Integrated Nutrients Management for Future Production: A Review

Abstract

As per the estimate bythe 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. Meeting human needs within the ecological limits of our planet calls for continuous reflection on and redesigning of agricultural technologies and practices. Such technologies include fertilizers, the discovery and use of which have been one of the key factors for increasing crop yield, agricultural productivity, and food security. Fertiliser use comes, however, at an environmental cost, and fertilizers have also not been a very economically effective production factor to lift many poor farmers out of poverty, especially in areas where an application on poor soils of unbalanced compositions of nutrients in fertilizers has shown limited impact on yield increase. Agronomic practices to apply existing mineral fertilizers, primarily containing N, P, and K, at the right time, the right place, in the right amount, and of the right composition can improve the use efficiency of fertilizers. However, the overall progress to reduce the negative side effects is inadequate for the desired transformation toward sustainable agriculture in poor countries. In order to meet the food demands of the rising population, farmers must managenutrients and soil fertility in an integrated way. 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

Introduction

Agriculture in this 21stcentury facessuperfluous 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 defective management of soils. The Indian soils exhibit at present very low level of productivity in comparison to world soils.To improve soil productivity, the proper understanding of the soil is unconditionally required. In acountry like India, the most vital challenge is to provide sufficient food for theever-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 accomplish this bad imbalance application of fertilizers, there is a need to recognize suitable integrated plant nutrient supply systems for different crops and their cropping systems. As fertilizers are expensiveagri-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 specific region may entirely differ from that inunlike region for anidentical crop. A number of soil test results generated by various soil testing laboratories at state as well as central government level, deliver valuable information about the distribution pattern of plant nutrients in soils. The data on soil testing parameters of the field helped to 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**(Adesemoye and Kloepper, 2009)**.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 straightforwardlyreliant on the amount of organic carbon content in the soil. Phosphorus statusof 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 arein the medium category range. However, potassium deficiency is much less widespread than nitrogen and phosphorus, since nearly three-fourths of the country'sland 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. Therice–wheat cropping is the predominant system in India and it contributes to about 75% of the nation's total food grain production**(Mahajan et al., 2002)**. This system has tremendously helped to the socioeconomic development of the rural population in the country. Rice and wheat are the staple food crops of the majority of the country's people. Though many of the farmers have now realized the sustainability issues relating tothe rice–wheat cropping system such as yield declining, reduction in the soil fertility status, physical properties, deterioration of soil biological health, the toxicity of heavy metals and contamination of groundwater with nitrateupto some extends. These significant sustainability issues must be narrowed down in light of the demand for food commodities which is increasing rapidly with the escalating population. Integrated nutrient management (INM) may be an option to increase agricultural production and protect the environment for future generations in a sustainable manner. It is an approach that involves the application of both organic and inorganic plant nutrient sources to attain higher crop productivity, prevent soil degradation, and thereby help to meet future food requirement needs. Required yield increases in major crops cannot be attained without ensuring that plants have a balanced supply of nutrients in adequate amounts.

Integrated nutrient managementstrategies refer to the combined use of chemical fertilizers, organic manure, and biofertilizers with the express objective of obtaining sustainable and environmentally sustainable crop production without deteriorating soil health. 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 admiring use of chemical fertilizers, organic fertilizers, and biofertilizers.

Health of the Indian Soils

The problem of soil health degradation is quite delicate in the country. About 120.8 Mhacountry's land area constituting 36.5% of the total geographical area (TGA) is degraded due to soil erosion, salinity/alkalinity, soil acidity, waterlogging, and some other complex problems **(NBSS&LUP, 2008)**. Soil erosion due to water is the major cause of soil degradation (82.6 Mha) followed by chemical degradation (24.7 Mha). About 5.34 billion tons (Gt) of soil is eroded in India at an average rate of 16.3 t ha^{-1} yr^{-1}. While 61% of eroded sediments get redistributed on land, nearly 29% are lost permanently to the sea and the remaining 10% are deposited in reservoirs reducing their holding capacity by 1 to 2% annually. About 8 Mt of plant nutrients are also washed away along with eroded sediments. Degraded lands are thepotential sources of soil erosion and flash floods. 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 **(Shukla and Pakhare, 2015)**.Sustenance ofcropyieldsrequiresexternalapplicationofthedeficientnutrients throughfertilizers.

Impact of fertilizers

Fertilizers are still the ‘Kingpin’ in the current structure of commercial agriculture. However, the scientific and balanced applicationof 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.

Fertilizer Use in India

India haswitnessedsteady growth in fertilizerapplication and consumption. Nutrient ($N+P_2O_5+K_2O$) consumption increased from 69,800 t in 1950-51 to 25.95 Mt in 2016-17. In terms of total nutrient consumption, India ranks second in the world after China and nutrient-wise, it stands 2^{nd} in N and P_2O_5consumption and 4^{th} in K_2O consumption. Food grain production increased from 50.8 Mt in 1950-51 to 275.68 Mt in 2016-17. Nutrient consumption and food grain production exhibited a cumulative annual growthrate (CAGR) of 9.38 and 2.60%, respectively (Figure 1); This progressive utilization of fertilizer nutrients played a critical role in making the country self-dependent in food and nutrition.

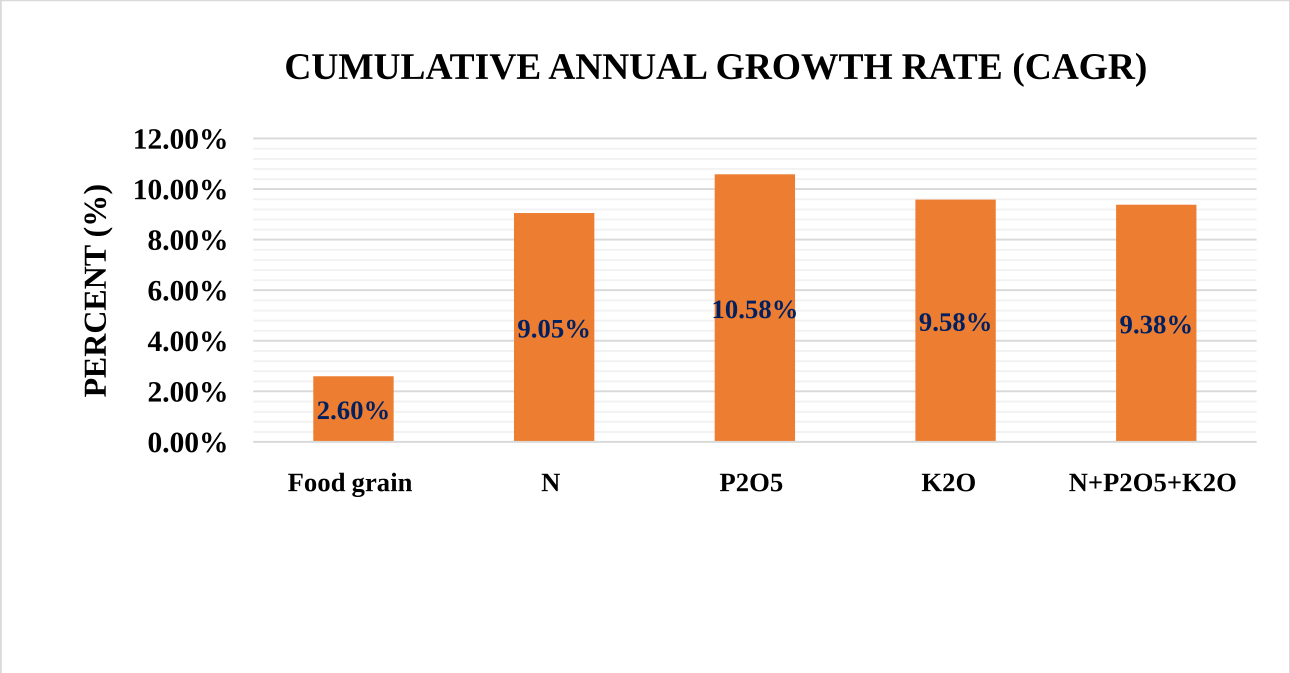

Fig.1 Cumulative Annual Growth Rate (CAGR)

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

The current NPK use ratio (employing K as base) of 6.7:2.7:1 for 2016-17 when measured against ideal NPK use ratio of 4:2:1 is tilted heavily towards N. This is not desirable both from crop need point of view or from a sustainable productivity growth angle. The NPK use ratio, averaged for the whole world is 3.4:1.3:1.

Regionaldisparitiesintheuseratioaremorestrikinginthecountry, beingwidestinNorth(15.1:5.1:1)againstlowestinSouth(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 West to 178.3 kg in North. Nutrient-wise, the use of K varied from 8.4 kg ha^{-1}in North and West to 24.0 kg ha^{-1}in South (Figure2). Per hectare P use was maximum in South (46.8 kg) and minimum in West (25.7 kg). Nitrogen use was highest in North (127.3 kg ha^{-1}) and lowest in West (59.3 kg ha^{-1}). States differ widely in terms of nutrient consumption and nutrient use ratios. In general, K use per unit area is highest in southernstatesandthelowestinnorthernstates. As a result, the NPK use ratio is narrow in southern states and wide in northern states.

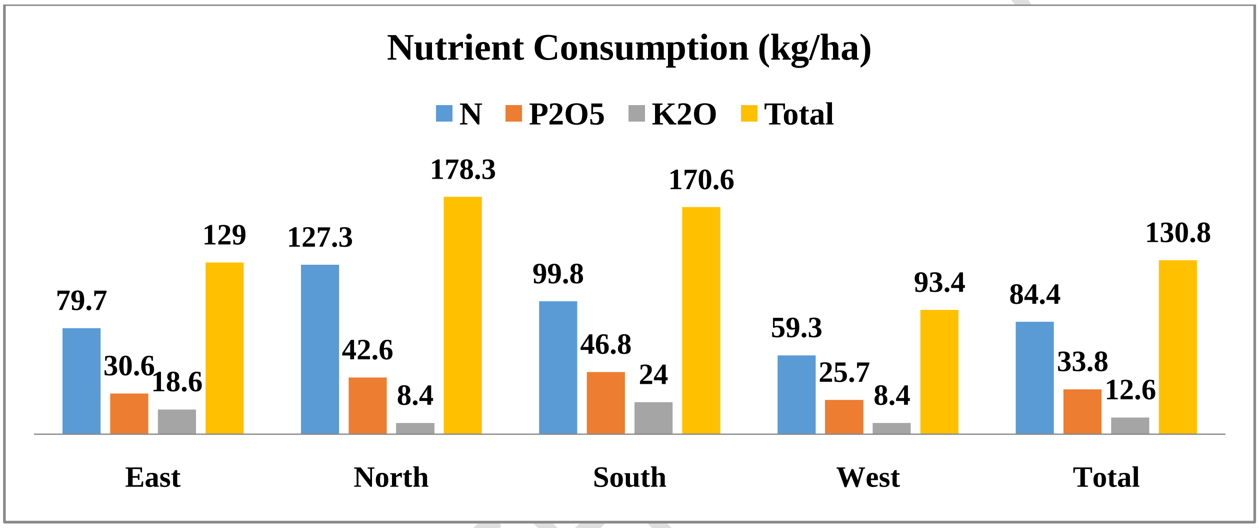

Fig.2 Nutrient consumption in zones of India (2016-17)

Source: FAI. 2017. Fertilizer Use and Environmental Quality.

The quantity of fertilizeruse isdependent onfarmsize as evidenced by the All-India Report of Input Survey (2011-12) which shows more use of fertilizer by the farmers having small and marginal size of land holding as compared to farmers having large holdings. Incontradiction, small and marginal farmers use a balanced dose of NPK than large farmers (table 1). For example, total NPK use was 187 kg ha^{-1}inirrigated areas in opposition to 82 kg ha^{-1}in non-irrigatedarea. Nutrient-wiseusewas115.7,51.9and19.4 kg $ha^{-1}$for N, P_2O_5 and K_2Oin irrigated areasand innon-irrigated areas, per hectare use was 48.8 kg for N, 24.4 kg for $P_2O_5$and 8.8 kg for K_2O.

Table 1. Land holding-wise fertiliser use or intensity of fertiliser use by different categories 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 (2011-12)

Integrated nutrient management (INM) refers to the maintenance ofsoilfertilityandofplantnutrientsupplyatanoptimumlevelfor sustaining the desired productivity through optimization of the benefits from all possible sources of organic, inorganic and biological components in an integrated manner. Nitrogen is centralin planning experiments on INM because rates of applicationofdifferentnutrientsourcesaredecidedonthebasisof relative contributions of N coming from them. Cultivation of mungbean (*Vignaradiata*) in a rice-wheat cropping system and incorporating the mungbean residues after first picking of pods into the soil sustains the rice-wheat productivity, provides on an average 1 t mungbean seeds ha^{-1}and adds 40-120 kg N ha^{-1}to the soil. Bio-fertilizers contribute 15-30 kg N ha^{-1}yr^{-1}besidesgiving ancillary benefits like promoting plant growth, improving seed/ fruit quality and sustaining soil biological health **(Prasanna et al., 2014)**. Balanced application of optimum NPK increased the crop NUE and the addition of 5-15 t FYM ha^{-1}yr^{-1}over and above the optimum NPK further enhanced it (Table 2).

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. (2012)

Changing scenario of nutrient management

The introduction of high-yielding varieties with increased use of commercial fertilizers 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 of organic recycling throughout the world. Nutrient management has gone through three phases of development.

Phase I: The period of 1950-1965 witnessed increased awareness of chemical fertilizers along with due consideration for the practice of application of organic sources of nutrients and green manuring.

Phase II: The beginning of the 'Green Revolution in the mid-sixties initiated a sudden spurt in use of chemical fertilizers and a gradual decline in organics and green manuring. This is evident from the fertilizer use growth from 7.84 lakh tones in 1965-66 to about 15 million tonnes in 1995-96 and 20.34 million tonnes in 2005-06.

Phase III: It can be traced to the mid-seventies, mid-eightiesown ward and the period since 1992 when oil crises witnessed globally with a shortage of fertilizers, renewed the interest in India in the propagation of integrated nutrient management involving greater recycling of organics into agriculture. Dependence on INM got greater interest with the concern of environmental pollution due to the heavy use of inorganics for commercial production.

Use of Organic Manures

Application of well-decomposed organic manures like farmyard manure, digested cow dung and compost (urban and rural) was usually neglected by the farmers with the advent of the Green Revolution, whereafter chemical fertilizers became the potent source of plant nutrients. The addition of these manures must now be revived. Organic manures besides having primary and secondary nutrients also contain micronutrients vis-à-vis growth-stimulating and growth-regulating substances. However, some materials used in the preparation of farmyard manure, rural compost or town waste compost contain toxic substances such as the heavy metals Ni, Cr, Cd, etc., which if present in excessive amounts in the organic manures can adversely affect the plant growth. It is worthwhile to mention that although organic manures ameliorate the physical,chemical and biological properties of the soils, they cannot substitute chemical fertilizers because of the low amount of plant nutrients present in them and because their bulky nature involves high transport cost. The addition of OM and biofertilizer in soil alters the soil reactions which in turn increase the metal solubility and availability **(Kumar et al., 2017)**

Green Manure Use

Growing legume as green manure to improve cropproductivityand soil health is one of the oldest practices. It becomes more beneficial,particularly for light soils having sandy and loamy sand texture and also for sandyloam soils or those having loam/silty loam texture.Green manures are crops grown specifically for building and maintaining soil fertility and structure, though they may also have other functions. They are normally incorporated back into the soil. Under such conditions, growingof dhaincha (*Sesbaniaaculeata*) and burying it into the soil before the floweringstage at the time of transplanting rice has been found useful not only to increasethe yield of rice but also to enhance the yield of wheat **(Gupta et al., 2005)**. Themain influence of green manuring is to augment the supply of nitrogen and othernutrients.Slow release of nutrients from the decomposition of green manure may provide a better time to uptake nutrients by plant possibly increasing nutrient uptake efficacy and crop production (**Pantaand Parajulee., 2021)**

Use of Rural Wastes and Crop Residues

Rural wastes like paddy straw, wheat straw, and residues of other crops like sorghum,pearl millet, sugar cane, and pulses have lot of potential as plant nutrients.

However,their use as such or after composting in sustaining rice and wheat yields cannot equal that of chemical fertilizers in view of the burgeoning population requiringmore food grain production. Another constraint of these organic residues is theirhigh C/N ratio which is sometimes 100:1 or even more. This results in the occurrenceof immobilization of nitrogen.Apart from the above, sewage and industrial effluents contain variable quantities ofplant nutrients and organic matter depending upon the source of origin **(Chhonkar, 2003)** as well as some toxic elements. Wastewater generated from various industries containsa considerable amount of plant nutrients **(Chhonkar, 2001)**.

Use of Bio-Fertilizers

The biofertilizer are carrier-based microbial inoculants, have effective viable cells of microorganisms. Biofertilizers are capable for the fixation of atmospheric nitrogen in ammonical form, solubilization of insoluble nutrients in the soil system, nutrient mobilization and releaseof plant growth hormoneswhich are required by the plants for their growth and development. The main bio-fertilizers which can be used as supplements to chemical fertilizers are blue-green algae (BGA) and Azolla for rice. BGA are capable of fixing atmospheric nitrogen, particularly under puddled rice soils and also produce growth-promoting substances **(Mahajan et al., 2003a)**.Azolla is a floating freshwater fern. It is ubiquitous in distribution in lowland rice fields and freshwater bodies. The fern harbors a nitrogen-fixing BGA – *Anabaenaazollae*. Due to its prolific growth character and association with nitrogen-fixingBGA, it can be used as a bio-fertilizer in rice cultivation. Azolla can contribute about 100–150 kg N ha^{-1}year^{-1}**(Mahajan et al., 2003b)**.Azotobacter culture, prepared from *Azotobacterchroococcum* or other species,can be used as a bio-fertilizer for direct-seeded rice and wheat crops **(Mahajan et al.,2008)**.Integrated use of biofertilizer and inorganic fertilizer was less effective than ECM in reducing the phytotoxic Al pool and enhancing the nutritional quality of rice **(Patra et al., 2020)**

Vermicompost Use

Vermicompost prepared from earthworms, known as the tillers of the earth, is anatural organic manure. It is also called bio-fertilizer. Vermicompost is a mixture ofworm castings and organic matter including humus, live earthworms, their cocoons,and other organisms. The earthworm species thatare presently being extensively used for vermicomposting are *Eiseniafoetida*, *Eudrilus Eugenia*, *Eudrilluseugeniae*, *Pheritimaelongata* and *Perionyxexcavatus*. However, *Eiseniafoetida*isthe most widely adopted species across the world. It is a rich source of plant nutrients, like N, P and K as well as micronutrients and vitamins/enzymes. The conjunctive use of vermicompost, phosphate solubilizing bacteria (PSB) and zinc (Zn) in collaboration with 100% recommended fertilizer dose produced significantly higher grain and straw yield of wheat compared to its counterpart of 50% NPK, whether applied alone or in combination with farmyard manure (FYM), PSB, Zn and vermicompost**(Rather and Sharma, 2009)**

Use of both Organics and Inorganics

From the foregoing discussion emerges the fact that the application of neitherinorganics–chemical fertilizers **(Gupta and Singh, 2006)** nor organics alone**(Mahajan and Sharma, 2005)** can assist in sustaining the yield. Another study conducted by the Indian Farmers Fertilizer Co-operative Limited Organization and Food Agricultural Organization has shown that 37.5% of the farmers have difficulty with regard to the availability of farmyard manure or compost. So, the need of the future is to tap all the organic sources to meet the increasing consumption of plant nutrients.The challenge before us is to develop a suitable technology package to make full use of organic manures and other sources along with inorganics to improve food production without impairing soil health. A certain supply of inorganic and organic nutrient sources is present in soils, but these often are supplemented with external fertilizer application for better plant performance **(Wu and Ma., 2015)**. Theoptimal and balanced use of nutrient inputs from inorganic and organic fertilizers is of fundamental importance for plant growth **(Mavi and Benbi, 2008)**

Nutrients need of intensified commercial cropping system

Crop production is the most important source of renewable wealth and the development of an integrated plant nutrient supply system involving an appropriate mixture of organics, biological N fixation, phosphate solubilizing microbes and need based chemical fertilizers would be crucial for the sustainability of commercial production. Intensive cropping has widened the scope and need of integrated nutrient management.Intensification of cropping system with greater use of high-analysis chemical fertilizers has resulted in mining of soils leading to deficiencies of secondary (sulphur) and micronutrients (Zn, Mn, Cu, B and Mo).**Shukla and Behera, 2019** reported that analysis of 2 lac GIS-based soil samples showed an astonishing trend of deficiencies of sulphur (S), zinc (Zn), iron (Fe), manganese (Mn), copper (Cu) and boron (B) in the country in the level of 40.5, 36.5, 12.8, 7.1, 4.2 and 23.2 percent, respectively.INM has also increased water use efficiency and water-holding capacity in a rice–wheat system **(Sharma et al., 2001)**. INM with organic material incorporation improves soil aggregation and structural stability and results in higher C content in macro aggregates in intensive rice-wheat system **(Das et al., 2014)**

Facts about integrated nutrient management

- **Plant needs several nutrients for growth and production:** These nutrients can be supplied to plants through different sources. Fertilizers constitute the main source. Organic manure also supplies nutrients but their content is very low. This supply can also be augmented with certain auxiliarynutrient-generating bio-fertilizers.
- **Integrated nutrient supply emphasis on the use of all resources for the supply of nutrients:** Fertilizers are essentially chemical in nature and organic manure are largely of bio-origin (animal and human waste, plant residue and by-products). City waste (urban compost and sewage and sludge) represents household wastes and are not strictly of bio-origin. Green manuring of bio-origin is also included in the integrated nutrient supply.
- **Fertilizers are the more concentrated source for the supply of nutrients than organic manures:** To supply any required level of nutrients to a crop, fertilizers can meet the requirement with far less quantity whereas more bulk will be needed to supply that much of the nutrient from organic manures.
- **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 have the ability to nip several budding nutrient deficiencies especially secondary and micro-nutrients.The addition of organic amendments represents an important strategy to protect agricultural lands from excessive soil resource exploitation and to maintain soil fertility**(Ranjan et al.,2020)**
- **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 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:**The nutrient supply from organic manure is not only low but also slow. In integrated nutrient supply, these materials should be considered as help to top up the supply of nutrients from chemical fertilizers.Organic manure decomposition products mediate improvement in soil physical, chemical, and biological environments enhance further the merit of harmonizing the use of chemical fertilizer and natural manure.
- **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.The use of organic sources of nutrients either alone or in combination with chemical fertilizer pertains to eco-friendly practices which lead to a holistic management of the soil-crop system**(Ranjan et al.,2020)**

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.In order to meet the food demands of the rising population, farmers must managenutrients and soil fertility in an integrated way. Required yield increases of major crops cannot be attained without ensuring that plants have a balanced supply of nutrients in adequate amounts. This balance will not be achieved until "nutrient cycles" are better understood, an issue that the government should address by establishing testing and monitoring systems. Genetic engineering may also contribute to better nutrient balancing by helping plants provide some of their own nutrients for enhanced growth. Government and extension services will need to facilitate the adoption of nitrogen-fixing species among farmers. The government will also need to continue to facilitate the widespread and responsible use of organic and in organic fertilizerssupplied to the farmers. The efforts include soil testing for nutrient depletion, cooperation between farmers and researchers, promotion of more productive use of organic nutrients, and encouragement of extension services and NGOs to pay attention to soil-related issues. Efforts may also include government and NGO-supported investments to enhance soil fertility. Integrated nutrient management can address many of theproblems besetting poor, smallholder farmers in India and elsewhere. But INM's success ultimately depends upon the timely and concerted efforts of extension programs, government, NGOs, researchers,and the farmers themselves.

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