International Journal of Plant & Soil Science

34(20): 433-446, 2022; Article no.IJPSS.87484
ISSN: 2320-7035

Integrated Nutrient Management: A Long-term Approach towards Sustainability

Tamanna Sharma [a], Vivak M. Arya [a], Vikas Sharma [a], Jyoti Sharma [b], Tajalee Gulshan [b], Anurag Bera [c*] and Yahiya Akram Laskar [a]

[a] Division of Soil Science and Agriculture Chemistry, Sher e Kashmir University of Agricultural Sciences and Technology, Jammu-180009, India.
[b] Division of Agronomy, Sher e Kashmir University of agricultural sciences and technology, Jammu-180009, India.
[c] Department of Agronomy, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi- 221005, India.

Authors' contributions

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

Article Information

DOI: 10.9734/IJPSS/2022/v34i2031171

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/87484

Review Article

Received 03 April 2022
Accepted 06 June 2022
Published 24 June 2022

ABSTRACT

Increased global food demand, as well as the need for an environmentally acceptable approach for a sustainable soil-plant-microbe-environmental system, necessitate special attention when it comes to agricultural productivity. Chemical fertilization is one approach to increase crop productivity as happened during the Green revolution. Food grain output in India increased from 115.6 million tonnes in 1960-61 to over 281.37 million tonnes in 2018-19 as a result of chemical fertilization. Similarly, yearly fertilizer use jumped from 0.07 million tonnes in 1951-52 to over 25.95 million tonnes in 2016-17.But due to injudicious use of chemical fertilizers soil, plant, human and animal health are at stake. Also, increased soil compaction and widespread multinutrient deficits have emerged as important restrictions limiting crop productivity and farm income. Because a major rise in fertilizer consumption is unlikely in the near future for economic and environmental reasons, there is a need to improve nutrient use efficiency through integrated and balanced fertilizer. On the other hand, organic manures, are unable to fulfill all of a crop's nutritional needs. Integrated nutrient management (INM) was created as a result of the aforesaid factors being taken into account. In this paper,role of INM in overcoming these difficulties is discussed, as it has been offered as a

---

**Corresponding author: E-mail: anuragbera123@gmail.com;*

promising solution for tackling these issues. Plant performance and resource efficiency can be improved in a variety of ways with INM while also allowing for environmental and resource protection quality. With the use of advanced INM procedures, chemical fertilizer inputs are reduced, resulting in fewer human and environmental costs without any negative impact on crop production.Long-term research in various soil-crop situations have demonstrated the advantages of integrated nutrient management (INM), which includes the utilisation of organic and biological resources as well as fertilizers. The purpose of this article is to provide an overview of the effect of various INM components on Physical, chemical, and biological properties of soil, nutrient use efficiency, crop productivity and the role of these components in improving soil health. The majority of INM research has been done using dominant crop rotations of main field crops cultivated in the subtropical North Western states of India and most of the experiments revealed that INM leads to long term sustainable production along with providing nutritional security and also reduces pollution and enhances soil health by improving various physical, chemical and biological properties of soil.

Keywords: Food demand; multinutrient deficit; INM; sustainable production; nutritional security.

1. INTRODUCTION

Maintaining and sustaining natural resources, such as soil and water, in order to enhance food production while protecting the environment is one of humanity's most important concerns today. The burden on natural resources increases as the world's population expands, making food security extremely difficult to attain. Long-term food security necessitates striking a balance between crop output, soil health, and environmental sustainability. Effective nutrition management helped India achieve a massive rise in food grain production from 52 million tonnes in 1951-52 to 230 million tonnes in 2007-08. However, the application of unbalanced and/or excessive nutrients resulted in decreased nutrient-use efficiency, making fertilizer consumption uneconomical and causing negative effects on the atmosphere [1] and groundwater quality [2], posing health risks and contributing to climate change. Soil organic carbon (SOC) losses have resulted from intensive farming systems that use synthetic fertilizers in an unbalanced manner to feed fertilizer-responsive cultivars [3] and Soil health [4] is frequently linked to crop production system sustainability. Organic nutrition sources are becoming more popular in agriculture, however owing to challenges such a shortage of appropriate quality and quantity of organic materials, the system may not be adequate to achieve and sustain cereal crop output in the proportions necessary for food security [5]. Integrated nutrient management (INM), also known as integrated plant nutrient supply system (IPNS), entails monitoring of all plant nutrient supply pathways in crops and cropping systems, as well as judicious fertilizer use., organic manures and biofertilizers (Prasad, 2008). This strategy isn't new in India. Prior to the Green Revolution, practically all nutritional requirements were satisfied through organic means, and fertilizers were not widely used. INM's benefits include I) restoring and maintaining soil fertility and crop productivity, ii) preventing secondary and micronutrient deficiencies, iii) reducing fertilizer use and improving nutrient use efficiency, and iv) having a positive impact on soil physical, chemical, and biological health [6]. IPNS is defined by the FAO as a method for maintaining or adjusting soil fertility and plant nutrient supply in order to attain a certain level of crop yield. Long-term food security necessitates striking a balance between crop production, soil health, and environmental sustainability. Effective nutrition management has contributed significantly to India's massive increase in food grain output from 52 million tonnes in 1951-52 to 230 million tonnes in 2007-08. However, the application of unbalanced and/or excessive nutrients resulted in a decrease in nutrient-use efficiency, making fertilizer consumption uneconomical and causing negative effects on the atmosphere [1] and groundwater quality (Aulakh et al., 2009), posing health risks and contributing to climate change. INM, which actually involves maintaining/adjusting soil fertility to an optimum level for crop productivity in order to get the maximum benefit from all possible sources of plant nutrients – organics and inorganics – in an integrated manner [7], is a critical step in addressing the twin concerns of nutrient excess and depletion. INM is also important for marginal farmers who cannot afford to supply crop nutrients through costly chemical fertilizers. This review article focus on the component and prospects of INM that will lead to sustainable soil health and quality.

2. PRINCIPLES OF INM

INM's main principles are listed below, and they include the following: a) the overall goal of INM is to maximize the use of soil nutrients to promote agricultural productivity and resource efficiency; (b) Spatially and temporally matching soil nutrient availability with crop demand. In order to obtain maximum yields and enhance fertilizer utilization, INM demands that nutrient application amounts and timing be in compliance with crop nutrient requirements [8]. N fertilizers applied in small amounts and frequently during periods of crop demand can potentially reduce N losses while enhancing crop yield and quality [9] (c) lowering nitrogen losses while increasing crop output. Excessive use of nitrogen fertilizer can lead to increased nitrate leaching into groundwater and higher emissions into the atmosphere. The goal of INM is to reduce nitrogen losses and their negative environmental effects while increasing crop output [10]. Crop N intake, immobilization, and residues in the soil, as well as N losses to the environment, such as ammonia volatilization, NOx emissions_denitrification, N leaching, and runoff, all affect the fate of N in the field [11]. Furthermore, INM supports organic fertilisation regimes, which have enormous potential for agricultural sustainability as well as more immediate environmental advantages. Organic manure, when used in conjunction with other management practises such as crop residue incorporation and the development of conservation tillage (no-tillage or reduced-tillage practises), reduces GHG emissions, improves soil quality, and increases C-sequestration, all while producing high crop yields [12,13,14]

3. INGREDIENTS OF INM

Fertilizers, organic manures, legumes, crop residues, industrial by-products and bio-fertilisers are the main ingredients of INM.

Fertilizers: Fertilizers were still the most significant component of INM. Because of the requirement to supply significant amounts of nutrients in intensive cropping with high productivity, fertiliser use has been steadily growing. Despite this, fertiliser consumption is not only insufficient but also unbalanced. The ratio of $N:P_2O_5:K_2O$ is relatively large, although K, S, and micronutrients are frequently overlooked. Introduction of nutrient based subsidy (NBS) scheme during 2010 further distorted the fertilizer consumption ratio. Domestic fertiliser production is insufficient to fulfil demand, and the situation is unlikely to improve very soon. Constraints such as global price hikes in fertilizers and raw materials, on the other hand, would prevent large-scale fertiliser imports, resulting in a large disparity between supply and demand. While organics and bio-fertilizers are projected to fill some of the gap, fertilizer efficiency in closing the nutrient supply gap requires further attention. The utilisation of fertiliser nutrients by crops varies from 30-50 percent for nitrogen, 15-20% for phosphorus, and less than 5% for micronutrients. As a result, a significant amount of administered nutrients is lost via multiple mechanisms. Enhancing nutrient use efficiency should therefore be a priority study area for restoring and improving soil health while lowering crop production costs [15].

Organic Manures: Organic manures with high nutrient potential include urban compost, FYM, crop residues, human excreta, municipal garbage, rural compost, sewage-sludge, pressmud, vermicompost, biofertilizers and other agro-industrial wastes. Traditionally, compost and FYM have been the most significant manures for sustaining soil fertility and yield stability. There are also other potential organic sources of nutrients, such as non-edible oil cakes and food processing waste. Furthermore, there are a number of industrial by-products and municipal trash that have a reasonable nutritious potential. These nutrient-carriers, on the other hand, have not been thoroughly tested to determine their fertilizer equivalents. These sources must be integrated based on their availability in various crops and cropping systems. Industrial wastes such as spent-wash from distilleries, molasses, pressmud, and other sugar industry byproducts, as well as wastes from other food processing businesses, have a high manurial value [15] Sulphitation pressmud (SPM) has a lot of potential for supplying nutrients and improving soil characteristics. The use of decomposed SPM was found to be beneficial in studies conducted at Modipuram [16,17]. Other major nutrient sources include municipal solid waste (MSW) and sewage sludge sources that can be integrated fertilizer inputs, despite the fact that should be handled with caution to prevent any possible threat of heavy metal load and pathogen. All India production of organic manures including FYM and composts is estimated at 229.4 million tonnes (Mt) [18]. These nutrient sources are large and heavy, low nutritional content in nature and in scarce supply. As a result, their relative importance has diminished. Crop production takes time.

However, fertilizer prices are high, and their supply is limited which makes production equal to or slightly higher than sole fertiliser treatment at recommended rates higher when using the INM package [19].

Legumes: Because of their capacity to obtain nitrogen from the atmosphere in symbiosis with Rhizobia, legumes have a long history of being soil fertility restorers. When cultivated for grain or fodder in a cropping system, or when introduced for green manuring, legumes could be a significant component of INM. The productivity of the rice-wheat cropping system was improved and soil fertility gets rejuvenated by using legumes as green manure, fodder, or grain crops [21,22]. Except for soybean, grain and fodder legumes, as well as green manures, can fix atmospheric N to the extent of 50-500 kg N ha^{-1} before the plant starts flowering (about 40-60 days of growth). Because of the optimal lignin concentration, the remains of legumes after grain harvest contain 25-100 kg N ha^{-1}, which is released at a consistent rate when incorporated. Grain legumes with deep roots can recycle subsoil nutrients for the benefit of the cropping system's succeeding cereal crops [23]. When a variety of leguminous crops were evaluated for satisfying the nitrogen need of a subsequent non-legume crop, it was discovered that legumes might provide as much as 50 to 60 kg N ha^{-1} on average. When a legume was used as a preceding crop, grain yield of cereal crops increased significantly compared to when a cereal crop was used. On an Inceptisol, the influence of previous crops, rice or legume, was assessed in wheat, and the N use efficiency indices viz. AE_N and ARE_N, were considerably higher in wheat following a legume (cowpea grain crop) than in wheat following rice [24] (Table 2).At Modipuram, the effects of including summer cowpea (fodder) after wheat harvest in a rice-wheat system were investigated, and it was discovered that cowpea inclusion resulted in a considerable increase in NUE when compared to summer fallow [25]. In addition, incorporating a legume crop into the rice-wheat combination could reduce the negative impact of persistent puddling on soil compaction. Experiments demonstrated that continuous rice-wheat cropping increased soil bulk density in sub-surface layers, whereas raising a summer fodder crop of cowpea or a substitute crop of pigeonpea negated this effect of puddling [25, 26].

Green Manures: The practice of incorporating green succulent biomass into the soil is known as green manuring (GM). Prior to the introduction of mineral fertilisers, GM was regarded as a necessary management practise. Green manuring, on the other hand, began to losses its importance as fertilisers became more readily available and intensive agricultural techniques became more popular. However, there has been a resurgence of interest in this method in recent years. Due to atmospheric nitrogen fixation, green manuring with legumes enhances soil N. As green manure decomposes, it has a solubilizing impact on N, P, K, and micronutrients in the soil. GM improves the physical, chemical, and biological aspects of soil in addition to lowering leaching and gaseous losses of nitrogen. The most frequent GM crops are sunnhemp (*Crotolaria juncea*) and dhaincha *(Sesbania aculeata)*, although Sesbania rostrata has the highest atmospheric N_2 -fixing capacity and can totally replace urea-N in rice farming [27].Cluster bean *(Cyamopsis tetragonoloba)*, berseem (*Trifolium alexandrinum)*, Indian clover (*Melilotus indicus)*, and other crops are occasionally utilised for GM. Long-term research conducted under the supervision of AICRP-IFS on the integrated use of fertilisers and GM revealed that GM of yield response of rice-wheat system might be used to replace up to 50% of fertiliser N needs in various cropping systems [28]. In around 50 days, GM collects 100-200 kg N ha^{-1}, of which 60-80% is fixed from the atmosphere, and can meet 60-120 kg ha^{-1} of rice's N demand. Apart from nitrogen, the crop mobilises less accessible P and K from the soil, which can be recycled back into the system. A 60-day GM was found to collect 20 kg P_2O_5 and 125 kg K_2O ha^{-1} in its biomass, which is released after decomposition and is less susceptible to soil fixation because to the organic environment. In many cases, GM can supply a crop's whole N demand more efficiently than urea. The C: N ratio of the GM crops was 14-15 at 30 days and 18-19 at 60 days, and they mineralized 41-43 % of the biomass N of a 30-day-old crop in 15 days, whereas a 45-day-old GM crop took 30 days to mineralize the same amount of biomass N. When a 60-day-old GM crop was integrated, it released 20-30% biomass N after 15 days and 26-30% after 30 days. Biomass N release rates are influenced by plant properties such as lignin concentration, N ratio, N content, residue age, etc [23].

Crop Residues: Crop residues have a variety of competing uses and may not always be available as an ingredient in INM; nevertheless, in locations like North-West India where mechanical harvesting is prevalent, a significant amount of residues is left in the field, which can contribute to nutrient supply. There are significant numbers of residues from other crops, such as potato, sugarcane, vegetables, and so on, that are almost always wasted. Although cereal crop leftovers are valuable bovine fodder, they could be used to supplement fertilisers where supplies are in excess of local requirements [15]. At numerous locations, studies conducted under the direction of the AICRP-IFS have revealed the feasibility of substituting cereal crop residues for a portion of the fertiliser N needs of monsoon cropsin intensive cereal-cereal cropping systems [29]. During the wheat season, a 7-year study (Singh et al., 2004). Found that rice and wheat productivity did not range from 6 to 9 kg N per hectare (Singh et al., 2004). Rice straw mixed into wheat had no effect on the succeeding rice crop. Although crop residue input can considerably influence organic C accumulation in soil [30, 31], the amount of C sequestered is determined by the inherent level of organic C in soil [32,33].

Table 1. Average nutrient composition of some organic manures/wastes

Category	Sources	Nutrient content (%)		
		N	P_2O_5	K_2O
FYM/Composts	Farmyard manure	0.5-10	0.15-0.20	0.5-0.6
	Poultry manure	2.9	2.9	2.3
	Urban compost	1.5-2.0	0.2	0.5
	Rural compost	0.5-1.0	0.2	0.5
	Vermi compost	1.27	0.50	0.19
Biogas slurry	-	0.98	0.66	0.14
Sewage sludge	-	0.97	0.27	0.11
Animal wastes	Cattle dung	0.3-0.4	0.10-0.15	0.15-0.20
	Cattle urine	0.80	0.01-0.02	0.5-0.7
	Sheep and goat dung	0.65	0.5	0.03
	Night soil	1.2-1.5	0.8	0.5
Oil cakes	Castor	5.5-5.8	1.8	1.0
	Coconut	3.0-3.2	1.8	1.7
	Neem	5.2	1.0	1.4
Animal meals	Horn and hoof	13.0	0.3-0.5	-
	Fish	4-10	3-9	1.8
	Raw bone	3-4	20-25	-

Diwedi et al. *[20]*

Table 2. N use efficiency of wheat grown after rice or cowpea on Modipuram's Inceptisol soil

Treatment	Agronomic efficiency of N (AE, kg grain kg^{-1}N) N			Apparent recovery efficiency of N(ARE, N%)		
	I year	II year	Mean	I year	II year	Mean
After rice						
N0	-	-	-	-	-	-
N60	20.0	19.2	19.6	47.5	38.2	42.9
N120	12.7	14.4	13.6	33.9	26.2	30.0
N180	8.7	10.2	9.5	25.9	17.9	21.9
Mean	13.8	14.6	-	35.8	27.4	-
After cowpea						
N0N6	-	-	-	-	-	-
0N12	33.3	34.3	33.8	50.7	61.2	56.0
0N18	19.4	22.0	20.7	40.7	35.4	38.1
0	12.8	14.4	13.6	31.2	23.4	27.3
Mean	21.8	23.6	-	40.9	40.0	-
S.E.						
Preceding crop	0.64	0.61	-	1.72	2.00	-
N rates(N)	0.79	0.75	-	2.11	2.45	-
C´N	1.12	1.06	-	2.98	3.47	-

Source: Yadav et al. *[24]*

Biofertilizers: Biofertilizers are products that include living cells from various agriculturally useful microorganisms. The majority of biofertilizers fall into one of three categories: N-fixing, P solubilizing and mobilising, or plant growth promoting rhizobacteria (PGPR). N-fixing biofertilizers convert atmospheric nitrogen into forms that plants can readily utilise. *Rhizobium, Azospirillum, Azotobacter,* blue green algae (BGA), and *Azolla* are among them. While Rhizobium requires a symbiotic relationship with legume root nodules to fix nitrogen, others can do so on their own. PGPR refers to a group of bacteria that promote plant growth by fixing nitrogen, solubilizing phosphorus, or producing plant growth-promoting compounds. Many PGPR strains could be employed as microbial inoculants to improve crop productivity [20]. In India, biofertilizer production has steadily increased from 2,000 t in 1992-93 to 65,500 t in 2013-14 [18]. When applied correctly, biofertilizers containing effective microbial strains can effectively reduce a portion fertilizer N requirement of crops. Under field circumstances, *Azotobacter* and *Azospirillum* inoculants typically contribute 20- 25 kg N ha-1, but the legume-Rhizobium symbiosis can meet more than 80% of the N need of legumes. Average N fixation through BGA and *Azolla*, on the other hand, is predicted to be 25-30 kg N ha^{-1} and 30-40 kg N ha^{-1}, respectively [34]. P solubilizing bacteria and fungi have been identified in several strains, and inoculation with Psolubilizing microbial cultures has been shown to promote the dissolution of sparingly soluble P in the soil.Using microbial cultures in combination with low-grade rock phosphate could add roughly 30-35 kg P_2O_5 per hectare. On Delhi's alluvial soil, soil inoculation with Pseudomonas striata increased wheat grain output while also having a residual effect on subsequent maize [34] Another major source of nitrogen for wetland rice is blue-green algae (BGA). The most commonly cited estimates of N fixed by BGA inoculation are in the 20-30 kg N ha^{-1} range. Extensive field experiments have showed that incorporating Azolla would allow N applications to be lowered by at least 30-40 kg/ha while also increasing root growth [15].

4. IMPACT OF INM ON SOIL HEALTH AND PROPERTIES

Impact on Soil Physical Properties: Because soil physical characteristics and microbial biomass are intimately related to SOC and OM, every soil management method that increases soil organic matter has a direct impact on soil physical properties and microbial biomass,for this a combination of organic and inorganic nutrient sources may be the best option, primarily for improving soil physical health. Many researchers have seen a significant improvement in the soil physical characteristics when organic manure and inorganic fertilisers are applied together [35]. Bulk density (BD) has been widely regarded as a significant metric for soil health evaluation among diverse soil physical qualities Because of its interactions with other soil state (strength and porosity) and rate (moisture retention and flow characteristics) variables. Excessive ploughing with heavy agricultural machinery, erosion, and loss of soil organic matter can all contribute to a rise in BD and, as a result, decreased yields [36]. The addition of NPK fertilizers, organic manure, lime, and biofertilizers boosted the soil's SOC, WSA, moisture-retention capacity, and infiltration rate while lowering the bulk density [37]. Organic matter, whether as crop residue, organic manure, or amendment, has a substantial impact on agricultural soil BD [38], soil aggregation [39], soil structure, soil moisture retention capacity [40] and infiltration rate [38]. It is frequently documented that adding organic materials to soil at higher rates reduces BDs and hence increases soil porosity. After the fourth cropping cycle, integrated usage of NPK and FYM resulted in 5.6 percent lower BD than NPK alone in a soybean-wheat system [41]. Long-term investigations have shown reductions in BD owing to the administration of cattle manure [42], poultry manure [43] and FYM [41]. Higher organic matter build-up in soil [44], better aggregation and subsequent improvement in total porosity, decrease in degree of compaction [45] and improved root growth [41] are likely to be responsible for these BD decreases. The integration of organics with inorganics improved the soil's SOC, BD, WHC, WSA, and fertility status [46]. Organic carbon and microbial biomass carbon increased in the treatments receiving organic manures (particularly FYM), green manure, and bio-fertilizers in combination with inorganic fertilizers. Because there is more organic matter in the surface layer (0-15 cm), the upper soil layer has a larger water holding capacity (WHC) than the deeper soil layers [41]. After 41 years of rice cropping [47] found that continuous composttreatment increased the proportion of large size aggregates while decreasing the proportion of small aggregates when compared to non-compost plots (NPK alone and the control).In comparison to micro-aggregates, the accumulation of organic carbon in soil was higher in macro-aggregates. [16,17, 48, 49].

Impact on Chemical Properties: According to several studies, converting forest lands to permanent cropping reduces SOC supplies, initially fast and then more slowly, eventually reaching a new equilibrium after 30 to 50 years [50, 51] Continuous agriculture has also been linked to a decrease in the organic matter content of tropical soils [52, 53]. When compared to the inclusion of organic amendments, a 19-year-old LTE in West Bengal found that continued farming without organic inputs significantly depleted total C content by 39-43 percent [54]. In contrast, in intensive irrigated rice systems in the lowland tropics with high temperatures and enough soil moisture throughout the year, SOC was conserved or even increased [55]. Under the AICRP-LTFE, studies on changes in SOC content due to continuous cropping and manuring revealed a decrease in SOC in unfertilized plots (control) by 41.5, 24.5, and 15.5 percent, respectively, compared to initial values under rice–wheat–jute, soybean–wheat, and sorghum–wheat systems, whereas treatments receiving NPK and NPK+FYM either maintained or improved SOC over initial content [56]. Enhancing C input through the return of crop residues and the addition of organic manures is critical for the RWS to sustain its productive capacity [57]. The use of fertilisers and manure in intensive cereal-cereal systems other than RWS had a significant impact on SOC content over time, as the SOC content and soil microbial activity in a maize-wheat-forage cowpea system on a Typic Haplustept were boosted with the application of NPK+FYM [58]. The LTEs at various locations in India's subtropical and tropical regions revealed that the recommended dose of NPK increased or at least maintained the SOC content over the initial values, whereas imbalanced (N or NP) and inadequate fertiliser use (50 percent of the recommended NPK) did not [59,21,22,60] found that applying rice straw compost at 2 t ha-1 along with fertilisers increased SOC and available N content significantly over control after 10 rice–wheat cycles on a sandy loam soil in Punjab, and that using rice straw compost at 8 t ha-1 increased SOC and available N content even further. The labile C pool is useful for determining the SOC state under various soil management methods. Changes in C inputs to the soil are especially responsive to labile fractions, which produce a quantifiable impact before any change in total organic matter [61]. The more stable (humified) pools, on the other hand, are most likely the most relevant and representative fractions for C sequestration characterisation [62]. According to Sleutel et al. (2006) Manure and fertiliser application, can increase the amount of OC present in free particulate organic matter, occluded particulate organic matter, and mineral linked organic matter over several decades. Data from a 20-year LTE on a wheat-maize cropping system on a loess soil in China demonstrated that the most efficient method for enhancing TOC and its labile pools was to combine manure and NPK, followed by NPK fertiliser+crop waste, and finally NP [63]. According to Moharana et al. [64], labile C increased considerably in six-year-old pearlmilletwheat plots receiving NPK+FYM compared to NPK and unfertilized controls. Mandal et al. [65] discovered that incorporating organic manures, especially FYM, into the fertilisation schedule improved SOC and mineral-N levels in the pigeonpea-wheat system.When imposed in the recommended NPK or NPK+organics plots, the addition of pigeonpea leaf-litter through forced defoliation increased labile SOC fractions larger than organic manures and increased wheat yield. SPM, on the other hand, showed to be an excellent nutrient source for increasing production, however its influence on SOC fractions was not as strong as FYM. The inclusion of more fresh plant residues and humified organic matter to these treatments may have caused this rise [61].

Impact on Biological Properties: Among the biological properties, Soil Microbial Biomass (MBC) is one of the most prominent property to be affected. Soil Microbial Biomass is a major labile fraction that comprises primarily of bacteria and fungi and accounts for 1-5 % of SOC [66]. The microbial quotient (MQ), which is defined as the ratio of MBC to TOC, has been shown to alter over time and to be a helpful indication of soil biological activity [67]. After six years of pearlmillet-wheat cropping on an Inceptisol of New Delhi, Moharana et al. [64] observed a 76.5 % increase in MBC with NPK+FYM treatments above control and a 43 percent increase under NPK fertiliser alone. Other researches have also reported that INM has a positive influence on soil MBC content (Gosh et al., 2010); [68,69]. Dehydrogenase activity is also an important property that is related to MBC and organic matter content. Dehydrogenase is a component of the respiratory chain of microorganisms, and its activity is frequently used as a measure of microbial biomass. Chu et al. [70] stated that the amount of organic matter in the soil influences enzyme activity. The addition of a balanced amount of fertilisers and manures increased the organic matter and MBC content of soils, resulting in increased enzyme activity [68]. According to an LTE at IARI, the maximum DHA was found under NPK+FYM. Dehydrogenase activity may be connected to increased substrate availability in the soil when organic sources are used. This is due to increased biological activity in the soil and the stability of extracellular enzymes through humic material complexation. Increases in DHA and microbial biomass were likewise related to the addition of nutrients in terms of both quantity and number [58].

Impact on Soil Fertility: Due to an uneven use of mineral fertilizers, the majority of agricultural soil fertility is degrading day by day. Accordingto manyreports, the state of soil fertility has improved by the adoption of INM. The amount of mineralizable N in the soil is frequently proportional to the amount of SOC in the soil [71, 72]. Consistent use of FYM on an annual basis for the past seven years on an Alfisol resulted in a large rise in the Contents of NH4-N and NO3-N, in contrast to the addition of a green leaf manures that didn't left behind any significantimpact [73]. Puranik et al. [74] and Prasad and Rokima [75] reported a decrease in NO_3-N content of the soil with the application of FYM alone, but the maximum N content was observed with the combined use of NPK and FYM. The majority of the research findings clearly demonstrated that INM increases crop yield potential beyond what can be achieved with recommended fertilisers, and results in better synchrony of crop N needs due to (a) slower organics mineralization; (b) lower N losses via denitrification and nitrate leaching; (c) improved nutrient use efficiency and recovery by crops; and (d) improvements in soil health and productivity, and thus could sustain high crop yields in the future [76,77,78] during a 4 years study observed higher apparent N recovery in rice with green manuring. Similarly, green manuring with millet and colza in wheat recorded higher yield, N uptake and NUE [79]. In the treatments where N was given simply only through fertilisers, soil NH_4- N content was low, although a benificial effect of 50% and 75% N replacement through FYM or vermicompost was detected in terms of improved NH_4-N contents of the soil due to slow release and retention by soil [80,65,81]. In comparison to other treatment combinations, judicious application of mineral fertilisers and organic manure, as well as biofertilizers and micronutrients, resulted in the maximum available NPK in soil [82,13,14,77,83] discovered that the amount of FYM applied in the soybean-wheat combination was directly proportional to the extent of improvement in extractable P content in soil. They also found that several nutrient management strategies, including integrated and solo organic sources, significantly enhanced the extractable P status of soil in puddled conditions under RWS. Organic P mineralization is vital for its availability in soils, especially in soils with a high SOC. The level of SOM is also said to affect the transformation of applied P fertilisers. Several researchers have found an increase in available P in soils as a result of adding legume residues to soils with or without fertilisers [84,85]. Because S deficiencies are common [86] and latest AICRP estimates on Secondary and Micronutrients, and pollutant Elements show that 41% of the soil samples is in limited supply of S [87]. Dwivedi et al. [88] investigated a large number of soils from RWS farms in Western Uttar Pradesh and found a substantial positive correlation between SOC and available S. In addition, in soils with high SOC concentration, the amount of S deficiency was always reduced. Because the organic S percentage of the soil is favourably connected to SOC [89,90] and is widely considered an important donor pool of available S [91] soils with high organic C or those getting organic manure together with fertilizers should have less S deficits. On Inceptisols (New Delhi), the highest levels of readily soluble and specifically adsorbed B (0.82 and 0.86 mg kg^{-1}, respectively) were found highest when NPK+FYM was used for long-term, while the lowest levels (0.61 and 0.60 mg kg^{-1}, respectively) were found when N was used alone . Organically bound B showed a similar trend, with the maximum level (5.86 mg kg^{-1}) under NPK+FYM and the lowest content (2.50 mg kg^{-1}) under control [92]. Increased chelation of B by organic matter and subsequent release on decomposition may explain the higher proportion of organically bound B under NPK+FYM. Under NPK+FYM, a significant increase in easily soluble B appears to be linked to a large organically bound proportion [93].

Impact on Nutrient Use Efficiency: The efficiency with which different nutrients are used is still remarkably low, and improving it has always been a top priority. Overall fertilizer efficiency has been estimated to be about or below 50% for nitrogen, less than 10% for phosphorus, and around 40% for potassium [94]. Long-term investigations revealed that INM aided

Table 3. Nitrogen use efficiency in different crops as affected by long-term

Nutrient supply with and without FYM						
SoilType	**Location**	**Crop**	**Nitrogen use efficiency(%)**			
			N	**NP**	**NPK**	**NPK+FYM**
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

in increasing the use efficiency of N at various locations. The N use efficiency in maize measured in Inceptisols (Ludhiana) under 100 % N (alone) was 16.7%, which climbed to 23.5, 36.4, and 40.2 % when combined with P, PK, and FYM, respectively (Table 3) [6]. Similar trend was noted in Mollisols (Pantnagar) in RWS. Absorption of N and K was significantly higher in the treatment with RD of NPK + FYM @ 10 t/ha in Cotton. Using 50 percent RD of NPK + FYM @ 10 t/ha + urea spray, considerably improved P uptake, agronomic efficiency, and partial factor productivity [95]. Baishya et al. [96] found that applying 100 %inorganic fertiliser (120:120:60 NPK kg ha^{-1}) or a combination of 25 % organic N + 75 % inorganic fertiliser resulted in higher NPK uptake and nutrient use efficiency in potato. In comparison to cereal-cereal cropping systems, Singh et al. [97] found that including legumes in the cereal-based farming system resulted in improved N recovery efficiency. In a long-term fertility experiment, [98] discovered that continuous application of mineral N and P fertilisers with FYM resulted in higher NFUE, PFUE, and KFUE in potatoes than continuous application of simply FYM. Under 50 percent N through urea + 50 percent through pressmud vermicompost treatment, Ramesh [99] observed the maximum agronomic efficiency, apparent N recovery, physiological, and internal efficiency in rice crop. A 50:50 split of P2 O5 and arbuscular mycorrhiza (AM) biofertilizer improved agronomic phosphorus use efficiency and partial factor pro productivity in sugarcane [100].

Future prospects: The number of benefits that INM techniques may provide to farmers, as well as the environmental benefits, is impressive [101]. We have synthesised several techniques and current opportunities that may be obtained and further enhanced by modification in the implementation of site-specific INM practices by evaluating numerous research publications [102]. INM's future strategic development will be guided by the following points i) soil and plant analysis (ii) fine-tuning to local environmental conditions (iii) mechanisation due to severe labour shortages (iv) conservation tillage and rainwater-harvesting technologies (v) organic nutrient recycling (vi) new innovative technologies, and (vii) appropriate policy interventions. Understanding flows and fluxes of nutrients under INM, refinement of the methodology for computing NUE under INM experiments, in situ decomposition and timely availability of Crop residues are all needed in order to promote INM and derive desired benefits [103].

5. CONCLUSION

Various studies have proved that the use of both organic and inorganic plant nutrition sources has a distinct advantage over the use of only inorganic and organic fertilizers.By improving soil fertility and carbon sequestration, it enhances soil quality, the INM technique can result in agronomically practicable, commercially successful, and ecologically sound sustainable crop production systems. When agricultural inputs interact, crop yield rises while N losses and GHG emissions are reduced significantly, judicious fertilization with minerals and organic matter enhance the resource efficiency along with increasing the Sustainability of soil, plants, microorganisms, and the environment.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Aulakh MS, Adhya TK. Impact of agricultural activities on emission of greenhouse gases – Indian perspective. In 'International Conference on Soil, Water and Environmental Quality – Issues and Strategies', (Indian Society of Soil Science: New Delhi). 2005;319-335.

2. Aulakh MS, Khurana MPS, Singh D. Water pollution related to agricultural, industrial and urban activities, and its effects on food chain: Case studies from Punjab. Journal of New Seeds. 2009;10:112-137.
3. Singh RP, Mundra MC, Gupta SC, Agrawal SK. Effect of integrated nutrient management on productivity of pearl millet-wheat cropping system. Indian Journal of Agronomy. 1999;44:250–253.
4. Anwar M, Patra DD, Chand S, Kumar A, Naqvi AA, Khanuja SPS. Effect of organic manures and inorganic fertilizer on growth, herb and oil yield, nutrient accumulation, and oil quality of French basil. Commmun. Soil Sci. Plant Anal. 2005;36:1737–1746.
5. Kumar U, Nayak AK, Shahid M, Gupta VVSR, Panneerselvam P, Mohanty S, et al. Continuous application of inorganic and organic fertilizers over 47 years in paddy soil alters the bacterial community structure and its influence on rice production. Agric. Ecosyst. Environ. 2018;262:65–75.
6. Singh M, Dwivedi BS, Datta SP. Integrated nutrient management for enhancing productivity, nutrient use efficiency and environmental quality. In Soil Science in the Service of Nation. 2012;55- 67, ISSS, New Delhi.
7. Aulakh MS, Grant CA. 'Integrated Nutrient Management for Sustainable Crop Production'. (The Haworth Press, Taylor and Francis Group: New York); 2008.
8. Cassman KG, Dobermann A, Walters DT. Agro ecosystems, nitrogen use efficiency and nitrogen management. Ambio. 2002;31:132-140.
9. Witt C, Dobermann A. Toward a decision support system for site-specific nutrient management. In: Dobermann, A., Witt, C. and Dawe, D. (Eds.), Increasing the productivity of intensive rice systems through site-specific nutrient management. Science Publishers, Inc., and International Rice Research Institute (IRRI), Enfield, NH (USA) and Los Baños (Philippines). 2004;17:359-395.
10. Gruhn P, Goletti F, Yudelman M. Integrated nutrient management, soil fertility and sustainable agriculture: current issues and future challenges. IFRPI Vision Brief; 2000.
11. Li Y, Simunek J, Zhang Z, Jing L, Ni L. Evaluation of nitrogen balance in a direct-seededrice field experiment using Hydrus-1D. Agril. Water Mgt. 2015;148:213–222.
12. Pittelkow CM, Liang X, Linquist BA, Groenigen KJV, Lee Juhwan, Lundy, ME, et al. Productivity limits and potentials of the principles of conservation agriculture. Nature. 2015;517:365-370.
13. Meena VS, Maurya BR, Verma R, Meena MD. Effect of concentrate manure and different levels of nutrients on growth and yield of rice in eastern Uttar Pradesh. Ann. Biolo. 2013;29(2):158-163.
14. Meena VS, Maurya BR, Verma R, Meena RS, Jatav GK, Meena SK, et L. Soil microbial population and selected enzyme activities as influenced by concentrate manure and inorganic fertilizer in alluvium soil of Varanasi. The Bioscan. 2013;8(3): 931-935.
15. Das D, Dwivedi BS, Meena MC, Singh VK, Tiwari KN. Integrated nutrient management for improving soil health and crop productivity. Indian Journal of Fertilisers. 2015;11(4): 64-83.
16. Singh AK. Soil quality parameters as influenced by management practices in rice-wheat and maize-wheat cropping systems. Proceedings of the 19th World Congress of Soil Science: Soil solutions for a changing world, Brisbane, Australia, 1-6 August 2010. Symposium 3.3.1 Integrated nutrient management. 2010;31:278-281.
17. Singh VK, Mishra RP. Integrated nutrient management in transplanted rice-wheat system. In: PDCSR Annual Report 2007-2008, PDCSR, Modipuram, India. 2010;44-50.
18. FAI. Specialty Fertiliser Statistics. 4th Edition. The Fertiliser Association of India, New Delhi; 2015.
19. AICRP-CS Annual Reports (1992- 93 to 2001-02), AICRP on Cropping Systems, PDCSR, Modipuram, India; 200.
20. Dwivedi BS, Singh VK, Meena MC, Dey A. Datta SP. Integrated nutrient management for enhancing nitrogen use efficiency. Indian J. Fertil. 2016;12:62-71.
21. Yadav RL, Dwivedi BS, Prasad K, Tomar OK, Shurpali NJ, Pandey PS. Yield trends, and changes in soil organic-C and available NPK in a long-term ricewheat system under integrated use of manures and fertilizers. Field Crop Res. 2000;68:219-246.
22. Yadav RL, Singh SR, Prasad K, Dwivedi BS, Batta RK, Singh AK, Patil NG, Chaudhary SK. In Yadav JSP and Singh GB (eds), Natural Resource Management

for Agricultural Production in India, ICMNR, New Delhi. 2000;775-870.

23. Rao DLN. Recent advances in biological nitrogen fixation in agricultural systems. Proc. Indian nation. Sci. Acad. 2014;80(2):359-378.
24. Yadav RL, Singh VK, Dwivedi BS, Shukla AK. Wheat productivity and N use-efficiency as influenced by inclusion of cowpea as a grain legume in a rice-wheat system. Journal of Agricultural Science Cambridge. 2003;141:213-220.
25. Dwivedi BS, Shukla AK, Singh VK, Yadav, RL. Improving nitrogen and phosphorus use efficiencies through inclusion of forage cowpea in the rice-wheat system in the Indo-Gangetic Plains of India. Field Crops Research. 2003;84:399-418.
26. Singh VK, Dwivedi BS, Shukla AK, Chauhan YS, Yadav RL. Diversification of rice with pigeonpea in a rice-wheat cropping system on a Typic Ustochrept: Effect on soil fertility, yield and nutrient use efficiency. Field Crops Research. 2005;92:85-105.
27. Chaudhury ATMA, Kennedy IR. Prospects and potentials for systems of biological nitrogen fixation in sustainable rice production. Biology and Fertility of Soils. 2004;39:219–227.
28. Hegde DM, Dwivedi BS. Nutrient management in rice-wheat cropping system in India. Fertiliser News. 1992; 37(2):27-41.
29. AICRP-IFS Reports (2005-2010), AICRP on Integrated Farming Systems, PDFSR, Modipuram, India; 2010.
30. Dalal RC. Long-term trends in total nitrogen of a vertisol subjected to zero-tillage, nitrogen application and stubble retention. Aus. J. Soil Res. 1992;30:223-231.
31. Lal R. Residue management, conservation tillage and soil restoration for mitigating greenhouse effect CO_2-enrichment. Soil Till. Res. 1997;43:81-107.
32. Gulde S, Chung H, Amelung W, Chang C, Six J. Soil carbon saturation controls labile and stable carbon pool dynamics. Soil Sci. Soc. Am. J. 2008;72:605-612.
33. Thomson AM, Izaurralde RC, Rosenberg NJ, He X. Climate change impacts on agriculture and soil carbon sequestration potential in the HuangHai Plain of China. Ag. Eco. Env. 2006;114:195-209.
34. Hegde DM, Dwivedi BS. Integrated nutrient supply and management as a strategy to meet nutrient demand. Fertiliser News. 1993;38(12):49-59.
35. Jat LK, Singh YV, Meena SK, Meena SK, Parihar M, Jatav HS, et al. Does integrated nutrient management enhance agricultural productivity, J Pure Appl Microbiol. 2015;9(2):1211-1221.
36. Das B. Integrated nutrient management effect on aggregate turnover and C stability in a sandy loam soil under a rice-wheat cropping system. M.Sc. Thesis, Division of Ag. Physics, IARI, New Delhi; 2012.
37. Saha R, Mishra VK, Majumdar B, Laxminarayana K, Ghosh PK. Effect of integrated nutrient management on soil physical properties and crop productivity under a maize (*Zea mays*) -mustard (*Brassica campestris*) cropping sequence in acidic soils of northeast India. Commun. Soil Sci. & Plant Ana. 2010;41: 2187-2200.
38. Sharma VK, Pandey RN, Sharma BM. Studies on long term impact of STCR based integrated fertilizer use on pearl millet (*Pennisetum glaucum*) -wheat (*Triticum aestivum*) cropping system in semi-arid condition of India. J. Environ. Bio.2015;36:241-247.
39. Saikia P, Bhattacharya SS, Baruah KK. Organic substitution in fertilizer schedule: Impacts on soil health, photosynthetic efficiency, yield and assimilation in wheat grown in alluvial soil. Agri. Eco. & Environ. 2015;203:102–109.
40. Abdollahi L, Schjonning P, Elmholt S, Munkholm LJ. The effects of organic matter application and intensive tillage and traffic on soil structure formation and stability. Soil Till. Res. 2014;136:28-37.
41. Bandyopadhyay KK, Misra AK, Ghosh PK, Hati KM. Effect of integrated use of farmyard manure and chemical fertilizers on soil physical properties and productivity of soybean. Soil Till. Res. 2010;110:115-1 25.
42. Nymangara J, Gotosa J, Mpofu SE. Cattle manure effects on structural stability and water retention capacity of a granite soil in Zimbabwe. Soil Till. Res. 2001;62:157-162.
43. Tejada M, Gonzales JL. Influence of two organic amendments on the soil physical properties, soil losses, sediments and runoff water quality. Geoderma. 2008;145:325-334.
44. Hati KM, Swarup A, Singh D, Misra AK, Ghosh PK. Long-term continuous cropping, fertilization and manuring effects on physical properties and organic carbon

content of a sandy loam soil. Aus. J. Soil Res. 2006;44:487-495.

45. Leroy BLM, Herath HMSK, Sleutel S, De Neve S, Gabriels D, Reheul D, Moens M. The quality of exogenous organic matter: Short term effects on soil physical properties and soil organic matter fractions. Soil Use Manage. 2008;24:139-147.
46. Aziz MA, Mushtaq T, Ali T, Islam T, Rai AP. Effect of integrated nutrient management on soil physical properties using soybean (*Glycine max (L.) Merill*) as indicator crop under temperate conditions. J. Envir. Sci., Comp. Sci. and Eng. Techn. 2015;4:56-64.
47. Lee SB, Lee CH, Jung KY, Park KD, Lee DK, Kim PJ. Changes of soil organic carbon and its fractions in relation to soil physical properties in a long-term fertilized paddy. Soil Till. Res. 2009;104:227-232.
48. Bhattacharyya R, Chandra S, Singh RD, Kundu S, Srivastva AK, Gupta HS. Longterm farmyard manure application effects on properties of a silty clay loam soil under irrigated wheat–soybean rotation. Soil & Tillage Res. 2007;94:386-396.
49. Mahanta D, Bhattacharyya R, Gopinathc KA, Tuti MD, Jeevanandan K, Chandrashekara C, et al. Influence of farmyard manure application and mineral fertilization on yield sustainability, carbon sequestration potential and soil property of Garden pea–French bean cropping system in the Indian Himalayas. Scient. Horti. 2013;164:414-427.
50. Arrouays D, Balesdent J, Mariotti A, Girardin C. Modelling organic carbon turnover in cleared temperate forest soils converted to maize cropping by using 13C natural abundance measurements. Plant and Soil. 1995;173:191-196.
51. Nieder R, Benbi DK. Carbon and Nitrogen in the Terrestrial Environment, Springer Science, Business Media B.V. 2008;430.
52. Brown S, Lugo AE. Effects of forest clearing and succession on the carbon and nitrogen content of soils in Puerto Rico and US Virgin Islands. Plant and Soil. 1990;124:53-64.
53. Lugo AE, Brown S. Management of tropical soils as sinks or sources of atmospheric carbon. Plant and Soil. 1993;149:27-41.
54. Ghosh S, Brian W, Ghoshal SK, Senapati N, Mandal B. Management of soil quality and carbon sequestration with long-term application of organic amendments. In 19th World Congress of Soil Science, Soil Solutions for a Changing World; 2010, Brisbane, Australia.
55. Dobermann A, Witt C. The potential impact of crop intensification on carbon and nitrogen cycling in intensive rice systems. In Kirk GJD and Olk DC (eds), Carbon and Nitrogen Dynamics in Flooded Soils. 2000;1-25, IRRI, Philippines.
56. Manna MC, Swarup A, Wanjari RH, Ravankar HN, Mishra B, Saha MN, et al. Long-term effect of fertilizer and manure application on soil organic carbon storage, soil quality and yield sustainability under sub-humid and semi-arid tropical India. Field Crop Res. 2005;93:264-280.
57. Timsina J, Connor DJ. Productivity and management of ricewheat cropping systems: issues and Indian Journal of Fertilisers, April 2015 83 challenges. Field Crop Res. 2001;69:93-132.
58. Manjaiah K, Singh D. Soil organic matter and biological properties after 26 years of maize– wheat–cowpea cropping as affected by manure and fertilization in Cambisol in semiarid region of India. Ag. Eco. Env. 2001;86:155-162.
59. Swarup A, Wanjari RH. Three decades of All India Co-ordinated Research Project on Long-term Fertiliser Experiments to study changes in soil quality, crop productivity and sustainability, IISS, Bhopal. 2000;59.
60. Sodhi GPS, Beri V, Benbi DK. Soil aggregation and distribution of carbon and nitrogen in different fractions under long-term application of compost in rice–wheat system. Soil Till. Res. 2009;103:412-418.
61. Gregorich EG, Janzen HH. Storage of soil carbon in the light fraction and macro organic matter. In Carter MA and Stewart BA (eds), Structure and Organic Matter Storage in Agricultural Soils, , Lewis Publication, Boca Raton, FL. 1996;167-170.
62. Cheng HH, Kimble JM. Characterization of soil organic carbon pools. In Lal R et al. (eds), Assessment Methods for Soil Carbon, Lewis Publishers CRC Press, Boca Raton, FL. 2001;117-129.
63. Yang X, Ren W, Sun B, Zhang S. Effects of contrasting soil management regimes on total and labile soil organic carbon fractions in a loess soil in China. Geoderma. 2012;177:49-56.

64. Moharana PC, Sharma BM, Biswas DR, Dwivedi BS, Singh RV. Long-term effect of nutrient management on soil fertility and soil organic carbon pools under a 6-yearold pearl millet–wheat cropping system in an Inceptisol of subtropical India. Field Crop Res. 2012;136:32-41.
65. Mandal N, Dwivedi BS, Meena MC, Dhyan-Singh, Datta SP, Tomar RK, Sharma BM. Effect of induced defoliation in pigeonpea, farmyard manure and sulphitation pressmud on soil organic carbon fractions, mineral nitrogen and crop yields in a pigeonpea–wheat cropping system. Field Crop Res. 2013;154:178-187.
66. Haynes RJ. Labile organic matter fractions as central components of the quality of agricultural soils: An overview. Adv. Agron. 2005;85:221-268.
67. Anderson TH, Domsch KH. Ratio of microbial biomass carbon to total organic carbon in arable soils. Soil Biol. and Biochem. 1989;21:471-490.
68. Mandal A, Patra AK, Singh D, Swarup A, Masto RE. Effect of long-term application of manure and fertilizer on biological and biochemical activities in soil during crop development stages. Biores. Technol. 2007;98:3585-3592.
69. Nayak AK, Gangwar B, Shukla AK, Mazumdar SP, Kumar A, Raja R, et al. Long-term effect of different integrated nutrient management on soil organic carbon and its fractions and sustainability of rice–wheat system in Indo Gangetic Plains of India. Field Crop Res. 2012; 127:129- 139.
70. Chu H, Lin X, Fujii T, Morimoto S, Yagi K, Hu J, Zhang J. Soil microbial biomass, dehydrogenase activity3 and bacterial community structure in response to long-term fertilizer management. Soil Biol. and Biochem. 2007;39:2971-2976.
71. Ferguson WS. Effect of repeated application of straw on grain yield and on some soil properties. Can. J. Soil Sci. 1967;47:117-121.
72. Zielke RC, Christenson DR. Organic carbon and nitrogen changes in soil under selected cropping systems. Soil Sci. Soc. Am. J. 1986;50:363-367.
73. Udayasoorian C, Ramula US, Paramasirand P. Effect of continuous manuring and fertilization on the fractions of soil nitrogen. MadrasAg. J. 1989;76:257-261.
74. Puranik RB, Ballal DK, Bandre N. Studies on nitrogen forms as affected by long-term manuring and fertilization on Vertisols. J. Indian Soc. Soil Sci. 1978;26:69-72.
75. Prasad B, Rokima J. Integrated nutrient management-I nitrogen fractions and their availability in calcareous soils. J. Indian Soc. Soil Sci. 1991;39:693-698.
76. Sharma GD, Thakur R, Raj S, Kauraw DL, Kulhare PS. Impact of integrated nutrient management on yield, Nutrient uptake, protein content of wheat (*Triticum aestivam*) and soil fertility in a Typic Haplustert. The Bioscan. 2013;8(4): 1159-1164.
77. Aulakh MS. Integrated nutrient management for sustainable crop production, improving crop quality and soil health, and minimizing environmental pollution. 19th World Congress of Soil Science, Soil Solutions for a Changing World 1-6 August Brisbane, Australia. 2010;79-82.
78. Aulakh M, Khera T, Doran J, Singh K, Singh B. Yields and Nitrogen Dynamics in a Rice–Wheat System Using Green Manure and Inorganic Fertilizer. Publications from USDA-ARS / UNL Faculty. 2000;303.
79. Dayegamiye A, Tran T. Effects of green manures on soil organic matter and wheat yields and N nutrition. Canadian Journal of Soil Science. 2001;81(4):371-382.
80. Duraisami VP, Perumal R, Mani AK. Changes in organic carbon, available nitrogen and inorganic nitrogen fractions under integrated nitrogen management of sorghum in a mixed black soil. J. Indian Soc. Soil Sci. 2001;49:435-439.
81. Yadav MD, Singh KD. Transformation of applied nitrogen in relation to its availability to sugarcane in a calcareous soil. J. Indian Soc. Soil Sci. 1991;39:292-297.
82. Jat LK, Singh SK, Latare AM, Singh RS, Patel CB. Effect of dates of sowing and fertilizer on growth and yield of wheat (*Triticum aestivum*) in an Inceptisol of Varanasi. Indian J. Agron. 2013;58(4):611-614.
83. Verma BC, Datta SP, Rattan RK, Singh AK. Monitoring changes in soil organic carbon pools, nitrogen, phosphorus, and sulfur under different agricultural management practices in the tropics. Env. Monitor. Assess. 2010;171:579-593.
84. Dhillon KS, Dhillon SK. Effect of crop residues and phosphorus levels on yield of

groundnut and wheat grown in rotation. J. Indian Soc. Soil Sci. 1991;39:104- 108.

85. Gupta AP, Antil RS, Narwal RP. Effect of farmyard manure on organic carbon, available N and P content of soil during different periods of wheat growth. J. Indian Soc. Soil Sci. 1968;36: 269-273.
86. Tiwari KN, Sharma SK, Singh VK, Dwivedi BS, Shukla AK, Site-specific Nutrient Management for Increasing Crop Productivity in India: Results with Rice-Wheat and Rice-Rice System, PDFSR, Modipuram and PPIC-India Programme, Gurgaon. 2006;92.
87. Shukla AK, Behera SK, Subba Rao A, Singh AK. AICRP on Micro and Secondary Nutrients and Pollutant Elements in Soils and Plants Research Bulletin No. 1/2012, IISS, Bhopal. 2012;1-40.
88. Dwivedi BS, Shukla AK, Singh VK, Yadav, RL. PDCSR Bulletin 2001-1, PDCSR, Modipuram. 2001;35..
89. Takkar PN. Sulphur status of Indian soils. In: Proceedings of TSI-FAI Symposium on Sulphur in Indian Agriculture, New Delhi. 1988; SI/2/1-31.
90. Pasricha NS, Sarkar AK. Secondary nutrients. In: Fundamentals of Soil Science (2nd Ed.) (N.N. Goswami et al. Eds.), New Delhi. 2009;449-460.
91. Tripathi SB, Hazra CR. Sulphur in balanced fertilization in red and black soils of Bundelkhand region of Uttar Pradesh. In TSI-FAI-IFA Workshop on Sulphur, FAI, New Delhi. 2000;43-55.
92. AICRP-LTFE Progress Report for Delhi Centre (2007-08 to 2011-12), AICRP on Long-term Fertilizer Experiments, IARI, New Delhi, India; 2012.
93. Dey A, Dynamics of boron in different soils under long-term fertilization and manuring. M.Sc. Thesis, Division of SS & AC, IARI, New Delhi; 2011.
94. Baligar VC, Fageria NK, He ZL. Nutrient use efficiency in plants. Communications in Soil Science and Plant Analysis. 2001;32(7):921-950.
95. Devraj AP, Sharma BS, Duhan, Kumari,P. Journal of Cotton Research and Development. 2008;22(1):69-73.
96. Baishya LK, Kumar M, Ghosh DC. Effect of different proportion of organic and inorganic nutrients on productivity and profitability of potato varieties in Meghalaya hills. Indian Journal of Agronomy. 2010;55(3):230–234.
97. Singh VK, Shukla AK, Singh MP, Majumdar K, Mishra RP, Rani M, Singh SK. Effect of site-specific nutrient management on yield, profit and apparent nutrient balance under pre-dominant cropping systems of Upper Gangetic Plains. Indian Journal of Agricultural Sciences. 2015;85(1):43-51.
98. Jate M. Impact of Mineral Fertilizer Integration with Farmyard Manure on Crop Yield, Nutrient Use Efficiency, and Soil Fertility in a Long-Term Trial. Crop production technologies. 2012;153-168.
99. Ramesh S. Grain yield, nutrient uptake and nitrogen use efficiency as influenced by different sources of vermicompost and fertilizer nitrogen in rice. Journal of Pharmacognosy and Phytochemistry. 2018;7(5):52-55.
100. Patil KB, Tripathi S, Thorave D. Studies on effect of phosphorus levels, time of its application along with arbuscular mycorrhiza on yield, quality and phosphorus use efficiency in sugarcane. International Journal of Chemical Studies. 2020;8(4):3626-3630.
101. FAO. Guide to Efficient Plant Nutrition Management. Land and Water Development Division, FAO Rome. 1998;1-19.
102. Prasad R, Power J. Nitrification inhibitors for agriculture, health and strategies for balanced fertilization. Fertiliser News. 1995;49(12):73- 80.
103. Yadvinder-Singh Bijay S, Ladha JK, Khind, CS, Gupta RK, Meelu OP, Pasuquin E. Long-term effects of organic inputs on yield and soil fertility in the rice-wheat rotation. Soil Sci. Soc. Am. J. 2004;68:845-853.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/87484