitigation and adaptation, as well as matching with other agricultural programs aimed at increasing production and ensuring the environment. INM technique that can minimize environmental degradation and continue to be the most effective way to achieve food security, enhance environmental quality, and fulfill ever increasing food demands without causing negative consequences (Selim *et al*. 2017; Selim, 2018; Zhang *et al*. 2012; Parkinson *et al*. 2004).

Integrated nutrient management is a simple system that can create a favorable soil condition and provide plants with a sufficient, efficient, and sustainable nutrient source. It is also a promising strategy that has made significant contributions to reducing negative environmental impact, increasing both the quantity and quality traits of global food supplies, and expanding land with a plan of sustainable and economical agricultural development (Wu *et al.* 2014; Mueller *et al.* 2012).

INM for improving soil structure and water conservation

Soil structure and water conservation is complex and largely dependent on a number of factors, including soil organic matter, both quality and quantity SOM is the indicator of improved physical (structure), chemically (nutrition), and biologically (biodiversity) (microorganisms) quality of soil. According to Brady and Weil (Brady and Weil, 2005), 100 kg of dry soil with 1% organic matter can hold 30 kg of water, whereas soil containing 5% organic matter may keep 195 kg of water. Several researchers came to similar conclusions in the same context (Duxbury, 2001; Bastida *et al*. 2008), as well as the association between soil structure and soil productivity (Yadav and Meena, 2009).

Numerous studies have established that organic and inorganic fertilizers, in combination with biofertilizers, can be utilized as soil amendments to improve soil organic carbon (SOC) content, aggregate stability, and moisture-retention capacity (Garai *et al*. 2014; Aula *et al*. 2016; Kumari *et al*. 2017). As a result, any further improvement in soil structure improves the plant water relationship while having no negative impact on the environment. Integrated nutrient management can improve soil organic carbon, which is an important indicator of soil structure and can directly indicate the state and type of soil quality. Other studies have found that combining organic manures with chemical fertilizers as part of an integrated nutrient management system improves physiochemical soil properties, which leads to improved water infiltration, water-holding capacity, and water flow down, as well as an increase in soil field capacity, which improves economic water use and water use efficiency and leads to more water conservation without reversible losses. Furthermore, increasing soil pH offers a favorable environment for macro- and micronutrient absorption.

INM effect on Crop Yield

Many factors influence plant growth, such as applying the recommended and ideal dose of inorganic and organic fertilizers, which is an important option and factor for improving crop growth and nutrient uptake, as well as a crucial component in supporting the crop life cycle and yield potential (Behera *et al*. 2007; Mavi *et al*. 2008). As a result, excessive fertilizer additions do not always imply an increase in crop production; a portion of the added fertilizers may not be absorbed by the crop and instead remain in the soil, or may be lost through volatilization or leaching to underground water, becoming dangerous and a source of pollution.

Several studies have found that INM has significant benefits and could play a role not just in crop growth but also in agriculture's long-term sustainability and environmental implications. It is well known that a rapid decline in soil fertility, which leads to low productivity, is linked to a variety of factors, including continuous and intensive cropping systems, excessive use of chemical fertilizers, and neglect of soil nutrient balance in planning agriculture programs, as well as intensive cultural practices (Mohammad *et al*. 2008) and ignoring the application of organic manures solely or primarily.

As a result, while implementing an agriculture strategy, special attention must be paid not only to fertilization programs but also to nutrient sources that are compatible, homogeneous, and blended in such a way that they are available for plant absorption and me*et al*l of the crop's requirements. INM playing a significant role in plant vigour, particularly in areas connected to root development, water and nutrient uptake, and dry matter buildup. Goyal *et al*. (1999), Sushila and Gajendra (2000). INM is critical for enhancing plant development in terms of plant height, dry weight accumulation, leaf area, LAI, LAD, and CGR, all of which have direct positive effects on crop yield per unit area, resulting in increased water use efficiency, conservation, and economic water use. High crop yields can be attained even without applying NPK rates beyond the recommended dose for the home-grown area due to the effect of INM on most crop growth metrics (Marimuthu *et al*. 2014; Bairwa *et al*. 2013). Many researchers have previously revealed strong and compelling evidence that INM practice can be an effective and environmentally friendly way to produce higher yields and sustain sufficient profitability for farmers (Ghosh, 2010; Diacono and Montemurro, 2011).

Residual effects of INM on succeeding crops

The majority of the research concluded that using organic and inorganic fertilizers in combination with biofertilizers over time is a better and more successful way to get the most out of the soil for current crops, with the possibility of extending to succeeding crops (Ghosh, 1980).

Furthermore, the papers (Selim, 2018; Khoshgoftarmanesh *et al*. 2010) suggested that INM is an important tool for assessing soil nutrient reserves, restoring soil health, and advancing the biological and physiochemical properties of soil, which are important components in assessing yield and yield contributing components of both preceding and succeeding crops.

CONCLUSION

Integrated nutrient management is a tool that can provide eco-friendly options and a cost-effective way to provide crop plants with adequate amounts of most macro- and micronutrients. It can reduce the use of chemical fertilizers, create favourable soil physiochemical conditions and a healthy environment, remove constraints, protect soil nutrient balance in the long run, and generate an optimum level for sustaining desired crop productivity. An additional benefit can be gained if a portion of the applied organic manure is left with a large amount of crop residue after harvesting for the following crop; these materials will quickly decompose and turn to high quality compost, which can improve soil properties and contribute to soil organic matter building, which is the primary method of preventing soil erosion. Finally, agriculture experts and farmers should focus their attention on a simple integrated nutrient management technique that is an acceptable option, a cost-effective practice that farmers can easily implement, and an environmentally friendly approach that reduces fertilizer use and can give higher yields with better quality traits while maintaining a satisfactory profit margin.

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