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Nutritional Management in Rice: Recent Advances for Sustainable Production

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Abstract

Owing to unique biological values, rice (*Oryza sativa L.*) is not only a staple diet for more than three billion humans, but it is also a significant bulwark to the economy of rice growing countries. According to FAOSTAT, the 740.9 million tons paddy was harvested from 159.8 million ha in 2016, and 24.14 million metric tons of fertilizers were applied. The rice grain demand is projected to be double in 2050 to ensure the global food security for more than 9 billion faces. The exclusive morphologies, physicochemical properties, and biological characteristics of the paddy soils require special attention due to low fertilizer use efficiencies. Nutrient mining, stagnation, and deceleration of rice productivity and loss of soil health are the results of imbalance fertilization. To increase productivity through increasing the yield, potentials can only be achieved through proper nutrient management. The indispensable role of recent smart technologies like (remote sensing), quick fertilizers, smart delivery systems, site-specific nutrient management, and 4R strategy is suggested for achieving the food security. Therefore, this chapter will highlight the recent advances focused on enhancing nutrient use efficiency as sustainable management tools to enhance the rice production. The best agronomic practices resulting in yield enhancement will also be highlighted in this chapter.

Keywords: Food security; Rice (Oryza sativa L.); Nutrient losses; Efficiency; Management

Abbreviations: AVHRR: Advanced Very High-Resolution Radiometer; AWD: Alternate wetting and drying; BMPs: Best management practices; Ca: Calcium; CRFs: Controlled released fertilizer; EPA: Environmental protection agency; FAPAR: Fraction of absorbed photosynthetically active radiation; GIS: Geographic Information System; GPS: Global Positioning System; IPNM: Integrated plant nutrient managements; IRRI: International Rice Research Institute; Fe: Iron; LAI: Leaf area index; LLC: Leaf color charts; Mg: Magnesium; MLC: Maximum likelihood classification; MH: Million hectares; MT: Million tonnes; MODIS: Moderate Resolution Imaging Spectroradiometer; NNI: N nutrition index; NT : Nanotechnology; NIR: Near infrared region; N: Nitrogen; NDVI: Normalized difference vegetation index; NUE: Nutrient use efficiency; P: Phosphorus; PGPR: Plant growth promoting rhizobacteria; PNC: Plant N concentration; PNU: Plant N uptake; RVI: Ratio vegetation index; RE: Relative error; RS: Remote Sensing; RMSE: Root mean square error; SSNM: Site-specific nutrient management; SI: Spectral index; S: Sulfur; SAR: Synthetic aperture radar; TPC: Total phenolic content; UN DESA: United Nations Department of Economic and Social Affairs; Vis: Vegetation indices; YGs: Yield gaps; Zn: Zinc

Introduction

Among the sturdy challenges to global food security and sustainability are; how to feed increasing human population while improving and sustaining the natural resources without exerting any hazard for the environment [1-4]. The urbanization is also among potential pressures on agriculture, which is not only engulfing productive lands but also degrading useful quality land resources [5]. The lack of best management practices (BMPs) to bring sustainability in the production of food to counteract the threat of global food insecurity. Poor management of crop husbandry is not only leading to low yields but also land degradation, ecosystem imbalances, climate change, and adverse impacts on human health. Moreover, the agriculture industry will be compelled to feed about 9.6 billion faces by 2050. The balanced fertilization is a crucial hindrance to increase the crop productivity [6]. Rice (Oryza sativa L.) is not only staple diet of approximately 50% of the global population [7], but it is the backbone for GDP based nation's economy in many developing countries [8]. Rice is among most diversified crop in kingdom Plantae, and it is spread across the globe [9]. It is cultivated on low and uplands ecosystems. Rice inhabits more than 57 M ha in South Asia only. Rice cropping systems comprises continuous rice-rice cropping, rice-wheat rotations, maize-rice rotation are followed in lowland rice ecosystems [5, 10-13]. Rice production systems differ widely in cropping intensity and yields ranging from single crop rainfed lowlands and uplands rice with small yields to three times higher crop yields in irrigated systems. Irrigated rice ecosystem in combination with lowland rice systems shares about 80% of worldwide harvested rice area and 92 percent of the total rice productions. The upland rice cultivation accounts only 8% of the global production. Overall, to meet increasing population growth, about 25% more production is required in the coming 20 years. The typical global yield of irrigated rice is 5t ha^{-1} per cultivation, but the regional and seasonal yields may vary with climatic conditions and adopted agronomic practices.

In recent decades, with the upsurge of the world population, the sustainability in paddy production has been questioned with yield stagnation [14,15]. Recently, significant development has seen in estimating rice production-yield gaps (YGs) with the help of crop modeling and data based on field experiments [3, 16-20]. There is a scarcity of information for the heterogeneity prevailing at farm-scale which causes the YGs. The distinctions and quantification of agronomic and environmental factors (e.g., climatic) affecting the YGs sustain as a significant trial [21]. The existing evidence indicates that inappropriate crop husbandry practices are the root cause of YGs [3, 8, 17, 22, 23]. Yield is significantly dependent on regional climate and soil properties [8, 24-28]. Fertilizer is a prime input to get sustainable production of rice and act as a backbone role in achieving food security. The global research experiences in rice cultivation have explained that rationalization of fertilizers is the primarily efficient and significant practice for increasing rice production [29,30]. About 30-50% rice yield is attributed to the application of commercial fertilizers [31]. Above all the challenges in rice production around the world, the low fertilizer/ nutrient use efficiencies remained a challenging issue not only for farmers but as well for the scientific community to deliver sustainable solutions [8,32,33]. Unsynchronized application of fertilizers with rice plant demand and exclusive losses of nutrients from paddy soil is the chief cause of low fertilizer use efficiencies [34]. Among the mineral nutrients, nitrogenous fertilizers have the lowest use efficiency and high environmental costs under paddy soils [4, 35-38]. The nutrient use efficiency (NUE) of conventional fertilizers barely surpass 30–35% for N, 18–20 % for P, and 35–40 % for K. Moreover, these efficiencies of nutrient are persistent for the past several decades [39].

Significant recommendations for enhancing NUE has been published since the introduction of mineral fertilizers, and farmers have gained benefits, but these recommendations are based on data from small regions with a similar climate. Among the conventional ways to boost the fertilizer use efficiencies, the 4-R practices are widely recommended and well appreciated for general farming practices, yet the paddy fields need special attention even 4-R works with the same efficiency in paddy fields as it benefits in aerobic soils. In "paddy soils nutrient management system," specific novel strategies, i.e., "fertilizer application without standing water condition" and "stimulation of N transport with water flow" are suggested to enhance NUE. Split applications, deep placements or foliar applications are among the best practices to improve NUE. Research has explored that placement of urea and ammonium bicarbonate fertilizers to appropriate depths has enhanced the yields up to 11.6%, compared with the routine surface broadcasting method.

Moreover, nitrogen use efficiency was also enhanced up to 12.8%. Balanced application of N, P, K, with other secondary micronutrients guarantees a sensible supply of essential elements for lucrative paddy yields. Due to intensive developments in science and technology, modern techniques and methods are being applied to boost paddy production. Contradictory to conventional practices, new strategies like "site-specific-time nutrient management (SSNM)," controlled release nano-fertilizer (CRF), site-specific precision nutrient management based on satellite sensing, and use of nitrification inhibitors have significantly assured to enhancements in NUE [29]. The integrated plant nutrient managements IPNM is also a holistic approach to optimize plant nutrient supply with an overall objective of adequately nourishing rice crop as efficiently as possible and achieving sustainable soil health while minimizing potential adverse impacts to the environment [30]. Moreover, the use of polymeric materials like biochars as carrier materials or bio-fertilizer is increasingly trending for enhancing nutrient release and nutrient use efficiencies under paddy soils [39,40].

Shortage and surplus of mineral nutrient in plant body result in stress-induced responses, therefore understanding the nutrient status of soil, as well as plant, become prerequisite for wise fertilization. Site-specific nutrient recommendations based on optical sensing using chlorophyll is being adopted at farm levels [32, 41]. Singh et al. [42] presented that excellent yields with high N use efficiency in puddled transplanted rice can significantly be gained through application N fertilizer in moderate quantity at the phase of transplanting which efficiently meets the N demands during the period of active tillering and panicle initiation. The use of optical sensing devices is hugely helpful in measuring N requirements. To deliver reliable and accurate status of nutrient at farmer fields to entire agro-ecological system, has only become doable due to inventions in the field of space-borne remote sensing measurements. Recently, the geo-informatics is among the fastest emerging sciences, surrounded with modern tools of global positioning system (GPS), remote sensing (RS), artificial intelligent simulation modeling and Geographic Information System (GIS). Such technologies provide an effective and accurate way of obtaining real-time data. The GIS delivers the chance to catalog the variability in data and maps of different nutrients [6,43].

The era of science dealing with the materials having dimensions in the array of 1-100 nm, termed as "Nanotechnology." This science of using nano-materials (NMs) has transformed every aspect of life, including the agriculture. However, applications of nanotechnology in the agricultural sector is still on its way to completely overtake the traditional inputs. Nanotechnology seems yielding a promising and sustainable solution to nutrient losses from paddy fields through the synthesis of advanced/slow released fertilizer and nutrient delivery systems in the plants [44]. NM is having the vast surface area, and suitable sorption properties that can reduce the losses by decreasing the runoff and controlling the release kinetics. Precisely, the NMs could also protect active ingredients from degradation or enhance uptake into the plant body. Nano-fertilizers are planned to improve the NUEs by manipulating the exclusive properties of NMs. The nano-fertilizers are being widely produced by fortification of nutrients wither singly or in conjugation/doping with other materials. Physico-chemical approaches are deployed to synthesize NMs. Nano-fertilizers are well-known for active release of nutrients with suitable rates, which helps in improving the NUE without yielding any hazards. The release can be synchronized with crop stage and growth patterns, therefore reducing the environmental issues too [45]. Current rapid growth in population demanding higher rice yields is continuously stimulating the scientific community to invest resources and directions in enhancing the yields. Nutrient management poses the most severe challenge under the rice-production system. Highly efficient strategies for the optimization of nutrient management practices are direly required. Therefore, in this chapter, the recent advances being developed to enhance nutrient use efficiency in rice system and modern agronomic practices have been highlighted.

Table 1: Nutritional components per 100 g rice of various categories [59].

Rice type	Energy	Water	Protein	Lipids	Carbohydrates*	Fibers**
	kcal	g				
Raw-white/long-grain	365	11.62	7.13	0.66	79.95	1.3
Raw-white/medium-grain	360	12.89	6.61	0.58	79.34	-
Raw-white/short-grain	358	13.29	6.50	0.52	79.15	-
Raw-brown/long-grain	367	11.80	7.54	3.20	76.25	3.6
Raw-brown/medium-grain	362	12.37	7.50	2.68	76.17	3.4
White/flour	366	11.89	5.95	1.42	80.13	2.4
Brown/Flour	363	11.97	7.23	2.78	76.48	4.6

2.0. Rice production, global food security, and human health

2.1.0. Why is rice a staple food for over three million people?

Rice is the second most cultivated cereal in all the continents except Antarctica. The high demand for the rice consumption is related to its exclusive nutritional values [46,47]. The food and agriculture organization (FAO), states that a staple food is one that which is eaten habitually and, in such quantities enough to establish the significant part of the diet with the substantial supply of a chief proportion of energy and vitamins/nutrient requirements. Whole rice grain has substantial quantities of protein, carbohydrates, fibers, and vitamins: especially vitamin B complex (B_1, B_2, B_3, B_5, $B_{6,}$ and B_9) and vitamin E along with other bioactive components [48,49,50]. However, the chemical composition and nutritional value of rice vary significantly, with the difference of variety (genetics), production technology, environmental conditions (geographical location), storage duration and primarily with the milling degree [48-51]. The typical proximate analysis of rice grain has been presented in **Table (1 and 2)**. The edible portion of rice or whole rice grain contains rice bran, the embryo (germ) and endosperm [52,53]. Minerals, fat vitamins and dietary fibers are a prominent part of rice bran while germ of the rice caryopsis has a significant portion of proteins and fats along with minerals and almost all the vitamins [54,50].

Table 2: Nutrition contents of brown rice (100 g^{-1}) at 14% moisture [46]

Protein	Crude fat	Available carbohydrates	Fiber			Crude ash	Energy
			Dietary	Water insoluble	Lignin		
(gN x 6.25)	(g)	(g)	(g)			(g)	(kcal)
7.3	2.2	71.1	4.0	2.7	0.1	1.4	384

Rice bran, as defined by FAO, is "a by-product of brown rice polishing, consists of the pericarp, aleurone layer, germ, and some endosperm" [51]. This aleurone layer is enriched with lipophilic antioxidants (tocopherols and γ-oryzanol) and phenolic acids [52,55]. The lipid content in bran ranges from 19.4-25.5% [55] while γ-tocopherol is major vitamin E component. These substances act as a defense against chronic cardiovascular diseases, help to capture the free radicals, and have anticancer effects [52]. Polyphenolic compounds present in rice grains specifically in rice husk are considered as the most effective natural antioxidant and prevent against chronic diseases such as atherosclerosis, diabetes, and obesity as well as cancer and cardiovascular problems [53,50]. One popular product extracted from bran is "bran oil" used for cooking in many Asian countries [55]. Rice embryo, also known as rice ger, has considerable quantities of vitamins B_1, B_2, B_6, and fiber. The critical component of vitamin E in the germ is α-tocopherol, that is five times higher than in bran, and lipid content of germ is about 34.1-36.5% [52,55]. It is estimated that about three-fourths of the fat and nearly fourth of the protein of whole rice grain are present in rice germ [54]. All these components together possess anti-inflammatory, anti-hyperglycemic, and anti-hypercholesteremic properties as well as antioxidant effect [52,54]. Milled white rice mainly consists of the starch and protein as the only endosperm is left. In endosperm, about 90% starch (including amylose and amylopectin) with 5-7% proteins and only 0.8-1% lipid content is present accompanied by trace quantities of vitamins and minerals [54,55].

Rice is processed before marketing and consumption. From harvesting to the production of polished and graded white rice, the whole practice is known as rice processing [52]. Harvesting and threshing processes yield paddy rice as a product with a moisture content of 20% that is then dried down to approximately 14% moisture content [56]. The paddy rice is passed through several milling processes to yield brown rice (husking) and white rice (whitening and polishing) together with other by-products like husk, bran, and germ. Rice straws, produced as a by-product of per kg harvested paddy, ranges from 0.41 to 3.96 kg depending on cutting-height of the stubbles, variety and moisture content. While the husk, bran, and white rice production range from an ideal milling process are established to 20%, 8-12%, and 68-72% respectively, depending on the variety and milling degree [52].The husk is removed to make rice edible, yielding brown rice, and process is known as husking or hulling [50,52]. Brown rice are subjected to whitening (removal of bran) followed by polishing (removal of remaining bran particles and kernel's exterior polishing) in order to increase shelf life of rice and to meet the consumer preference for white rice over brown rice like softness, digestibility, appearance, lightness and shorter cooking time [48]. Oil contents present in bran reduce the storage life of rice by making it rancid [57]. However, this process results in a significant loss of nutrients, as stated in the table (3). Other pre-consumption operations like washing and cooking using ample water volumes also reduce the mass of nutrients, thus making rice a diet with low nutrition level [48,56]. Other problems associated with rice consumption are exposure to toxic substances such as heavy metals like arsenic and cadmium, pesticides residues like organochlorines and whitening agents added during the process of polishing like chlorine dioxide [49].

Table 3: Nutrients loss during normal milling process

Nutrient	**Loss (%)**
Vitamin B complex	
(B_1)/Thiamin	68-82
(B_2)/Riboflavin	57
(B_3)/Niacin	64-79
(B_5)/Pantothenic acid	51-67
B_6/pyridoxine	43-86
(B_7)/Biotin	86
(B_9)/Folic Acid	60-67
Vitamin E (α, β, γ, δ-tocopherol, tocotrienols)	82
Protein	10-16
Fibers	63-78
Fats	77-82

2.2.0. Global rice production; an overview

United States Department of Agriculture Statistics revealed that about 50% population of the world is using rice as their chief food source [58]. Rice, a semi-aquatic annual grass plant, belongs to genus (*Oryza)* that in which 24 species of rice are included, from which only two are cultivated, i.e., *Oryza glaberrima, and Oryza sativa L*. The leftover 22 are wild species [46,52,60]. The *sativa* Sp. is commercially cultivated in more than 112 countries globally because of its high adaptability to a wide range of climatic conditions from dry hilly slopes to deeply flooded lands, whereas *Oryza glaberrima*, which is highly tolerant to heat and iron toxicity, is grown only in the West Africa [46,52]. The global annual production for the previous 10 years is presented in table (4). Data indicates that global rice production is increased considerably in contrast to the cultivation area. Approximately above than 90 percent of the total rice is produced only in Asia [46,52,58]. China being the top producer and India as the second largest contributor in global rice production, collectively shares about 50% of total rice output [52,56]. While Indonesia, Bangladesh, Vietnam, Myanmar, and Thailand, together produce 30% of total global rice production [61, 62]. Other prominent rice producing Asian countries are the Philippines, Republic of Korea, Indonesia, Cambodia, Japan, Pakistan, Nepal, and Sri Lanka. Non-Asian countries which are contributing about 5% of total rice output include Brazil, Egypt, Madagascar, Nigeria, and the United States. The total production of top 10 rice producing countries in 2016 with per unit yield is given in table (5). Despite such a large production, the export quantities of rice are meager because rice is consumed usually in the same countries where it is produced, so, the global rice trade is about 7% of total rice production [56].

Table 4: Global Paddy Rice Production (million tons) from 2007-2016 in comparison to harvested area (million hectares) and per unit yield

Year	**Production**	**Area**	**Yield**
	(MT)	(MH)	(kg/ha)
2016	740.96	159.80	4636
2015	740.08	160.76	4603
2014	742.42	162.91	4557
2013	741.98	164.53	4509
2012	736.26	162.18	4539
2011	726.37	162.71	4464
2010	701.10	161.67	4336
2009	685.65	157.79	4345
2008	687.05	160.07	4292
2007	656.55	155.31	4227

Source: (62) FAOSTAT, 2018 (http://www.fao.org/faostat/en/#data/QC)

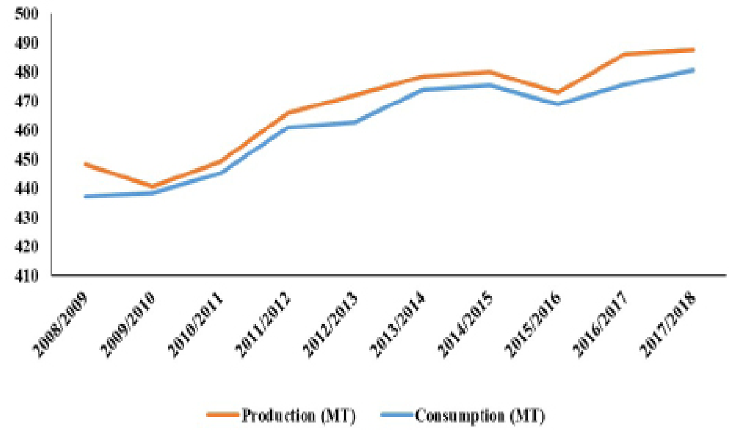
Table 5: Top 10 highest rice producing countries in 2016

Country	Production	Area Harvested	Yield
	(MT)*	(MH)**	(kg/ha)
China	211.090	30.449	6932
India	158.756	42.964	3695
Indonesia	77.297	14.275	5415
Bangladesh	52.590	11.385	4619
Vietnam	43.437	7.783	5581
Myanmar	25.672	6.723	3818
Thailand	25.267	8.677	2912
Philippines	17.627	4.556	3869
Brazil	10.622	1.943	5464
Japan	8.044	1.479	5439

2.3.0. The current yield-demand gap in rice production:

Until now, the gap in rice demand and production was not so wide because the average rice production of the world increased proportionately to the growth of population during the era of the green revolution [56,61]. Such as in the years 1966-2000, paddy rice production amplified by 130% while during the same period, the population of developing countries increased by 90% [56]. This rise in yield, along with technological advancements, improved verities, and increased fertilizers input, is also attributed to the expansion of cultivated area [61,63]. However, from the last decades of the 20th century to onward, no significant rise in rice yield has been observed as compared to the period of the green revolution [47,54]. Annual rice production and consumption data are given in figure (1). Despite the fact that consumption is lower than production, still, a huge number of populations is suffering from the supply-demand gap of rice such as those living in poor Asian countries, i.e. Afghanistan, North Korea, Vietnam and Nepal [61]. Global climate change, extreme weather conditions, water scarcity, soil salinity and low nutritional status of soil along with increasing population have potentially affected rice production in terms of quantity and quality [54]. Micronutrients deficiencies specially of calcium, iodine, iron, zinc and vitamin-A are reported in many people who are using rice as their main food source [54,64,65]. Conditions are going to be adverse with time as farmers must grow rice in the coming decades with a lesser amount of water and inputs on less existing lands for more population [66]. Estimation shows that at least, additional two million tons of rice per annum are required to fulfill the increasing demand of top rice utilizing countries where the population is rising at a rate of 1.5% annually [47]. Approximately 75% of global rice and 90% of rice in Asia is cultivated under flooded/submerged puddled soils [63]. In such type of systems with irrigation, about 2672 L of water is needed to produce about 1 kg of rice.

Figure 1: Year wise data of global milled rice production and consumption
Source: Statista – The portal for statistics (www.statista.com/statistics)



Overall per capita, rice consumption is also increasing with time such as in 2000, Asian annual per capita rice consumption was 81 kg, which exceeded to >110 kg in 2014. Per capita consumption has been presented for some regions in the table (6). Likewise, Asia, annual per capita rice consumption in other continents is also increasing with years, for instance, in South and North America it is recorded to reach 45 and 70 kg in 2014 from 31.1 and 11.2 kg in 2000, respectively [56,67]. According to the United Nations Department of Economic and Social Affairs, the presented that the global population of 7.6 billion is expected to touch 8.6 billion in 2030 and 9.8 billion in 2050 [68]. International Rice Research Institute states that to feed one billion people, about 100 million tons of paddy rice are required [69]. So, net demand for milled-rice is expected to touch 481.9 MT in 2025 and 525 MT in 2050 [61]. According to an estimate, the demand of rice in Asian countries will be increased by 70% in the next 30 years with rising in population while the rice production should be increased by 40% before 2030 to meet the demands of a growing population [54,56]. For growing such a large quantity, the same land area is required as of today with less water and chemical inputs [54].

Table 6: Per capita rice consumption in different regions of world [56,67]

Country/Region	Annual per capita consumption (kg)	
	Year-2000	Year-2014
Asia	81	>110
South America	31.1	45
North America	11.2	70

3.0. Soil sufficiency levels of mineral nutrients for proper rice production

Soil sufficiency of mineral nutrients is a relative term which is mostly expressed in nutrient concentration range. This range lies between the extremes of critical deficiency to nutrient toxicity. Determination of soil sufficiency level is a pre-requisite for efficient usage of amendments and thereby improved crop production. Soil sufficiency level of mineral nutrients varied greatly from site to site. Application of balanced fertilizer (NPK) in soil improved both the agronomic and recovery efficiency while imbalanced application leads to micro-nutrients deficiency. Deficiency of zinc (Zn), phosphorus (P), or iron (Fe) is reported in rice fields of Asia, which further limits rice production [12]. In about 179 rice fields of China, India, Vietnam, Indonesia, and the Philippines, the recovery efficiency of nutrients was as; N (33%), P (24%) and K (38%) [70]. While globally compiled data documented, 46% was the average recovery efficiency of N [71]. In modern rice production technology, the use of proper nutrient management has an important role in enhancing the crop yield by enhancing the agronomic efficiency of crop. These practices strived to accomplish nutrient management in the form of balanced fertilizer recommendations, proper timing of fertilizer application, their placement, and methods of application [72].

3.1. Why paddy soils need high attention to nutrient management

Efficient nutrient use and appropriate management have become important tools to achieve higher rice productivity. Use of proper organic and inorganic nutrient amendments, appropriate fertilizer inputs, efficient methods, soil pH and water management, high yielding varieties and keeping the timing of fertilizer application in consideration can provide large potential in improving crop productivity. Therefore, nutrient management has supreme importance in enhancing rice yield and profitability [72].

3.1.1. Nutrient management for lowland rice

In lowland rice production of the aerobic environment of the root zone is converted to anaerobic, which significantly affected the availability of nutrients. The flooded condition in lowland rice cultivation showed minimal nitrogen use efficiency because most of the N applied is lost via leaching and denitrification [73]. Therefore, N appropriate application for optimal production and losses should be maintained by following different management options. Thus, it is important to choose the appropriate N fertilizer and formulation and added in soil with the judicious amount with proper placement at the right time [78]. For low land rice production, an ammoniacal form of N is recommended such as urea. Ammoniacal form of N contains NH^{4+} which may be fixed to soils cation exchange complex near to its placement, thereby enhanced the N use efficiency [73]. The fertilizer use efficiency of nitrogen in rice varies greatly with the time of application and fertilizer source. Nitrogen fertilizer recovery efficiency in rice is 20-80% [74] with 30-40% average range [75]. The nitrogen not accounted in recovery efficiency may be lost through leaching, denitrification and/or volatilization, while a small amount of this nitrogen becomes part soil organic carbon by incorporated in microbial biomass. The recovered N from organic fraction generally ranges from 16-25% [76]. The shift from blanket recommendation to site-specific demands is management practice to be considered critically for the improvement of synchrony between supplies of N to the actual demand of plant [72]. Guo et al. [77] surveyed 735 farmers and conducted 6 experiments; the results showed an increase in crop yield by adjusting the application timing of fertilizer and controlling the N rates.

In the United States, the recommendation for P fertilizer is 10-40 kg P ha^{-1} for maximum rice production [79]. In Asia, to obtain maximum rice yield, 26 kg has^{-1} is recommended [80] and for high fixing capacities of soil, the input of 97–175 kg P ha^{-1} is required for optimum growth [81]. The rate, method, and timing all have a significant role in improving P use efficiency. According to Massawe and Mrema, [82], 60 kg P ha^{-1} should be applied to avoid P depletion with time from the soil as well as to ensure the build-up of P in soil. The management of P is focused more on keeping the soil adequate P level to ensure the crop productivity [83]. The residual effects of P fertilizers from all input sources should also be kept in mind during nutrient management to avoid unbalanced fertilizer addition [83]. The broadcasting of nitrogenous materials earlier to the tillering stage is mostly subjected to losses due to the low requirement of paddy crop. While at the tillering stage and panicle initiation stage N is excessively and quickly taken up. To obtain optimum rice yield under flooded condition, 50 kg K ha^{-1} is recommended to apply in the rice field [80]. Fairhurst et al. [83] suggested that 25 kg K ha^{-1} must be applied in a rice field for each increase in a ton of target yield. The incorporation of crop residues also added a substantial amount of K back into the soil. According to Pillai [84], recommended "NPK" rates for lowland rice production in different geographical regions are as given in **Table (7)**:

Table 7: Recommended "NPK" for rice production in lowland ecosystem of different countries

Region/Season	Country	Recommended fertilizer level (kg ha^{-1})		
		N	P	K
Haryana	India	125	11.4	41.5
Pattambi, Kerala		90	19.6	37.3
Wangdipho-drang	Bhutan	75	21.8	0.0
–	Egypt	100	16.2	0.0
Muridke	Pakistan	120	11.4	0.0
Dera Ismail Khan		135	17.5	30.7
Dry season	Indonesia	140	15.3	24.9
Wet season		80	7.9	24.9
West Java		115	10.9	33.2
Nueva Ecija	Philippines	90	12.2	23.2
Guadalupe, Laguna		100	13.1	0.0
Tarlac		80	21.8	24.9
–	Sri Lanka	73	25.3	48.1
Hyogo Prefecture	Japan	170	53.3	141.1
MUDA	Malaysia	80	13.1	24.9
Hathazari	Bangladesh	80	12.2	14.1

The anaerobic environment developed by flooding leads to reduced redox potential or oxidation-reduction which ultimately converted the unavailable Fe^{3+} and Mn^{4+} form to available Fe^{2+} Mn^{2+} form. Thus, the concentration of Fe and Mn increase by reduction. The reduced paddy soil condition results in the improvement of some nutrients like (Ca, Mg, Fe, Mn, Mo, and Si) [85].

3.1.2. Nutrient management for upland rice

In upland rice growing, extensive N deficiency is reported due to soil acidity, erosion, low organic matter, N fertilizers high cost and low usage, low N use efficiency, imbalanced fertilizer usage, and insects, disease or weeds infestation.

Appropriate application of N fertilizers along with efficient N varieties of rice provided better N use efficiency and higher yield of the crop [86]. High P sorption capacity of the soil or innate P low concentration in the soil makes deficiency of P in soil. To cope with P deficiency, appropriate P application, placement of P in bands in high P adsorbed to soil, and low P content soil, us of advance and productive genotypes improve the mycorrhizal association and lime usage in acidic soils [9]. In upland rice production regions, K deficiency is not common, but still, soil K reserves will be insufficient for the long run. Keeping in view, the economic feasibility applies K fertilizer in soil along with the following two management practices. First practice is to incorporate the remains of crop into the soil as 70-80% of K taken up by rice and wheat is remained in shoots. In this way, substantial K amount can be recycled. The second practice is to improve K use efficacy by using K efficient varieties [9]. Calcium (Ca) and Magnesium (Mg) deficiencies in upland rice cultivation are alleviated by the use of dolomite lime and efficient Ca and Mg rice cultivars (87). Sulfur (S) deficiency is not common in upland rice regions because the fertilizer applied for N and P contain the content of S as well. But in the long run, the use of fertilizers which do not contain S content could lead to S deficiency in the soil. Malavolta et al. [88] reported that 10 mg kg^{-1} is the critical value of S in upland rice soil and showed increased yield of rice with S application.

Zinc (Zn) is widespread in upland rice cultivation and contributes a limiting factor in crop production. The most common practice to deal with deficiency is the application of Zn with other fertilizers. The required/pre-available quantity is measured through the amount of Zn in soil, organic matter content, pH, soil base saturation, and cultivar to be used. In upland rice grown regions, application of 5 to 10 kg Zn ha^{-1} via zinc sulfate is an adequate amount to overcome the deficiency. Zn deficiency can also be resolved through the foliar treatment of 0.5% liquid. The amount of application depends on deficiency severity. In the selection of Zn sources, the solubility of the source should be kept in mind because it is effective for the crop if the used fertilizer source is 40% water-soluble [89]. Iron (Fe) deficiency is most common in calcareous soils with high pH. The plant available form of Fe^{2+} usually is present in Fe^{3+} form. Thus reduction of Fe is an obligatory step for plant uptake. Liming is another factor contributing to Fe deficiency in upland rice grown regions. As compared to soil application, foliar application proved more effective in ameliorating Fe deficiency. Foliar application of 2% solution by Iron sulfate corrected the deficiency. A n, The number of applications, depends on the severity of the condition (90).

3.2. Farmer practice in rice-producing regions

According to the classification system presented by the international rice research institute (IRRI), There exist four agroecosystems for rice production, which are recognized as:

- Irrigated ecosystem/farming
- Rainfed lowland ecosystem/ farming
- Upland ecosystem/ farming
- Deepwater ecosystem/ farming

The cultural practices varied from condition to condition. Like in irrigated areas, both transplanting and direct seeding of rice establishment is in practice. That's why one set of cultural practices do not work efficiently in all rice ecosystems. According to Meera et al. [91], four ecosystems were developed and currently exist in India. The choice of method depends upon a topography of the land, the pattern of rainfall, type of soil, availability of labor, availability of water, etc. [92,93]. The methods for rice establishment are:

- Dry/semi-dry upland cultivation
- Wet/lowland cultivation

In general, direct seeding and seedling transplanting are the most common methods for rice cultivation. In direct seeding, seeds are sown directly in the field either by row seeding on by broadcasting in dry or wet soils. While, in transplanting, seedlings are grown on seed beds before transferring to the main rice field. Direct seeded rice (DSR) follows major three methods principally described by Thakur et al. [94] and Balasubramanian and Hill, [95]:

- Seeding in dry soil (sowing seeds in dried soil)
- Seeding in wet soil (Transplanting of pre-sown seedlings in soil having puddled conditions)
- Seeding under entirely submerged soils (dry or pre-germinated seeds grown in standing water)

DSR production is becoming popular because transplanting method needs intensive water, labor, and energy and have adverse effects on soil physical properties and the environment by methane emission [96,97]. Direct seeding is a commonly adopted method in America, Europe, and Australia and to some extent in Japan and South Korea. Onaverage, 23% of rice is grown by the direct seeded method. In , china, the proportion of direct seeded cultivation increased by 10 % (98). Transplanting methods are divided into 2 categories [99].:

- Manual transplanting
- Mechanical transplanting (growing nursery in matt nursery by self-propelled rice trans-planter)

Transplanting method ensure less weed problem and high yield. Seedlings raised from seeds and grown in a nursery for 4-6 weeks, then transplanted in puddles soil, which in consequence ensure uniform plant stand [93]. The direct-seeded rice production area has been enlarged from 2 % to 11 % in 2000 and 2009 respectively. At the same time, the mechanical transplanting practice has increased from 2 % to about 13% [100].

3.3.0. Soil-plant nutrient analysis: a pre-requisite for nutrient management

The uncertainty faced by farmers in determining how much and at what time fertilizer to be added in soil, is important factors limiting nutrient efficiency. Therefore, synchrony of supply-demand must be attained by fertilizer management keeping in focus the field to field variability. Within a small recommendation domain, the amount, timing, and a number of splits of nutrients varied considerably. Thus, soil-plant nutrient analysis is a pre-requisite for nutrient management. In term of N, the doubt can be suppressed by keeping correct information on soil N supplying capacity which in result improve grain yield by 7% and N-use efficiency by 30 to 40% in 179 rice fields of Asia [41]. Excessive N application and inefficient N splitting are some other major reason for low N-use efficiency. Recovery efficacy of N was improved from 31 to 40% when rice cultivated in field-specific management [101]. Buresh, [102] focused onthe application of N inappropriate time using crop and soil specific needs. In many developing countries, the practice of blanket recommendation of N on broad-based is a common practice for N management. This fixed rates and timings for variable fields cannot provide beyond limit relief in improving N-use efficiency [103]. No doubt, blanket recommendations could provide optimum production compared to low nutrient supplies in any region. It is a simple adoption with no expense on soil analysis, but the variation in soil fertility is not kept under consideration as fertilizer wastage in some fields.

For synchrony of site-specific nutrient demand with the demand for rice, soil and plant analysis are done. But these analyses are time-consuming and do not consider the weather variation during the crop season. Mostly, the farmer used leaf color as an indicator in rice for the need for N fertilizer. Diagnostic tools which can help in assessing the real N requirements at the specific growth stage of the plant originates from spectral characteristics of rice leaves are “leaf color charts” (LCC), ground-based remote sensors, digital, aerial, and satellite imageries, and chlorophyll meters. Among these, LCC, Green Seeker optical sensor and chlorophyll meters have been widely used for more than a decade in improving N-use efficiency. For example, the use of chlorophyll meter as N management significantly improved N-use efficiency of different rice fields [104,105]. Compared to chlorophyll meter, LCC is simple, inexpensive, and easy to use that measures greenness of leaf by visually comparing with the LCC and proved beneficial for low-income farmers of Asia [106]. LCC used two major approaches

- Real-time approach
- Fixed splitting pattern approach

For P fertilizer recommendation, calibrated soil tests provide the best estimate while on the other hand, routine soil tests may not deliver the authentic criteria for P requirement to lowland rice. Because in flooding, the reduced condition aggravated the accessibility of P to rice and reduced the P desorption. For example, soil test showed low P values for growing lowland rice but either responded to P fertilization or not [107]. Likewise, many extractants under or overestimated the P availabilit, and this prediction is further compromised by anaerobic condition used for lowland rice production. Sanyal and De Datta [108] reported that measurement of P through “Olsen method” is commonly used method which gives accurate and reliable estimation of available P. Extractable K from soil is significant pointer to gauge the quantity of available K in paddy soils, but their levels showed immense changes under strong K fixation and in aerobic-anaerobic soil conditions. In rice soil, 0.17– 0.21 cmol K kg^{-1} is generally accepted a critical level in rice soils for 1N ammonium acetate extractable K. In US, K fertilizer is recommended when soil exchangeable potassium is <60 mg K kg^{-1} [109]. Zn deficiency in lowland rice production is a limiting productivity phenomenon [110]. The critical soil Zn concentration ranges from 0.5-2.0 mg Zn kg^{-1} and up to 3.0 mg Zn kg^{-1} for DTPA and Mehlich-1 extraction, respectively [111]. Fe deficiency is identified by different analysis of plant and soil. 5 mg K kg^{-1} is the critical soil Fe level in upland rice when DTPA is used as an extractant, and for plant analysis interpretation 70-300 mg K kg^{-1} is the Fe-sufficiency range of dry plant tissues (tops of rice plant collected at the tillering stage) [112].

4.0. Role of balance fertilization for optimum rice yields

Imbalanced use of mineral fertilizers in paddy field has led to decreased quality and productivity of rice [113]. Efficient use of fertilizer is not only pre-requisite to fulfill the food security but also necessary to maximize farmers' profits. Truth can't be denied that imbalanced availability of mineral nutrients not only results in reduced yields and quality of grain but also leads to depletion/mining of nutrient reserves in the soil and subsequently resulting in soil degradation. Such condition also results in low NUE of applied fertilizers, mainly NPK [114]. Balanced use of inorganic fertilizers is a key to improve quality, increased yield, and disease and stress resistance for rice crop. Imbalanced, inappropriate and overuse of fertilizers are a significant cause of low rice productivity in developing countries, especially in Asia [115]. This unbalanced and excessive use of inorganic fertilizers not only environmental issues but also a nutrient imbalance in agricultural areas [116]. The notion of "balanced fertilization" is simple and was developed about 150 years earlier [114]. Balanced fertilization is related to optimal usage of inorganic and organic fertilizers of good quality in appropriate quantities to supply a balanced ratio of nutrients and ensuring the soil capacity to maintain profitable yields in a sustainable way. Balanced fertilization strategy is primarily designed to supplement limiting nutrients. Although the benefits of balanced fertilization in rice have been logged by the research community, cases from farmer fields are scarce.

In recent years, indiscriminate application of N, P, K fertilization has been practiced either due to subsidized prices of N fertilizers or high prices of P and K fertilizers (like south Asia and other countries around the globe. Lack of basic agriculture training and knowledge to small scale farmers in developing countries is also leading to imbalanced fertilization practices. The decreasing of "factor of productivity" or "response ratio" in rice crop mainly due to imbalance fertilization to 6 kg is another alarming situation [117]. In the post green revolution era, multiple nutrient deficiencies, including micronutrients, being one of the crucial problems making systems unsustainable [118]. Moreover, deficiency of Zn is very frequently being reported under rice-based cropping system [119]. The current micronutrient mining, especially the depletion of Zn in paddy soils, is the result of unbalanced fertilization. The nutrient harvested by the crops very far exceeds the quantities replenished by applied fertilizer, causing a much greater strain on the indigenous resources of soil and its productivity. Nitrogen is the element which confines the most the rice production, and it is the topmost applied element in paddy soils. In Asia, above than 90 percent of global rice is produced. About 60% of N-fertilizers are consumed only for rice production. The N loss as ammonia volatilization or nitrate leaching from a flooded rice field can be as high as 50% of the applied N [120]. Optimum, N-fertilizer application is essential for higher rice yield but overdose of fertilization by farmers has reduced nitrogen use efficiency in many paddy soils, consequently causing low yield and socio-economic harms (1, 121). This excessive N fertilization also causes a non-point pollution source [122]. Despite the overdose of N fertilizer in the last three decades, rice yield remains stagnant, which leads to decreased nitrogen recovery efficiency [113,123]. Mostly, in conventional methods, N is applied in three splits to rice, e.g., one basal dose and two top dressings. This inappropriate application results in N loss in shape of ammonia by volatilization and leaching attributes.

Phosphorus is a crucial nutrient for photosynthesis and energy transfer processes in plants [124]. Phosphorus deficiency is common around the globe, which affects plant growth and metabolism and leads to a reduction in leave numbers, delayed maturity, and disease resistance [125]. Phosphorus availability under many tropical and sub-tropical paddy soils has been decreased. Application of phosphorus in rice field will go for substantial fixation or lost by runoff or leaching attributes. This P fertilizer loss can be minimized by applying different strategies, e.g., P source evaluation, time, and method of P application. For a better understanding of rice phosphorus nutrition, the response of applied P to rice growth, P availability, and adsorption in paddy soil is important before the addition of phosphatic fertilizers [126,127]. Potassium is the major plant nutrient found in soil, but its appropriate application is neglected by farmers. Addition of the right dose of potassium in paddy field helps in decreasing nutritional disorders and increasing plant resistant against pest and diseases [128]. Potassium is found in soluble and exchangeable forms in soil and inadequate application results in depletion of soil fertility. There is a big gap between addition and removal of all essential nutrients and been increasing day by day. For 1 ton of rice grains production, 9 kg potassium is required for maximum yield [129].

Together with macro mineral elements including (N, P, K, Ca, Mg and S), the eight other essential nutrients (Cu, Zn, Fe, Mn, Mo, B, Ni, Cl) also need significant attention. Moreover, the scientific debate on the essentiality of Si, Se, and Na is going on but the fact which can't be denied that plant gets benefits from these nutrients [124]. Si has been ranked as agronomically essential for rice crop in Japan and Brazil [130]. Collectively, these nutrients not only play also play crucial roles in plant physiology but also in humans. Micro-elements have a direct metabolic role in growth and development and support our immunity system to respond to several diseases. Most of the enzymes, proteins, and many other biological structures in our body functioning vital process could be stopped due to micronutrients deficiencies. "Hidden hunger" presents the deficiencies of micronutrients present in daily diets. Soil-micronutrient deficiencies are globally spread phenomenon [131,132]. Yet, soils contain substantial quantities of micronutrients, but deficiencies could occur depending upon the physiochemical characteristic of soil. Availability microelements can be delimited through manipulation of soil physical, biologica, and chemical features. Micronutrients are highly dynamic, and their mobility is usually controlled by soil pH and ionic strengths. These cationic nutrients usually show strong attraction for complexation with anionic nutrient like phosphates and carbonates [124,133-135]. The application of micronutrient either applied as soil fertilizers alone/ combination with major fertilizers or foliar dressing have been seen to increase yields. Shivay et al. [136] confirmed that Zn application along with urea in rice, promoted the biomass, grain yield, and grain Zn nutritional quality up to 20, 29, and 57%, respectively. From a 41-year field experiment conducted by Shahid et al. [137] consisted of rice-rice cropping system aimed for balanced fertilization demonstrated that micronutrients with manures in combination with mineral fertilizers yielded a positive balance of nutrients (Fe, Zn, and Cu) but the Mn-balance was reported negative. The highest positive balance computed for Fe in "NPK + FYM treatment." The results claimed that the balances nutrients were harmful in treatments having no manure or any kind of fertilizer application. Manures and phosphatic fertilizer application increased the concentrations of all micronutrients. Many studies concluded that applying micronutrient through foliar application in rice results in profitable yields [138,139].

5.0. Nutrient regulation to enhance nutrient use efficiency (NUE)

The statistical data available for the year 2010 presents that globally, about 15% of nitrogen and 13% of P/K of fertilizer were used in rice cultivation [140]. Fertile soil, in combination with favorable climate and good management practices leads to high nutrient use efficiency and maximum yield. To narrow down the yield gap between research and farmer's field, there is a need to improve nutrient use efficiency by improving the agronomic practices. Thus, location-based solution and technologies need to be addressed to nutrient use efficiency.

5.1.0 Site-specific nutrient management

The concept of "Site-specific nutrient management (SSNM)" for rice cultivation came to practice from the middle of the 1990s as a best management practice and alternative approach to synchronize the fertilizer applications in field-specific needs [41]. The SSNM strongly emphases on evolving a nutrient management program that considers the following features into considerations [70,141].

- Temporal variability in land originated due to any factor (Season specific etc.)
- Indigenous soil nutrient supply capability at each site (site specific etc)
- Medium-term fluctuations in soil nutrients (N, P, K supply) based on the cumulative nutrient balance or the cultivar differences.
- The physiochemical characteristics of soil (drainage capacity, water holding capacity, etc.)
- The edaphic factors/ environmental factors.

5.2.0. Integrated nutrient management (INM)

Integrated nutrient management (INM) is a point to discuss. either this is a new concept or old one, but this concept has directed the crop production towards the sustainability. Many of our crop production snags (increasing cost, declining yield, loss of soil productivity) is resulted due to poor nutrient use efficiency. INM combined the nutrient cycle keeping in consideration of crops, livestock, organic recycling, soil, use of organic manures along with inorganic fertilizers and biological N fixation [142]. INM focused on preserving the atmosphere for the future by improving the agriculture production. In this approach, the combined application of organic and inorganic fertilizers is applied to preserve soil degradation, enhance crop production and most importantly maximizing the future food supply requirements [143]. Proper fertilization and application methods such as split application of fertilizer at important phenological phases of the crop. Combined application of organic and inorganic fertilizers and use of slow release fertilizers are also important for enhanced crop production. Ding et al. [144] performed a meta-analysis to quantify the effects of substitute fertilization techniques, i.e. slow-release nitrogen fertilizer (SRF), organic fertilizer, (OF), straw return (SR), green manure (GM) secondary/micronutrient fertilizer. Alternative fertilization gives better yield as compared to conventional fertilizers. Increasing order of yield: OF (7.8%)>SRF (7.4%)>GM (6.7%)>SR (5.4%)>SMF (4.6%). Nitrogen recovery efficiency 6.0-34.8% and the partial factor productivity of nitrogen were increased by 4.7–6.9% when alternative fertilization options were used.

INM can be reflected in an effective way to ensure global food security and improving the quality of the environment by minimizing the run-off, improving plant uptake and nutrient use efficiency [100,145,146]. INM significantly enhanced the yield of rice, and the application of azotobacters significantly enhanced the availability of P and N [147,148]. Jha et al. [148] also depicted that INM significantly decreased the rates of N-application; while improved rice yield and soil nutrient resource. Nath et al. [149] suggested that INM treatments resulted in the significant increase of grain yields of rice (3.68 t ha^{-1}) even over the 100% inorganic NPK treatment. INM strategy was also helpful in increasing the organic carbon, bacterial populations, microbial biomass carbon, and soil enzymes. Sharma and Sharma [150] reported that INM augmented straw yields 0.7–2.3 t ha^{-1}, grain yield 1.2–1.3 t ha^{-1}, uptake of N 38–45 kg ha^{-1}, P uptake 7–10 kg ha^{-1}, and K by 25–42 kg ha^{-1}, available N by 6–24 kg ha^{-1}, available P by 7–8 kg ha^{-1}, and K by 7–32 kg ha^{-1} and organic C content of soil by 0.09–0.15%, of rice-wheat system. Singh et al. [151] documented that average grain yield of rice (3.2 t ha^{-1}) and wheat (2.9 t ha^{-1}) and subsequent wheat yield was also improved from 43.1 to 48.9% when INM practices were applied. NPK pool of soil was increased under INM treatments. Utilization of indigenous and regionally produced resources like press mud, compost, industrial by-products, etc. or neem cake could be cheaper sources of nitrogen and other nutrient and their application in combination with urea or other inorganic fertilizer in the ratio of 5:1 could result in improved NUE. Long term fertilization investigation conducted dhad concluded that the efficiencies for P and K increased noticeably when both were applied in combination with any organic additives [142,152,100,153].

5.3.0. Inorganic and organic fertilization

Imbalanced fertilization and exhaustive cultivation in soil-plant environment system posed a disastrous impact on soil fertility and worsened the crop production sustainability. Addition of organic matter in the form of manure as a nutrient source is rejected substantially. In addition to that, repetitive and excessive addition of few inorganic fertilizers into the soil leads to lower soil fertility, micronutrient deficiency, and thereby resulted in unsustainable crop yield. Among the various organic manures, the compost produced by earthworms (vermicompost) and FYM ismain sources of macro and micronutrients. Due to increasing prices of chemical or inorganic fertilizers, most the Asian countries have encouraged organic materials as nutrient sources for rice production. Plant uptake nutrient in inorganic form, so the application of organic material first decomposes (by soil microbes) and releases nutrient in an inorganic form that can uptake by roots of rice crop. Nutrient releases from organic material decomposition cannot meet the demand of paddy for all yield-limiting nutrients as well as can surpass some nutrients than a requirement. Wei et al. [154] explored thirty- two long term experiments conducting in China, evaluatethe yield of rice and SOM contents and their time by nutrient management responses (TNMR). Treatments in these trials involved in chemical fertilizers, organic materials, and a combination of organic and chemical fertilizers. Combine application of fertilizer, and organic amendments give better results as compared to only chemical fertilizer application. Organic matter application either alone or combined with chemical fertilizer, can increase SOM and their TNMR over fertilizers applied alone.

Nitrogen requirement of rice cannot cover only with organic fertilizers, so to eliminate N deficiency integrated use of fertilizers is necessary. Mi et al., [155] reported the results of 4-year field experiment applying inorganic fertilizer in contrast with the combined application of organic manures (mushroom compost, green manure, cattle manure, rice straw) and inorganic on rice grain yield, the rice grain yields for 2014 under the NPK + cattle manure and NPK + rice straw treatments were 11.4% and 9.3% higher, respectively, compared with the NPK alone treatment. Organic material, including crop residues addition into the soil can have injurious effects. They can accelerate the modifications in soil constituents. This can speed up the transformation of sulfate to sulfide which in return precipitate Zn and consequently reduced its uptake to rice plants and enhance production and release of methane and increase organic acids formation that can affect unfavorably affect rice growth. The hazardous effect can be reduced by soil drying and aeration. The high concentration of NPK and other nutrients are present in oil cake, which can increase growth and productivity [156].

5.4.0. The 4R strategy

4R Nutrient Stewardship; demonstrates outline for right nutrient source, applied at the right time, right rate and in the right place, to accomplish improved sustainability. 4R Nutrient Stewardship involves the execution of best management practices that elevate the fertilizer use efficacy. The area of fertilizer best management practices is to supply nutrients in accordance with crop demands to maximize yield while decreasing nutrient losses. An assortment of management practices varied with crop type, soil and climatic conditions, site, management system, and other site-specific factors. The principle of 4R nutrient stewardship is applied in all conditions wherever fertilizer is used for the productivity of crop [157].

5.4.1.0. Right source

Appropriate fertilizer source must be understood like fluid nitrogen fertilizer gives N; half of total N of urea and a quarter of nitrate and ammonium. Soluble fertilizer addition in early irrigation would lead to leaching of nutrient and in late irrigation leads to poor circulation in the soil which further promote the growth of algae as it left N in irrigation line [158]. For wetted soil, fluid nitrogen fertilizer proved best in solution form when added to irrigation water in the middle of the irrigation cycle of drip irrigation Hanson et al [159]. Fluid nitrogen fertilizer will be applied near the irrigation system ina buried drip system to allow fertilizer to accumulate near greatest root density.

5.4.2.0. Right rate

Proper rate of fertilizer application according to plant and soil requirement can enhance efficiency. In-season fertilization rates can be refined by using various symbols (e.g., leaf color charts) or sophisticated analytical monitoring tools. For example, electronic sensors can track soil nitrate concentrations and plant tissue status, thereby allowing farmers to improve nitrogen application.

5.4.3.0. Right time

Time of fertilizer or nutrient application is significant. Application of N in split form is nowndays, a recommended practice. Rice crop mostly grow in submerged conditions. Application of full N dose at the time of transplantation can increase the risk of nitrate loss. Fertigation aptitudes let farmers respond in accordance with proper nutrient application timing that is coordinate with the requirement of the crop.

5.4.4.0. Right place

Placement of nutrients or fertilizers in the root vicinity is the promising technique to increase the efficiency of fertilizers [160]. In shallow-rooted crops, heavy irrigation can easily leach many important nutrients below the root zone; inthis scenario; fertilizer placement plays an important role.

5.5.0. Decrease in nutrient losses through water management

Irrigated rice ecosystems inhabit about 58% of the total cultivated rice area around the globe and yields more than 75% of rice supply to the world [161]. Single rice crop in a year is grown in some temperate regions and high-altitude of tropics. Continuous rice cropping limited to two, and/or occasionally three crops in a single year is seen in irrigated plains of Asia. Generally, a significant decrease in submergence can enhance N, P, and K requirements fora targeted yield. In aerobic soils, lower BNF and lower nutrient mineralization could lead to higher N requirement compared to submerged conditions. Very high needs for P fertilizer can originate from low solubility and bioavailability of native P in submerged condition [162]. The K requirement is inclined by poor management of crop residues and low K inputs. Similarly, the paddy soils are often subjected to Zn deficiency. The alternate wetting and drying cycle have a significant effect on Zn availability, especially in submerged acid soils [163]. The iron availability is also a subject of discussion for high-pH soils [164].

5.6.0. Managing water and fertilizer for sustainable agricultural intensification:

Rate of fertilizer application for a specific region must be adjusted earlier, considering the water-limited grain yield of rice [165]. The use of safe alternate wetting and drying (AWD) practice for rice production on puddled paddy soils without loss of rice yield results is an important management and skill, but the extent and duration of soil drying phase must be critically evaluated, and it must be a mild phase. The current research never suggested that a significant change in SOM and macronutrients availability for safe AWD as compared to continuous incubation phase. The BNP are the same for rice grown with AWD and continuous soil incubation unless the AWD is leading to soil crusting or some other degradation [166]. The AWD might favor gaseous loss N and soil N by the sequential nitrification-denitrification process [73], or it may also favor the contaminant uptake if soil possesses significant levels of contaminants [167]. Application of urea through broadcasting immediately before irrigation spread can help to ensure the vertical movement of N into the soil, but the event of high flooding can result in loss of N depending upon the physical properties of soil [73]. The "coupling effect" due to the combination of nutrient and water at the same time is usual in paddy soil. Few studies [168-173] have highlighted that there was a marked interaction between N application and water management on N uptake and utilization by rice grain.

6.0. Recent technologies for enhancing NUE and nutrient management

6.1.0. Remote sensing and geographical information system for rice management

The Geospatial Information Systems (GIS) and Remote Sensing (RS) techniques are among novel strategies which efficiently contribute knowledge and understanding to food security through helping in precision agriculture. These strategies include techniques which examine local food environments, assess changes in land use and land cover, identify areas of importance in specific regions to determine the relationships between biophysical and socioeconomic attributes, and the use of 3D models to demonstrate landscape and construct methods to sustain our food sources [174-178]. The recent trends and race among developing countries in launching the remote sensing satellite (RSS) have enhanced the capabilities for better utilization of this technology. Significant progress has been made in soil and land cover mapping, assessment of crop conditions, crop acreage, and production estimates [179].

RS is the science of acquiring information about an object through the analysis of data obtained by a device that is not in contact with the object [180]. Remotely sensed data take many forms, including variations in force distribution, acoustic wave distribution or electromagnetic energy distribution using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the plant/earth's surface. The data can be obtained from a variety of platforms, such as satellites, aircraft, unmanned aerial or underwater vehicles, and hand-held radiometers. Remotely sensed data be gathered by various devices such as sensors, cameras, and video recorders [180]. From the point of view of interaction mechanisms, the wavelengths (visible infrared) from 0.3 μm to 16 μm can be divided into three regions. The spectral band from 0.3 μm to 3 μm is known as the reflective region. In this band, the radiation reflected by the plant/earth's surface is sensed by the sensor. The 8 μm to 14 μm band analogous to the atmospheric window is known as the thermal infrared band. Thermal emission from the earth surface is the energy behind this band for remote sensing. In the intermediate band from 3 μm to 5.5 μm, reflection and self-emission are important.

Successful crop production is dependent upon effective nutrient management that includes identifying nutrient deficiencies and excesses [181]. Reliable nutrient recommendations are dependent upon accurate soil tests and crop nutrient calibrations based on extensive field research. Spatial variability of soil properties is inherent in nature, and it always exists whether it is observed in large-scale or small-scale. A better understanding of the spatial variability of soil nutrients is important for refining the nutrient and agronomic management practices for paddy soils. Quantification of soil spatial variability is also important in ecological modeling, environmental prediction, precision agriculture, and natural resources management. Similar, the chemical concentration of vegetation traditionally has been measured by chemical analyses of field samples. Sampling can be logistically difficult in wetlands/paddy soils, and often, data collection is restricted to a small area. Remote sensing of foliar chemistry potentially provides a method to assess ecosystem function on a range of spatial scales and in locations that are difficult to sample. The information on accurate demands and supply for the soil-plant system could easily be achieved through the utilization of RS based real time methods with extensive area coverage. Therefore, timely detection or forecasting of nutrient imbalance/stress can help the growers avoiding mineral deficiencies and thus the yield losses [182]. RS provides the essential technology and methodology to monitor, map, and observe rice-growing ecosystems over large areas, at repeated time intervals, to interpret rice-growing areas under a variety of aspects. The RS technologies can support the assessment and measures plant health and nutrient status based on the reflectance of light from the rice crop at two different wavelengths, visible and near infrared. Spectral reflectance data is inversely related to leaf chlorophyll level and relies on the interaction that occurs when light penetrates plant tissue, where it will be absorbed, reflected from the surface or transmitted through the leaf. These optical spectra are dependent on the leaf pigment content of different absorption wavelengths. Chlorophyll is used to determine N requirements in rice crop because it provides an indirect indicator of N status, especially in optical reflectance-based variable-rate nitrogen application technology.

Most of the passive remote sensors can provide information about soils from reflectance spectra in the visible (0.40 µm to 0.70 µm), near infrared (0.70 to 1.10 µm) and short-wave infrared (1.10 to 2.50 µm) regions of the electromagnetic spectrum. Besides this thermal infrared regions (3.0 to 5.0 µm and 8.0 to 12.0 µm) do provide diagnostic information about soils. Plant chlorophyll concentration provides valuable farmer information regarding potential crop yield. Variances in leaf's coloration and synthesis of different biochemical molecules under the deficiency or toxicity of any mineral element like (N, P, K and S etc) within plants body yields changes in the pattern of spectral reflectance of crop canopy. The variation in absorption bands related to structure or molecules can be paired as follows: (i) 460 and 670 nm for chlorophyll a and b, (ii) 530 nm for carotenoids and (iii) 1500 nm for N–H bonds. This information is highly helpful in nutritional monitoring through RS. A chief absorption characteristic of di-sulfide bonding within plant body is available to visible (VIS) region (500–600 nm) for RS sensors [182] However, the reflectance spectrum of a rice canopy is yielding a highly complex relationship among biophysical and biochemical characteristics. Alterations in one or more circumstances of growth like climate change, water stress, and clouds covers, or nutritional stresses may significantly affect or disturbs the reflection bands and patterns. Even if, such conditions are similar then the varietal differences of rice crop may show similar temporal spectral results [183-185]. RS can provide timely and consistent information on rice based agricultural systems, like:

- Monitoring and mapping of rice ecosystems
- Rice crop health, nutritional and growth assessment
- Quantification of disease incidence or climatic perils
- Climate-change estimation by estimating relevant methane emission
- Evaluation of the efficiency of rice-based cropping pattern/systems
- Quantification of rice crop vigor and other indices like leaf area index etc.
- A basic tool for the precision rice farming helping in yield predictions, fertilizer/pesticide requirements.
- Environmental hazards like land degradation and soil quality/salinity
- Moisture sensing for the hydrologic or irrigation modeling.

Hyperspectral reflectance gathered from crop canopy has the ability to sense typical plant population nutrition status rather than individual/each leaf or plant [186]. Processing of hyperspectral RS data can be characterized into major three groups (i) Narrowband or hyperspectral vegetation indices (VIs) (ii) multivariate data analysis and (iii) hyperspectral data which is base for wide band VIs. New RS sensors are swiftly producing a massive amount of data in higher resolutions as well as are cost effective. For fertilizer management and stress mapping procedures, images (both Hyperspectral and multispectral) are inferred in term physical parameters like crop health, the moisture of soil or crop cover and are useful for operations such as stress mapping, fertilization management [187-189]. Nutrient contents of different crops such as wheat [188,190], paddy rice [191], sorghum [192], corn [193], broccoli [194], citrus [195], grape [196], apple [197] have also been assessed using hyperspectral and multispectral RS data. Regarding the work procedure and methodology of RS for mapping and monitoring of rice fields, the selected procedures/methodology strongly depends on the type of sensor being used in the RS device. For low to medium resolution data, "maximum likelihood classification (MLC)" is the one of most general approach [198,199]. On the contrary, hyperspectral RS of rice areas emphases on the recovery of an ideal number of bands which are best suited for mapping. Therefore, the favored methodology is based on various "multiple regression models" [200]. MLC is unsuitable due to the severe variability which is easily handled by "synthetic aperture radar (SAR)" approach [201, 202]. Low spatial resolution sensors like "Advanced Very High-Resolution Radiometer (AVHRR)," "Moderate Resolution Imaging Spectroradiometer (MODIS)," and SPOT VEGETATION is also equipped with high temporal resolution and broad swath width, which provides coverage for extensive areas at low cost [203].

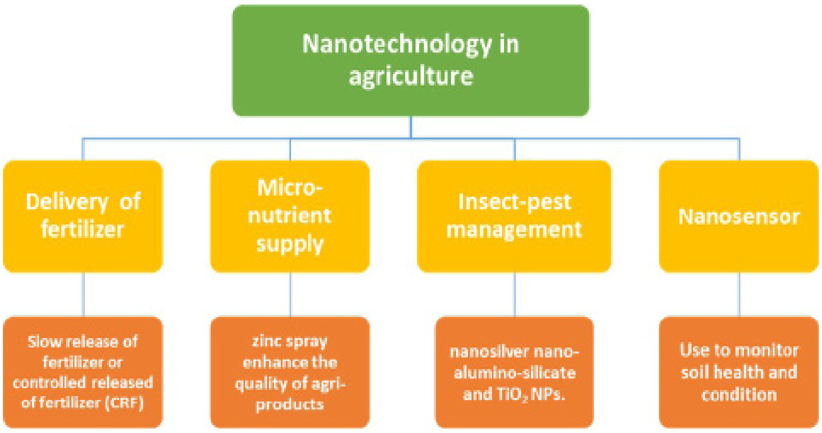
Using time-series data collected from MODIS for mapping of the rice ecosystem and nutrient management is widely recommended and reliable technique. Time series data from spatial resolution composites of images from the MODIS-sensors are widely used for the production of rice maps and other characteristics, i.e., intensity of rice cropping etc. The surface reflectance product based on MODIS collected from the "Terra platform (MOD09A1)" are highly suited for monitoring rice ecosystems on a continental scale. The bands of reflectance data resolution of about 15 arcs/500 m, conjugated with highly-repeated frequencies, are capable of capturing the seasonal variations in rice vigor, and rice plant moisture, and soil surface water which are also the key indicators for rice growth status considering the differences in stages of rice transplanting/cultivations. The "reflectance data" undergo several preprocessing and treatments, i.e., algorithms for climatic factors correction etc. Moreover, the rate of observation, coverage area, view angle, cloud intensity or cloud shadows on canopy, smog, and aerosol are assessed on a "pixel-by-pixel" to ensure that each pixel covers best observations. In rice cropping systems, application of RS has been trending. Some fields reports have been summarized here as follow; Zhang et al. [204] explored the relationship between rice canopy spectral reflectance and N supply. It was concluded that marked variations in N concentrations of canopy present at different stages of growth. A significant relationship among N status, the visible, NIR ranges of the spectrum was found. Subsequently used NDVI and RVI analysis also predicted the N status. Xue et al. [205] also confirmed similar findings relating the seasonal canopy reflectance, different ratios in bands and NDVI with N status and N accumulation in rice during different treatments of N. NIR and the green band were in the ratio of (R810nm/R560nm). A linear relationship of N accumulation during the whole growth period was independent of the applied N treatment levels. Therefore, band ratio was recommended for the N monitoring in rice plants [205]. Lee et al. [206] also tested a simpler spectral index (SI), containing the first derivative of rice canopy reflectance at 735 nm, for the measurement of N concentration in rice plants and reported a significant linear relationship of N with panicle initiation stage.

A study by Huang et al., [207] evaluated the "FORMOSAT-2 satellite images" for measurements of N status in rice crop for evaluating N application rate for top dressings at the stem elongation phase of rice crop. This study was conducted in Northeast China based at Five farmers' fields and six agronomic variables; (i) aboveground biomass, (ii) leaf area index, (iii) plant N concentration, (iv) plant N uptake (PNU), (v) CM readings and (vi) N nutrition index (NNI) were included. The NNI was demonstrated as the ratio of actual PNC to critical PNC. Collectively, 50 VIs were calculated and correlated with the value collected from field-based variables. The ArcGIS (ESRI, Redlands, CA, USA) and ENVI were deployed to read the pixels data from images collected through "FORMOSAT-2 satellite images," and VIs were computed for corresponding sites. The 6 variables were treated separately during the regression analysis. Results declared that 45% of NNI variability was explained through Ratio Vegetation Index 3 (RVI3). The computed differences between the estimated PNU and critical PNU based on the indirect methods can be used to draw guidelines for evaluation of fertilizer requirements for N-topdressing [207]. A study by Mosleh et al. [208] also focused on the development of RS based methodology to forecast yield of rice through rice canopy greenness during initial and peak color stages. A compound of normalized difference vegetation index images collected at 250 m spatial resolution demonstrated a significant relation between the MODIS-based model and ground-based calculation during the 2010-2012 period showing (R^2= 0.93). Authors also found a strong agreement between forecasted (MODIS-based) yields and yields obtained from ground-based data 2010-2012 period showing R^2 value 0.76.

6.2.0. Nano-Technology for nutrient management in rice

Nanotechnology (NT) is being visualized as a rapidly evolving field that has the potential to counter the present-day challenge of food security [209,210]. The word "Nanotechnology" has initiated from a Greek word "Nanos" which means "Dwarf". The term "Nanotechnology" was first used by Norio Taniguchi in 1947 [211]. Just like in human history, the Stone Age, Bronze Age and Iron Age, currently "Nano Age" is reckoned in the same regard. Now a day, nanotechnology has commenced in agriculture to revolutionize it with new concepts, tools, and ideas for maximizing the productivity [212]. Nanotechnology has many potentialities to agriculture (**Figure 2**), and the ambition of the nanotech in agriculture is to diminish the number of hazard chemicals, minimize nutrient losses in fertilization and increased yield through nutrient management [213].

Figure 2: Schematic description of applications of nanotechnology in agriculture [214]



6.2.1. Nanotechnology and nutrient management in rice:

Pitiable usage efficacy of present fertilizers is a major topic. World's largest consumer of nitrogen fertilizer is China, which can be lost up to 50% by volatilization and another 5–10% by leaching [215]. Fertilizers loss can cause serious environmental issues, i.e., eutrophication [1]. The aim of involving nanotechnology in the field of plant nutrition is to increase the fertilizer use efficiency either by increasing the bioavailable fraction of nutrients (for example, phosphorus, zinc) and/ or by controlling losses of mobile nutrients to the neighboring environment, e.g. nitrate [216]. Food production has been increased substantially with the use of excessive use of fertilizers in the form of nitrate or phosphate compounds, ammonium salts, and urea, but on the other hand, they also have many detrimental consequences on the beneficial soil microflora. Nano-coated particles have strong tenacity to hold materials due to strong surface tension, this property has strong contribution in fertilizer slow release compared to other particles having conventional surfaces. Moreover, larger particles are being surface protected by nano-coatings [214]. The strength of the nano-coating decreases the fertilizer dissolution rate and allows the fertilizers to release slowly into the soil to be efficiently absorbed by plants. Slow release fertilizers usage has become an advanced approach to overcome the gigantic problems of environmental pollution and excessive fertilizer consumption [217]. To meet the crop demands, many polymers have been used to release fertilizers slowly and sustainably. For example, polymeric chitosan nanoparticles depicted positive result for NPK slow release Corradini et al. [218]. Fernando et al. [219] concluded that the nutrient transfer rate increases with increased nano calcium carbonate in wax cation layer.

6.2.2.0. Nano fertilizers

Nanofertilizer can be defined as the provision of essential and beneficial nutrient to plant at the nano scale, which can improve plant growth and yield [216,220,221]. Nanofertilizer has three categories 1) macro-nano fertilizers, 2) micro-nanofertilizer 3) nano-particulate fertilizer based on nutrient requirements of the plants [221]. The overall use of nano-based fertilizer use and mechanism have been summarized in figure (3). Nano fertilizers increase the Nutrient use efficiency (NUE) by 3 times, and it also provides stress tolerating ability. Since thesenano-fertilizers contain nutrients, growth promoters encapsulated in nanoscale polymers; they will also have a slow andtargeted, efficient release [222]. When comparing to chemical fertilizers requirement and cost, nano fertilizers are economically cheaper and are required in lesser amount. For years farmers have found that nitrogen uptake is the main reason for improper yield. Nanofertilizers can improve the uptake of nutrients by plants [223]. Nanoparticles of silicon dioxide enhanced both the root development and seedling growth [224]. Synthetic or biopolymers have been used to develop many controlled-release fertilizers (CRFs) and slow-release fertilizers (SRFs) to avoid the potential leaching and denitrification of nitrogen fertilizers [225,226]. Benzon et al. [227] performed a greenhouse experiment to find the effects of nanofertilizer application. Results showed that application of nanofertilizer significantly enhances total antioxidant activity and phenolic content in rice and improved plant nutrition and crop productivity. The significance of nanoparticles is studied widely by many researchers. Such as, nano-K fertilizer application has provided higher grain yield in rice Sirisena et al [228]. Likewise, Liu and co-workers [229] documented that 20-40% of crop yield has been increased by the application of nanofertilizer. Some common methods of nonfertilizer application and some commercially available nano-products available for farmer usage are summarized in table (8) and (9) respectively.

Figure 3: Some types of nanotechnology-based products used in agriculture

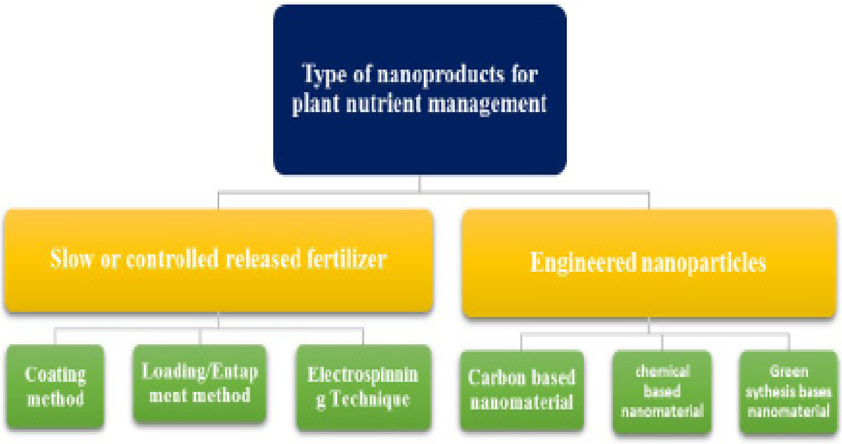


Table 8: Method of nanofertilizer application

Method	References
Spray or foliar application	[214]
Soaking method	[234]
Soil application	[235]

Table 9: Nanotechnology based commercial products and their application in agriculture

Nanoproducts	Suggested Role	References
Nano-sized nutrient (ZnO and TiO_2 nanoparticles)	Boost in growth and antioxidants	243
Hydrolyzed collagen/Nano-Na alginate composite	Preservation	244
Macronutrient fertilizers coated with nano-metal oxide	Enhancement of nutrients absorption by plants and the delivery to specific sites	245
Nano-emulsion	Nano-emulsion as larvicidal agent	246
Acetamprid loaded alginate-chitosan nano-capsules	Improved delivery of agrochemicals in the field, better efficacy,	247

6.2.2.1. Advantages of nano-fertilizer:

a. Nano fertilizer is using no ethylene compounds in its structure. Ethylene enhances growth process and prevents appearing indications caused by chlorosis in leaves [230].

b. Nano-fertilizer increases the nutrient use efficiency of the crop and minimizing the cost of environmental protection.

c. Nano-fertilizer causes improvement in the taste and nutritional content of the crops

6.2.2.2. Nano-fertilizer formulations and their smart delivery system

Nanofertilizer formulate keeping in view the following criteria:

- High solubility
- Stability
- Effectiveness
- Controlled or slow release
- Targeted activity
- Eco friendly in terms of safe delivery and disposal [231,232].

6.2.2.3. Mechanism of loading

In living systems target specific delivery of nutrients can be easily done with nanotechnology applications. The loading of nutrients on the nanoparticles is usually accomplished by

- absorption
- ligands mediated the attachment
- encapsulation
- entrapment of polymeric nanoparticles
- Synthesis nutrient-based nanoparticle [231,233].

6.2.3.0. Smart fertilizer

Smart fertilizer i.e. timely release fertilizers can be prepare by means of clay minerals, polymers, nano-composites such as clay minerals and hybrid polymer and metal oxides via different techniques i.e., nano-encapsulation, core shell preparations, spray drying and electro spinning. The nanoparticles are obtaining much attention in soil management and nutrient studies especially carbon and metal oxide based engineered nanoparticles. The “green synthesis” of nanoparticles makes use of eco-friendly, nontoxic, and safe chemicals. Nanoparticles manufactured with biological techniques or green technologies are diverse, with great stability and large dimensions. Synthesis of nanoparticles can be done by chemical, physical and biological techniques [236]. For nanonutrients synthesis, microorganisms are provided with necessary growth conditions and grown over selected nutrients. After desire growth, the biomass was detached, and the filtrate was used for isolation of extracellular specific proteins, and these were used for nanoparticle synthesis [235]. Similarly, Okorie et al. [237] and Chhipa [221] reported that some nanoparticles could be used in nano-fertilization, which produced through the biosynthesis process.

6.2.4.0. Nanotechnology in micronutrient supply:

Intensive farming and green revolution showed a significant rise in crop yields but in consequence make soil deficient in soil micro-nutrients like Zn, Mo, and Fe [238]. The practice of Nanotechnology can be practiced making micro-nutrients available to plants. Thus, different nano-formulations of micronutrients has been used to apply on soil or spayed on plants to augment soil health [239]. The formulation was found to have the potential for the slow release of agrochemicals such as “hormones” [240]. For plant micronutrients, many nanoparticles have been certified. The prevailing problem of Fe-deficiency in high pH calcareous soils can be resolved by nanotechnology practice [241]. Similarly, Alidoust and his coworker [242] reported the effect of foliar application of iron nanoparticles. Foliar spray of iron nanoparticle improved plant growth in rice enhances nutrient absorption by enhancing microbial enzyme activity in rhizosphere.

6.3.0. Biofertilizer

The beneficial-living microorganism like Rhizobium, *Azospirillum, Azotobacter,* blue-green algae, fungal mycorrhizae, *Pseudomonas,* etc. are termed as Biofertilizers. These microorganisms play an important role in increasing essential nutrient availability to plants and thereby enhanced crop yield and soil fertility by breaking OM into simpler compounds [248]. Silver and gold nanoparticles could be proved effective as growth promoting materials [249]. Under in vitro conditions, nanoparticles with biofertilizers (*Pseudomonas fluorescens, Bacillus subtilis* and *Paenibacillus elgii*) showed augmented growth promotion. Plant growth promoting rhizobacteria (PGPR) showed maximum growth promoting activities in comparison to several soil microorganisms of the rhizosphere. Gold nanoparticles effect was checked on PGPR in *B. subtilis P. elgii P. fluorescens,* and *P. putida* and its effect can be exploited in nano-biofertilizers as *B. subtilis, P. elgii* and *P. fluorescens* a showed significant increase [250]. Biofertilizers may augment plant growth by several mechanisms such as the production of siderophores, fixation of atmospheric nitrogen (by chelating the element to make it available to plant), mineral solubilization (e.g., P) and synthesis of phytohormones [235]. Organic acid production played an important role in some minerals solubiliztion, for instance, in the mineralization of organic S organic phosphorous played a major role [251]. Likewise, Wong et al. [252] documented that phytohormones in biofertilizers played an important role in plant growth by regulating cell division. For example, cytokinins (Phytohormones in biofertilizers) helped plants in improving growth with the production of more cells.

Table 10: Commercial products of biofertilizer and nanofertilizer:

Name	Interaction	Role	Formula
I. Biofertilizer			
Okadin	Symbiotic	N_2- fixation	Powder
SWERI	Non-Symbiotic	N_2- fixation	Powder
SWERI (NPK)	Non-Symbiotic	N_2- fixation P and K solubilizers	Powder
Cyanobacteria	Non-Symbiotic	N_2- fixation	Powder
Mycorrhizal	Symbiotic	P- solubilizers	Powder
Compost tea	Non-Symbiotic	Plant nutrition	Liquid
II. Nanofertilizer			
Name	**Method production**	**Role**	**Formula**
Nano-Se	Biological	Mitigation of the different stress i.e. salinity, drought, and heat.etc.	Liquid
Nano-Si	Biological	Plant nutrition and control from insects.	Liquid
Nano-cu	Biological	Plant nutrition and control from plant diseases.	Liquid

6.4.0. Summary

More than half the population of the globe is dependent on rice cultivation. Rice production will continue to share its role in achieving global food security but needs to achieve these goals looks very high. The fundamental question here is whether the traditional methods of rice cultivation and management practice adopted can guarantee the sustainability of rice production. Hence the nutrient management is one of a prime issue for the traditional methods of rice cultivation. Under the fluctuating climatic perils, continuous land degradation and expanding rate of urbanization will need more intensive practices for rice cultivation. The paddy soils due to their unique characteristics need special attention in term of management. The current fertilization practices will unlikely to work in the future for sustainable rice production. The paddy cultivation is not a local industry, yet it is spread on the globe comprising various ecosystems for rice climatization and hence the most diversified. Moreover, the cropping system and cultivation methods also differ but in low land plains where most of the rice is cultivated as rice-rice cropping or rice-wheat cropping, Normally, alternate-wetting drying cycles of irrigation are adopted which have substantial impacts on soil quality. Under existing cultivation practices, not only macronutrients have low use efficiencies, but soil deficiencies for micronutrients are also being reported worldwide. Despite the fact, the more than 50% of globally produced fertilizers are applied in the rice yet the crop yields are being stagnant and non-profitable. Rice cultivation has become a major source of groundwater pollution, greenhouse gases, algal blooms, and loss of soil productivity. Therefore, it is dire need to sustain the rice cultivation through managing the applied fertilizer. The 4-R stewardship for rice is widely recommended, which results in enhancing the nutrient use efficiency but reduce the losses of NPK. The practice integrated nutrient management ensures the sustainability of paddy soil to act as a source of all nutrient for longer periods. The key to profitable and maximum rice yield is balance fertilization, and there are no further doubts over this concept. Moreover, the rice yields can be more sustainable through precision agriculture with the help of site-specific nutrient management, optical sensing, or remote sensing. The nanotechnology is still a new concept for fertilizers, but it has significant potential to boost rice productivity at continentals' scales. Adoption of such modern practices which are key component precision crop management can ensure the enhancement in nutrient efficiencies and thus can ensure the food security.

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