Nitrogen Uptake and Use Efficiency in Rice

N.K. Fageria, V.C. Baligar, A.B. Heinemann, and M.C.S. Carvalho

Abstract

Rice is a stable food for a large proportion of the world's population. Most of the rice is produced and consumed in Asia. Rice is produced under both upland and lowland rice systems, with about 76 % of the global rice produced from irrigated-lowland rice systems. Nitrogen (N) is one of the most important inputs in the production of rice. Recovery efficiency of N is less than 50 % in both upland and lowland systems. Most of the applied N is lost due to volatilization, leaching, denitrification, and soil erosion. In addition, fertilizers account for almost half of energy used in world agriculture, and the manufacture of N fertilizer is about 10 times more energy intensive than that of P and K fertilizers. Therefore, improving N use efficiency is important not only to improve yield and reduce cost of production but to avoid environmental pollution and to maintain sustainability of the cropping system. Production practices which can improve N use efficiency are liming acid soils, supplying N in adequate rates, use of proper sources, use of suitable methods and time of application, use of crop rotation, use of cover crops, adopting conservation tillage system, planting N efficient genotypes, and control of diseases, insects, and weeds.

Keywords

Rice ecosystems • Nitrogen harvest index • Water use efficiency • Genotypes • Nutrient use efficiency

1 Introduction

Rice is the staple food for more than 50 % of the world population. Xiong et al. (2013) reported that rice is the staple food for about 60 % of the population in China. Furthermore, rice provides 35–60 % of the dietary calories consumed by

N.K. Fageria (✉) • A.B. Heinemann • M.C.S. Carvalho
National Rice and Bean Research Center of EMBRAPA, Caixa Postal 179, Santo Antônio de Goiás, GO, Brazil
e-mail: nand.fageria@embrapa.br

V.C. Baligar
USDA-ARS Beltsville Agricultural Research center, Beltsville, MD 20705-2350, USA
e-mail: VC.Baligar@ars.usda.gov

A. Rakshit et al. (eds.), *Nutrient Use Efficiency: from Basics to Advances*,
DOI 10.1007/978-81-322-2169-2_18, © Springer India 2015

nearly 3.5 billion people (Fageria et al. 2003a). It occupies about 23 % of the total area under cereal production in the world (Wassmann et al. 2009; Jagadish et al. 2010). Rice is produced and consumed in all the continents, except Antarctica. However, major part of the rice is produced and consumed in Asia. In Asia, India and China are the major producers as well as consumers of rice. Rice is also consumed in large quantities in North America and Europe by native and immigrants from Asia, Africa, and South America. The population in Africa and South America consume substantial amount of rice. In South America, rice is eaten everyday with dry bean (*Phaseolus vulgarsi* L.) by all section of society (Fageria 2013).

Nitrogen is one of the most yield-limiting nutrients in rice production in all rice-growing regions worldwide. Uptake of N is maximum by rice (sometimes equal to K) compared to other essential nutrients. Recovery efficiency of N is lower than 50 % in most cropping systems (Fageria et al. 2011; Fageria 2013). The major part of N in soil is lost through volatilization, leaching, denitrification, and soil erosion (Fageria and Baligar 2005). Low recovery of N is not only responsible for higher cost of crop production but also for environmental pollution. Hence, improving N use efficiency (NUE) is desirable to improve crop yields, reduce cost of production, and maintain environmental quality. To improve N efficiency in agriculture, integrated N management strategies that take into consideration improved fertilizer along with soil and crop that includes improved fertilizer application timing and methods along with soil and crop management practices are necessary (Fageria and Baligar 2005).

By the year 2025, it is estimated that it will be necessary to produce about 60 % more rice than what is currently produced to meet the food needs of a growing world population (Fageria 2013). Similarly, Normile (2008) reported that increase of 1.2 % per year of rice production will be required to meet the growing demand for food that will result from population growth and economic development in the next decade. Enhancement of rice production and sustainability are important features of grain production to benefit the world's 3.5 billion people who depend on rice for their livelihood and as their basic food. Adequate amounts of essential nutrients are needed by modern rice cultivars with improved cultural practices to achieve higher yields. In this context, efficient use of inputs is vital to safely produce the additional food from limited resources with minimal adverse impact on the environment. The objective of this chapter is to discuss nitrogen uptake and use efficiency and a summation of best management practices that could help scientists and rice farmers to develop practical, integrated recommendations that improve nitrogen use efficiency in various types of rice production systems.

2 Rice Ecosystems

Ecosystem is defined as the environmental factors around the crop plants. The main environmental factors which influence rice growth are related to climatic and soil conditions. Rice is mainly grown under two ecosystems known as upland and lowland. Upland rice is defined as the rice grown on undulated well-drained soils, without water stagnation in the plots or fields, and totally depends on rainfall for its water requirements. Upland rice is also known as aerobic rice because it is grown on well-drained soils. Lowland rice is defined as the rice grown on flat, saturated soils, with water stagnation in the plots or field for most of the growing season, and generally has controlled irrigation. Lowland rice is also known as irrigated, flooded, or submerged rice. Such systems of productions contributes about 76 % of the total world rice production (Fageria et al. 2003a). The yield of upland rice is relatively low compared to lowland rice, because many abiotic and biotic stresses are associated with low yield. The main abiotic stresses in upland rice are drought, low soil fertility, and use of low technology by the farmers. The main biotic stresses are diseases, insects, and weeds.

For example, in Brazil, yield of upland rice is less than half of lowland rice. Average yields of lowland rice in Brazil is about 5.5 Mg ha^{-1}, whereas average yields of upland rice is about 2.2 Mg ha^{-1}. In upland rice blast disease is a serious constraint in reducing yield in most of the upland rice growing areas. In addition upland rice in Brazil is mainly cultivated in the central part of Brazil, locally known as "Cerrado" region. Most soils of the Cerrado region are acidic and deficient in most of the essential plant nutrients (Fageria and Baligar 2008).

3 Soil Used for Rice Cultivation

The Soil Science Society of America (2008) defined soil as the unconsolidated mineral or organic material on the immediate surface of the earth that serves as a natural medium for the growth of plants. Soil quality is an important factor in crop production. Soil quality is mainly determined by crop yields. When a determined soil produces higher crop yields, it indicates a productive soil. Soil quality is defined in terms of its physical, chemical, and biological properties. Physical properties which determine soil quality are texture, structure, bulk density, and water infiltration rate or porosity, whereas chemical properties of soil are mainly associated with soil fertility. The biomass of a soil is represented by its microbial population. The microbes may be beneficial or may be harmful for the growth of plants. Soils are classified into orders and according to US soil taxonomy, there are 12 soil orders. These soil orders are Alfisols, Andisols, Aridisols, Entisols, Gelisols, Histosols, Inceptisols, Mollisols, Oxisols, Spodosols, Ultisols, and Vertisols. Rice can be grown on all the 12 soil orders. Detailed discussion of characteristics of these soils under rice cultivations are given by Fageria (2014).

4 Functions and Deficiency Symptoms

Nitrogen plays significant role in many physiological and biochemical processes in the plants. It improved tillering in rice and consequently panicle density. Nitrogen also increases panicle length and grain weight and reduces spikelet sterility (Fageria and Baligar 2001a; Fageria 2007). Adequate rate of nitrogen improves root growth (Fig. 1) in rice which is very important for the absorption of water and nutrients (Fageria 2013). In rice N deficiency symptoms are characterized by yellowing of the leaves. Since nitrogen is mobile nutrient in the plants, hence, deficiency symptoms first start in the older leaves. If deficiency persists longer, all the leaves become yellow. Figure 2 shows growth of two lowland rice genotypes at low and high N rates. Nitrogen deficiency symptoms are very clear at low level of N.

5 Nitrogen Uptake and Partitioning

Uptake of N is maximum in rice, except K. It is absorbed in the form of NO_3^- and NH_4^+ by plants. In oxidized soil NO_3^- is the dominant form of N uptake and in reduced soils N is mainly absorbed as NH_4^+. The topic of NO_3^- vs. NH_4^+ uptake of N by rice is discussed in detail by Fageria (2014).

5.1 Nitrogen Concentration

Uptake of N is expressed in concentration which is defined as the N content per unit of dry matter. The unit of N concentration in plants is generally g kg^{-1} or percentage. Generally, concentration values are used to diagnose nutrient sufficiency, deficiency, or excess in plants. Nutrient concentrations can be extrapolated or used for identifying nutritional disorders in the same crop species from different agroecological regions. This is possible because nutrient uptake in plants is an integral part of all factors affecting nutrient availability.

One of the most important considerations in defining adequate concentrations is plant age (Fig. 3). Fageria (2003) determined a relationship between dry matter yield of shoots or grain and N concentration in the shoot or grain of

Fig. 1 Influence of low and high N levels on root growth of two upland rice genotypes

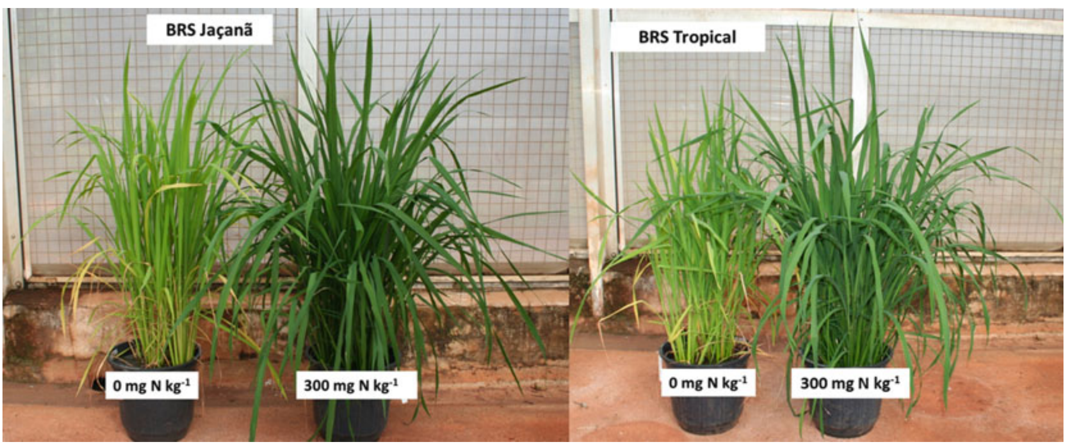

Fig. 2 Growth of two lowland rice cultivars at two N levels

lowland rice at different growth stages. Based on this relationship, optimum N concentrations in shoots at different growth stages and in the grain at harvest were determined in rice. Optimum N concentrations in shoots varied from 43.4 g kg^{-1} at initiation of tillering to 6.5 g kg^{-1} at physiological maturity. The N concentration in the grain at physiological maturity was 11 g kg^{-1}. Hence, optimal N concentration in shoots of rice decreased with

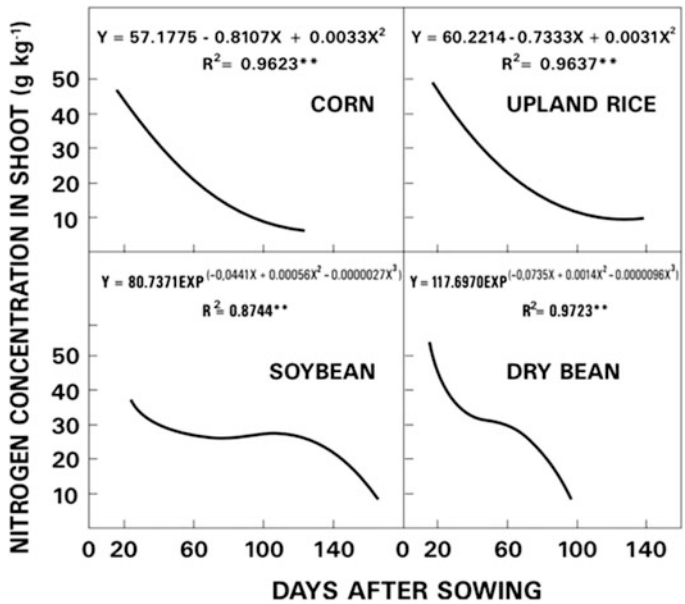

Fig. 3 Nitrogen concentration in principal crop species during growth cycle (Source: Adapted from Fageria 2004)

advanced plant age. During grain filling, N content of non-grain tissue generally decreases, while grain N content increases (Fageria and Baligar 2005). However, shoot dry weight increased with age advancement up to the flowering growth stage and then decreased (Fageria 2003). Decreases in shoot dry weight at harvest was related to translocation of assimilate to the panicle from flowering to maturity (Fageria and Baligar 2005). In rice, 60–90 % of the total C accumulated in panicles at the time of harvest was derived from photosynthetic after heading, and the flag leaves are the organs that contribute most to grain filling (Yoshida 1981).

5.2 Nitrogen Accumulation

When dry matter or grain yield is multiplied by concentration, the results are a measure of nutrient uptake and expressed in accumulation or uptake units. Under field conditions, the nutrient uptake or accumulation unit is kg ha^{-1} for macronutrients and g ha^{-1} for micronutrients. Nutrient uptake values are useful indicators of soil fertility depletion and are related to crop yield levels. Nutrient accumulation patterns in crop plants, including rice, followed dry matter accumulation (Fageria 2004). A study was conducted at the National Rice and Bean Research Center of EMBRAPA, Santo Antônio de Goiás, Brazil, to study the association between dry matter and grain yield of lowland rice and N accumulation during growth cycle (Table 1). The N uptake into shoots as well as into grain of lowland rice was significantly related to shoot dry weight and grain yield (Table 1). Fageria and Baligar (2005) reviewed the literature on this topic and reported that accumulation of N in cereals, including rice, dry matter production, is closely related to N accumulation. Nitrogen uptake as well as shoot dry weight increased up to the flowering stage (Fageria 2003). At harvest, more N was accumulated in grain than in dry matter. Yoshida (1981) reported that during plant ripening, about 70 % of the N absorbed by the straw will be translocated to the grain and maintain N contents of the grain at certain percentages. Nitrogen absorbed by rice during the vegetative growth stage contributes to growth during the reproductive and grain filling growth stages via translocation (Fageria and Baligar 2005).

Accumulation and distribution of N in the vegetative and reproductive organs of rice are

Table 1 Relationship between grain yield (*Y*) and N uptake in the shoot and grain of lowland rice at different growth stages

Plant growth stage	Regression	R^2	N uptake for maximum shoot or grain yield (kg ha^{-1})
IT (22)	$Y = 166.46 + 9.4552X - 0.1565X^2$	0.61^{NS}	16
AT (35)	$Y = -391.29 + 63.8885X - 0.5898X^2$	0.93^{**}	54
IP (71)	$Y = 40.32 + 101.2576X - 0.3939X^2$	0.97^{**}	129
B (97)	$Y = -2069.44 + 185.7829X - 0.6725X^2$	0.94^{**}	138
F (112)	$Y = -367.39 + 167.8636X - 0.4528X^2$	0.97^{**}	185
PM (140)	$Y = -2330.74 + 335.1191X - 2.3641X^2$	0.99^{**}	71
PM (140)[a]	$Y = -3547.09 + 261.4988X - 1.7099X^2$	0.99^{**}	76

Source: Adapted from Fageria (2003)
Where regression equation was nonsignificant, average value across the N rates was considered as quantity of N uptake for maximum yield
Values are averages of 3 years field experimentation
**, NS, Significant at the 1 % probability level and nonsignificant, respectively. *IT* initiation of tillering, *AT* active tillering, *IP* initiation of panicle, *B* booting, *F* flowering, *PM* physiological maturity. Values in the parentheses represent age of the plants in days after sowing
[a]In this line, values are for grain yield

the important processes in determining grain yield (Fageria 2014). Xiong et al. (2013) reported that super high yielding early cultivars had higher total N content at heading and maturity compared to ordinary early rice cultivars. Xiong et al. (2013) also reported that the differences in N translocation parameters among rice varieties or variety group were associated with the N accumulated in plants before heading. Mae (1997) reported that the amount of N absorbed by the plant during grain-filling period is much smaller than the amount of N accumulated in mature grain, and a large part of grain N is translocated from vegetative organs. Nitrogen distribution studies showed that 30–80 % of the N accumulated in the rice grain originated from translocation from vegetative tissue after heading (Ntanos and Koutroubas 2002).

5.3 Nitrogen Harvest Index

Nitrogen harvest index (NHI) is defined as the portioning of total plant N into grain. It is calculated by N accumulation in grain divided by N accumulation in grain plus straw. It is an important index in defining rice yield. Because it is positively related to grain yield (Fageria and Baligar 2005; Fageria 2007; Fageria et al. 2011). In addition, it is also an important index in measuring N partitioning in crop plants, which provide an indication of how efficiently the plant utilizes acquired N for grain production (Fageria and Baligar 2005).

The NHI values varied from crop species to crop species and among genotypes of the same species. This trait is important for selecting crop genotypes for higher yield. Fageria (2007) reported that NHI in lowland rice varied from 0.53 to 0.64, with an average value of 0.60.

5.4 Nitrogen Use Efficiency

Efficiency is defined as the output divided by input. The higher the output value, the higher is the efficiency. In case of N use efficiency in crop plants, it can be defined as the maximum economic yield produced per unit of N applied, absorbed, or utilized by the plant to produce grain and straw. However, nutrient use efficiency has been defined in several ways in the literature, although most of them denote the ability of a system to convert inputs into outputs. Definitions of nutrient use efficiencies have been grouped or classified as agronomic efficiency, physiological efficiency, agrophysiological efficiency, apparent recovery efficiency, and utilization efficiency. Fageria and Baligar (2001a) calculated these efficiencies for lowland rice and results are

Table 2 Nitrogen use efficiencies as affected by N fertilizer rate

N rate (kg ha^{-1})	AE (kg ha^{-1})	PE (kg ha^{-1})	APE (kg ha^{-1})	ARE (%)	UE (kg kg^{-1})
30	35	156	72	49	76
60	32	166	73	50	83
90	22	182	75	37	67
120	22	132	66	38	50
150	18	146	57	34	50
180	16	126	51	33	42
210	13	113	46	32	36
Average	23	146	63	39	58
R^2	0.93^{**}	0.62^{*}	0.87^{**}	0.82^{**}	0.90^{**}

Source: Fageria and Baligar (2001a)
AE agronomic efficiency, *PE* physiological efficiency, *APE* agrophysiological efficiency, *ARE* apparent recovery efficiency, *UE* utilization efficiency
*, ** Significant at the 0.05 and 0.01 probability levels, respectively

presented in Table 2. The determination of NUE in crop plants is an important approach to evaluate the fate of applied chemical fertilizers and their role in improving crop yields.

6 Management Practices to Improve Nitrogen Use Efficiency

Recovery efficiency of applied fertilizer N is less than 40 % for lowland rice (Fageria and Baligar 2001a; Fageria 2014). It is reported by Raun and Johnson (1999) that average world N recover efficiency of cereals is about 33 %. Hence, a large part of the N is lost in the soil-plant system by leaching, denitrification, volatilization, and surface runoff. Improving nitrogen use efficiency (NUE) is fundamental to improve crop yield, reducing crop production cost and keeping clean environment. Nitrogen use efficiency of rice can be improved with the adoption of appropriate soil, fertilizer, and plant management practices. These management practices that could improve NUE are discussed in the succeeding sections.

6.1 Liming Acid Soils

Soil acidity is one of the major constraints in crop production throughout the world. Acid soils are found over extensive areas in the tropics, subtropics, and temperate zones. Globally, soil acidity affects land area of about 3.95 billion hectares (Sumner and Noble 2003). This is about 30 % of the world's ice-free land area. Soil acidity is a main constraint in crop production in South America. In South America, 85 % of the soils are acidic, and approximately 850 million ha of such land area is underutilized (Fageria and Baligar 2001b). Liming is the most economical and effective practice to reduce soil acidity. Liming has many beneficial effects in the soils. These includes improvement in soil physical (structure), chemical (Ca, Mg, pH), and biological properties. In addition, liming also neutralize Al, Mn, and H^+ ions toxicity (Fageria 2001). All these practices improve N use efficiency in crop plants.

6.2 Use of Effective Source, Appropriate Method, and Timing of Application

Use of effective source of N is fundamental in improving N use efficiency and consequently achieving higher yields of crops. There are several sources of nitrogen. Urea and ammonium sulfate are the main nitrogen carriers worldwide in annual crop production. However, urea is generally favored by the growers over ammonium sulfate due to lower application cost because urea has a higher N analysis than ammonium sulfate (46 % vs. 21 % N). In developed countries like the USA, anhydrous NH_3 is an important N source for annual crop production. At normal pressures, NH_3 is a gas and is transported and handled as liquid under pressure. It is injected into the soil to prevent loss through volatilization. The NH_3 protonates to form NH_4^+ in the soil and becomes XNH_4^+ which is stable (Foth and Ellis 1988). The major advantages of anhydrous NH_3 are its high N analysis (82 % N) and low cost of transportation and handling. However, specific equipment is required for storage, handling, and application. Hence, NH_3 is not a popular N carrier in developing countries. Stanford (1973) and Campbell et al. (1995) reported that ammonium nitrate is generally superior to urea which may volatilize easily.

Nitrogen is a mobile nutrient in soil-plant system and different from P and K which are immobile in the soil-plant system. Hence, it can be moved from distance to plant roots and can be absorbed. However, if it is broadcast and there is no rainfall or irrigation, it may be lost due to evaporation or volatilization. Hence, application in the band or incorporating into the soil may reduce its loss and improve N use efficiency (Fageria 2009). Campbell et al. (1995) also reported that banding of N fertilizers is superior to broadcasting.

To improve applied fertilizer efficiency, for different cropping systems and environmental conditions, fertilizer industries are manufacturing slow release fertilizers (SRF) and controlled release fertilizers (CRF) either with single nutrient or with multiple nutrients. These fertilizers when added to soil improve recovery efficiency by plants by lowering the rate of release, thereby reducing leaching losses (NO_3) and emission/volatilization (N_2O, NH_3) and providing N during the entire plant growing season (Trenkel 2010). Nitrification inhibitors (N-Serve, Nitropyrin, DCD, DMPP) improve applied fertilizer efficiency by keeping N in ammonia form longer, thereby control loss of nitrate by leaching (Peoples et al. 1995; Prasad and Power 1995; Trenkel 2010). Urease inhibitors (NBPT, PPD/PPDA, hydroquinone) improve urea efficiency by suppressing the transformation of urea to ammonia and ammonium hydroxide thereby preventing volatile losses of ammonia to air (Hendrickson 1992; Trenkel 2010).

Timing of N application during crop growth is an important strategy in improving N use efficiency. The N application according to plant needs may improve its efficiency and avoid its loss from soil-plant system, In other words, synchronizing of N application with N demand of plants. It has been reported by Matson et al. (1996) and Tilman et al. (2002) that nutrient use efficiency is increased by appropriately applying fertilizers and by better matching temporal and spatial nutrient supplies with plant uptake. Applying fertilizer during periods of highest crop uptake, at or near the point of uptake (roots and leaves), as well as smaller and more frequent applications have the potential to reduce losses while maintaining or improving crop yield quantity and quality (Matson et al. 1996; Cassman et al. 2002). Rose and Bowden (2013) reported that split application of N fertilizer after crop emergence improves N use efficiency. Because plant roots had a chance to penetrate to depth and crop sink sizes are sufficient to take up significant quantities of the soil-mobile nitrate.

6.3 Use of Adequate Rate

Use of adequate rate of N is very important to increase yield and reduce cost of crop production and environmental pollution. Since N is a mobile nutrient in the soil-plant system, field trials are required to determine adequate rate for a given crop under given agroclimatic conditions. Fageria and Baligar (2001a) conducted field experiment involving lowland rice with different N rates in a Brazilian Inceptisol. Based on regression equations, in the first year, maximum grain yield (6,937 kg ha^{-1}) was obtained at 209 kg N ha^{-1}, in the second year maximum grain yield (6,958 kg ha^{-1}) was obtained at 163 kg N ha^{-1}, and in the third year maximum grain yield of 5,682 kg ha^{-1} was obtained at 149 kg N ha^{-1}. The average data of 3 years showed that maximum grain yield of 6,465 kg ha^{-1} was obtained with the application of 171 N ha^{-1}.

Singh et al. (1998) reported that maximum average grain yield of 7,700 kg ha^{-1} of 20 lowland rice genotypes was obtained at 150–200 kg N ha^{-1} at the International Rice Research Institute in the Philippines. Results of this study fall more or less in the same range as reported by Fageria and Baligar (2001a). In our fertilizer experimentations, however, 90 % of maximum rice yield is considered as an economical rate (Fageria and Baligar 2001a); in the first year it was (6,298 kg kg^{-1}) achieved at 120 kg N ha^{-1}. In the second and third years, 90 % of the maximum grain yields (6,345 and 5,203 kg ha^{-1}) were achieved at 90 and 78 kg N ha^{-1}, respectively. The average of 3 years data showed that 90 % of the maximum grain yield (5,731 kg ha^{-1}) was obtained at 84 kg N ha^{-1}. This means, that there was a residual effect of N application in lowland rice grown on an Inceptisol. The increase in grain yield of lowland rice at the economical rate (120 kg N ha^{-1}) in the first year was 76 % as compared to control N treatment. Similarly, the increase in grain yield in the second and third years at the economical N rates (90 and 78 kg ha^{-1}) was 69 and 41 %, respectively. The average increase of grain yield across the 3 years was 56 % at the economical N rate of 84 kg ha^{-1}. At the zero N level, the grain yield was 3,579, 3,754, and 3,702 kg ha^{-1} in the first, second, and third years, respectively. The average value of grain yield across the 3 years was 3,678 kg ha^{-1} at zero N rates. This means rice grain yield under the control treatment (no N application) was quite good during 3 years of experimentation. In control N treatment, rice yields increased during the second and third years of cultivation as compared to the first year of cultivation. Fageria and Baligar (1996) also reported significant increases in grain yields of lowland rice grown on an Inceptisol in the central part of Brazil. These authors reported that an average yield of 3 years (5,523 kg ha^{-1}) of lowland rice was achieved with the application of 100 kg N ha^{-1} and that in grain yields at low soil fertility level increased with succeeding cropping years.

6.4 Use of Crop Rotation

Planting rice in rotation with legumes can improve crop yield, reduce N application rates and nitrate leaching from soil-plant system. In Brazil rice is rotated with dry bean or soybean to get beneficial effects of legume-cereal rotation. Randall et al. (1997) reported that changing from continuous corn to a corn-soybean rotation has been shown to reduce NO_3^- leaching. Crop rotation also controls diseases, insects, and weed infestations which may improve N use efficiency (Fageria 1992). Dinnes et al. (2002) reported that diversifying crop rotation can reduce nitrate leaching and consequently improved nitrogen use efficiency.

6.5 Use of Conservation Tillage

Tillage improved microbial oxidation of organic matter and improved nitrification processes in the soil profile. Nitrogen mineralization increased with tillage. If nitrification or N mineralization exceeds the N demand of the plant, nitrate leaching may occur. On the other hand, conservation tillage may reduce microbial activities and release the nitrate slowly. In addition, conservation tillage reduces soil erosion and conserves more moisture in the soil profile. These favorable effects may improve plant growth and consequently higher N use efficiency.

6.6 Use of Cover Crops

Use of cover crops with main crops or cash crops is an important strategy in reducing nitrate leaching from soil-plant system. Cover crops function by accumulating the inorganic soil N between main crop seasons and holding it in an organic form, thus preventing it from leaching (Magdoff 1991; Dinnes et al. 2002). The N is subsequently released to the next crop as the cover crop residue decomposes. Cover crops also protect against soil erosion and thus preventing N losses from soil-plant systems.

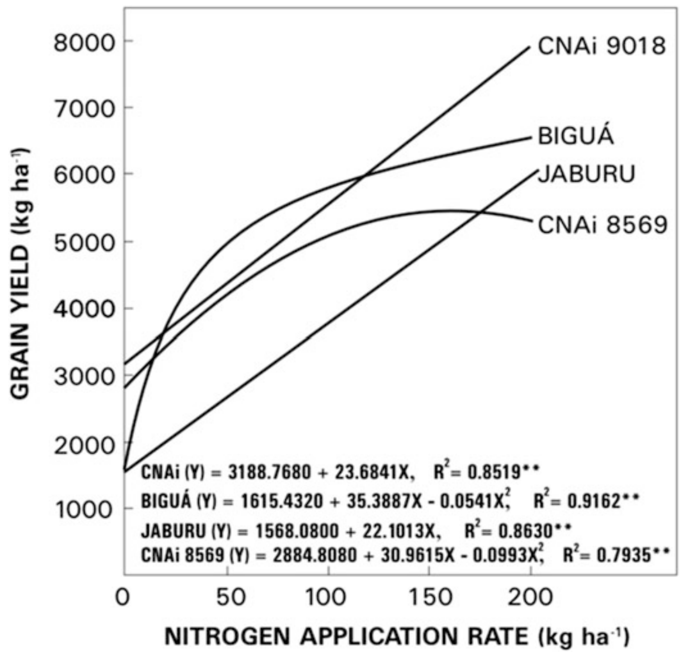

Fig. 4 Response of lowland rice genotypes to N fertilization (Source: Fageria et al 2003b)

In addition, organic matter of soil can be increased by the decomposed cover crop residues which help in improving physical, chemical, and biological properties of the soil and improve N use efficiency.

6.7 Improve Water Use Efficiency

Soil moisture is one of the most important factors affecting nutrient use efficiency in crop plants (Fageria 2009, 2013). The solubility and transport of nutrient in the rhizosphere is controlled by water availability to plants. Soil moisture at field capacity known to improve nutrient movement and availability to plants. If soils are deficient in water, nutrient use efficiency decreased significantly.

6.8 Use of Efficient Genotypes

Planting N-efficient genotypes is an important strategy. Differences in N uptake and use efficiency of upland and lowland rice genotypes has been reported widely (Fageria et al. 2011; Fageria 2013, 2014). Figure 4 shows different responses of four lowland rice genotypes. Two were having quadratic responses and two were having linear responses when N was applied in the range of 0–200 kg ha^{-1}. The difference in N uptake and utilization may be associated with better root geometry, ability of plants to take up sufficient nutrients from lower or subsoil concentrations, plants' ability to solubilize nutrients in the rhizosphere, better transport, distribution and utilization within plants, and balanced source-sink relationships (Fageria et al. 2008).

6.9 Control of Diseases, Insects, and Weeds

Diseases, insects, and weeds of agricultural crops are as old as agriculture itself (Fageria 1992). The resultant losses in economic terms are impossible to estimate accurately because the severity of diseases, insects, and weeds varies greatly from place to place, crop to crop, season to season, and year to year owing to changes in environmental factors (Fageria 1992). Kramer (1967) estimated that average worldwide losses for the main agricultural crops were 11.8 % for diseases and 12.2 % for insect pests. The average combined losses caused by diseases, insects, and weeds are put at 33.7 %. Control of diseases, insects, and weeds is an important factor in improving N use efficiency in crop production (Fageria and Gheyi 1999). Crops infested with diseases, insects, and weeds have lower photosynthetic efficiency, lower rate of absorption of water and nutrients, and competition for light, water, and nutrients, consequently reducing yields and resulting in low N use efficiency.

Conclusions

In the twenty-first century, improving nutrient use efficiency, including N, will play a major role in increasing crop yields compared to the twentieth century, mainly due to limited land and water resources available for crop production, higher cost of inorganic fertilizer inputs, declining trends in crop yields globally, and increasing environmental concerns. Furthermore, at least 60 % of the world's arable lands have mineral deficiencies or elemental toxicity problems, and on such soils fertilizers and lime amendments are essential for achieving improved crop yields. Fertilizer inputs are increasing cost of production of farmers, and there is a major concern for environmental pollution due to excess fertilizer inputs. Higher demands for food and fiber by increasing world populations further enhance the importance of improving nitrogen use efficiency. Rice is the staple food for more than 50 % world population, and use of N balanced with other essential nutrients is fundamental to improve rice yield and to maintain sustainability of cropping system. In this chapter N uptake and use efficiency and adopting practices which can improve N use efficiency are discussed.

Yields of modern cultivars is primarily source limited (supply of carbohydrates), and the source capacity should be increased, either genetically or by adopting appropriate cultural practices. More information should be generated about physiological and biochemical mechanisms involved in the efficient use of nutrients by crop plants. The use of biotechnology in identifying and creating nutrient-efficient crop species or genotypes offers exciting potential. However, this needs to be put in appropriate perspective.

References

Campbell CA, Myers RJK, Curtin D (1995) Managing nitrogen for sustainable crop production. Fertil Res 42:277–296

Cassman KG, Dobermann A, Walters D (2002) Agroecosystems, nitrogen use efficiency, and nitrogen management. AMBIO 31:132–140

Dinnes DL, Karlen DL, Jaynes DB, Kaspar TC, Hatfield JL, Colvin TS, Cambardella CA (2002) Nitrogen management strategies to reduce nitrate leaching in tile-drained Midwestern soils. Agron J 94:153–171

Fageria NK (1992) Maximizing crop yields. Marcel Dekker, New York

Fageria NK (2001) Effect of liming on upland rice, common bean, corn, and soybean production in cerrado soil. Pesq Agrop Brasileira 36:1419–1424

Fageria NK (2003) Plant tissue test for determination of optimum concentration and uptake of nitrogen at different growth stages in lowland rice. Commun Soil Sci Plant Anal 34:259–270

Fageria NK (2004) Dry matter yield and shoot nutrient concentration of upland rice, common bean, corn, and soybean grown in rotation on an oxisol. Commun Soil Sci Plant Anal 35:961–974

Fageria NK (2007) Yield physiology of rice. J Plant Nutr 30:843–879

Fageria NK (2009) The use of nutrients in crop plants. CRC Press, Boca Raton

Fageria NK (2013) The role of plant roots in crop production. CRC Press, Boca Raton

Fageria NK (2014) Mineral nutrition of rice. CRC Press, Boca Raton

Fageria NK, Baligar VC (1996) Response of lowland rice and common bean grown in rotation to soil fertility levels on a varzea soil. Fertil Res 45:13–20

Fageria NK, Baligar VC (2001a) Lowland rice response to nitrogen fertilization. Commun Soil Sci Plant Anal 32:1405–1429

Fageria NK, Baligar VC (2001b) Improving nutrient use efficiency of annual crops in Brazilian acid soils for sustainable crop production. Commun Soil Sci Plant Anal 32:1303–1319

Fageria NK, Baligar VC (2005) Enhancing nitrogen use efficiency in crop plants. Adv Agron 88:97–185

Fageria NK, Baligar VC (2008) Ameliorating soil acidity of tropical oxisols by liming for sustainable crop production. Adv Agron 99:345–399

Fageria NK, Gheyi HR (1999) Efficient crop production. Federal University of Paraiba, Campina Grande

Fageria NK, Slaton NA, Baligar VC (2003a) Nutrient management for improving lowland rice productivity and sustainability. Adv Agron 80:63–152

Fageria NK, Stone LF, Santos AB (2003b) Soil fertility management of lowland rice. EMBRAPA-Rice and Bean Research Center, Santo Antônio de Goiás

Fageria NK, Baligr VC, Li YC (2008) The role of nutrient efficient plants in improving crop yields in the twenty first century. J Plant Nutr 31:1121–1157

Fageria NK, Baligar VC, Jones CA (2011) Growth and mineral nutrition field crops, 3rd edn. CRC Press, Boca Raton

Foth HD, Ellis BG (1988) Soil fertility. Willey, New York

Hendrickson LL (1992) Corn yield response to the urease inhibitor NBPT: five-year summary. J Prod Agric 5: 131–137

Jagadish SVK, Cairns J, Lafitte R, Wheeler TR, Price AH, Craufurd PQ (2010) Genetic analysis of heat tolerance at anthesis in rice. Crop Sci 50:1633–1641

Kramer HH (1967) Plant protection and world crop production. Bayer AG, Leverkusen, Germany, p 524

Mae T (1997) Physiological nitrogen efficiency in rice: nitrogen utilization, photosynthesis, and yield potential. Plant Soil 196:201–210

Magdoff FR (1991) Managing nitrogen for sustainable corn systems: problems and possibilities. Am J Altern Agric 6:3–8

Matson PA, Billow C, Hall S (1996) Fertilization practices and soil variations control oxide emissions from tropical sugarcane. J Geophys Res 101:18533–18545

Normile D (2008) Reinventing rice to feed the world. Science 321:330–333

Ntanos DA, Koutroubas SD (2002) Dry matter and n accumulation and translocation for Indica and Japonica rice under Mediterranean conditions. Field Crop Res 74:93–101

Peoples MB, Freney JR, Mosier AR (1995) Minimizing gaseous losses of nitrogen. In: Bacon PE (ed) Nitrogen fertilization in the environment. Marcel Dekker, New York, pp 565–602

Prasad R, Power JE (1995) Nitrification inhibitors for agriculture, health and environment. Adv Agron 54: 233–281

Randall GW, Huggisns DR, Russelle MP, Fuchs DJ, Nelson WW, Anderson JL (1997) Nitrate losses through subsurface tile drainage in conservation reserve program, alfalfa, and row crop systems. J Environ Qual 26:1240–1247

Raun WR, Johnson GV (1999) Improving nitrogen use efficiency for cereal production. Agron J 91: 357–363

Rose T, Bowden B (2013) Matching soil nutrient supply and crop demand during the growing season. In: Rengel Z (ed) Improving water and nutrient use efficiency in food production systems. Wiley, Ames, pp 93–103

Singh U, Ladha JK, Castillo EG, Tirol-Padre PA, Duqueza M (1998) Genotypic variation in nitrogen use efficiency in medium and long duration rice. Field Crop Res 58:35–53

Soil Science Society of America (2008) Glossary of soil science terms. SSSA, Madison

Stanford G (1973) Rationale for optimum nitrogen fertilization in corn production. J Environ Qual 2: 159–166

Sumner ME, Noble AD (2003) Soil acidification: the world story. In: Rengel Z (ed) Handbook of soil acidity. Marcel Dekker, New York, pp 1–28

Tilman D, Cassman K, Matson P (2002) Agricultural sustainability and intensive production practices. Nature 418:671–677

Trenkel ME (2010) Slow- and controlled-release and stabilized fertilizers: an option for enhancing nutrient use efficiency in agriculture. International Fertilizer Industry Association (IFA), Paris

Wassmann R, Jagadish SVK, Heuer S, Ismail A, Redona E, Serraj R, Singh RK, Howell G, Pathak H, Sumfleth K (2009) Climate change affecting rice production: the physiological and agronomic basis for possible adaption strategies. Adv Agron 101:59–122

Xiong J, Ding CQ, Wei GB, Ding YF, Wang SH (2013) Characteristic of dry matter accumulation and nitrogen uptake of super-high yielding early rice in China. Agron J 105:1142–1150

Yoshida S (1981) Fundamentals of rice crop science. IRRI, Los Banos