



Integrated Nutrients Management for Future Production: A Review

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This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

As per the estimate by the United Nations, the world population will increase to 11 billion, by 2050. This rapid increase in the population is of global concern, creating responsibilities on the shoulders of the scientists to fetch the rapidly increasing population along with the problem of reduced land holding, sudden climatic challenges, and imbalanced nutrition coupled with deficiencies of nutrients. It is necessary to continuously review and modify agricultural practices and technologies in order to meet human demands while respecting the ecological boundaries of our planet. Among these technologies application of fertilizers has been crucial for raising crop yield, agricultural productivity and food security. However, the application of fertilizer has an environmental cost and they haven't been a very productive factor in helping many poor farmers to escape poverty economically,

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especially in the areas where the fertilizer application has an imbalance and inappropriate fertilizer has been applied on the lower fertile soils which have little or no desirable effect on the crop yield. The efficient use of fertilizers can be increased by using agronomic practices to apply existing mineral fertilizers, which generally contain N, P, and K, at the proper time, place, amount, and composition. However, the overall progress made to minimize the negative consequences is insufficient to bring about the necessary change toward sustainable agriculture in underdeveloped nations. Farmers must integrate the management of nutrients and soil fertility into their farming practices in order to meet the increasing population's demand for food. This paper reviews the concepts of integrated nutrient management in the context of its eco-friendly nature and sustainability.

Keywords: Conventional agriculture; environmental safety; food security; Indian agriculture; soil health; soil productivity.

1. INTRODUCTION

Agriculture in this 21st century faces superfluous challenges, like the decline in productivity and degradation in soil quality. That is probably caused by numerous factors like insufficiency of moisture, deficiency of plant nutrients, and faulty management practices of soils. In present contrast, the Indian soils exhibit a very low level of productivity in comparison to world soils. To improve soil productivity, the proper understanding of the soil is unconditionally required. In a developing country like India, the most vital challenge is to provide sufficient food for the ever-growing population at reasonable and inexpensive prices from nonflexible land resources. The use and application of agrochemicals have given abundant rise in agriculture production at the cost of soil health and its condition. To mitigate this faulty applied agrochemical consequences on environment and soil, it is necessary to identify appropriate integrated plant nutrient supply systems for various crops and their cropping systems. As fertilizers are expensive agri-inputs, the orderly approach towards lucrative agriculture would recommend the additional use of plant nutrients from other sources to cater to the real need of the situation. The fertilizer recommendation for a crop in a specific region may entirely differ from that in a unlike region for an identical crop. A number of soil test results generated by various soil testing laboratories at the state as well as central government levels, deliver valuable information about the distribution pattern of plant nutrients in soils. The data on soil testing parameters of the field helped the planners, decision makers and farmers to make the appropriate use of fertilizers. Variation in the soil nutrient composition is a common situation in agricultural systems. Undeniably, only 30 to 50 % of applied Nitrogen fertilizers and 10 to 20% of

Phosphatic fertilizers are used by plants [1]. Assessment of nitrogen in the soil is made in terms of the organic carbon content of the soil. Because of the tropical climate of the country, organic matter is immediately decomposed and sent off to the atmosphere. Soils are, poor in nitrogen content as the amount of nitrogen content in soil is straightforwardly reliant on the amount of organic carbon content in the soil. Phosphorus status of course found low in nearly half of the arable land of the country. Only a few districts of the country are found to have the rich status of available phosphorus, and the remaining ones are in the medium category range. However, potassium deficiency is less widespread than nitrogen and phosphorus, since nearly three-fourths of the country's land comes under the medium to high fertility range. But at the same time, it has been brought out that although a profitable response to potassium application has not always been observed, Indian soils can no longer be generalized to be rich in available potassium. The major farming system in India is rice wheat, which accounts for over 75% of the country's total production of food grains [2]. This approach has made a significant contribution to the socioeconomic advancement of the nation's rural people. The majority of population of the nation depends on wheat and rice as their primary food sources. Even though many farmers are now aware of the sustainability problems associated with the rice-wheat cropping system, declining yield, decreased soil fertility, physical properties, deterioration of soil biological health, toxicity of heavy metals, and up to some extents, nitrate contamination of groundwater. In light of the need for food commodities, which is rising quickly with the expanding population, these important sustainability issues must be distilled down. Integrated nutrient management (INM) may be an option to bolster agricultural output while

safeguarding the environment for the foreseeable future in a sustainable manner. It is an approach that involves the application of both organic and inorganic plant nutrient sources to increase crop output, protect the soil, and contribute to meeting future food needs. Major crops cannot achieve the required production improvements unless plants receive a balanced supply of nutrients at sufficient levels.

The use of chemical fertilizers, organic manure, and biofertilizers in combination with the specific aim of achieving sustainable and environmentally sustainable crop production without decreasing soil health is referred to as "integrated nutrient management strategies. The concept relies on sound crop husbandry, harnessing the natural nutrient capacity through bio-engineering and mining of soil reserves. It also stresses on search for more efficient nutrient natural resources. It is the admirable application of chemical, organic, and biological fertilizers.

2. HEALTH OF INDIAN SOILS

Degradation of soil health is a serious issue in the nation. The land area of the country, which is 120.8 Mha and makes up 36.5% of the total geographical area (TGA), is deteriorated as a result of soil erosion, salinity/alkalinity, soil acidity, waterlogging, and other complicated issues [3]. The main source of soil degradation (82.6 Mha) is water-induced soil erosion, which is followed by chemical degradation (24.7 Mha). India experiences soil erosion at a rate of 16.3 t ha⁻¹ yr⁻¹ on average, or 5.34 billion tonnes (Gt). A total of 61% of eroded sediments is redistributed on land, while about 29% are permanently lost to the ocean, and 10% are deposited in reservoirs, reducing their holding capacity by 2% each year. The soil is also degraded, and about 8 Mt of plant nutrients are washed away with the sediment. Degraded areas have the ability to cause flash floods and soil erosion. The extent of nutrient-wise deficiencies is 89% N (63% low & 26% medium), 80% P (42% low & 38% medium), 50% K (13% low & 37% medium), 41% S, 43.4% Zn, 20.6% B, 14.4% Fe, 13% Mo, 7.9% Mn and 6.1% Cu [4]. Applying externally the lacking nutrients through fertilizers is necessary to maintain crop production.

3. IMPACT OF FERTILIZERS

Fertilizers are still the 'Kingpin' in the current structure of commercial agriculture. However, the scientific and balanced application of fertilizers

assumes vital importance in commercial and sustainable crop production. Efficient use of fertilizers pays back to the farmers more profit per unit investment. This indicates that fertilizer is the key agri-input for achieving target commercial production.

4. FERTILIZER USE IN INDIA

India has had consistent growth in fertilizer application and consumption. Nutrient (N+P₂O₅+K₂O) consumption increased from 69,800 t in 1950-51 to 25.95 Mt in 2016-17. India is the second-largest consumer of nutrients overall in the world, following China, and it ranks second in N and P₂O₅ consumption and fourth in K₂O consumption. The amount of food grain produced increased from 50.8 Mt in 1950–1951 to 275.68 Mt in 2016–17. The cumulative annual growth rates (CAGR) of nutrient intake and food grain production were 9.38 and 2.60%, respectively (Fig. 1); It was largely due to this progressive use of fertilizer nutrients that made nation self-sufficient in food and nutrition.

The optimal use of NPK ratio is 4:2:1, while the current NPK use ratio (with K as base) for 2016–17 is 6.7:2.7:1, which is excessively skewed in favor of N. From the perspective of agricultural needs as well as a sustainable productivity growth aspect, this is not ideal. The global average for the NPK usage ratio is 3.4:1.3:1. Regional differences in the use ratio are more obvious across the nation, with the North having the biggest disparity (15.1:5.1:1) and the South having the smallest (4.2:1.9:1). These are 7.1:3.1:1 in West and 4.3:1.6:1 in East. The per hectare nutrient (NPK) use varied from 93.4 kg in the West to 178.3 kg in the North. In the North and West, 8.4 kg ha⁻¹ of K were used, while in the South, 24.0 kg ha⁻¹ were used (Fig. 2). P₂O₅ consumption per hectare was highest in the south (46.8 kg) and lowest in the west (25.7 kg). Nitrogen consumption per hectare was highest in North (127.3 kg ha⁻¹) and lowest in the West (59.3 kg ha⁻¹). The ratios of nutrients used and consumed vary greatly between states. In general, southern states have the most K use per unit area, whereas northern states have the lowest. As a result, states in the south consume less NPK than states in the north.

The quantity of fertilizer use is dependent on farm size as evidenced by the All-India Report of Input Survey [7] which shows more use of

fertilizer by farmers having small and marginal size of land holding as compared to farmers having large holding. In contradiction, small and marginal farmers use a balanced dose of NPK than large farmers (Table 1). For instance, total NPK consumption in irrigated areas was 187 kg

ha⁻¹ as opposed to 82 kg ha⁻¹ in non-irrigated areas. Nutrient-wise use was 115.7, 51.9 and 19.4 kg ha⁻¹ for N₂, P₂O₅ and K₂O in irrigated areas and in non-irrigated areas, per hectare use was 48.8 kg for N, 24.4 kg for P₂O₅ and 8.8 kg for K₂O.

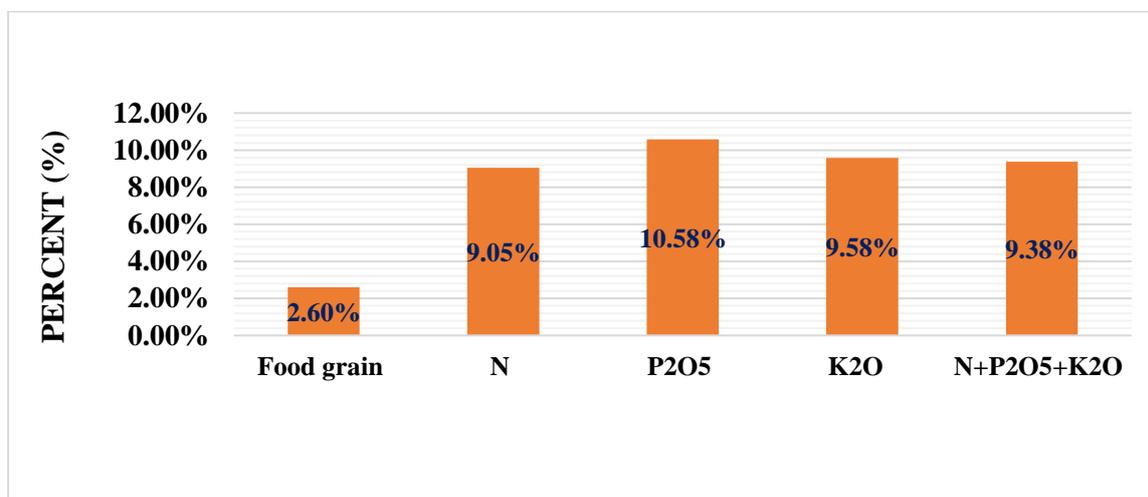


Fig.1. Cumulative Annual Growth Rate (CAGR)

Source: FAI [5] and Annual Review of Fertiliser Production and Consumption (2016-17)

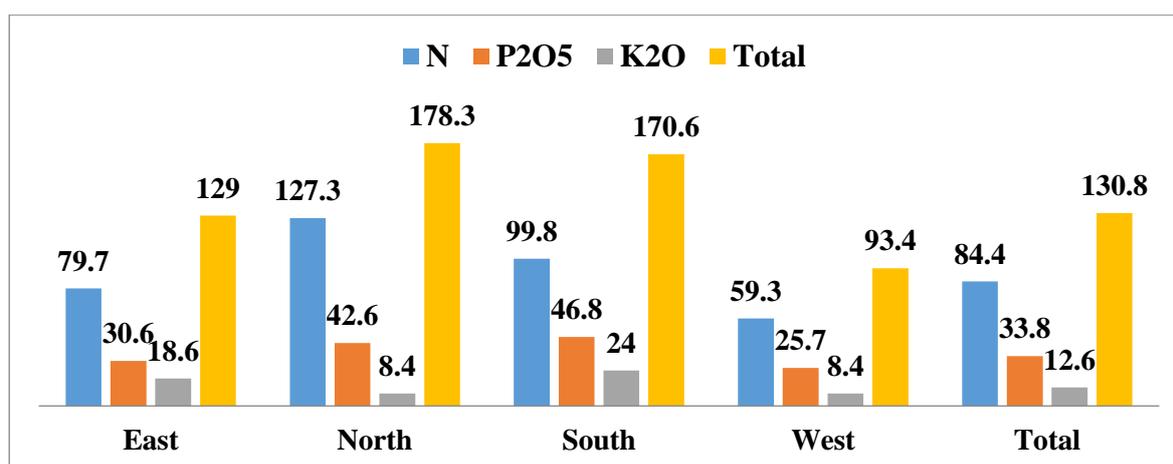


Fig. 2. Nutrient consumption in zones of India (2016-17)

Source: FAI. [6] Fertilizer Use and Environmental Quality

Table 1. Use of fertilizer by land holding or fertilizer intensity by various types of farmers

Landholding	NPK Use kg ha ⁻¹	NPK consumption ratio
Large	84.7	10.5:4.4:1
Marginal	188.7	5.6:2.3:1
Small	130.6	4.9:2.4:1
Semi medium	113	5.8:2.8:1
Medium	99.4	7.5:3.6:1

Source: All India Report of Input Survey [7]

The term "integrated nutrient management" (INM) refers to the process of maximizing the benefits from all potential sources of organic, inorganic, and biological components in a coordinated manner in order to maintain soil fertility and plant nutrient supply at an optimal level for maintaining the desired productivity. Planning experiments involving INM revolves around nitrogen since rates of application of various nutrient sources are determined by the relative contributions of N originating from them. In the rice-wheat cropping system, the cultivation of moong bean (*vigna radiata*), together with the first pod, should be reversed into the soil after selecting the first pod, it maintains the productivity of the crop (on average produces 1 t moong seed ha⁻¹) as well as enriches 40-120 kg N ha⁻¹ in the soil. Bio-fertilizers contribute 15-30 kg N ha⁻¹ yr⁻¹ in addition to providing ancillary benefits including fostering plant development, enhancing the quality of seeds and fruits, and maintaining the biological health of the soil [8]. The crop's NUE was raised by the balanced application of the ideal NPK, and it was further

improved by the addition of 5 to 15 tonnes of FYM per hectare each year (Table 2).

5. CHANGING SCENARIO OF NUTRIENT MANAGEMENT

Greater use of commercial fertilizers the development of high-yielding cultivars and improved irrigation facilities have resulted in a spectacular increase in yield of crops. The recent energy crises and consequent price hike of fertilizers coupled with low purchasing power of farmers in mass have again reviewed the interest in organic recycling throughout the world. Nutrient management has gone through three phases of development.

5.1 Phase I

Between 1950 and 1965, there was a rise in the use of chemical fertilizers and a careful examination of the application of organic nutrient sources and green manuring.

Table 2. Apparent recovery efficiency (ARE) of nutrients in maize-wheat and rice-wheat systems as affected by long-term nutrient supply with and without FYM

Soil type	Location	Crop	Treatments			
			N	NP	NPK	NPK + FYM
Apparent recovery efficiency of N (%)						
Inceptisol	Ludhiana	Maize	16.7	23.5	36.4	40.2
		Wheat	32.0	50.6	63.1	67.8
Alfisol	Palampur	Maize	6.4	34.7	52.6	63.7
		Wheat	1.9	35.6	50.6	72.6
Mollisol	Pantnagar	Rice	37.5	40.7	44.4	61.7
		Wheat	42.4	46.1	48.4	47.9
Apparent recovery efficiency of P (%)						
Inceptisol	Ludhiana	Maize		10.3	21.4	26.3
		Wheat		20.6	30.7	34.8
Alfisol	Palampur	Maize		21.8	35.6	51.1
		Wheat		10.7	15.2	24.6
Mollisol	Pantnagar	Rice		18.2	23.3	53.0
		Wheat		11.2	10.4	23.3
Apparent recovery efficiency of K (%)						
Inceptisol	Ludhiana	Maize			43.8	58.2
		Wheat			88.1	112.8
Alfisol	Palampur	Maize			23.0	38.9
		Wheat			22.6	66.8
Mollisol	Pantnagar	Rice			34.5	108.3
		Wheat			13.7	35.8

N: recommended N; NP: recommended N and P; NPK: recommended NPK to both crops; NPK+FYM: recommended NPK to both crops + FYM (15 t ha⁻¹ yr⁻¹ up to 2008-09 and 5 t ha⁻¹ yr⁻¹ thereafter) to kharif crop only.

Source: Singh et. al. [9]

5.2 Phase II

Beginning in the middle of the 1960s, the "Green Revolution" led to an abrupt increase in the usage of chemical fertilizers and a steady reduction in organic fertilizers and green manuring. This is evident from the fertilizer use growth from 7.84 lakh tonnes in 1965-66 to about 15 million tonnes in 1995-96 and 20.34 million tonnes in 2005-06.

5.3 Phase III

It can be linked to the mid-1970s, the mid-1980s, and the years since 1992 when the oil crises witnessed globally with a deficit of fertilizers, renewed the interest in India in promoting integrated nutrient management that involves more organic waste recycling in agriculture. Dependence on INM got greater interest with the concern of environmental pollution due to the heavy use of inorganics for commercial production.

6. USE OF ORGANIC MANURES

With the introduction of the Green Revolution, chemical fertilizers replaced well-decomposed organic manures including farmyard manure, digested cow dung, and compost (urban and rural) as the most effective source of plant nutrients. Reviving the addition of these manures is now necessary. In addition to main and secondary nutrients, organic manures also contain micronutrients in the form of compounds that promote and inhibit growth. However, some materials used to make farmyard manure, rural compost, or urban waste compost contain hazardous elements such as the heavy metals Ni, Cr, Cd, etc., which, if present in large enough quantities in the organic manures, can negatively impact the plant growth. It is important to note that while organic manures improve the physical, chemical, and biological characteristics of soils, they cannot replace chemical fertilizers due to their low concentration of plant nutrients and the high transport costs associated with their bulky nature. The alteration of the soil processes brought about by the addition of OM and biofertilizer increases the metal solubility and availability [10].

7. GREEN MANURE USE

Growing legumes as green manure to improve crop productivity and soil health is among the oldest practices. It gains more advantages,

especially for light soils with sandy and loamy sand textures, as well as sandy loam soils or soils with a loam/silty loam texture. Although they may serve other purposes as well, green manures are crops planted particularly to improve and preserve the fertility and structure of the soil. In these circumstances, growing dhaincha (*Sesbania aculeata*) and burying it in the soil before the flowering stage at the time of transplanting rice has been found effective in raising the yield of both rice and wheat [11]. Green manure mostly affects the supply of nitrogen and other nutrients. A better period for plants to absorb nutrients from decomposing green manure may be provided, thereby improving nutrient uptake efficiency and crop yield [12].

8. USE OF RURAL WASTES AND CROP RESIDUES

There is a lot of opportunity for rural wastes to be used as plant nutrients, including paddy and wheat straw, as well as the leftovers of other crops including sorghum, pearl millet, sugar cane, and pulses. However, given the growing population's need for more food grain output, their use as such or after composting cannot match that of chemical fertilizers in maintaining rice and wheat yields. These organic residues' high C/N ratio, which can be as high as 100:1, is another restriction. Nitrogen becomes immobilized as a result of this. Aside from the aforementioned, sewage and industrial effluents also contain various harmful substances as well as varying amounts of organic matter and plant nutrients depending on the place of origin [13]. There are significant amounts of plant nutrients in the wastewater produced by various corporations which can be utilized after passing through appropriate treatments [14].

9. USE OF BIO-FERTILIZERS

The biofertilizer contains efficient live cells of microorganisms and is a carrier-based microbial inoculant. Biofertilizers are able to mobilize nutrients, solubilize insoluble nutrients in the soil system, fix atmospheric nitrogen in ammonia form, and release plant growth hormones that are needed by plants for development and growth. Blue-green algae (BGA) and Azolla are the major organic fertilizers for rice that can be used in place of chemical fertilizers. BGA can fix atmospheric nitrogen, especially in rice soils with standing water, and they secrete chemicals that encourage growth [15]. Azolla is a floating

freshwater fern. It is widely dispersed in freshwater basins and lowland rice fields. *Anabaena azollae*, a nitrogen-fixing BGA, is found inside the fern. It can be utilized as a bio-fertilizer in rice agriculture due to its prodigious growth characteristics and interaction with nitrogen-fixing BGA. Azolla can fix 100–150 kg N per hectare per year [16]. For direct-seeded rice and wheat crops, azotobacter culture made from *azotobacter chroococcum* or other species can be utilized as a bio-fertilizer [17].

10. VERMICOMPOST USE

Vermicompost is a naturally occurring organic manure made from earthworms, sometimes known as the earth's tillers. Worm castings and organic debris, such as humus, live earthworms, their cocoons, and other creatures, are combined to create vermicompost. The earthworm species that are now being utilized widely for vermicomposting are *Eisenia foetida*, *Eudrilus Eugenia*, *Eudrilus eugeniae*, *Pheritima elongata*, and *Perionyx excavatus*. However, *Eisenia foetida* is the species that is most frequently used globally. It is a rich source of minerals, vitamins, and enzymes, as well as macronutrients for plants like N, P, and K. The combined use of 100% recommended fertilizer doses of vermicompost, phosphate solubilizing bacteria (PSBs) and zinc (Zn) produced significantly higher amounts in wheat grain and straw yield than the equivalent to 50% of NPK, whether alone or in combination with farmyard manure (FYM), PSB, Zn and vermicompost [18]. Enriched compost was more successful than integrated use of biofertilizer and inorganic fertilizer in lowering the phytotoxic Al pool and improving the nutritional value of rice [19].

11. USE OF BOTH ORGANICS AND INORGANICS

As discussed, the use of neither organics alone [20] nor inorganic [21] can help to maintain the yield. Another study conducted by Indian Farmers According to evidence from the Fertilizer Co-operative Limited Organization and the Food and Agriculture Organization, 37.5% of farmers struggle with the accessibility of compost or farmyard manure. In order to meet the growing demand for plant nutrients, it will be necessary to use all organic sources. The task at hand is to create an appropriate technological platform that will fully utilize organic manures and other sources in addition to inorganics to attain self-sufficiency without degrading soil health.

Although soils contain a certain amount of inorganic and organic nutrition sources, for improved plant performance, these are frequently supplemented with external fertilizer application [22]. It is crucial to use nutrients from both inorganic and organic fertilizers in a balanced and optimal manner to flourish the plant as well as soil, which may somewhat reduce the hazardous impact on the environment [23].

12. NUTRIENTS NEED OF INTENSIFIED COMMERCIAL CROPPING SYSTEM

The development of an integrated plant nutrient supply system involving an appropriate combination of organics, biological N fixation, phosphate solubilizing microbes, and need-based chemical fertilizers would be crucial for the sustainability of commercial production. Crop production is the most significant source of renewable wealth. Intensive cropping has widened the scope and need for integrated nutrient management. As farming systems have been intensified and high-analysis chemical fertilizers have been used more frequently, soils have been mined, resulting in deficits of secondary (sulphur) and micronutrients (Zn, Mn, Cu, B, and Mo). Shukla and Behera, [24] reported that analysis of 2 lac GIS-based soil samples showed an astonishing trend of shortages in sulphur (S), zinc (Zn), iron (Fe), manganese (Mn), copper (Cu), and boron (B) in the nation in the level of 40.5, 36.5, 12.8, 7.1, 4.2 and 23.2 percent, respectively. In a rice-wheat system, INM has also improved water use efficiency and water-holding capacity [25]. In an intensive rice-wheat system, INM with the incorporation of organic material increases soil aggregation, structural stability, and macroaggregate C content [26].

13. FACTS ABOUT INTEGRATED NUTRIENT MANAGEMENT

- **For optimum growth and Development of the plants:** Plants needs various nutrient element that can be supplemented by various sources. The major plant nutrient source includes fertilizer application while these organic sources also supply plant nutrients. The availability of these applied different nutrient sources can be increased by applying biofertilizers that have the tendency to convert the plant's unavailable form to available form.

- **Integrated nutrient supply emphasis on the use of all resources for the supply of nutrients:** The majority of organic manure is of a bio-origin (animal and human waste, plant residue, and byproducts), whereas fertilizers are synthetic in nature. City garbage is not strictly biodegradable and includes domestic wastes such as urban compost, sewage, and sludge. The integrated nutrient supply also includes green manuring of bio-origin.
- **Fertilizers are the more concentrated source for the supply of nutrients than organic manures:** Fertilisers can meet nutrient needs for crops at any level with considerably less material than organic manures, which would require more material to provide the same amount of nutrients.
- **Organic manures contain several nutrient elements:** However, thus far it is their N value that has received the major emphasis. Research results have established that organic manures, particularly secondary and micronutrient deficits, have the power to stop a number of nutrient shortages from developing. An essential tactic for preventing the overuse of soil resources on agricultural fields and maintaining soil fertility is the provision of organic amendments [27].
- **The greatest challenge before India has always remained to produce more food to meet the growing demand created by the ever-increasing population:** In modern agriculture, fertilizers have contributed up to a 50 percent rise in food grain output. Therefore, axing fertilizer use will never be a viable strategy. However, there is always a need to maximize the efficiency of fertilizer use which is presently quite low (efficiency is less than 50 percent for N and 10-30 percent for P).
- **The nutrient needs for higher yields cannot be met exclusively through organics and bio-fertilizers:** Nutrient supplying capability may be a problem but its long-term benefits cannot be ignored. These resources ought to be viewed of a supplement to supply plant nutrients with chemical fertilizers in an integrated approach. Organic manure decomposed

by-products mediated to improve soil physical, chemical and biological environment of soil, which shows the fruitful impact of harmonizing use of chemical fertilizer along with natural (organics).

- **An integrated nutrient supply approach is economically viable and environment friendly:** However, fertilizers will continue to be the dominant contributor for meeting the nutrient requirements of crops in India. Utilizing chemical fertilizer as well as organic sources of nutrients contributes to environmentally friendly practices that result in the comprehensive management of the soil-crop system [27].

14. CONCLUSION

For commercial agriculture production, considering environmental conservation, the integrated nutrient management system seems to be the most sustainable system of nutrient management. However, its package of practices may vary from region to region and from one farming system to another farming system. Farmers must integrate the management of nutrients and soil fertility into their farming practices in order to meet the increasing population's demand for food. Major agricultural yield gains cannot be achieved without making sure that plants receive a balanced supply of nutrients in sufficient quantities. The government should address this issue by developing testing and monitoring mechanisms because unless "nutrient cycles" are better understood, this equilibrium cannot be achieved. By enabling plants to furnish part of their own nutrients for improved growth, genetic engineering may also assist in maintaining a more balanced nutrient supply. Farmers will need assistance adopting nitrogen-fixing species, which will require the assistance of the government and extension agencies. Additionally, the government must continue to support the farmers' broad and responsible use of organic and inorganic fertilizers. The initiatives include nutrient depletion testing of the soil, farmer-researcher collaboration, encouraging the more effective use of organic nutrients, and urging extension agencies and NGOs to pay attention to soil-related concerns. Investments to increase soil fertility may also be supported by government and NGO initiatives. Many of the issues that poor, smallholder farmers in India and

other countries face can be solved by integrated nutrient management. However, the timely and coordinated efforts of extension programs, the government, NGOs, researchers, and the farmers themselves are ultimately what determine INM's effectiveness.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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