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Prospective Study

Role of integrated nutrient management for enhancing nitrogen use efficiency in crop

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Abstract

Nitrogen is the most limiting nutrient for crop production in many of the world's agricultural areas and its efficient use is important for the economic sustainability of cropping systems. In the past several years, the application of synthetic Nitrogen (N) fertilizer to farmland resulted in a dramatic increase in crop yields but with considerable negative impacts on the environment. Furthermore, the dynamic nature of N and its tendency for loss from soil-plant systems creates a challenge for its efficient management. New solutions were therefore needed to reduce N loss and to maximize the nitrogen use efficiency with a simultaneous increase in crop yield. Studies undertaken so far on enhancing the NUE have emphasized integrated nutrient management (conjoint use of inorganic fertilizers, organic fertilizers and bio-fertilizers) and other management practices involving the right source, time, rate and method of application. This review paper discusses N dynamics in soil-plant systems and outlines the possibilities of enhancing Nitrogen-Use Efficiency (NUE) through different Integrated Nutrient Management (INM) approaches.

Introduction

Global food production depends on resources such as land, soil, water, biodiversity, and plant nutrients. Inefficient use of these valuable resources is harmful to society and the environment. The need for plant nutrients in agriculture is large and expected to increase in the coming decades because of the increasing world population and anticipated changes in food consumption patterns [1]. That is why most world issues emphasized resource use efficiency and measures to increase the efficient use of nutrients. This is especially critical for nitrogen as it is essential for life and required in large quantities on one side and highly vulnerable to lose from soil-plant systems with which resulting sever environmental pollution on the other side.

The importance of nitrogen for plant nutrition and productivity is increasingly being recognized, and in many cases, it is considered as the most common growth-limiting factor. In many of the world's agricultural areas Sustainable and economically viable crop production depends largely on N application through external sources, besides the use of other agricultural inputs and adoption of appropriate crop management practices. Among all the plant nutrients essential for crop development, N is needed by plants in large quantities, because of its critical role in almost all metabolic activities of plants and its heavy losses associated with soil-plant systems [2]. To fulfill this large demand for N in crop plants, globally farmers using about 120 million metric tons of nitrogenous fertilizer every year [3]. However, the application of a substantial amount of N has economical and environmental negative impacts. Nitrogen fertilizers are expensive inputs, costing agriculture more than US$50 billion per year [4]. Therefore, it requires significant investment from farmers. On the other hand, excessive utilization of N in agriculture leads to its leaching into the soil resulting in severe environmental pollution and climate change [5]. These considerations make it essential to enhance Nitrogen Use Efficiency (NUE) in order to maximize economic returns while minimizing ecological and environmental risks.

N is universally deficient in almost all the agricultural soils and cropping systems of the world so, it is important to use external nitrogen inputs to produce the crops for satisfying the ever-increasing demands of human populations [6]. Farmers need to apply a huge amount of nitrogen fertilizer in agricultural crops because of its lower recovery (30%–50%) due to its various losses from the soil-plant system [7]. Although progress has been made to optimize N fertilization, more than half of the worldwide N applied to crops is currently lost into

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the environment [8]. That means the recovery of N in crop plants is usually less than 50% worldwide. Low recovery of N is associated with its loss by volatilization, leaching, surface runoff, de-nitrification and plant canopy. To maintain the long-term sustainability of agriculture, effective and efficient approaches to slow the removal and returning nutrients into the soil is required. The overall strategy for increasing crop yields and sustaining them at a high level must, therefore, include an integrated approach to the management of soil nutrients, along with other complementary measures. In this case, the availability and utilization of the yield-limiting essential nutrients particularly N use efficiency will be improved. Hence, in this review, it is attempted to discuss several works done on this approach with deep emphasizing on the role of integrated nutrient management in enhancing nitrogen use efficiency to achieve sustainable agricultural production in annual crops.

The objective of this review is to discuss the role of integrated nutrient management in the improvement of nitrogen use efficiency by annual crops.

Literature review

Nitrogen use efficiency: Concepts and definitions

Nitrogen-Use Efficiency (NUE) is a complex term involving more than one component and there are several methods of expression. It can be expressed in terms of total crop Dry Weight (DW) accumulated per kilogram of absorbed N; or based on the sole marketable DW yield or Marketable Fresh Weight Yield (MFWY) per kilogram of absorbed N, or sometimes in terms of harvest index on a DW basis and N; because of this it is difficult to use and compare available information from different literature on this subject [9]. The NUE is often defined because the maximum economic yield produced per unit of N applied, absorbed, or utilized by the plant to apply grain and straw [10]. However, nutrient use efficiency has been defined in several ways in the literature, although most of them indicate the ability of a system to convert inputs into outputs. Definitions of nutrient use efficiencies have been classified as Agronomic Efficiency (AE), Physiological Efficiency (PE), Agro-Physiological Efficiency (APE), Apparent Recovery Efficiency (ARE), and Utilization Efficiency (UE) and are calculated by using the following formulas [11-13]:

AE ($kgkg^{-1}$) = (Gf-Gu)/Na

PE ($kgkg^{-1}$) = (BYf-BYu)/(Nf-Nu)

APE ($kgkg^{-1}$) = (Gf-Gu)/(Nf-Nu)

ARE (%) =100*(Nf-Nu)/Na

UE ($kgkg^{-1}$) = PE×ARE

Where,

Gf = Grain yield of the fertilized plot (kg),

Gu = grain yield in the unfertilized plot (kg),

Na = quantity of nutrient applied (kg),

BYf = total biological yield (grain plus straw) of the fertilized plot (kg),

BYu = total biological yield in the unfertilized plot (kg),

Nf = Nutrient accumulation in the fertilized plot in grain and straw (kg),

Nu = Nutrient accumulation in the unfertilized plot in grain and straw (kg).

Hence N use efficiency is the result of two main components: N uptake efficiency, which is the ability of crops to take up N from the soil [14,15], and use efficiency of the absorbed N, that is the efficiency with which crops use the absorbed N to grow and give yield [16].

Global trends of nitrogen use efficiency

The overall observed global trend is a distinct decrease of NUE in 1961–1980 period (from 68% to 45%), followed by a stabilization during the last 30 years around 47% Figure 1(b), although crop yield is increased with increase in total nitrogen input as shown Figure 1(a) [8], i.e. currently, only 47% of the reactive nitrogen added globally onto cropland is converted

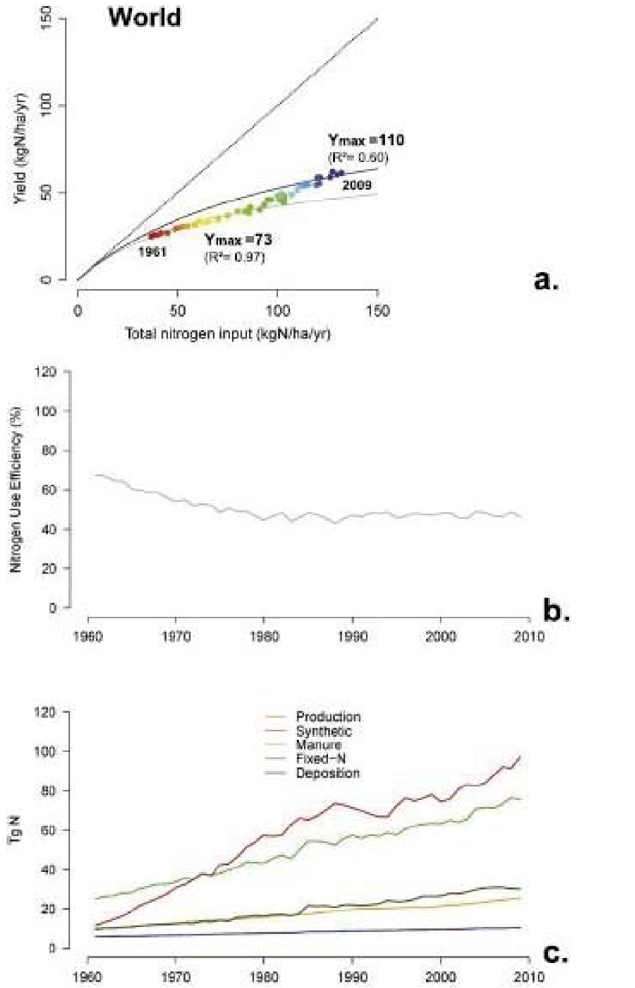

Figure 1: Trajectory followed by global world cropping systems: (a) Crop yield versus total N inputs to the cropland, kg ha^{-1} yr^{-1}). (b) Trends in nitrogen use efficiency of the global cropping system. (c) Evolution of the components of the global cropping system budget. Source [8].

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into harvested products, compared to 68% in the early 1960s, this indicated that more than half the nitrogen used for crop fertilization is currently lost into the environment. The share and change of the different sources of N in the total inputs to cropland are also clearly depicted in Figure 1(c) by these authors.

Factors influencing N use efficiency

NUE is a dynamic and complex concept, affected by a number of factors that can be classified into three groups namely factors related to nitrogen demand, controlling the N supply to the plants and controlling the losses of N from the soil-plant system [17]. High crop N demand can be achieved through sound agronomic management practices and genetic crop improvements under optimum climate conditions. Adoption of more efficient fertilizer, soil and water and crop management helps to increase the higher crop demand of N by creating a better and favorable production condition. These holistic management approaches will maximize crop N uptake, minimize N losses and optimize indigenous soil N supply including non-symbiotic N fixation by maintaining soil health [4]. Climate factors such as temperature, solar radiation, rainfall and relative humidity have influenced the whole physiological activity of plans and the activity of soil microbes which are essential for N mineralization [17]. Without sufficient water, plants cannot extract nutrients from the soil and yield is constrained by moisture availability [18].

Many authors showed that NUE decreases with increasing N-application. When N supply is in excess of crop N demand, they are asynchronous and N can accumulate in soils and be susceptible to various loss pathways [19,20]. Therefore, efficiencies of N uptake will vary greatly depending upon cropping systems and strategies for N application in terms of timing, splitting of applications, and forms of N used, which vary enormously [21].

Consequences associated with low N use efficiency

Nitrogen cycling is dynamic in nature which consists a range of biochemical transformation processes within the soil-plant system. The addition, transformation, utilization, and possible losses of N from soil-plant systems are the main components of N cycling [10]. The major processes in which contributors to N losses and severe environmental pollution are ammonia volatilization, nitrate leaching, denitrification and soil erosion [22]. Large N fertilizer input rates and low NUE enhanced losses of reactive N to the environment [23,24]. Nitrogen that has been lost beyond the root zone of the plant system through leaching can cause groundwater pollution [17]. For instance, excessive reactive nitrogen can lead to the disturbance of aquatic and terrestrial ecosystems through eutrophication [17,25]. Eutrophication is the process of enrichment of water bodies with chemicals especially N and phosphorus that can cause excessive algal growth of aquatic algal communities. This can cause a shortage of oxygen and may produce substances that are directly toxic to aquatic communities and indirectly to livestock and humans [26]. Loss of reactive N from N-fertilizer with runoff water from agricultural land can be a major factor in eutrophication [17]. After a heavy rain surface applied nitrate can be dissolved in water and lost through the process of runoff [7].

Among the plant nutrients applied to the soil, N is the only essential element that volatilizes into the atmosphere as ammonia (NH_3) Consequently, NH_3 is the third most abundant N gas after N_2 and N_2O in the atmosphere [27]. Therefore NH_3 volatilization not only causes N loss but also influences air quality and human well-being [28]. The other important process for the loss of reactive nitrogen is the microbial mediated reduction of nitrate form of N to a variety of gaseous form of N (NO, N_2O and N_2) under anaerobic conditions which is termed as de-nitrification [29]. De-nitrification converts most of the reactive Nitrogen back into un-reactive nitrogen but is also coupled to the production of the greenhouse gas and ozone-depleting substance of N_2O [25].

Therefore inefficient utilization of nitrogen leads to groundwater pollution, greenhouse effect, negative impacts on human welfare and reduction in productivity of aquatic ecosystems.

Improved practices for enhancing N use efficiency

Nitrogen efficiency can be improved through the adoption of locally as well as scientifically available means of nitrogen management to ensure efficient use of agricultural inputs (chemical fertilizers, land, water, and crops) that will enhance the beneficial use of N in crops and minimize its losses [17]. According to Balasubramanian, et al., [30], improved practices used for nitrogen management of crops focused on two core principles (1) enhancing beneficial use of externally applied fertilizer nitrogen as well as native soil N during the growing season and (2) conserve soil nitrogen by reducing the amount of N losses through various mechanisms and ensure higher beneficial use of this conserved N by the subsequent grown crops of the production system. As discussed by [17], these improved practices or strategies includes site-specific nitrogen management i.e. establishing an optimum synchronization between supply and demand of N for plant growth; integrated nitrogen management (optimum use of indigenous N components and chemical fertilizer and their complementary interactions to increases N recovery; use of efficient fertilizers (N fertilizers either Slow release or nitrogen inhibitors); improved method of N application (like deep placement, use of super granules and foliar spray of N fertilizer) and adoption of resource conservation practices like application of Conservation tillage, organic manure and proper crop rotations. All these practices reduce various losses of nutrients associated with the production system and enhance their beneficial use to plants.

Integrated nutrient management

Integrated Nutrient Management (INM) refers to the maintenance of soil fertility and of plant nutrient supply at an optimum level for sustaining the desired productivity through optimization of the benefits from all possible sources of organic, inorganic and biological components in an integrated manner. It has multifaceted potential for the improvement of plant performance and resource efficiency while also enabling

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the protection of the environment and resource quality [31]. The advantages of INM include the restoration of soil fertility, sustenance of crop productivity, prevention of secondary- and micronutrient deficiencies, improving nutrient use efficiency, and favorable effect on the physical, chemical and biological health of soils [32].

Under INM practices, the losses through leaching, runoff, volatilization, emissions, and immobilization are minimized, while high nutrient-use efficiency is achieved (Figure 2) [33].

Recent N budgeting suggests that in maize, rice, and wheat, 48% of their N requirement is met from synthetic fertilizer-N, and an equal portion of crop N comes from other sources (Table 1) [35]. Therefore, this finding indicates that the need to consider all the sources of N, and not only synthetic fertilizer N, when designing strategies to improve N use efficiency (Figure 3).

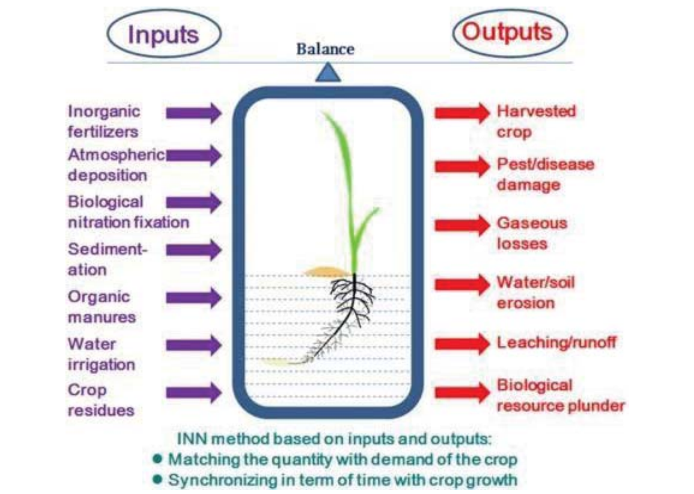

Figure 2: The nutrient budgets between inputs and outputs, and the principles of INM method. This figure is taken from [34].

Table 1: Effect of integrated use of organic and chemical fertilizers on grain yield, straw yield and grain protein of wheat (data over two seasons). The table is adopted from [36].

	Treatments	Grain yield (q/ha)	Stover yield (q/ha)	Grain protein content %
T1	Control	2.90	4.06	10.48
T2	RDF(N,P,K 150:60:40kg ha-1)	4.11	5.72	11.32
T3	125 % RDF	4.37	5.98	11 .35
T4	RDF+Vermicompost (VC) at 2.5 t ha-1	4.67	6.45	11 .78
T5	RDF+VC at 5 t ha-1	5.19	7.16	11.93
T6	RDF+FYM at 5 t ha-1	4.65	6.42	11 .78
T7	RDF+FYM at 10 t ha-1	5.09	7.02	11 .89
T8	RDF+VC at 2.5t ha-1+Azotobacter	4.91	6.77	11.86
T9	RDF+FYM at 5 t ha-1+Azotobacter	4.82	6.64	11 .80
T10	RDF+VC at 2.5 t ha-1+FYM at 5 t ha-1+Azotobacter	5.62	7.53	11 .96
	SE± (d)	0.116	0.98	0.178
	C.D. (P=0.05)	0.247	0.207	0.377

Where, RDF: Recommended Fertilizer; VC: Vermicompost; FYM: Farm Yard Manure.

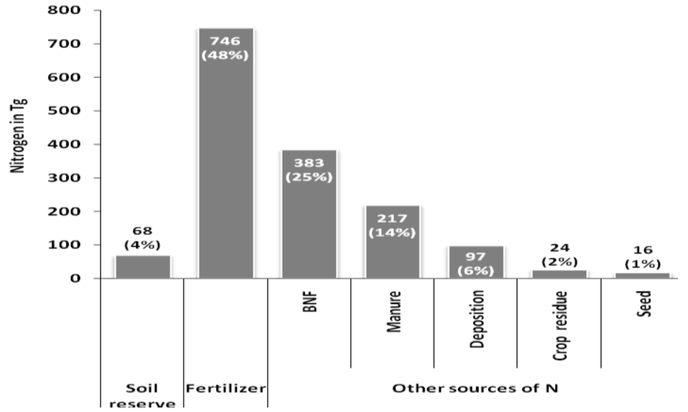

Figure 3: Global estimates of sources of N in crop harvest of maize, rice, and wheat production systems: total (Tg) for 50 years (1961-2010).nSource Ladha, et al., [4].

Various researches indicate that organic manure and bio-fertilizers are needed along with chemical fertilizers for better yield and better quality of the produces. According to Kakraliya, et al., [36], wheat yield with synthetic fertilizer (NPK) was 42% more compared with control (unfertilized), and further increased with the layering of organic and inorganic fertilizers along with bio-fertilizers. Besides grain yield, the protein content of the grain was significantly higher under integrated treatments than unfertilized and chemical fertilizer alone (Table 1). These authors suggested that the increase in grain and straw yields might be due to Improved physical and chemical properties of the soil through the application of organic manure and adequate quantities and balanced proportions of plant nutrients supplied to the crop as per need during the growth period resulting in favorable increase in yield attributing characters which ultimately led towards an increase in economic yield.

The positive effect of integrated nutrient management on yield and quality of crops has also been found by different researchers on other crops some of them include maize [37,38], rice, [39], Barley [38,40,41], Potato [42-44] and Sesame [45,46]. Therefore use of sufficient organic, inorganic and bio-fertilizers in an integrated manner not only reduces the fertilizer requirement and cost of crop production but also improves soil health, yield and quality of produce.

Components of integrated nutrient management: Organic manures, green manures, compost, soil fertility restoring crops /legumes/, crop residues, industrial wastes and by-products, sewage-sludge, Biochar, bio-fertilizers, chemical fertilizers, genetically improved crops, and proper crop rotation and intercrops are main ingredients of integrated nutrient management.

Integration of soil fertility restoring crops: Soil fertility restoring crops like green manures and legume crops have multi-direction benefits. Leguminous green manure crops have the ability to fix unusable nitrogen into a usable form and supply it to the following crops and add organic matter for soil property improvement. In addition to nutrients cycling for sub squint crop, green manure suppresses weed, optimize soil temperature and reduce soil erosion, i.e. proved better soil coverage [47]. Therefore, the use of green manures is

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economically viable and sustainable as they are characterized as soil conditioner plants [48]. Green manure is often terminated before maturity and incorporated into the soil although it may be allowed to grow to maturity when it is needed for ground cover or increasing soil organic C [49]. Common green manure species include mucuna *Mucuna pruriens*, several crotalaria species, *Canavalia ensiformis, Dolichos lablab* and cowpea [49].

Crop rotations are a fundamental component of organic systems, and legume crops are often planted to enhance nutrient cycling and availability to other crops in the rotation [50]. Crops with high N demands like cereals are usually grown after a green manure or legume crops. Rotation of cereals with leguminous crop not only enhance nutrient cycling but also reduce the use of inorganic fertilizer [51] and decrease the quantity of reactive N lost from the ecosystem [52]. Therefore, legume-based crop rotations can deliver environmental and economic benefits [53].

Mono cropping is the dominant factor influencing plant nutrient uptake and loss of soil quality in Ethiopia whereas intercropping of cereal-legume has positive environmental qualities [54]. Intercropping is an agricultural practice of cultivating two or more crops in the same space at the same time and has many advantages over sole cropping [55] It increases productivity per unit of land via better utilization of resources, reduced risk of crop failure, improves soil fertility, reduces weed competition and stabilizes the yield [56,57]. The observed advantage of intercrops over sole crops was associated with an enhanced radiation use efficiency by intercrops [58]. The cultivation of maize intercropped with green manures is enabled to utilize more effectively the growth factors in the cropping area [59], produce yield from both crops and increase soil coverage during the development of maize [48,60].

Recycling of crop residues: The portions of crops left in the field after seed harvesting such as corn Stover or small grain straw and stubble are called crop residues [61]. Plant residues are primary sources and sinks for C and N [62] and affect the number of nutrients available to crops [63]. The export of agricultural products from the farm leads to the removal of nutrients from the soil. When crop residues are incorporated into the fields on which they have grown the nutrients they contain are returned to the soil and will be available to the following crop. Ambus and Jensen [64], showed that the incorporation of crop residues into soil provides substantial amounts of nutrients for succeeding crops. It helps to increases soil organic matter [65], improve soil structure [66] and increases soil microbial biomass [67]. Besides improving soil physical and chemical quality returning crop residues to fields rather than burning can reduce air pollution and improve nutrient availability in agricultural ecosystems [68].

Residues allow N to be available to plants for longer periods of time through initially immobilizing, and then gradually mineralizing N [69]. Legumes residues generally have high N contents and lower C/N ratios while Cereal straws usually have high C/N ratios, and may induce temporary N deficiency in crops due to N immobilization by soil microbial populations when the straw is not incorporated or decomposed in advance [10].

Returning crop residues to cropland is a sustainable farming practice which enhances the utilization efficiency of easily lost nutrients, such as N and enables to reduce the need for inorganic nutrient inputs and environmental pollution [31].

Use of organic manures: Many researchers have realized that the application of organic manure, such as farmyard manure, green manure, poultry manure compost, biochar, Sulage silage and other organic waste have positive effect on soil health, crop productivity and environment [38,48,70,71].

Farmyard manure, that prepared from cattle dung, urine and bedding material, along with recommended fertilizer improved soil biological activity and regulate the transformation process of elements required for plant growth [70]. Poultry manure which is a mixture of excreta, bedding material, waste feed, and feathers, contains appreciable amounts of calcium, sulfur, magnesium, calcium, chlorine, sodium, manganese iron, copper, zinc, molybdenum, and arsenic which are important for plant growth [72].

The use of green manures is an economically viable and sustainable alternative, as they are characterized as soil conditioner plants [48]. A green manure crop is a legume that is grown for biological N fixation to supply N to following crops and organic matter for soil property improvement [47]. In addition to nutrients cycling for sub squint crop, it proved better soil coverage. Green manure is often terminated before maturity although may be allowed to grow to maturity when maximized production of a relatively higher C: N biomass is desired such as for ground cover or increasing soil organic C [49]. It is commonly incorporated into the soil but may be left on the soil surface as a mulch.

Biochar is a carbon-rich product that results from the low temperature, oxygen-starved combustion of carbonaceous biomass such as crop residues, stall bedding, cull timber and sawmill wastes [73]. Recent evidences showed that the application of biochar can play a significant role in improving soil organic carbon [74], increases cation exchange capacity [75] and water holding capacity [76], stimulate the activity of soil microbes [77], increase soil porosity and nutrient availability [78], improving soil quality [79] and ultimately lead to increase total biomass and grain yield of crop [38].

Another available organic matter which has an important role in improving soil productivity, if it is properly utilized is sewage sludge product. Chu et al., [80], stated that a considerable amount of sludge and sewage is produced each year across the world and its disposal has become a significant challenge in environmental management. Sewage sludge could be used as an organic fertilizer due to its richness in nutrients and organic matter [81] and application of it exhibits better effects on the growth habit of several landscape plants [82].

Pathak, et al., [83], suggested that instead of applying simply fresh sewage sludge with larger amounts of heavy metals as landscaping fertilizers, using Sewage Sludge Compost (SSC) could be more advantageous since SSC has less odorous emission and the likelihood of the bioleaching of heavy metals. Sewage sludge compost can be used to improve

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the physical and chemical properties of depleted or eroded soil [81,84]. Several soil properties, such as bulk density, porosity, and water-holding capacity showed improvement because of the addition of SSC [85]. However, an overdose of SSC will increase the heavy metal contents in plants and inhibit plant growth [86]. Therefore the application of appropriate amount of sewage sludge is essential to positively modify soil chemical property, structure and function of soil microorganisms as well as plant performance [87].

Compost influences the chemical, physical and biological properties of soil. It contains different nutrients including the trace elements that are needed by the plant [88]. The pH of acid soils can be improved using compost depend on the quantity of calcium present in it [89]. In some cases, very high pH value in the soil can even be reduced by applying compost Therefore, compost has a very good buffer capacity effect in the soil, increasing its pH when its value is below 7 and decreasing it when it is above 7 [90]. Compost amendments improve the quantity of organic matter in the soil [91]. It increases the stability of soil structure [92], soil macroporosity and water holding capacity with a corresponding decrease in bulk density [93]. Composts have also influenced the soil biology. Zaccardelli, et al., [94], showed that the composition of the microbial communities is affected by the application of compost. After their use, the microbial biomass is increased [95]. In general application of compost to the soil increase soil organic matter and nutrient cycling which has a positive effect on the soil structure, its water retention capacity, air balance and resistance to erosion [96].

The organic fertilizers derived from Sugar Press Mud or the sugarcane filter-cake are the residue of sugarcane industry which results from the processing of sugarcane where sugar mud is separated from the crush. The sugar filter cake is used as a suitable fertilizing agent since it is rich in micro and macronutrients along with organic carbon and it is used to maintain soil fertility and promotes plant growth [97].

In general proper utilization of organic manures positively influences soil physical, chemical, and biological properties which leading to enhance plant growth and increase crop yield as realized by many Authors above. The integrated use of one such organic fertilizer with inorganic fertilizers provide a balanced ratio of organic and inorganic nutrients, maintain improvements in soil fertility, and enhance the efficiency of growth and yield generation in the crop.

For example, Ram et al., [98], showed that Long-term integrated use of inorganic fertilizers and organic manure (FYM) found superior in comparison to alone application of inorganic fertilizers to increase soil organic carbon and available N, P, and K in a rice-wheat cropping system (Table 2).

Bio-fertilizer: Biofertilizer is a substance which contains one or more beneficial living microorganisms which when applied to seed, plant surfaces, or soil colonizes the rhizosphere or the interior of the plant and promotes growth by increasing the availability of primary nutrients to the host plant [99]. The modes of action of these biofertilizers include fixing N_2, increasing the availability of nutrients in the rhizosphere, positively influencing root growth and morphology and promoting other beneficial plant-microbe

Table 2: Effects of long-term fertilizers application on soil organic carbon and available NPK.

Treatments	Over the years (1972–2013)					In 41^{st} year (2012–13)				
	SOC (g	Available nutrients (kg ha-1)			Zn	SOC (g	Available nutrients (kg ha-^{1})			Zn
	kg-1)	N	P	K	(ppm)	kg-1)	N	P	K	(ppm)
50% NP(SSP)K+Zn	9.9	142.93	17.81	118.5	1.48	8.50	221.58	19.28	122.98	0.81
100% NP(SSP)K	10.7	224.87	21.10	125.5	0.98	7.93	237.08	21.60	134.55	0.79
150% NP(SSP)K	10.9	335.26	32.36	145.0	0.79	8.63	337.01	37.25	148.33	0.77
100% NP(SSP)K+HW+Zn	10.8	286.07	20.71	123.1	1.74	8.15	231.57	21.15	118.37	1.06
100% NP(SSP)K+Zn	11.1	275.75	19.67	128.5	1.58	8.97	230.29	18.85	120.36	1.02
100%NP(SSP)+Zn	10.1	300.25	20.29	104.3	1.50	8.37	262.40	18.54	94.37	0.87
100% N+Zn	10.0	290.11	10.68	106.4	1.49	8.83	243.46	10.19	90.30	0.67
100% NP(SSP)K+FYM	13.3	401.98	29.57	142.5	1.37	16.08	531.96	34.32	158.65	1.16
100% NP(DAP)K-S+Zn	9.6	283.16	20.55	125.9	1.52	8.23	231.56	21.06	122.43	0.73
control	7.7	119.16	9.19	104.1	1.10	5.58	178.10	7.35	93.67	0.52
SEM ±	0.11	2.35	0.32	0.60	0.02	0.23	5.03	0.90	4.06	0.08
LSD0.05	0.34	6.99	0.96	1.79	0.07	0.66	14.60	2.60	11.79	0.23
Initial soil	14.8	392.0	18.0	125.0	2.4					
Natural fallow	-	-	-	-	1.5	12.9	360.50	16.53	120.00	1.9

Notes: HW: Hand Weeding; FYM: Farmyard Manure; SSP: Single Superphosphate; DAP: Diammonium Phosphate; SOC: Soil Organic Carbon; N: Nitrogen; P: Phosphorus; K: potassium; Zn: Zinc; ppm: Parts Per Million; SEm: Standard Error of Mean; and LSD: Least Significant Difference at 5% probability level. Source [98].

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symbioses [100]. The application of biofertilizers in agriculture has a greater impact on organic agriculture and also on the control of environmental pollution, soil health improvement and reduction in input use [101]. Biofertilizers add nutrients through the natural processes of nitrogen fixation, solubilizing phosphorus, stimulates plant growth through the synthesis of growth-promoting substances, safely convert complex organic material into simple compounds, maintain the natural habitat of the soil, Increase crop yield by 20%-30%, replaces chemical nitrogen and phosphorus by 25% [102]. Therefore, Bio-fertilizers offer a safe option to utilize renewable inputs to improve the fertility of land using biological wastes with those beneficial micro-organisms which impart organic nutrients to the farm produces [103]. The use of biofertilizers is environment-friendly easy to apply, non-toxic and cost-effective and helps to reduce indiscriminate and imbalanced use of chemical fertilizers. The microorganisms, which are used as biofertilizers belong to families of bacteria, blue-green algae and fungi which may be N fixers, P solubilizers, S- oxidizers or organic matter decomposers [103].

Inorganic fertilizers: It a substance containing one or more of the essential plant elements that, when added to a soil/plant system, aids plant growth and/or increases productivity by providing additional essential elements for plant use. The primary function of synthetic N-fertilizer is to provide the crop with an immediately available source of N, often the most limiting nutrient for plant growth. Good fertilizer use practices including the right fertilizer source applied at the right rate, at the right time and in the right place. The right fertilizer source or type is the fertilizer that needs to supply one or more nutrients that are inadequately available in the soil to meet crop needs. Considering the type of fertilizers is also helped to control the loss of nitrogen. Compare to amide and ammoniums containing N fertilizers, nitrate-containing fertilizers are susceptible to leaching, but the contrast to this, ammonium and amide containing fertilizers are more prone to volatilization loss than nitrate-containing nitrogen fertilizers [17]. Because of its positive charge, NH_4^+ is adsorbed by negatively charged soil colloids and it is protected from leaching whereas the negatively charged NH_3^- is subjected to leaching.

Nitrogen fertilizers are usually added as pre-plant or basal fertilizer to soils before planting and/or supplied to soils or sprayed on plant leaves as top-dressing at different growth stages. Among the various methods of N application, deep placement, use of super granules and foliar spray of N fertilizer can enhance the recovery of applied N fertilizer [17]. Two to three split applications of N usually during the growing season, rather than a single, large application prior to planting, are known to be effective in increasing NUE and yield [104,105]. The amount of nitrogen fertilizer to be applied is varied depend on soil type, crop type, variety response, water availability and other sources of nutrients.

Use of varieties with high nitrogen use efficiency: Different genotypes may have different abilities to uptake and utilize nitrogen. Breeding efforts are aimed at developing crop varieties that are more efficient at capturing soil N, thereby decreasing N leaching and denitrification losses and reducing plant N requirements [104]. In general, modern varieties have greater NUE and HI than older varieties did [18]. Thus, breeding new cultivars with higher yield and NUE has become a new and effective approach to improve NUE [106].

Physiological traits that may affect N uptake efficiency include root architecture and any other characteristic that impacts the roots' ability to extract available N from the soil [107]. The capacity of the root for uptake depends on the degree to which the root extends its absorption area, which is determined by complex root morphology such as root mass and depth, root axis length, and lateral branching related to NUE [108]. Specific characteristics amenable to gene dissection may include genes for root architectural traits, nutrient uptake, all aspects of metabolism genes, and processes relating to development including canopy longevity [21]. Genetic improvement of NUE through plant selection, breeding, and genetic engineering is, therefore, another important aspect on which most scientists are highly emphasized at the current time.

Enhancing nitrogen use efficiency through integrated nutrient management

The role of integrated use of organic and inorganic fertilizer on NUE has been reviewed by many authors [33,34,36,38,39,50,109]]. The combined use of organic manure and N fertilizer maintains a continuous N supply, checks losses and thus helps in more efficient utilization of the applied nitrogen [110]. The recent experiment that carried out with a combination of different levels of inorganic fertilizer with different types of organic fertilizer revealed a significant effect on NUE. Four levels of inorganic fertilizer (0%, 50%, 75%, and 100% NPK), on the bases of recommended rates of 150kg Nha-1, 70kg P_2O_5 ha-1 and 120kg K_2O ha-1 were used with cow manure, poultry manure, and vermicompost (5t ha-1each) to examine the NUE of rice in dry and wet season at Japan, and the result was indicated that the greatest N use efficiencies were obtained with 50% NPK + ether of poultry manure, cow manure or vermicompost, Figure 4 [111-113].

Conclusion

Nitrogen is the most limiting nutrient for crop production in many of the world's agricultural areas and its efficient use is important for the economic sustainability of cropping systems. Globally farmers applied a huge amount of nitrogen fertilizer in agricultural crops every year but an only small portion of it is converted into harvested products while a large portion of it lost to the environment and cause severe environmental pollution. Inefficient utilization of nitrogen leads to groundwater pollution, greenhouse effect, negative impacts on human welfare and reduction in productivity of field crops and aquatic ecosystems. The dynamic nature of N and its tendency for loss from soil-plant systems creates a challenge for its efficient management. Nitrogen is lost from the soli-plant system to the environment through various means including volatilization, leaching, surface runoff and de-nitrification. Although crop yield is increased with an increased in total

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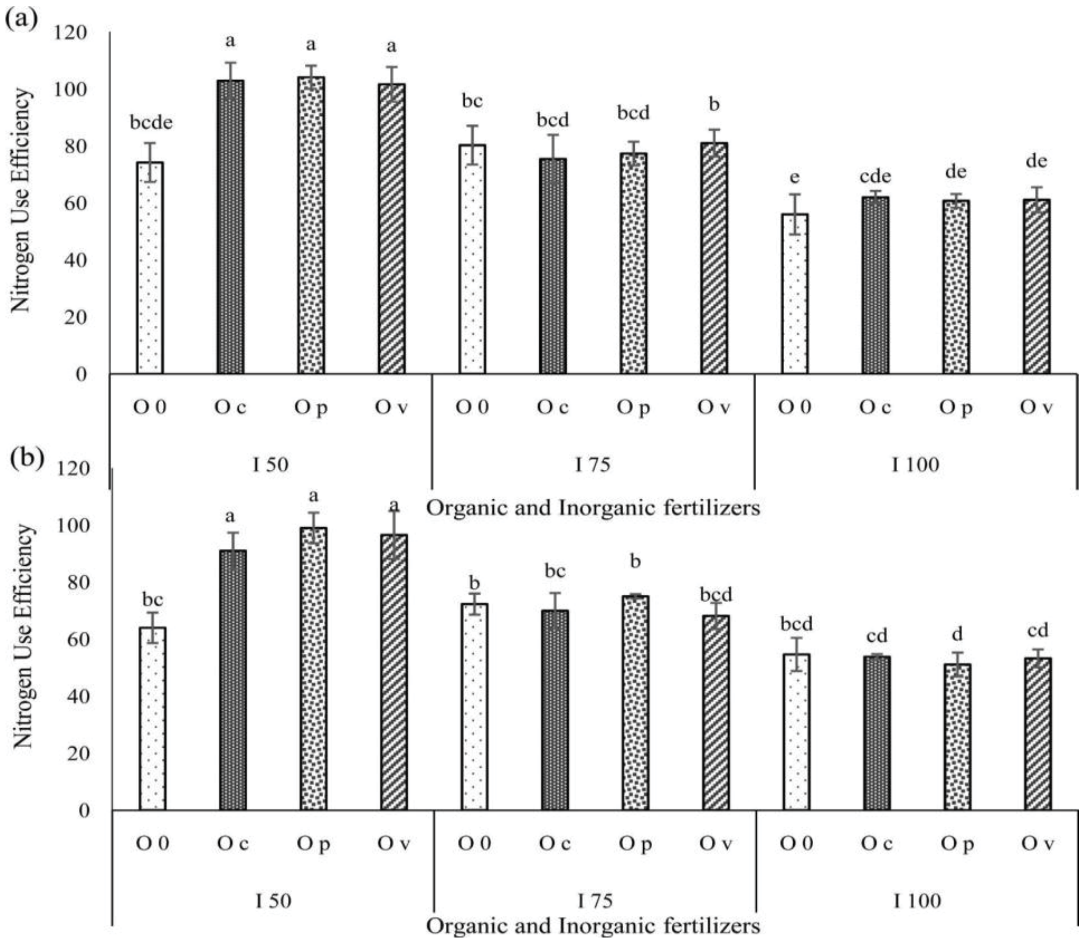

Figure 4: Nitrogen use efficiency of hybrid rice (Palethwe-1) as affected by the combined application of organic manures and inorganic fertilizers. (a) dry season and (b) wet season, in 2015. The histograms with the same letter are not significantly different from the Tukey HSD test ($p < 0.05$). The bar on each histogram indicates the standard deviation. The numbers followed by I show the percentage of NPK applied based on 150 kg N ha^{-1}, 70 kg P_2O_5 ha^{-1} and 120 kg K_2O ha^{-1}. I = Inorganic fertilizer; Oc = cow manure, Op = poultry manure and Ov = vermicompost. Adopted from [111].

nitrogen input, the overall observed global trend showed that a decrease in NUE at the current time compared to past centuries. In order to maintain the long-term sustainability of agriculture efficient approaches to reduce the loss of N and to return nutrients into the soil is required. Nitrogen efficiency can be improved through the adoption of locally as well as scientifically available means of nitrogen management. These improved nitrogen management practices include site-specific nitrogen management, integrated nitrogen management, use of slow-release N- fertilizer or nitrogen inhibitors, an improved method of N application and adoption of resource conservation practices.

Integrated Nutrient Management refers to the maintenance of soil fertility and of plant nutrient supply at an optimum level for sustaining the desired productivity through optimization of the benefits from all possible sources of organic, inorganic and biological components in an integrated manner. Integrated use of all sources of fertilizers like organic, inorganic and biological fertilizers is enabled to maintain a continuous N supply, checks losses and this leading to more efficient utilization of the applied nitrogen.

Perspectives

As discussed above the nitrogen use efficiency of crops is decreased from time to time due to the huge dose application of only inorganic fertilizer and the susceptible nature of nitrogen for various losses. These conditions have a negative impact on the environment, economy and crop quality. To overcome such problems current and future crop nutrient management practices should be emphasized on:

- Promoting effective and environmentally sound management of plant nutrients: Nitrogen use efficiency can be improved by adopting integrated fertilizer, soil, water, and crop management practices to maximize crop N uptake and minimize N losses.

- Optimizing the plant nutrient demand from all possible sources of organic, inorganic and biological components in an integrated manner.

- Increase crop N demand: crop N demand can be increased by genetic modification of crops and by removing plant growth limiting factors.

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- Use of control or slow-release nitrogen fertilizer instead of easily mobile and volatile forms of N fertilizer
- Continues awareness about the negative impact of inefficient nitrogen utilization and multidirectional benefit of integrated nutrient management should be created to farmers, decision-makers and other concerning bodies who engaged in crop production.

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