NITROGEN MANAGEMENT IN LOWLAND RICE

N. K. Fageria and A. B. Santos

National Rice and Bean Research Center of Embrapa, Santo Antônio de Goiás, Goiás, Brazil.

ABSTRACT

Rice is staple diet for more than fifty percent of the world population and nitrogen (N) deficiency is one of the major yields limiting constraints in most of the rice producing soils around the world. The lowland rice N recovery efficiency is <50% of applied fertilizers in most agro-ecological regions. The low N efficiency is associated with losses caused by leaching, volatilization, surface runoff, and denitrification. Hence, improving N use efficiency is crucial for higher yields, low cost of production, and reduced environmental pollution. Adequate N supplies, as crop demands is one of the most effective practices for improving N use efficiency. Based on experimental results, on an average, the N rate for maximum economic rice yield (6500 to 7000 kg ha^{-1}) varied from 90 to 140 kg ha^{-1}. The application timing also varied from total required amount applied at sowing to split in up to two or three applications during crop growth cycle. However, most appropriate or economic results could be expected when half of the required N is applied at sowing and remaining half at active or mid-tillering growth stage. The N applied at booting and flowering did not improve grain yield. Urea and ammonium sulfate are dominant N sources of N for annual crops, including rice, especially in developing countries. Results obtained under field and greenhouse conditions show that ammonium sulfate is better source of N for lowland rice compared to urea under Brazilian conditions.

Key words: Flooded rice, Grain yield, N deficiency, Yield components.

INTRODUCTION

Rice is an important cereal because it is a staple food for more than 50% of the world population. (Fageria et al. 2003a). It is produced in all continents, except Antarctica. Furthermore, rice is a basic diet for the people of Asia, Africa, and Latin America. Rice is mostly produced and consumed in Asia. China and India are the largest rice producing as well as consuming countries. Rice ecosystems are classified into several categories based on type of soil, soil drainage and topography, temperature and water management (IRRI, 1984; Santos et al. 2003). However, upland and lowland are most dominant rice producing ecosystems (Fageria, 2007).

Lowland rice also known as flooded rice is responsible for about 76% of total rice production at the world level (Fageria et al. 2003a). In lowland rice culture, two basic methods of sowing are adopted. These methods are transplanting and direct seeding. In recent years, direct seeding is becoming more common where there is labor shortage and mechanization is practiced. Nitrogen is one of the nutrients, which limits rice yields in all rice growing soils of the world (Fageria et al. 2003a; Fageria and Baligar, 2005; Fageria et al. 2007). Nitrogen application significantly increased lowland rice yield in Brazil (Fageria and Baligar, 2001; Fageria et al. 2003b; Fageria et al. 2007), China (Yang, 1987), India (De Datta, 1986), Philippines (Dobermann et al. 2000), Japan (Yoshida, 1981), Africa (Gaudin and Dupuy, 1999) and USA (Wilson et al. 2001).

Leaching, volatilization, denitrification, and surface runoff are principal pathways of N loss in lowland rice (Fageria and Baligar, 2005). Hence, lowland rice provides unique and challenging environment for N management. Crop response to applied N and use efficiency is important criteria for evaluating crop N requirements and testing efficiency of N management practices for maximum economic yield. In Brazil about 60% of the rice production comes from lowland rice ecosystem. Other rice ecosystem is known as upland or aerobic rice. Upland rice is distinct from lowland rice, which is usually grown in saturated or submerged soil for part or all of the growing season. Yield of upland rice in Brazil is quite low (≈2000 kg ha^{-1}) compared with lowland or flooded rice (≈5000 kg ha^{-1}) (Fageria, 2001). In Asia, upland rice yields average only about 1000 kg ha^{-1} vs. about 4900 kg ha^{-1} for irrigated lowland rice (George et al., 2002). Among technological factors, which increase lowland rice yield, use of adequate rate of N is most important (Fageria et al. 2003a; Fageria et al. 2007).

Brazil has about 35 million hectares of lowland areas, locally known as “Varzea”. These areas are distributed throughout the country. At present less than 2 million hectares of these areas are under cultivation (Fageria and Barbosa Filho, 2007). Most of these lands are located near natural lakes or river basins and have water supply throughout the year. Climatic conditions are favorable in most parts of the Brazil throughout the year, these soils present largest agricultural potential lands in the world. Lowland rice is the main components of cropping systems on these lands during rainy season, which normally lasts from October to March in Brazil. During dry period other crops such as common bean, corn, soybean, cotton and wheat can be cultivated with sub-irrigation. It is possible to produce two or three crops annually on these lands. After adequate drainage system, soil fertility, is the one of the main constraints for annual crop production on varzea soils (Fageria and Baligar, 1996; Fageria et al. 2003b). Among essential plant nutrients, N is one of the important factors in determining lowland rice yield in the varzea soils of central part of Brazil (Fageria et al. 2003a; Fageria et al. 2007). The objective of this article is to discuss N management for lowland rice to improving N-use efficiency and yield of this important cereal, especially under Brazilian conditions. tions.

GROWTH AND DEVELOPMENT OF RICE

Knowledge of a crop growth and development is essential for adopting improved management practices during its growth cycle for higher yields. Additionally, knowledge of occurrence of growth stages can also be used in many physiological studies to identify the critical growth stage during plant growth and development that are sensitive to environmental factors (Fageria, 2007). Growth is defined as the irreversible change in the size of a plant cell or organ (Fageria, 1992). On the other hand, plant development is defined as the sequence of ontogenetic events, involving both growth and differentiation, leading to change in function and morphology (Landsberg, 1977). Development is most clearly manifested in changes in the form of organisms, as when it changes from vegetative to reproductive stage and from reproductive to maturity in crop plants. The development can be studied through morphological as well as physiological changes (Fageria, 1992). Different growth stages of lowland rice (cultivar Metica 1 grown in central part of Brazil) and their occurrence timing and definitions are given in Table 1.

Table 1. Timing (DAF, days after sowing) of lowland rice cultivar Metica 1 growth stages and their definitions.

Growth stage	DAF	Definition
Germination	5	Defined as the stage when the coleoptile tip first became visible.
Tillering initiation	20	Defined as the crop growth stage when first tiller from the main shoot is visible.
Active tillering	45	Defined as the development stage at which maximum tillering rate per unit time during crop growth
Panicle primordia initiation	75	Defined as initiation of panicle
Booting	100	Defined as the development stage at which panicle is enclosed by the sheath of the uppermost leaf
Flowering	110	Defined as the physiological stage at which flowers are visible on the panicles
Physiological maturity	140	Defined, as the growth stage at which grains are ripened and panicles are ready for harvest.

Rice phenology (development of a plant through successive growth stages) is generally divided into vegetative (from emergence to panicle primordia initiation), reproductive (from panicle primordia initiation to flowering) and spikelet filling (from flowering to physiological maturity) (Fageria, 2007). Fig. 1 shows growth stages of lowland rice cultivar Metica 1 having growth cycle of 140 days from sowing to physiological maturity or 135 days from germination to physiological maturity under Brazilian conditions or tropics. Vegetative growth stage was having 70 days growth duration (germination to initiation of panicle primordia), reproductive growth stage was having 35 days growth duration (panicle primordia initiation to flowering), and spikelet-filling stage was also having 30 days growth duration (flowering to physiological maturity). The plant growth stages from panicle initiation to flowering and from flowering to physiological maturity or spikelet filling are important for yield determination because during these stages the potentials for seed number and seed weight components of yield are formed (Fageria, 2007). Nitrogen is required for tillering, formation of leaf area index and major part of dry matter formation during vegetative growth stage. These plant morphological characters are positively associated in increasing grain yield (Fageria et al. 1997; Fageria, 2007). The N is also needed by rice during reproductive growth stage for panicle development and for gain weight increase during grain filling growth stage. Hence, rice plant needs N during whole growth cycle for yield improvement.

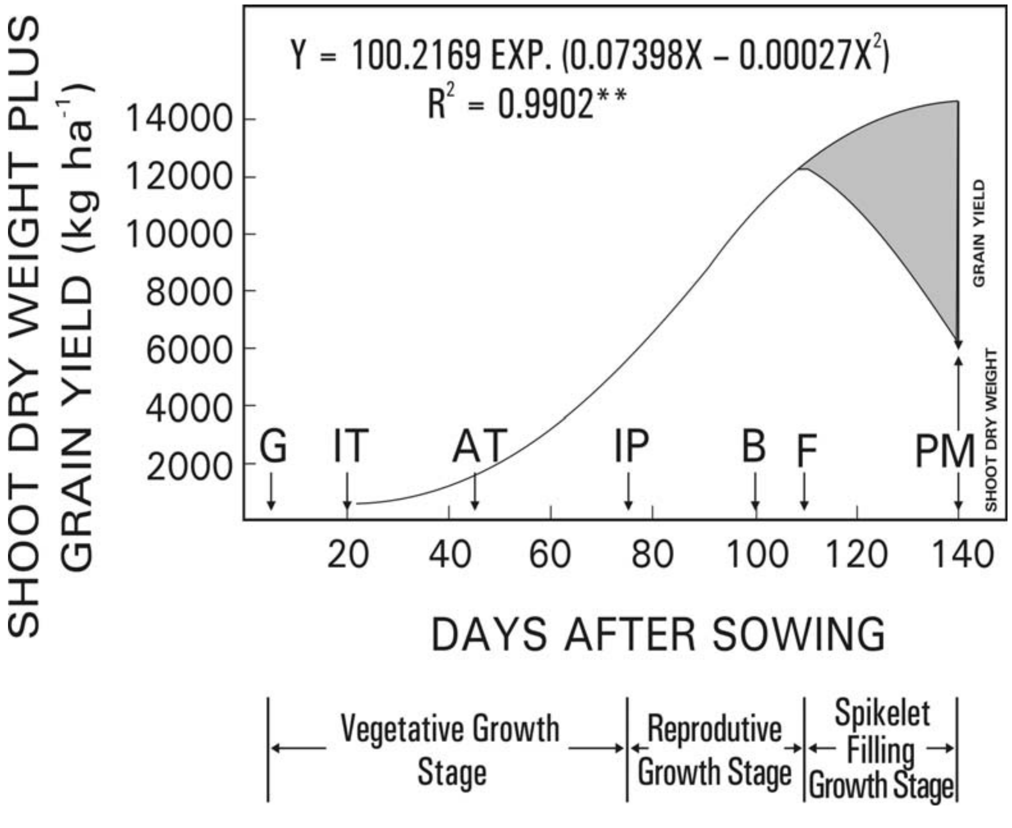

Fig. 1. Lowland rice shoot dry weight during growth cycle and grain yield.

NITROGEN CONCENTRATION AND UPTAKE

Knowledge of adequate N concentration (content per unit dry weight) and uptake (concentration X dry weight) is an important plant parameter for appropriate N management of a crop. The adequate N concentration and uptake varied with yield level, which is affected with crop management practices. Data presented in Table 2 and 3 show relationship between shoot dry weight or grain yield and N concentration and uptake in the shoot or grain of lowland rice grown on Brazilian Inceptisol. Based on regression equations, adequate concentration and uptake for the maximum shoot and grain yield can be calculated (Fageria, 2003). The N adequate concentration level in rice shoot varied from 43.4 to 6.5 g kg^{-1} depending on plant age (Fageria, 2003). It decreases with the advancement of plant age reflecting dilution effect with the advancement of plant age (Fageria et al. 1997). At physiological maturity optimum N concentration in the grain was 10.9 g kg^{-1}, which was 68% higher, compared with shoot concentration. The N uptake in shoot and as well as in the grain was significantly related to shoot dry weight and grain yield (Table 3). The higher R^2 values of N uptake in shoot after 35 days of growth stage indicate N uptake increased in the shoot with the advancement of plant age. The maximum variability (99%) in N uptake was at physiological maturity. This means that N uptake determination during this growth stage is more important for knowing quantity of N removed from the soil by rice crop and adopting appropriate N management practice to supply desired N rate. Optimum value of N for maximum shoot yield increased with the advancement of plant age up to flowering and then decreased (Fageria, 2003). The decrease may be associated with translocation of greater part of N to grain formation after flowering. Total N uptake in shoot and grain was 147 kg ha^{-1}. Accumulated N at harvest or physiological maturity produced 9545 kg ha^{-1} shoot dry weight and 6550 kg ha^{-1} grain weight. Hence, to produce 1 Mg grain yield, rice needs 22 kg N uptake in shoot and grain. Yoshida (1981) reported that to produce one metric ton of rough rice, the N requirement was 20 kg ha^{-1}.

Table 2. Relationship between dry matter yield of shoot or grain (Y) and N concentration in shoot or grain at different growth stages in lowland rice. Values are averages of 3 years field experimentation.

Plant Growth Stage	Regression	R^2
IT (22)[a]	$Y = -439.4654 + 22.5403X - 0.0946X^2$	0.39^{NS}
AT (35)	$Y = -8974.3480 + 586.9736X - 8.4265X^2$	0.74^{*}
IP (71)	$Y = 211.7915 - 34.9390X + 28.1748X^2$	0.88^{**}
B (97)	$Y = -36286.13 + 7325.2430 - 285.4674X^2$	0.77^{*}
F (112)	$Y = -44383.16 + 10690.71X - 485.6974X^2$	0.94^{**}
PM (140)	$Y = -100159.00 + 33792.63X - 2605.362X^2$	0.94^{**}
PM (140)[b]	$Y = 1141085.70 + 27046.20X - 1237.72X^2$	0.78^{*}

*, **, NS, Significant at the 5 and 1% probability level and nonsignificant, respectively. IT, initiation of tillering; AT, active tillering; IP, initiation of panicle; B, booting; F, flowering; PM, physiological maturity. [a]Values in the parentheses represent age of the plants in days after sowing. [b]In this line, values are for grain yield. Source: Adapted from Fageria (2003).

Table 3. Relationship between grain yield (Y) and N uptake in the shoot and grain of lowland rice at different growth stages. Values are averages of three years field experimentation.

Plant growth stage	Regression	R^2
IT (22)[a]	$Y = 166.46 + 9.4552X - 0.1565X^2$	0.61^{NS}
AT (35)	$Y = -391.29 + 63.8885X - 0.5898X^2$	0.93^{**}
IP (71)	$Y = 40.32 + 101.2576X - 0.3939X^2$	0.97^{**}
B (97)	$Y = -2069.44 + 185.7829X - 0.6725X^2$	0.94^{**}
F (112)	$Y = -367.39 + 167.8636X - 0.4528X^2$	0.97^{**}
PM (140)	$Y = -2330.74 + 335.1191X - 2.3641X^2$	0.99^{**}
PM (140)[b]	$Y = -3547.09 + 261.4988X - 1.7099X^2$	0.99^{**}

**, 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. [a]Values in the parentheses represent age of the plants in days after sowing. [b]In this line, values are for grain yield. Source: Adapted from Fageria (2003).

NITROGEN USE EFFICIENCY

Nitrogen use efficiency is an important index in determining how the applied N was used by rice crop. Hence, knowledge of this plant parameter in fundamental in improving N use efficiency and consequently N management. In the literature, N use efficiency is defined and calculated in several ways. Fageria and Baligar (2005) suggested five definitions and methods of calculating N use efficiency in crop plants. These efficiencies are known as agronomic efficiency (AE), physiological efficiency (PE), agrophysiological efficiency (APE), apparent recovery efficiency (ARE) and utilization efficiency (UE). Definitions of these efficiencies and their methods of calculation are given in Table 4. Fageria et al (2007) calculated these five N use efficiency in lowland rice genotypes and results are presented in Table 5. There were distinct differences among genotypes in N use efficiency. Overall, 29% of the N applied was recovered, indicating large amount of N is lost in soil-plant systems and appropriate management practices are necessary to improve its efficiency.

Table 4. Definitions and methods of calculating nitrogen use efficiency.

Nutrient efficiency	Definitions and formulas for calculation
Agronomic efficiency (AE)	The agronomic efficiency is defined as the economic production obtained per unit of nutrient applied. It can be calculated by: AE (kg kg^{-1}) = (G_f – G_u/N_a) Where, G_f is the grain yield of the fertilized plot (kg), G_u is the grain yield of the unfertilized plot (kg), and N_a is the quantity of N applied (kg).
Physiological efficiency (PE)	Physiological efficiency is defined as the biological yield obtained per unit of nutrient uptake. It can be calculated by: PE (kg kg^{-1}) = (BY_f – BY_u/N_f – N_u) Where, BY_f is the biological yield (grain plus straw) of the fertilized plot (kg), BY_u is the biological yield of the unfertilized plot (kg), N_f is the N uptake (grain plus straw) of the fertilized plot (kg), and N_u is the N uptake (grain plus straw) of the unfertilized plot (kg).
Agrophysiological efficiency (APE)	Agrophysiological efficiency is defined as the economic production (grain yield in case of annual crops) obtained per unit of nutrient uptake. It can be calculated by: APE (kg kg^{-1}) = (G_f – G_u/N_{uf} – N_{uu}) Where, G_f is the grain yield of fertilized plot (kg), G_u is the grain yield of the unfertilized plot (kg), N_{uf} is the N uptake (grain plus straw) of the fertilized plot (kg), N_{uu} is the N uptake (grain plus straw) of unfertilized plot (kg).

Apparent recovery efficiency (ARE)	Apparent recovery efficiency is defined as the quantity of nutrient uptake per unit of nutrient applied. It can be calculated by: ARE (%) = $(N_f - N_u/N_a)$ X 100 Where, N_f is the N uptake (grain plus straw) of the fertilized plot (kg), N_u is the N uptake (grain plus straw) of the unfertilized plot (kg), and N_a is the quantity of N applied (kg).
Utilization efficiency (UE)	Nutrient utilization efficiency is the product of physiological and apparent recovery efficiency. It can be calculated by: UE (kg kg^{-1}) = PE X ARE

Table 5. Nitrogen use efficiency by five lowland rice genotypes

♣	AE (kg kg^{-1})	PE (kg kg^{-1})	APE (kg kg^{-1})	ARE (%)	EU (kg kg^{-1})
CNAi 8886	23	105	56	37	39
CNAi 8569	17	188	69	29	55
BRSGO Guará	21	222	123	29	64
BRS Jaburu	16	114	64	26	30
BRS Biguá	19	145	74	23	33
Average	19	155	77	29	44

Source: Adapted from Fageria et al. (2007)

NITROGEN MANAGEMENT PRACTICES

Lowland rice ecosystem is different compared to upland rice. The anaerobic soil environment created by flood-irrigation of lowland rice creates a unique and challenging environment for the efficient management of soil and fertilizer nutrients (Fageria et al. 2003a). Main N management practices, which can improve its uptake and use efficiency, are adequate rate, appropriate timing of application and planting efficient genotypes.

ADEQUATE RATE

Nitrogen is a dynamic and mobile nutrient in soil plant-systems. Major part of the N in the soil is present in the organic form. Mineralization of organic N depends on microbial activity, which is influenced by environmental factors. Further, there are many sources of addition and loss pathways of N in soil-plant system, which complicate more its balance and use by plants. Hence, N concentration changes in the rhizosphere with time and space. Therefore, soil analysis test is not applicable to N as in the case of immobile nutrient like P and K. Hence, a crop response curve showing yield versus N rates is most efficient and effective method of defining N requirement of a crop (Fageria and Baligar, 2005). Fig. 2 shows response of lowland rice to applied N in a Brazilian Inceptisol.

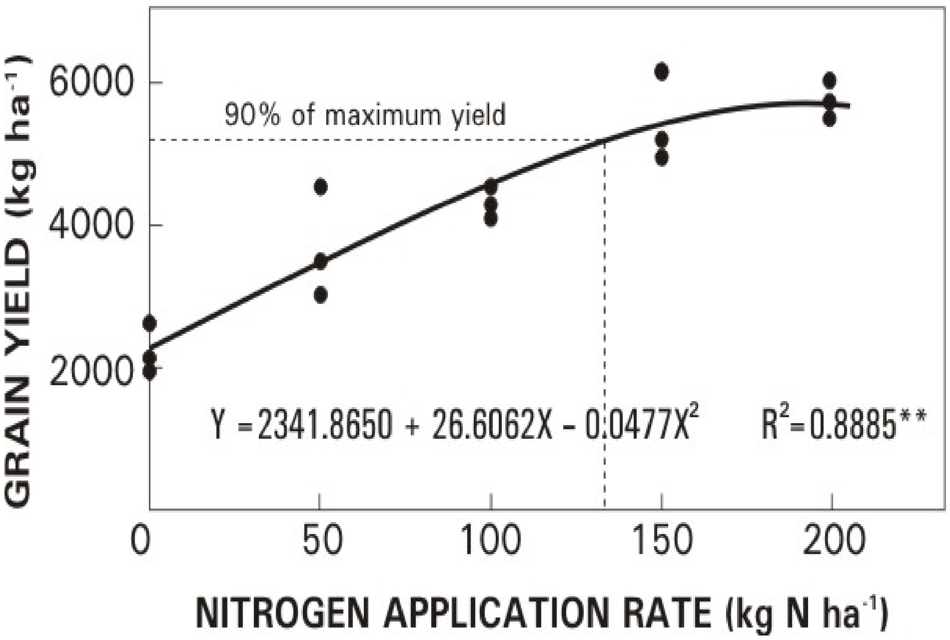

Fig. 2. Relationship between N rate and grain yield of lowland rice.

There was a significant quadratic increase in grain yield with increasing N rate in the range of 0 to 200 kg ha^{-1}. Fageria and Baligar (2001) also reported a significant quadratic increase in the lowland rice yield in a Brazilian Inceptisol when N was applied in the range of 0 to 210 kg ha^{-1}. The N rate to obtain 90% of maximum yield, which is considered as an economic rate, was obtained at the N rate of about 135 kg ha^{-1}. Fageria and Baligar (2001) reported that maximum economic yield of lowland rice cultivated for 3 consecutive years in the same area was obtained with the application of 90 kg N ha^{-1}. Dobermann et al. (2000) reported that irrigated rice cultivar IR 72 yield increased significantly up to 150 kg N ha^{-1} at the International Rice Research Institute in the Philippines. Tem Berger and Riethovem (1997) reported that in China adequate rate of N for lowland rice cultivars of medium growth cycle varied from 100 to 150 kg ha^{-1}. When N is applied at recommended rate to crops, N use efficiency is higher and N losses are minimum. When N is applied at higher rates than those are necessary for maximum economic yield, N accumulates in the soil profile and losses are higher.

TIMING OF NITROGEN APPLICATION

The N is lost from soil-plant system via volatilization, leaching, denitrification, or runoff (Fageria and Baligar, 2005; Fageria et al. 2006). This suggests that there is more N available for loss at any time during crop growing season if N is applied only once during crop growth. Hence, splitting the N fertilizer applications during crop growth can reduce nitrate leaching and improve N use efficiency. For lowland rice under Brazilian conditions, applying half of the N in a band at sowing and the remaining six to seven weeks later should increase both N fertilizer use efficiency and N uptake by minimizing leaching opportunity time and better timing the N application to N uptake (Fageria and Baligar 1999). Fageria and Baligar (1999) reported that agronomic efficiency of N in lowland rice was higher when N was applied in three-split application (one-third at sowing + one-third at active tillering + one-third at panicle initiation) compared with the entire N applied at sowing. Split application of N in sandy soils and high rainfall areas is most desirable.

A study conducted by Fageria and Prabhu (2004) in the Brazilian Inceptisol showed that N fractionated into two or three equal doses produced higher grain yield of lowland rice compared with total applied at sowing (Fig. 3).

Fageria and Baligar (1999) studied different timimg of N application in a greenhouse experiment in lowland rice. Maximum grain yield was obtained with total N (240 mg kg^{-1}) total N applied at sowing followed by one-third applied at sowing + one-third at active tillering + one-third at panicle initiation growth stage. Minimum grain yield was obtained when one-third N was applied at sowing + one third at panicle initiation + one-third at flowering followed by one-third at sowing + one-third at tillering initiation + one-third at flowering. The N applied treatment which received one-third at sowing + one third at panicle initiation + one-third at booting also produced lower yield. Hence, a part of N applied at late reproductive growth stage or at the initiation of grain filling growth stage produced lowest grain yield compared to N applied at vegetative or the initiation of reproductive growth stage. The lower yield with late application of N was associated with lower number of panicles per pot, lower number of filled spikelets and lower grain harvest index (Fageria and Baligar, 1999). Number of panicles per pot and grain harvest index was having highest correlation with grain yield (Fageria and Baligar, 1999). Nitrogen harvest index and N use efficiency were also lower for part of the N applied late or at booting and flowering compared to N applied at early or in the vegetative or initiation of reproductive growth stage (Fageria and Baligar, 1999).

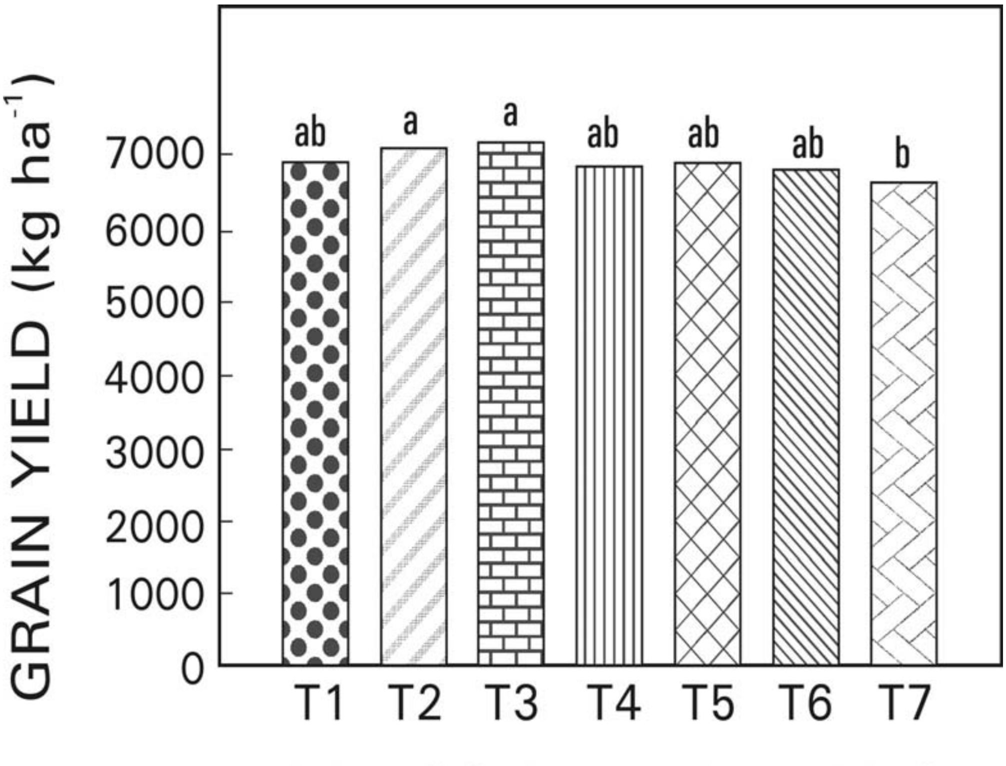

Fig.3. Grain yield of lowland rice as influenced by N timing treatments. T_1 = all the N applied at sowing, T_2 = 1/3 N applied at sowing + 1/3 N applied at active tillering + 1/3 N applied at the initiation of panicle primordia, T_3 = 1/2

N applied at sowing + 1/2 N applied at active tillering,T_4 = 1/2 N applied at sowing + 1/2 N applied at the initiation of panicle primordia, T_5 = 2/3 N applied at sowing + 1/3 N applied at active tillering, and T_6 = 2/3 N applied at sowing + 1/3 N applied at initiation of primordia floral and T_7 = 1/3 N applied at sowing + 2/3 N applied at 20 days after sowing.
Source: Adapted from Fageria and Prabhu (2004).

SOURCE AND METHOD

Nitrogen sources and methods of application significantly influence N uptake efficiency in crop plants. Important considerations in selecting source of N by growers are availability, economics, convenience in storage and handling and effectiveness of the carrier. Generally, urea and ammonium sulfate are the principal sources of N fertilization. However, there are number of fertilizers containing N are available in the market (Table 6). In USA agriculture, anhydrous ammonia (NH_3) is an important source of N fertilization. At normal pressure 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. The major advantages of anhydrous ammonia are its high N analysis (82% N) and low cost of transportation and handling. However, specific equipment's are required for storage, handling, and application. Hence, it is not a popular N carrier in developing countries (Fageria and Baligar 2005). Results obtained by the authors under field and greenhouse conditions show that ammonium sulfate is better source of N for lowland rice compared to urea under Brazilian conditions

Table 6. Major nitrogen fertilizers

Common name	Formula	N (%)
Ammonium sulfate	$(NH_4)_2SO_4$	21
Urea	$CO(NH_2)_2$	45
Anhydrous ammonia	NH_3	82
Ammonium chloride	NH_4Cl	26
Ammonium nitrate	NH_4NO_3	35
Potassium nitrate	KNO_3	14
Sodium nitrate	$NaNO_3$	16
Calcium nitrate	$Ca(NO_3)_2$	16
Calcium cyanamide	$CaCN_2$	21
Ammonium nitrate sulfate	$NH_4NO_3(NH_4)_2SO_4$	26
Nitrochalk	$NH_4NO_3 + CaCO_3$	21
Monoammonium phosphate	$NH_4H_2PO_4$	11
Diammonium phosphate	$(NH_4)_2HPO_4$	18

Nitrogen fertilizers are broadcast and mixed into soil before a crop sowing. They may also be applied in row below seed at sowing and may be banded in row beside seed at planting or preemergence. During postemergence, fertilizers may be sidedressed, injected into subsurface and top dressed. Fertilizers, mixed into soil or injected into subsurface are more efficient methods of N application compared to broadcast and left on the soil surface. The sidedress application, N fertilization several weeks after corn emergence, has maximized the efficiency of fertilizer N in most situations (Fageria and Baligar, 2005). Placement of urea or ammonium sulfate in the anaerobic layer of flooded rice is an important strategy to avoid N losses by nitrate leaching and denitrification (Fageria and Baligar, 2005).

USE OF N EFFICIENT GENOTYPES

Utilization of plant species or genotypes of same species efficient in absorption and utilization of N is an important strategy in improving N use efficiency and sustainable agricultural system. Differences in N uptake and utilization among lowland rice genotypes have been reported by many workers (Fageria et al. 1997; Fageria and Barbosa Filho, 2001; Fageria and Baligar, 2003; Fageria et al. 2003a; Fageria and Baligar, 2005). Fig. 4 shows response of five lowland rice genotypes to N fertilization. These genotypes differ in yield response to applied N. These genotypes can be grouped into three classes according to their response to N fertilization. The first group was efficient and responsive. The genotype which produced above the average yield compared to all the genotypes tested at the low N level and responded well to applied N. The genotype BRSGO Guará fall into this group. The second classification was efficient and nonresponsive. The genotype, which produces well at low N rates but did not respond well at higher, N rates. The genotype CANi 8886 and CNAi 8569 fall into this group. The third group is genotypes, which produce low at low N rates but respond well at higher N rates. This genotype can be designated as inefficient and responsive. The genotypes BRS Bigua and BRS Jaburu fall into this group.

From a practical point of view, the genotypes which fall into efficient and responsive are the most desirable, because they can produce well at a low soil N levels and also respond well to applied N. Thus, this group can be utilized with low as well as high input technology with reasonably good yield. The second most desirable group is efficient nonresponsive. Genotypes of this type can be planted under low N level and still produce more than average yield. The inefficient responsive genotypes can be used in breeding program for their N-responsive characteristics. In the literature several reasons have been cited why some genotypes are more efficient in N utilization compared to others (Fageria et al. 1997; Fageria and Baligar 2003; Fageria etal. 2003b).

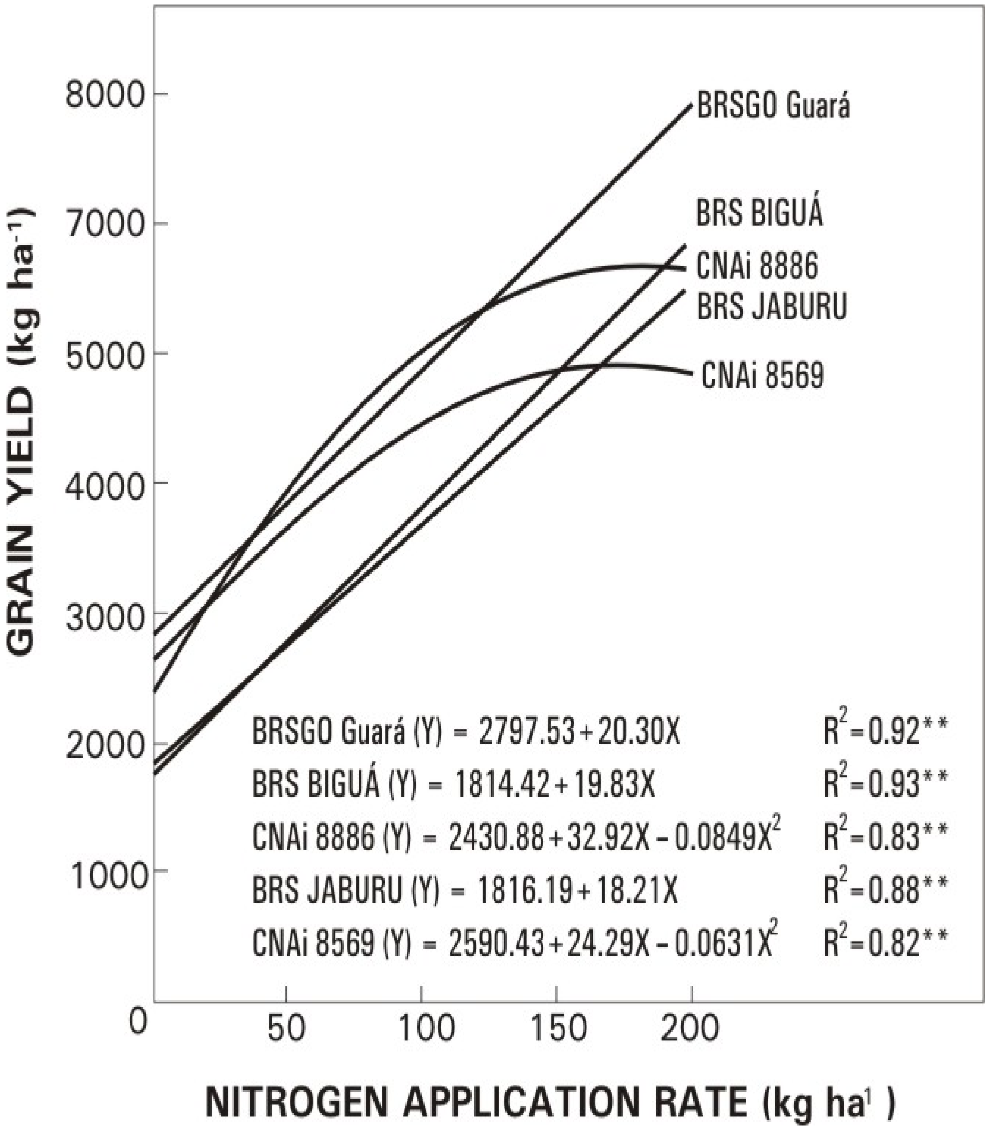

Fig. 4. Grain yield of five lowland rice genotypes as influenced by N application rate.

Regarding genotype variability for N use efficiency, Rosielle and Hamblin (1981) reported that heritability for grain yield are usually lower under low vs. high N, making potential progress less for low N than high N target environments. Banziger et al. (1997) also reported that heritability of grain yield usually decreases under low N. Banziger and Lafitte (1997) reported that secondary traits (ears per plant, leaf senescence, leaf chlorophyll concentration) are a valuable adjunct in increasing the efficiency of selection for grain yield when broad-sense heritability of grain yield is low under low N environment.

CONCLUSIONS

Rice is the staple food in the diet of about one-half of the world's population and produced under both upland and lowland ecosystems. However, lowland ecosystem produces about 76% of the global rice. Nitrogen is usually the most yield-limiting nutrient in lowland rice production in most of the rice producing soils. The N requirement of rice is equal or little less than K. Furthermore, N recovery by rice is less than 50% because it is lost by leaching, denitrification, volatilization, soil erosion, and plant canopy. On an average N balance in rice plant soil-system is 40% uptake by plants, 25% immobilized in soil plant system and 35% is lost through volatilization, leaching, and denitrification. Soil available N (organic and inorganic) is an important source to sustain rice yield even in cases where fertilizer N is applied at high rates in most situations. If other crop producing factor are at favorable level (water, cultivars, control of diseases, insects and weeds), on an average, N source of soil (without application of chemical fertilizers) can sustain 3 Mg ha^{-1} rice yield for long duration under most agroecological conditions. Other essential plant nutrients, especially P, and K as well as clay and organic matter contents should also be at an appropriate level to sustain this yield.

Improving N use efficiency of rice is important for higher yield, low cost of production, and to avoid environmental pollution. Nitrogen as a mobile nutrient in soil plant-system, N recommendations based on field trials that determine the crop response to various rates of fertilizer application are most efficient and effective. Plant tissue test comparing with specified benchmark concentrations that separate deficient, sufficient, or toxic levels are an important diagnostic method of plant N status. The amount of N required producing maximum economic yield varied from 90 to 130 kg N ha^{-1}. This N rate generally produces 6500 to 7000 kg ha^{-1} rice yields. On an average 20 kg N is absorbed by rice plant (grain plus straw) to produce one ton of rough rice grain.

Nitrogen application rate should be applied in split doses. Under tropical conditions, half of the required N should be banded at sowing and remaining half should be applied at active or midtillering. Second option is one-third should be banded at sowing, one-third as topdressing at active tillering, and remaining one-third should be applied at panicle initiation. Adopting other management practices such as sowing high yield potential cultivars, crop rotation, water management, use of appropriate N source, Conservation tillage, control of diseases, insects and weeds can improve N use efficiency. The N partitioning and use efficiency varied with crop species and cultivars with in species. Hence, planting N efficient genotypes is a very attractive strategy for reducing cost of crop production, improving crop yields and keeping healthy environment.

REFERENCES

Banziger, M., and H. R. Lafitte. 1997. Efficiency of secondary traits for improving maize for low nitrogen target environments. Crop Sci. 37:1110-1117.

Banziger, M., F. J. Betran, and H. R. Lafitte. 1997. Efficiency of high nitrogen selection environments for improving maize low nitrogen target environment. Crop Sci. 37:1103-1109.

De Datta, S. K. 1986. Improving nitrogen fertilzer efficiency in lowland rice in tropical Asia. Fert. Res. 9: 171-186.

Dobermann, A., Dawe, D., Roetter, R. P. and Cassman, K. G. 2000. Reversal of rice yields decline in a long-term continuous cropping experiment. Agron. J. 92:633-643.

Fageria, N. K. 1992. Maximizing crop yields. Marcel Dekker, New York.

Fageria, N. K. 2001. Nutrient management for improving upland rice productivity and sustainability. Commun. Soil Sci. Plant Anal. 32:2603-2629.

Fageria, N. K. 2003. Plant tissue tests for determination of optimum concentration and uptake of nitrogen at different growth stages in lowland rice. Commun. Soil Sci. Plant Anal. 2003:34:259-270.

Fageria, N. K. 2007. Yield physiology of rice. J. Plant Nutr. 30:843-879.

Fageria, N. K. and Baligar, V. C. 1996. Response of lowland rice and common bean grown in rotation to soil fertility levels on a varzea soil. Fert. Res. 45:13-20.

Fageria, N. K., and V. C. Baligar. 1999. Yield and yield components of lowland rice as influenced by timing of nitrogen fertilization. J. Plant Nutr. 22:23-32.

Fageria, N. K. and Baligar, V. C. 2001. Lowland rice response to nitrogen fertilization. Commun. Soil Sci. Plant Anal. 32:1405-1429.

Fageria, N. K., and V. C. Baligar. 2003. Methodology for evaluation of lowland rice genotypes for nitrogen use efficiency. J. Plant Nutr. 26:1315-1333.

Fageria, N. K. and Baligar, V. C. 2005. Enhancing nitrogen use efficiency. Adv. Agron. 88:97-185.

Fageria, N. K., V. C. Baligar, and R. B. Clark. 2006. Physiology of crop production. The Haworth Press, New York.

Fageria, N. K., and M. P. Barbosa Filho. 2001. Nitrogen use efficiency in lowland rice genotypes. Commun. Soil Sci. Plant Anal. 32:2079-2089.

Fageria, N. K. and Barbosa Filho, M. P. 2007**.** Dry matter and grain yield, nutrient uptake, and phosphorus use efficiency of lowland rice as influenced by phosphorus fertilization.. Commun. Soil Sci. Plant Anal. 38:1289-1297.

Fageria, N. K., Baligar, V. C. and C. A. Jones. 1997. Growth and mineral nutrition of field crops, 2nd edition, Marcel Dekker: New York.

Fageria, N. K., and A. S. Prabhu. 2004. Blast control and nitrogen management in lowland rice cultivation. Pesq. Agropec. Bras. 39:123-129.

Fageria, N. K., A. B. Santos, and V. A. Cutrim. 2007. Yield and nitrogen use efficiency of lowland rice genotypes as influenced by nitrogen fertilization. Pesq. Agropec. Bras. 42:1029-1034.

Fageria, N. K., N. A. Slaton, and V. C. Baligar. 2003a. Nutrient management for improving lowland rice productivity and sustainability. Adv. Agron. 80:63-152.

Fageria, N. K., F. Stone, and Santos. A. B. 2003b. Soil fertility management for irrigated rice. Embrapa Arroz e Feijão, Santo Antônio de Goias, Brazil.

Gaudin, R., and J. Dupuy. 1999. Ammonical nutrition of transplanted rice fertilized with large urea granules. Agron. J. 91:33-36.

George, T., R. Magbanua, D. P. Garrity, B. S. Tubana, and J. Quiton. 2002. Rapid loss of rice cropped successively in aerobic soil. Agron. J. 94:981-989.

IRRI (International Rice Research Institute). 1984. Terminology for rice growing environments. IRRI, Los Bãnos, Philippines.

Landsberg, J. J. 1977. Effects of weather on plant development. p.289-307. In: J. J. Landsberg and C. V. Cuttings (ed.) *Environmental effects on crop physiology*. Academic Press, London.

Rosielle, A. A., and J. Hamblin. 1981. Theoretical aspects of selection for yield in stress and non-stress environments. Crop Sci. 21:943-946.

Santos, A. B., Fageria, N. K and Prabhu, A. S. 2003. Rice ratooning management practices for higher yields. Commun. Soil Sci. Plant Anal. 34:881-918.

Tem Berger, H. F. M., and J. J. M. Riethoven. 1997. Application of a simple rice nitrogen model. p. 793-798. In: *Plant nutrition for sustainable food production and environment,* Eds. T. Ando, K. Fuzita, T. Mae, H. Matsumoto, S. Mori, and J. Sekiya, Kluwer Academic Publishers, Dordrecht.

Wilson, C. E. Jr., N. A. Slaton, R. J. Norman, and D. M. Miller. 2001. Efficient use of fertilizer. p. 51-74. In: Ed. N. A. Slaton (ed.) *Rice production handbook.* Cooperative Extension Service Misc. Publication No. 192, Little Rock: Arkansas.

Yang, X. 1987. Physiological mechanisms of nitrogen efficiency in hybrid rice. Ph. D. Dissertation, Zhejiang Agriculture University, Hangzhou, China.

Yoshida, S. 1981. Fundamentals of rice crop science. International Rice Research Institute. Los Bãnos, Philippines: