

NITROGEN NUTRITION IN RICE

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ABSTRACT

Nitrogen nutrition in rice though widely discussed, still modern concepts and findings are enriching us. It is also a difficult concept due to large variability of cultivation practices and environment. A clear idea of nitrogen nutrition will not only enhance productivity but also the nitrogen use efficiency. These concepts will be elaborated hereunder.

Keywords: *Rice, Nitrogen Nutrition, Nitrogen Use Efficiency, Nitrogen Management, Ammonium, Nitrate*

INTRODUCTION

Most of Earth's atmosphere (78%) is nitrogen, making it the largest pool of nitrogen. However, atmospheric nitrogen has limited availability of biological use, leading to a scarcity of usable nitrogen in many types of ecosystems. Nitrogen is essential for many processes and is crucial for any life on Earth. It is a component in all amino acids, as incorporated into proteins, and is present in the bases that make up nucleic acids, such as RNA and DNA. In plants, much of nitrogen is used in chlorophyll molecules, which are essential for photosynthesis and further growth (Smil, 2000). Chemical processing or nitrogen fixation is necessary to convert gaseous nitrogen into forms usable by living organisms, which makes nitrogen a crucial component of food production.

Nitrogen in Soil

Nitrogenous compounds are inherently available in soil due to decomposition of organics by microorganisms or by the fixation of gaseous nitrogen by microorganisms. As the soil types may be different depending on the ecosystem, the nitrogen content of the soil varied widely.

One of the differences between acidic and neutral or alkaline soils is that in acidic soils the prominent form in which nitrogen is available to plants through the microbial mineralization of organic soil matter is, in general, the ammonium ion, and in neutral or alkaline soils it is nitrate the reason of this is that the activity of nitrifying bacteria is reduced in acidic mineral soils.

It appears calcifuges plants grow better in $\text{NH}_4\text{-N}$ form whereas calcicoles grow better under $\text{NO}_3\text{-N}$ form. There was no indication of nitrogen deficiency in adversely affected plants or lack of nitrate reductase systems in the calcifuges species.

There was no apparent antagonism for uptake between nitrate and phosphate ions but there were strong indications of antagonisms between ammonium and potassium ions (Gigon and Rorison, 1972).

Nutrient uptake in the soil is achieved by cation exchange, where root hairs pump hydrogen ions into the soil through proton pumps.

These hydrogen ions displace cations attached to negatively charged soil particles so that the cations are available and taken up by roots. It is generally stated that the uptake of anions are more readily absorbed by plant roots when associated with monovalent cations than with di or polyvalent cations. It is well known that anion uptake is related to the expense of energy.

According to Epstein (1972) the criteria for an element to be essential for plant growth are

(1) In the absence, the plant is unable to complete a normal life cycle or (2) That the element is part of some essential plant constituent or metabolite.

Nitrogen in Plants

Nitrogen is an essential component of all proteins. Nitrogen deficiency most often results in stunted growth, slow growth, and chlorosis. Nitrogen deficient plants will also exhibit a purple appearance on the stems, petioles and underside of leaves from an accumulation of anthocyanin pigments. Most of the nitrogen taken up by plants is from the soil in the forms of NO_3 , although in acid environments such as

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boreal forests where nitrification is less likely to occur, ammonium NH_4^+ is more likely to be the dominating source of nitrogen. Amino acids and proteins can only be built from NH_4^+ so NO_3^- must be reduced. Under many agricultural settings, nitrogen is the limiting nutrient of high growth. Some plants require more nitrogen than others, such as corn. Because nitrogen is mobile, the older leaves exhibit chlorosis and necrosis earlier than the younger leaves. Soluble forms of nitrogen are transported as amines and amides (Huner and Hopkins, 2008).

Nitrogen increases plant height, panicle number, leaf size, spikelet number, and number of filled spikelets, which largely determine the yield capacity of a rice plant. Panicle number is largely influenced by the number of tillers that develop during vegetative stage. Spikelet number and number of filled spikelets are likely determined in the reproductive stage. Farmers use split applications for nitrogen. The number and rate of application can be varied. Ability to adjust number and rate allow the synchronization to real time demand by the crop. The initial symptom of nitrogen deficiency in rice is a general light green to yellow color of the plant. It is first expressed in the older leaves because nitrogen is translocated within the plant from the older leaves to the younger ones. Prolonged nitrogen deficiency causes severe plant stunting, reduced tillering and yield reduction.

Models and experimental studies of the rhizosphere of rice plants growing in anaerobic soil show that two major processes lead to considerable acidification (1-2 p^{H} units) of the rhizosphere over a wide range of root and soil conditions. One is generation of H^+ ion in the oxidation of ferrous ion by O_2 released from the roots. The other is release of H^+ from roots to balance excess intake of cations over anions, N being taken up chiefly as NH_4^+ . CO_2 exchange between the roots and soil has a much smaller effect. The zone of root influence extends a few mm from the root surface. There are substantial differences along the root length and time. The acidification and oxidation cause increased sorption of NH_4^+ ions on soil solids, thereby impeding the movement of N to absorbing root surfaces. But they also cause solubilization and enhances uptake of soil phosphate (Kirk 1993). Nitrogen fixing bacteria in the rhizosphere of the rice plant exhibit diurnal cycles that mimic plant behavior, and tend to supply more fixed nitrogen during growth stages when the plant exhibits a high demand for nitrogen (Sims and Dunigan, 1984). Rice roots require the presence of oxygen in the rhizosphere, which protects them from the toxic effect of reduced compounds like H_2S , CH_4 etc. Oxidation by roots of surrounding soil in which reducing processes predominate is an adaptive reaction characteristic of rice. Free iron and manganese, which can be present in the soils of rice field in abundance play the same role. The presence of their layer of ironoxide covering rice roots has an effect on their oxidative processes.

Ammonium or Nitrate

Nitrogen is one of the essential macronutrients for rice growth and one of the main factors to be considered for developing a high yielding rice cultivar. In a paddy field, ammonium (NH_4^+) rather than nitrate (NO_3^-) tends to be considered the main source of nitrogen for rice (Wang *et al.*, 1993). However, in recent years, researchers have paid more and more attention to the partial NO_3^- nutrition (PNN) of rice crops, and their results have shown that lowland rice was exceptionally efficient in absorbing NO_3^- formed by nitrification in the rhizosphere (Kirk and Kronzucker, 2005; Duan *et al.*, 2006). Rice roots can aerate the rhizosphere by excreting oxygen (O_2). Kirk (2001) reported that substantial quantities of NO_3^- were produced in the rhizosphere of rice plants through nitrification, and microbial nitrification was partially responsible for maximum overall rate of microbial O_2 consumption. Most recently, using model calculations and experiments, Kirk and Kronzucker (2005) and Kronzucker *et al.*, (1999, 2000) concluded that NO_3^- uptake by low land rice might be far more important than was previously thought, its uptake rate could be comparable with that of NH_4^+ and it could amount to one third of the total N absorbed by rice plants. Therefore, although the predominant species of mineral nitrogen in bulk soil for paddy rice

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fields is likely to be NH_4^+ , rice roots are actually exposed to a mixed nitrogen supply in the rhizosphere (Briones *et al.*, 2003; Li *et al.*, 2003).

When rice plants in solution culture were fed with a mixture of NH_4^+ and NO_3^- compared with either of the nitrogen sources applied alone at the same concentration, yield increase of 40-70% were observed (Heberer and Below, 1989; Qian *et al.*, 2004). The growth and the nitrogen acquisition of rice were significantly improved by the addition of NO_3^- to nutrition solution with NH_4^+ alone (Cox and Reisenauer, 1972; Duan *et al.*, 2005). The increased nitrogen acquisition could be attributed to the increased influx of NH_4^+ by NO_3^- (Kronzucker *et al.*, 1999), NH_4^+ is taken up by plant roots through ammonium transporters (AMTS).

Rice is known as ammonium (NH_4^+) tolerant species. Nevertheless, rice can suffer NH_4^+ toxicity, and excessive use of nitrogen (N) fertilizer has increased NH_4^+ in many paddy soils to levels that reduce vegetative biomass and yield. Ammonium (NH_4^+) one of the two inorganic nitrogen sources used by plants (NH_4^+ and NO_3^-), is beneficial for plant growth under many circumstances and indeed serves as a ubiquitous intermediate in plant metabolism (Glass *et al.*, 1992). Its assimilation is simple and has been shown to act as an inducer of resist further more entails lower energy costs compared to NO_3^- (Mehrer and Mohr, 1989).

Additionally, studies have been shown NH_4^+ can improve the capacity to tolerate water stress in rice in combination with NO_3^- (Guo *et al.*, 2007). Nevertheless, NH_4^+ frequently reaches levels in soils that affect plant growth negatively. These negative affects manifest in stunted root growth, yield depression and chlorosis of leaves (Britto and Kronzucker, 2002; Balkos *et al.*, 2010; Li *et al.*, 2011b). However higher plants display widely differing responses to NH_4^+ nutrition (Marchner, 1995) and accordingly, can be divided in to tolerant and sensitive species (Britto and Kronzucker, 2002). Despite its reputation as NH_4^+ tolerant species, rice can be affected negatively by high NH_4^+ , particularly at low K^+ (Balkos *et al.*, 2010) which in turn may be relieved by elevated K^+ similar to conclusions reached in Arabidopsis. Several studies have shown declines in K^+ bearing clay minerals over extended cultivation periods in many rice growing areas of china.

Nitrogen Uptake

Following the broadcasting of fertilizer on the rice field flood water, the concentration of N in the flood water and soil solution near it are initially sufficiently large that rates of uptake are not limited by root properties. However, after the N in the flood water has been exhausted, whether by uptake or gaseous loss, the crop relies on N in the soil, and there the concentration in solution is much smaller because of NH_4^+ cation – the main form of plant available N – is absorbed on soil clays and organic matter. Therefore, rates of N transport to and absorption by root surfaces may limit N acquisition. In addition, morphological and physiological adaptations to anoxic soil conditions may affect the root's N absorption capacity. An important difference is that the concentration of N as NH_4^+ in the soil solution of a flooded soil is likely to be one to two orders of magnitude smaller than that of NO_3^- in a dry soil with an equal quantity of N (Krik, 2001).

Basuchaudhuri and Dasgupta (1983) working with two high yielding indica rice varieties viz. Sashyashree and Jaya on utilization of major nutrients noted that while considering the nutrient concentrations in different organs of the rice cultivars at various stages of growth, it is evident that nitrogen concentrations in different plant parts, decrease with ageing. However a sharp decline in nutrient concentrations in leaves and stem was noted during ripening. Reduction in concentration of nutrients in plant parts, with time may

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possibly be attributed to slow rate of uptake along with dilution effect caused by gradient movement of nitrogen to the developing grains (Ishizuka, 1965).

Amongst plant parts, the leaf blades exhibited maximum concentration of nitrogen at panicle initiation stage. It may be argued that the leaf blades are the active centers of physiological activity; the nitrogen is initially translocated to the leaves, where assimilation, photosynthesis and other interrelated metabolic processes take place. On the other hand, at maturity, the concentration of nitrogen was more in panicles and grains. During ripening, the panicle being active site for physiological activities, movement of current and reserve photosynthates take place rapidly and thus, the nutrient concentration is relatively higher in panicles than in leaves and stem. Nutrient accumulation or uptake in different plant parts, as well as in the whole plant, during different phases of growth, clearly indicate higher nitrogen accumulation in stems and leaves during vegetative phase. Hence, nitrogen accumulation in different organs and in the whole plant follows a parabolic pattern during ontogenic development of the plant.

Takahashi *et al.*, (1955) in their studies on the composition of the leaf blade and stem of rice plants at the elongation stage under different levels of nitrogen supply observed the gradual increase in the concentration of nitrogen and protein with the increasing levels of applied nitrogenous fertilizer in different plant parts. But total sugar and starch concentration decreased gradually. Between the leaf blade and stem the nitrogen concentration was higher in leaf blades. It was noted to be due to more chlorophyll synthesis and protein synthesis in the leaf blades with the increasing level of nitrogen.

Critical Concentration

The critical nitrogen concentration of a plant can be defined as the minimum nitrogen concentration required for maximum growth rate at anytime. It has been suggested that the relationship between the critical nitrogen concentration and dry matter per unit ground area for a wide range of crops is the same and is independent of climatic zone. However, the critical concentration of nitrogen varied with stages of growth. Results support the concept of critical nitrogen content dilution curve for yield of rice, which may be independent of climatic zone. The similarity between the nitrogen dilution curves for temperate and tropical environments indicates that there is no intrinsic difference in the ratio of carbon-nitrogen capture in those environments even though final above ground biomasses differed. Both the rate and duration of resource capture are probably limiting yields in tropical environments (Sheehy *et al.*, 1998).

The critical limit (0.92%) has been identified for total nitrogen of rice grain in relation to the optimum grain yield at different combinations of water and nitrogen levels (Prasad *et al.*, 2002).

Nitrogen Response

The plant root system is an important organ which supplies water and nutrients to growing plants. Information is limited on influence of nitrogen fertilization on upland rice root growth. A green house experiment conducted to evaluate influence of nitrogen (N) fertilization on growth of root system of 20 upland rice genotypes. The nitrogen rate used was 0 mg kg⁻¹ (low) and 300 mg kg⁻¹ (high) of soil. Nitrogen x genotype interactions for root growth (length) and root dry weight were highly significant (P<0.01), indicating that differences among genotypes were not consistent at two nitrogen rates. Overall, greater root length, root-dry weight and tops-roots ratio were obtained at a nitrogen fertilization rate of 300 mg kg⁻¹ compared with the 0 mg kg⁻¹ soil. However, genotypes differ significantly in root length, root dry weight and top-root ratio. Nitrogen fertilization produced fine roots and more root hairs compared with absence of nitrogen fertilizer. Based on root dry weight efficiency index (RDWEI) for nitrogen use efficiency, 70% genotypes are classified as efficient, 15% as moderately efficient and 15% were classified as inefficient. Root dry weight efficiency index trait can be incorporated in upland rice for improving water and nutrient efficiency in favor of high yields (Fageria, 2007). The limited understanding of the mechanisms that govern the partitioning of captured resources (carbohydrates, mineral nutrients) between different plant parts and organs is considered to be the main factor restricting the development of process based modeling of whole plant growth (Dewar, 1993; Carmell and Dewar, 1994). For biomass partitioning between shoot and roots, Thornley (1972) has proposed a simple model which is widely used. In the model, growth is dependent on the supply of carbon from the shoot to roots (phloem transport) and that of nitrogen from roots to shoot (xylem transport). The fluxes are dependent on the concentration

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gradients of carbon and nitrogen between the two compartments, shoot and roots. According to Thornley's model, conditions which lead to an increase in carbon concentration should, therefore lead to all increase in biomass partitioning towards the roots, where as an increase in nitrogen concentration should favor biomass partitioning towards the shoot. In principle, the model is also considered suitable to take into account the effects of various environmental factors including mineral nutrients on the shoot, root ratio (Wilson, 1988).

The well documented increases in both carbon allocation to roots and in the root-shoot dry weight ratio under conditions of nitrogen limitation are consistent with the Thornley concept, despite nitrogen cycling from shoot to roots (Cooper and Clarkson, 1989) and the key role played by root borne phytohormones, particularly cytokinins, in the effect of nitrogen supply on the root shoot ratio (Fetune and Beck, 1993). However, the effect of mineral nutrition at status on shoot-root partitioning of photoassimilates and shoot-root dry weight ratio is markedly element specific.

Nitrogen accumulation in the apical spikelet of the primary branch (superior spikelet) and the second spikelet of the lowest secondary branch (inferior spikelet) of the panicle on the main stem of the rice plant (cv. Sasanishiki) was characterized during grain filling. In the superior spikelet the accumulation of dry matter and nitrogen, which started immediately after flowering, proceeded rapidly, and reached the maturation level at 20 days after flowering. In the inferior spikelet, however, the amount of dry matter and nitrogen accumulation was minimal immediately after flowering. It increased when grain filling of the superior spikelet was almost completed. ^{15}N -labeled ammonia was administered to the plants at different stages of ripening and the amount of incorporation in the spikelets was analyzed at harvest. The labeled nitrogen administered at the early stages of ripening was the main source of labeled nitrogen incorporated in the superior spikelet. However, the labeled nitrogen incorporated in the inferior spikelets largely consisted of the labeled nitrogen administered at the late stages of ripening. When all the spikelets except for the five inferior spikelets were removed from the panicle at various stages of ripening, the amount of dry matter and nitrogen accumulation increased immediately irrespective of the stage of ripening (Wasaki *et al.*, 1992).

Nitrogen deficiency is one of the most important yield limiting nutrients in lowland and plant tissue analysis is an important criteria for diagnosis of nutritional disorders in crop plants. A field experiment conducted during 3 consecutive years in central part of Brazil on a Haplaquepts. Nitrogen rates used were 0, 30, 60, 90, 120, 150, 180 and 210 kg. nitrogen per hectare. Nitrogen concentration in the shoot at different growth stages was significantly ($P < 0.01$) affected by nitrogen fertilization. Optimum nitrogen concentration for maximum dry matter yield was 43.4 gkg^{-1} at initiation of tillering, 12.7 gkg^{-1} at initiation of panicle, 12.8 gkg^{-1} at booting, 11.0 gkg^{-1} at flowering and 6.5 gkg^{-1} at physiological maturity stage. In the grain, the optimum nitrogen concentration was 10.9 gkg^{-1} . Nitrogen uptake varied from 16 to 185 kgha^{-1} in the shoot from initiation to flowering. At physiological maturing, nitrogen uptake was 71 kgha^{-1} in the shoot and 76 kgha^{-1} in the grain. Accumulated nitrogen at harvest produced 9545 kgha^{-1} straw and 6450 kgha^{-1} grain yield. Shoot dry weight increased with the increase in shoot nitrogen uptake up to flowering. At harvest nitrogen uptake in the shoot decreased due to translocation to the grain. Rice needs nitrogen during its whole growth cycle, however, relatively initiation of panicle, flowering and physiological maturity were the most critical growth stages for nitrogen tissue analysis to determine optimum concentration or nitrogen uptake for maximum shoot and grain yield (Fageria, 2003; Li *et al.*, 2003).

A field experiment conducted for two years (1977 and 1978) at IARI, New Delhi showed that yield and nitrogen uptake by rice was more in the case of medium duration (135 days) variety, Improved Sabarmati than in the case of short duration (105 days) variety Pusa-33. Highest yield and nitrogen uptake by rice was recorded when it was transplanted and lowest when rice was direct seeded (drilled in moist soil). Broadcasting sprouted seeds on puddle seedbed gave yield and nitrogen uptake in between transplanting and direct seeding and provides a reasonably acceptable method of planting. Rice responded well to nitrogen and the economic optimum dose was found to be 160-170 kg nitrogen per hectare. It is noted that urea briquettes give the highest yield and nitrogen uptake by rice and was superior to sulphur coated urea

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or neem-cake coated urea with respect to nitrogen uptake. All these nitrogen fertilizers were better than urea (Prasad and Prasad, 1980).

Considering the dynamics of nitrogen in rice seedlings the following were observed

1. The nitrogen source to make-up new leaves comes not only from the root (medium nutrient) but also from old leaves.
2. Nitrogen balance in a mature leaf is controlled by the influx and efflux of nitrogen
3. Amino acids move out from a leaf partly before incorporating into peptides-proteins and their subsequent breakdown.
4. Retransferred nitrogen is transported mainly to young leaves and roots with very little going to old organs (Yoneyama and Sano, 1978).

Source of Nitrogen

The nitrogen source had little effect on growth, gas exchange, Chl_a fluorescence parameters and photosynthetic electron allocation in rice plants, except that NH_4^+ grown plants had a higher O_2 independent alternative electron flux than NO_3^- grown plants. NO_3^- reduction activity was rarely detected in leaves of NH_4^+ grown cucumber plants, but was high in NH_4^+ grown rice plants (Zhou *et al.*, 2011). CO_2 assimilation rate, stomatal conductance, intercellular CO_2 and transpiration rate also noted slightly high in NH_4^+ plants (Zhou *et al.*, 2011).

Rate of Nitrogen

Maintenance respiration rate R_M , irrespective of growth stages, increased with increase the nitrogen supply. The R_M increased almost in proportion with net photosynthetic rate. Significant biomass production during early growth stages, while it declined after anthesis.

Significant positive correlation was observed between biomass production and P_N at all growth stages except tillering.

Though R_M was positively correlated with biomass production during early growth stages, it was negatively correlated with the rate of increase in shoot biomass after flowering, which could indicate a possibility identify certain cultivars endowed with low maintenance expenses despite building up biomass (Swain *et al.*, 2000).

Grain yield and yield components were reduced at higher rates of urea ($>300 \text{ mgkg}^{-1}\text{N}$) but these plant parameters responses to ammonium sulfate at higher rates was constant. In the intermediate nitrogen rate range (125 to 275 mgkg^{-1}) urea was slightly better compared to ammonium sulfate for grain yield. Hence, improving these plant characteristics by using appropriate soil and plant management practices can improve upland rice yield (Fageria *et al.*, 2011).

Yoseftabar (2013) studied on nitrogen management on panicle structure and yield in rice showed that panicle number, panicle length, panicle dry matter, number of primary branches, total number of grains and grain yield were highest by the application of 300 kg/ha of nitrogen than 100 or 200 kg/ha of nitrogen. Effect of different split application of nitrogen fertilization increased significantly with increase of split application up to 3 splits.

In lowland rice losses of applied nitrogen take place through (a) ammonia volatilization, (b) denitrification, (c) leaching and (d) run off. The recovery of fertilizer nitrogen applied to rice seldom exceeds 30-40%. Fertilizer nitrogen use efficiency in lowland rice may be maximized through a better timing of application to coincide with the stages of peak requirement of the crop and placement of nitrogen fertilizer in the soil. Other possibilities are the use of controlled release nitrogen fertilizer and exploitation of varieties suitable to nitrogen efficiency utilization.

In the anaerobic environment of lowland rice soils, the only stable mineral form of nitrogen is NH_4^+ , nitrate NO_3^- forms of nitrogen, if applied, will enter the anaerobic zone and be subjected to heavy denitrification losses. At planting time, the base dressing of nitrogen should never be supplied as nitrate. For topdressing the growing plants, however, NH_4^+ and NO_3^- forms may be used with almost equal

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efficiency. Fully established rice can rapidly take up applied NO_3 before it is leached down to the anaerobic soil layer and can become denitrified.

The upland rice cultivar Zhongham 3 (Japonica) and the paddy rice cultivar Yangjing 9538 (japonica) were field grown under moist cultivation (Mc) and dry cultivation (Dc) with 3 level of nitrogen viz. 100 kg ha^{-1} (LN), 200 kg ha^{-1} (NN) and 300 kg ha^{-1} (HN) compared with 200 kg ha^{-1} of nitrogen, 300 kg ha^{-1} of nitrogen reduced grain yield for both upland and paddy rice cultivars under dry cultivation and for the paddy rice cultivar under moist condition, where as, it increased the yield of upland rice under moist cultivation. With an increase in nitrogen level, both upland and paddy rice showed higher productive tillers, more or fewer spikelets per panicle, and lower percentage of ripened grains under moist cultivation and dry condition. However, the seed setting rate reduced to a greater, extent in paddy rice than in upland rice. There was no significant difference in 1000 grain weight for the upland rice among the 3 nitrogen levels, whereas, the 1000 grain weight reduced with the increase in nitrogen level in the paddy rice. Compared with moist cultivation, dry cultivation had no significant influence on grain weight of upland rice, however, a significantly negative effect was observed in paddy rice, dry cultivation increased the seed setting rate in both cultivars, with more increase in upland rice than paddy rice. The upland rice had less number of adventitious roots, lower nitrogen absorption ability, lower productive tillering ability, fewer panicles, fewer spikelets per panicle and lower grain yield than paddy rice. However, upland rice showed more rapid increase in adventitious roots and a slower decline in leaf nitrogen content from jointing to heading and a faster decline in leaf chlorophyll content (SPAD value) after anthesis. In addition, upland rice had a weak negative response to water stress and a strong positive response to nitrogen level. The responses of cultivation methods and nitrogen level varied largely between upland and lowland rice (Zhang *et al.*, 2008).

Nitrogen Use Efficiency

Through variation and frequency analysis, the genotypic differences in nitrogen utilization efficiency (NUE), nitrogen absorption efficiency (NAE) and nitrogen utilization efficiency response (NUER) of 88 rice germplasms were studied. NUE, NAU and NUER of the tested rice at seedling stage had notable genotypic discrepancy, and were influenced by nitrogen application. NUE differed significantly under low, medium and high nitrogen and dropped with the increase of nitrogen application. NAE was not significantly different under low and medium nitrogen, but was notably smaller than that under high nitrogen. NUER between low and high nitrogen was more notably higher than that between low and medium nitrogen or between medium and high nitrogen, and the latter two had not significant difference. The coefficients of variation among NUE, NAE and NUER of rice germplasms at seedling stage were greatly different (above 20%) and the order of them was $\text{NUER} > \text{NAE} > \text{NUE}$. The phenotypic distributions of NUE, NAE and NUER of rice germplasms at seedling basically resembled a normal curve, the order of good of fitness was $\text{NUE} > \text{NAE} > \text{NUER}$ (Cheng *et al.*, 2005).

It is noted that total N uptake, physiological nitrogen use efficiency (PUNE), apparent nitrogen use efficiency (ANRE) and agronomic nitrogen use efficiency varied in different cultivars significantly. Total nitrogen uptake, physiological nitrogen use efficiency, agronomic nitrogen use efficiency varied significantly with the increment of nitrogen applied. As total nitrogen uptake increased with increasing in nitrogen fertilizing contents but physiological nitrogen use efficiency ANUE decreased. There were significant differences in the effects of applying nitrogen fertilizer on nitrogen use efficiency and characteristics of nitrogen uptake.

Nitrogen use efficiency (NUE) defined as the ratio of grain yield to supplied nitrogen, is a key parameter for evaluating a crop cultivar and it is composed of nitrogen uptake efficiency and nitrogen physiological use efficiency (De Macle and Velk, 2004).

Nitrogen uptake efficiency is the nitrogen accumulation relative to its supply, while nitrogen physiological used efficiency represents grain yield relative to nitrogen accumulation. While the amount of nitrogen available from soil and fertilizer is difficult to measure, grain yield can be used for evaluating the NUE, and high NUE cultivars can be defined by their ability to produce higher grain yield than others under the same experimental conditions. As PNN can be attributed to improve nitrogen uptake, cultivar

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with a higher NUE has a more positive response to PNN than with a low NUE, suggesting that there might be a relationship between PNN and NUE.

Method and Timing of Nitrogen Application

Experiments regarding timing of nitrogen application had shown the clear superiority of pre plant nitrogen application.

Urea is generally the nitrogen fertilizer of choice. Most of the nitrogen fertilizer should be applied pre flood and pre plant in water seeded rice if the soil is not allowed to dry during the growing season. Nitrogen fertilizer should be placed either on dry soil and flooded immediately or shallow incorporated and flooded within 3-5 days. If several days elapse between the period of nitrogen application in ammonical form and flooding, much of the nitrogen will convert to nitrate. When the soil is flooded nitrate is broken down by bacteria and released to the atmosphere as a gas, a denitrification process.

Denitrification losses can be avoided by flooding the soils within 3-5 days after nitrogen application. These losses are greatest when nitrogen is applied into water on young rice. When most of the nitrogen is applied pre plant, rice field should not be drained or drained only temporarily. In this situation, if the field must be drained during the growing season, the field should not be allowed to dry up before re- flooding. The field should be maintained in a saturated condition to protect the pre plant nitrogen.

From internode elongation (green ring) through the beginning of head formation nitrogen must be available in sufficient quantity to promote the maximum number of grains. Nitrogen deficiency at this time reduces the number of potential grains and limits yield potential. Sufficient nitrogen should be applied preplant or pre flood to assure that the rice plant needs no additional nitrogen until the panicle initiation (green ring) or the panicle differentiation stage. When additional nitrogen is required, it should be top dressed at either of these plant stages or whenever nitrogen deficiency symptoms appear. Usually only 20-50 kg per ha are required if the earlier nitrogen application was sufficient, if nitrogen deficiencies are observed prior to these growth stages, apply nitrogen top dressing immediately. Early nitrogen deficiency may greatly reduce yields.

Table 1: General guidelines for efficient nitrogen management

Situation	Strategy
Upland (dry land)	Broadcast and mix basal dressing in top 5cm of surface soil. Incorporate top-dressed fertilizer by hoeing in between plant rows and then apply light irrigation, if available.
Rainfed deep water	Apply full amount as basal dressing
Lowland (submerged)	Use non-nitrate sources for basal dressing
Soil very poor in N	Give relatively more nitrogen at planting
Assured water supply	Can top dress every 3 weeks upto panicle initiations drain field before top dressing and reflood two days later.
Permeable soils	Emphasis on increasing number of split applications
Short duration varieties	More basal N and early top dressing preferred
Long duration varieties	Increased number of top dressing
Colder growing season	Less basal nitrogen and more as top dressing
Overaged seedlings used	More nitrogen at planting
High p ^H soil	Nitrogen may be applied as ammonium sulphate.

CONCLUSION

In view of the above, proper nutrition by nitrogenous fertilizers to rice need to be elucidated to maximize growth and yield. Rhizosphere changes of nutrient constituents and availability is to be found out under different situations of rice cultivations. Emphasis should be laid to optimize nitrogen efficiency under moderate level of nitrogenous fertilizer.

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REFERENCES

- Balkos KD, Britto DT and Kronzucker HT (2010).** Optimization of ammonium acquisition and metabolism by potassium in rice (*Oryza sativa* L). *Plant Cell and Environment* **33** 23-34.
- Basuchaudhuri P and Dasgupta DK (1983).** Utilization of major nutrients by improved rice varieties. *Indian Journal of Plant Nutrition* **2** 5-11.
- Briones AM, Okabe S Jr, Yumemiya, Ramsing NB, Reichardt W and Okuyama H (2003).** Ammonia-Oxidising bacteria on root biofilms and their possible contribution to N use efficiency of different rice cultivars. *Plant and Soil* **259** 335-348.
- Britto DT and Kronzucker HJ (2002).** NH₄⁺ toxicity in higher plants: a critical review. *Journal of Plant Physiology* **159** 567-584.
- Britto DT and Kronzucker HJ (2006).** Futide cycling at the plasma membrane: a hallmark of low-affinity nutrient transport. *Trends in Plant Science* **11** 529-534.
- Carmell MGR and Dewar RC (1994).** Carbon allocation in trees: a review of concepts for modeling. *Advances in Ecological Research* **25** 60-102.
- Cheng JF, Dai TB, Cao WX and Jiang D (2005).** Genotypic differences on nitrogen nutrition characteristics of rice germplasms at seedling stage. *Chinese Journal of Rice Science* **19** 533-538.
- Cooper HD and Clarkson DT (1989).** Cycling of amino nitrogen and other nutrients between shoots and roots in cereals: a possible mechanism integrating shoot and root in regulation of nutrient uptake. *Journal of Experimental Botany* **40** 753-762.
- Cox WJ and Reisenauer HM (1972).** Growth and ion uptake by wheat supplied nitrogen as nitrate or ammonium or both. *Plant & Soil* **38** 363-380.
- De Macle MAR and Velk PLG (2004).** The role of Azolla cover in improving the nitrogen use efficiency of lowland rice. *Plant and Soil* **263** 311-321.
- Dewar RC (1993).** A root shoot partitioning model based on carbon – nitrogen – water interactions and Munch phloem flow. *Functional Ecology* **7** 356-368.
- Duan YH, Zang YL, Shen QR and Wang SW (2006).** Nitrate effect on rice growth and nitrogen absorption and assimilation at different growth stages. *Podosphere* **16** 707-717.
- Epstein E (1972).** In *Mineral Nutrition of Plants: Principles and Perspectives* (John Wiley and sons Inc.) New York.
- Fagaria NK (2003).** Plant tissue test for determination of optimum concentration and uptake of nitrogen at different growth stages in lowland rice. *Soil Science & Plant Analysis* **34** 259-270.
- Fagaria NK (2007).** Root growth of upland rice genotypes as influenced by nitrogen fertilization. *Journal of Plant Nutrition* **30** 843-879.
- Fagaria NK, Moreira A and Coelho AM (2011).** Yield and yield components of upland rice as influenced by nitrogen sources. *Journal of Plant Nutrition* **34** 361-370.
- Fetune M and Beck E (1993).** Reversal of the direction of photosynthate allocation in *Urtica dioica* plants by increasing cytokinin import into the shoot. *Botanica Acta* **106** 235-240.
- Glass ADM, Shaff JE and Kochian V (1992).** Studies of the uptake of nitrate in barley 4. *Ecophysiology & Plant Physiology* **9** 456-463.
- Gigon A and Rorison IH (1972).** The response of some ecologically distinct plant species to nitrate and ammonium nitrogen. *Journal of Ecology* **60** 93-102.
- Guo SW, Chen G, Zhou Y and Shen QR (2007).** Ammonium nutrition increases photosynthesis rate under water stress at early development stage of rice (*Oryza sativa* L). *Plant & Soil* **296** 115-124.
- Heberer JA and Below EE (1989).** Mixed nitrogen nutrition and productivity of wheat grown in hydroponics. *Annals of Botany* **63** 643-649.
- Huner NP and Hopkins W (2008).** In: *Introduction to Plant Physiology*, 4th edition (John Wiley & Sons Inc.) New York.
- Ishizuka Y (1965).** Nutrient uptake at different stages of growth. In: *The Mineral Nutrition of the Rice Plant* (the Johns Hopkins Press) Baltimore, Maryland 199-217.

Review Article

Kirk GJD (1993). Root Ventilation, rhizosphere modification and nutrient uptake. In: *Systems, Approaches for Agricultural Development* (Academic Publishers) Dordrecht 221-232.

Kirk GJD (2001). Plant mediated processes to acquire nutrients: nitrogen uptake by rice plants. *Plant & Soil* **232** 129-134.

Kirk GJD and Kronzucker HJ (2005). The potential for nitrification and nitrate uptake in the rhizosphere of wetland plants: a modeling study. *Annals of Botany* **96** 639-646.

Kronzucker HJ, Siddiqi MY, Glass ADM and Kirk GJD (1999). Nitrate-ammonium synergism in rice: a subcellular flux analysis. *Plant Physiology* **119** 1041-1045.

Kronzucker HJ, Glass ADM, Siddiqi MY and Kirk GJD (2000). Comparative kinetic analysis of ammonium and nitrate acquisition by tropical lowland rice: implication of rice cultivation and yield potential. *New Phytologist* **14** 471-476.

Li P, Velde B and Li DC (2003). Loss of K bearing clay minerals in flood irrigated rice growing soil in Jiangxi province. *China Clayminer* **51** 75-82.

Marchner H (1995). *Mineral Nutrition of Higher Plants* (Academic Press) London.

Mehrer I and Mohr H (1989). Ammonium toxicity: description of the syndrome in *Synapis alba* and the search for its causation. *Physiologia Plantarum* **77** 545-554.

Prasad LK, Saha B, Haris A, Rajan K and Singh SR (2002). Critical grain nitrogen content for optimizing nitrogen and water in rice (*Oryza sativa* L.). *Journal of Biological Science* **2** 746-747.

Prasad M and Prasad R (1980). Yield and nitrogen uptake by rice as affected by variety, method of planting and new nitrogen fertilizers. *Fertilizer Research* **1** 207-213.

Qian XQ, Shen QR, Xu GH, Wang JJ and Zhor MY (2004). Nitrogen form effects on yield and nitrogen uptake of rice crop grown in aerobic soil. *Journal of Plant Nutrition* **27** 1061-1076.

Sheehy JE, Dionora MJA, Mitchell PL, Speng, Cassman KG, Lamaire G and Williams RL (1998). Critical nitrogen concentrations: implications for high yielding rice (*Oryza sativa* L) cultivars in the tropics. *Field Crops Research* **59** 31-41.

Sims GK and Dunigan EP (1984). Diurnal and seasonal variations in nitrogenase activity (C_2H_2 reduction) of rice roots. *Soil Biology and Biochemistry* **16** 15-18.

Smil V (2000). *Cycles of Life* (Scientific American Library) New York.

Swain P, Baig MJ and Nayak SK (2000). Maintenance respiration of *Oryza sativa* leaves at different growth stages as influenced by nitrogen supply. *Biologia Plantarum* **43** 587-590.

Takahashi J, Yanagisawa M, Kono M, Yazawa F and Yoshida T (1955). Studies on nutrient absorption by crops (in Japanese, English summary). *Bulletin Watt Institute of Agricultural Science, B* **4** 1-83.

Thornley JHM (1972). *Mathematical Models in Agriculture* (CABI publishing) 56-57.

Wang MY, Siddiqi MY and Glass ADM (1993). Ammonium uptake by rice roots 1, Fluxes and subcellular distribution of $^{13}NH_4^+$. *Plant Physiology* **103** 1249-1258.

Wasaki T, Mae A, Makino K and Nihiko O (1992). Nitrogen accumulation in the inferior spikelet of rice ear during ripening. *Soil Science & Plant Nutrition* **38** 517-525.

Wilson JB (1988). A review of evidence on the control of shoot root ratio, in relation to models. *Annals of Botany* **61** 433-449.

Yoneyawa T and Sano C (1978). Nitrogen nutrition and growth of the rice plant II. Correlations concerning the dynamics of nitrogen in rice seedlings. *Soil Science Plant Nutrition* **24** 191-198.

Yoseftabar S (2013). Effect of nitrogen management on panicle structure yield in rice (*Oryza sativa* L). *International Journal of Agriculture and Crop Sciences* **5** 1659-1662.

Zhang YJ, Zhou YR, Du B and Young YC (2008). Effects of nitrogen nutrition on grain yield of upland and paddy rice under different cultivation methods. *Acta Agronomica Sinica* **34** 1005-1013.

Zhou YH, Zhang YL, Wang XM, Cui JX, Xia XJ and Yu JQ (2011). Effects of nitrogen form on growth, CO_2 assimilation, chlorophyll fluorescence and photosynthetic electron allocation in cucumber and rice plants. *Journal of Zhejiang University of Science B* **12** 126-134.