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Effect of silicon on real time nitrogen management in a rice ecosystem

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Field experiments were conducted during *Kharif* season of 2009 on sandy loam soil at Doddajala, Bangalore, India of eastern dry zone soils of Karnataka to investigate the effect of silicon (Si) and nitrogen application on the growth and yield of rice, using Cv. BI-34, a medium duration genotype. The results revealed that higher grain and straw yield was noticed with application of calcium silicate at 2 t ha^{-1} along with application of N at 100 kg ha^{-1} recommended dose of fertilizer (RDF) followed by silica gel at 500 kg ha^{-1} over RDF under both aerobic and wetland rice conditions. The combined application of Si sources along with Leaf Colour Chart (LCC) based N application of 75 kg N ha^{-1} (Basal 30 kg N ha^{-1}+LCC) under aerobic and wetland rice recorded on par grain and straw yield compared to RDF alone. Combined application of silicon and nitrogen significantly increased the effective number of tillers, number of grains per panicle, 1000-grain weight. Higher agronomical efficiency (AE_N), recovery efficiency (RE_N), Partial factor productivity (PFP_N) values were noticed with LCC based application along with calcium silicate at 2t ha^{-1} under both aerobic and wetland rice.

Key words: Rice, silicon, nitrogen use efficiency, leaf colour chart, real time N management.

INTRODUCTION

Rice is the staple food of about 3 billion people and demand is expected to continue to grow as population increases (Carriger and Vallee, 2007). Globally rice is grown over an area of about 149 million ha with an annual production of 600 million tons (Bernier et al., 2008). In India, rice is cultivated round the year in one or the other part of the country, in diverse ecologies spread over 44.6 M ha with a production of 132 MT of rice and average productivity of 2.96 t ha^{-1} (Rai, 2006). The 79 million ha of irrigated lowlands provide 75% of the world's rice production (Maclean et al., 2002).

Asia's food security depends largely on the irrigated rice fields, which produces three quarters of all rice harvested. But rice is a profligate user of water, consuming half of all developed fresh water resources. The increasing scarcity of water threatens the sustainability of the irrigated rice production system and hence the food security and livelihood of rice producers

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and consumers. Aerobic rice is a rice production system for water-short environments where adapted rice varieties are grown under aerobic soil conditions (Atlin et al., 2006; Bouman et al., 2006; Wang et al., 2002). Although the system of aerobic rice can produce high yields (Bouman et al., 2006; Wang et al., 2002, Peng et al., 2006).

Silicon (Si) is the second most abundant element in the earth's crust, with soils containing approximately 32% Si by weight (Lindsay, 1979). Si is a major constituent of the Earth's crust, forming the silicate minerals. In soils, these minerals undergo chemical and physical weathering, resulting in the release of Si in solution, which is either combined with other elements to form clay minerals, or released toward the streams and the oceans or absorbed by the vegetation. In agronomy, Si is generally not considered an essential element. The major reason is that there is no evidence to show that Si is involved in the metabolism of plant, which is one of the three criteria required for essentiality established by Arnon and Stout (1939). Although agricultural soils are largely composed of silicate minerals, many soils contain an inadequate supply or are naturally low in plant available Si. Most likely, the Si content in some regions might be limiting to sustainable rice production (Savant et al., 1999). In addition, Si depletion can occur in traditional rice soils from the continuous monoculture of high-yielding cultivars with intensive cultivation practices (Miyake, 1993).

Rice is considered to be a Si accumulator plant and tends to actively accumulate Si to tissue concentrations of 5% or higher. Recently Si has been regarded as quasi-essential element (Epstein, 2002). Some of the studies suggest that Si, enhances disease resistance in plants, imparts turgidity to the cell walls and has a putative role in mitigating the metal toxicities (Datnoff et al., 1997). It is suggested that the Si plays a crucial role in preventing or minimizing the lodging in the cereal crops (Munir et al., 2003), a matter of great importance in terms of agricultural productivity.

Nitrogen fertilizer has played an important role in increasing rice yields, and total consumption of N for rice production has increased gradually worldwide (Singh et al., 2012). However, fertilizer N use efficiency of rice is generally low for rice grown in a transplanted culture ranging from 25 to 45%, and average about 35% (Dobermann and Cassman, 2002).

A deficiency of N that is directly involved in synthesis of protein or chloroplast pigments or electron transfer, however, lowers the photosynthetic efficiency (Takahashi 1990). Nitrogen is one of the most important plant nutrients and plays a vital role in plant photosynthesis and biomass production. Several studies showed that when N is slightly deficit within plants, the demand for NO_3, free amino acid, and free amino N increases quickly, without necessarily bringing a simultaneous marked change in total nitrogen (Wang et al., 2005). More than half of the N fertilizer applied is lost and results not only in an environmental hazard but also a substantial economic loss (Li et al., 2009). About one-third of applied N is lost by different processes (Abrol et al., 2007). Blanket or packages of fertilizer recommendations over large areas are not efficient because indigenous nitrogen supply (INS) varies widely among rice field. Rice crops require different amount of nutrients, depending on native nutrient supply and demand. Leaf colour chart (LCC) and chlorophyll meters are the promising tools developed in recent years for need-based N management in rice crops. Application of N with the LCC usage helps in reducing the leaching loss and enhances the nutrients uptake of crop. The LCC is simple and alternative method for monitoring the relative greenness of a rice leaf as an indicator of leaf N status (Shukla et al., 2004). Fertilizer application for wetland rice with the usage of LCC helps in saving N to an extent of 27 to 56 kg ha^{-1} in Punjab, 19 to 39 kg ha^{-1} in Haryana, 30 to 40 kg ha^{-1} in Bihar and 42 to 50 kg ha^{-1} in West Bengal as compared to fixed-time blanket N recommendation or farmers practice (Bijay and Yadvinder, 2003). However, there is no information regarding N management in aerobic rice by adopting LCC method.

Application of nitrogenous fertilizers is an important practice for increasing rice yields. However, when applied in excess may limit yield because of lodging, promote shading and susceptibility to insects and diseases. These effects could be minimized by the use of Si (Ma et al., 1989; Munir et al., 2003). Due to a synergistic effect, the application of Si has the potential to raise the optimum N rate, thus enhancing productivity of existing lowland rice fields (Ho et al., 1980). Silicon has been reported to raise the optimum level of N in rice. However, information on Si and N interaction in aerobic/upland/rainfed rice is very limited. In this context the present study was undertaken to evaluate the effect of Si and N on yield, yield components and NUE of aerobic and wetland rice.

MATERIALS AND METHODS

Experimental site

The experimental site belongs to eastern dry zone of Karnataka, situated at Doddajala, Bangalore North with latitude of 12°10' N and longitude of 76°35' E 650 m above mean sea level (MSL) and receives annual rainfall of 766 mm during the cropping period. The meteorological data of the location indicating rainfall, temperature and humidity recorded during the experimental period is mentioned in Table 1. The initial pysico-chemical soil analysis of the experimental is given in Table 2.

Experimental design

Two field experiments were conducted during *Kharif 2009*, under aerobic and wetland conditions simultaneously, the experiments consisted of seven treatments with three replications laid out in randomized block design (same set of treatments were followed for

Table 1. Normal and actual monthly weather data recorded at Doddajala, Bengaluru (North) during 2009.

Month	Rainfall (mm)			Mean temperature (°C)						Mean relative humidity (%)			No. of rainy days
				Maximum			Minimum						
	N	A	D	N	A	D	N	A	D	N	A	D	
July	102.0	55.8	-46.8	28.2	28.7	0.5	19.0	19.5	0.5	87	69.5	-17.5	2
Aug	129.0	106.8	-22.2	27.2	28.3	1.1	18.8	19.2	0.4	88	75.0	-13.0	7
Sep	203.2	231.5	28.3	28.1	28.0	-0.1	18.8	19.2	0.4	88	84.0	-4.0	12
Oct	173.9	29.6	-144.3	27.7	28.1	0.4	18.3	17.5	-0.8	87	71.5	-15.5	4
Nov	53.9	49.4	-4.5	26.6	27.0	0.4	16.6	17.7	1.1	86	74.5	-11.5	5
Dec	13.3	11.0	-2.3	26.1	26.8	0.7	14.3	16.3	2.0	86	73.0	-13.0	1

N, Normal meteorological data (Mean of 1972-2008); A, actual meteorological data (Year 2009-2010); D, deviation from the normal (A-N).

Table 2. Pre-sowing physico-chemical soil analysis.

Parameter	Aerobic rice	Wetland rice
pH (1:2.5)	6.29	6.30
EC (d Sm^{-1})	0.23	0.20
OC (g kg^{-1})	6.40	6.90
Particle size distribution		
Sand (%)	65.39	61.80
Silt (%)	15.48	17.60
Clay (%)	18.57	20.30
Textural class	**Sandy loam**	
CEC (Cmol $P^{(+)}$ kg^{-1})	17.25	19.57
Available N (kg ha^{-1})	378.00	389.00
Available P_2O_5 (kg ha^{-1})	39.30	54.10
Available K_2O (kg ha^{-1})	144.50	156.6
Available S (ppm)	18.30	17.50
Exchangeable Ca (c mol $P^{(+)}$ kg^{-1})	1.40	2.20
Exchangeable Mg (c mol $P^{(+)}$ kg^{-1})	1.00	0.90
Available Si (ppm) (0.5 M Acetic acid extractable)	44.00	45.93

both aerobic and wetland rice).

Field experiment

Aerobic rice

Rice seeds of BI 34 were sown at 2 seeds $hill^{-1}$ with spacing of 30 × 10 cm and the crop was irrigated once in 4 to 5 days.

Wetland rice

25th day old seedlings of BI 34 were transplanted at two seedlings per hill with spacing of 20 × 10 cm and irrigation was given to maintain the submergence condition throughout the crop growth period. The calculated quantity of silicon sources, viz. calcium silicate and silica gel were applied to soil two weeks prior to sowing/transplanting. All the treatments received a common recommended dose of 50 kg ha^{-1} of P_2O_5 and K_2O. For RDF (Recommended dose of fertilizer) treatment, 100 kg N ha^{-1} was applied at three splits (50 kg N ha^{-1} at the time of sowing / transplanting and remaining 50 kg as two equal splits during maximum tillering and panicle initiation stage). The LCC treatments receives, 30 kg N ha^{-1} at the time of sowing and remaining amount of N supplied based on LCC critical values. During the growth periods, the LCC readings were taken at ten days intervals starting from 14 days after transplanting in wetland rice and 21 days after sowing in case of aerobic rice. Based on critical value (LCC-3 for aerobic rice and LCC-4 for wetland rice) assessed in the respective treatment, N was applied at at 15 kg ha^{-1} at each time when LCC value fell below the critical value. Grain and straw yield and yield components were recorded in each treatment at harvest and grain yields were adjusted to 14% of moisture level. Grain and straw samples were analyzed by using CHNS (LECO - 900, USA) analyzer for total N content. Nitrogen use efficiency (NUE) in rice was calculated by using different efficiency formulae (Cassman et al., 1998).

Source of silicon and composition

Calcium silicate was used as a source of silicon which was procured from Excell Minerals, USA (www.excellminerals.com) which consists of Si 12%, CaO 30%, Mg 7%, S 0.2%, Fe 4%, Mn 1%, Al 3% Cr 0.2%, Ti 0.5% and Ni 0.04% and another source was silica gel which was procured from Shijo, Japan.

Nitrogen use efficiency parameters

$$AE_N \text{ (kg grain kg}^{-1} \text{ N applied)} = \frac{\text{Grain yield (kg ha}^{-1}\text{) in N fertilized plot - grain yield (kg ha}^{-1}\text{) in no N plot}}{\text{Quantity of fertilizer N applied (kg ha}^{-1}\text{) in N fertilizer plot}}$$

$$RE_N \text{ (\%)} = \frac{\text{Total N uptake (kg ha}^{-1}\text{) in N fertilized plot - Total N uptake (kg ha}^{-1}\text{) in no N plot}}{\text{Quantity of fertilized N applied (Kg ha}^{-1}\text{) in N fertilizer plot}} \times 100$$

$$PFP_N \text{ (kg grain kg}^{-1} \text{ N applied)} = \frac{\text{Grain yield (Kg ha}^{-1}\text{) in N fertilized plot}}{\text{Quantity of fertilized N applied (Kg ha}^{-1}\text{)}}$$

Where, AE_N = Agronomic efficiency; RE_N = Apparent recovery efficiency, and PFP_N = Partial factor productivity.

Method of application of N based on LCC

Leaf colour chart procured from Nitrogen parameter, Adambakkam, Chennai - 600088. India, (e-mail:lccenquiry@gmail.com) was used in the present investigation. LCC is a simple, cheap, and easy-to-use tool that can help farmers to manage N judiciously. The critical value of LCC-3 was used for aerobic rice and LCC-4 for wetland rice. The critical or threshold value of the LCC is defined as the intensity of green colour that must be maintained in the uppermost fully opened leaf of the rice plant and fertilizer N needs to be applied whenever leaf greenness is below the critical LCC value. Leaf greenness or leaf N content is closely related to photosynthesis rate and biomass production and is a sensitive indicator of changes in crop N demand during the growing season. Thus, maintaining the leaf greenness just above the LCC critical value ensures high yields with need-based N application thereby leading to high fertilizer N use efficiency.

Estimation of total N in plant samples

The total nitrogen was determined using CHN analyzer (CHNS, LECO). The powdered samples were weighed (5-10 mg) and mixed with an oxidizer [vanadium pentoxide (V_2O_5)] in a tin capsule, which is then combusted in a reactor at 1000°C. The sample and container melt, and the tin promote a violent reaction (flash combustion) in a temporarily enriched oxygen atmosphere. The combustion products CO_2 and NO_2 are carried by a constant flow of carrier gas (helium) that passes through a glass column packed with an oxidation catalyst of tungsten trioxide (WO_3) and a copper reducer, both kept at 1000°C. At this temperature, the nitrogen oxide is reduced to N_2. The CO_2 and N_2 are then transported by the helium and separated by a 2-m-long packed column (Poropak Q/S 50/80 mesh) and quantified with a thermal conductivity detector (**TCD)** (set at 290°C.).

Statistical analysis and interpretation of data

The analysis and interpretation of the data were done using the Fisher's method of analysis and variance technique as given by Panse and Sukhatme (1967). The level of significance used in 'F' and't' test was 5% probability and wherever 'F' test was found significant, the 't' test was performed to estimate critical differences among various treatments.

RESULTS AND DISCUSSION

Growth parameters

The plant height was significantly affected by the combined application of Si and N under aerobic rice, but not in wetland rice (Table 3). There was a significant increase in the plant height with the application of calcium silicate at 2 t ha^{-1} along with RDF (100 kg N ha^{-1}) (87 cm) over control (78 cm). Application of Si was effective in preventing lodging in rice by increasing the thickness of the culm and size of the vascular bundles thereby enhancing the strength of the culm (Shimoyama, 1958). Application of calcium silicate at 2 t ha^{-1} along with basal 30 kg N ha^{-1} with LCC recorded higher number of productive tillers in both aerobic and wetland rice. Higher number of productive tillers was recorded in aerobic rice compared to wetland rice mainly due to rice plants develop relatively more tillers at wider spacing because of advantage of space, nutrition and sunlight. The plant spacing significantly influenced tillering capacity of rice.

Yield parameters

Number of grains per panicle was significantly increased by application of silicon and N under aerobic and wetland condition (Table 3). In the present study LCC based N was applied at different crop growth stages (basal, tillering stage and before flowering stage, Table 5). Increase in the number of grains per panicle was mainly attributed increased application of N from 0 to 100 kg ha^{-1} along with the application of calcium silicate or silica gel, which might have enhanced the accumulation of photosynthates under both aerobic and wetland condition. However, there was no significant difference in the number of grains per panicle with application of calcium silicate at 2 t ha^{-1} along with RDF (124 and 137) and LCC (121 and 129) based N application under both conditions, respectively. Fageria et al. (2001) reported that number of panicles along with number of grains per

Table 3. Effect of silicon and nitrogen on growth and yield parameters of aerobic and wetland rice.

Treatments		Plant Height (cm)		No. of productive tillers		No. of grains per panicle	
Fertilizer	**Silicon source**	**A**	**W**	**A**	**W**	**A**	**W**
RDF P and K (Control -N)		78	82	11	7	97	120
RDF P and K + Basal 30 kg N ha^{-1} + LCC	Without silicon	81	88	15	8	120	128
	$CaSiO_3$ at 2 t ha^{-1}	86	88	17	10	121	129
	Silica gel at 500 kg ha^{-1}	84	87	16	9	121	129
RDF NPK	Without silicon	84	90	14	9	118	125
	$CaSiO_3$ at 2 t ha^{-1}	87	93	16	9	124	137
	Silica gel at 500 kg ha^{-1}	80	91	16	10	122	132
LSD (0.05)		**8**	**10**	**3**	**4**	**5**	**9**

RDF, Recommended dose of fertilizer (100:50:50 kg ha^{-1}); A, Aerobic. W, Wetland; $CaSiO_3$, Calcium Silicate; LCC, Leaf Colour Chart; N, Nitrogen; P, Phosphorus; K, Potassium.

Table 4. Effect of silicon and nitrogen on test weight (g), grain and straw yield of aerobic and wetland rice

Treatments		Test weight (g)		Yield (kg ha^{-1})			
				Grain		Straw	
Fertilizer	**Silicon source**	**A**	**W**	**A**	**W**	**A**	**W**
RDF P and K (Control -N)		18.8	20.1	2712	3723	3828	4705
RDF P and K + Basal 30 kg N ha^{-1} + LCC	Without silicon	22.8	24.7	4045	4409	5397	5265
	$CaSiO_3$ at 2 t ha^{-1}	24.0	25.1	4544	4692	5502	5649
	Silica gel at 500 kg ha^{-1}	23.1	24.5	4405	4622	5440	5370
RDF NPK	Without silicon	23.4	24.8	3807	4805	4999	6041
	$CaSiO_3$ at 2 t ha^{-1}	23.7	25.4	4640	5425	5539	6842
	Silica gel at 500 kg ha^{-1}	23.1	24.9	4588	5077	5523	6173
LSD (0.05)		**1.4**	**1.4**	**626**	**567**	**763**	**316**

RDF, Recommended dose of fertilizer (100:50:50 kg ha^{-1}); A, Aerobic. W, Wetland; $CaSiO_3$, Calcium Silicate; LCC, Leaf Colour Chart; N, Nitrogen; P, Phosphorus; K, Potassium.

panicle and paddy yield was significantly affected by N application in splits at different growth stages.Application of Si sources along with RDF and LCC based N application significantly increased the test weight under both aerobic and wetland situations over control. It may be due to higher N rates, which primarily increased the chlorophyll concentration in leaves and thereby higher photosynthetic rate and ultimately plenty of photosynthates available during grain development (Mahzoor et al., 2006). Increase in test weight could also be due to greater deposition of Si on paleae and lemma (Balastra et al., 1989). Application of silicon sources along with N significantly increased grain yield of rice when applied along with 100 kg N ha^{-1} as compared to RDF alone and control (Table 4). However, there was numerically increased in yield of LCC based N management in aerobic rice compared to wetland rice. The grain yield response to Si application may be due to increased leaf erectness, decreased mutual shading caused by dense planting and high N application. N increases susceptibility to various disease in rice but application of Si decreases the occurrence of pest and disease in rice (Yoshida et al., 1969). Increase in yields of flooded rice with Si fertilization has been already reported in India. Prakash et al. **(**2002) reported that application of calcium silicate at 3 to 4 t ha^{-1} as Si source significantly increased grain yield over control and other treatments; Prakash et al. (2010) also reported that there was response of rice for the application of calcium silicate in coastal and hilly zone soils of Karnataka, South India. Takahashi et al. (1990) reported particularly striking rice yield responses to Si application especially when application rates of other conventional fertilizers were rather high. Snyder et al. (1986) showed that calcium silicate application increased rice yield on Histosols mainly due to the supply of plant available Si and not due

Table 5. LCC values recorded at different growth stages of Aerobic and Wetland rice.

Treatments		Aerobic rice					
Fertilizer	Silicon source	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS	90 DAS
RDF P and K (Control -N)		1.9	2.1	2.6	2.3	2.6	2.6
RDF P and K + Basal 30 kg N ha^{-1} + LCC	Without silicon	2.6*	2.8*	3.1	2.9*	3.1	3.2
	$CaSiO_3$ at 2 t ha^{-1}	2.5*	2.7*	3.1	2.9*	3.1	2.8
	Silica gel at 500 kg ha^{-1}	2.6*	2.9*	3.3	2.8*	3.2	2.9
RDF NPK	Without silicon	3.2	3.4	3.3	3.6	3.4	3.4
	$CaSiO_3$ at 2 t ha^{-1}	2.8	3.0	2.9	3.1	3.0	3.1
	Silica gel at 500 kg ha^{-1}	2.9	3.2	3.3	3.1	3.0	3.1
Treatments		Wetland rice					
		20 DAT	30 DAT	40 DAT	50 DAT	60 DAT	-
Fertilizer	Silicon source						
RDF P and K (Control -N)		3.5	3.3	3.4	3.5	3.5	-
RDF P and K + Basal 30 kg N ha^{-1} + LCC	Without silicon	3.7**	3.6**	3.7**	4.1	4.0	-
	$CaSiO_3$ at 2 t ha^{-1}	3.9**	3.6**	3.7**	4.1	3.9	-
	Silica gel at 500 kg ha^{-1}	3.8**	3.6**	3.9**	4.2	4.0	-
RDF NPK	Without Silicon	4.2	4.2	4.0	4.2	4.2	-
	$CaSiO_3$ 2 t ha^{-1}	4.0	3.8	4.0	4.2	4.0	-
	Silica gel at 500 kg ha^{-1}	4.2	4.1	4.1	4.1	4.2	-

DAS, Days after sowing; DAT, days after transplanting; *, **, 15 kg N was applied based on the LCC reading for aerobic and wetland rice respectively.

to supply of other nutrients. The results of field trials on rice soils with different levels of available Si in South China suggested a synergistic effect of added N on performance of Si fertilizer (Ho et al., 1980). Higher grain yield levels at 75 kg N ha^{-1} as compared to RDF under rice was mainly due to efficient utilization of applied N at spilt doses, which matches the crop N requirement. Adequate N supply is needed throughout the active growing period of rice. Thus proper N management is very crucial for successful rice production. Excessive and moderate application lead to an inefficient N acquisition by the crop and results in reduced yield.

Among the different sources, application of calcium silicate and silica gel found to be on par with each other in their yield levels under both aerobic and wetland conditions respectively. The lower yield with the silica gel compared to calcium silicate application may be due to leaching and fixation loss of silicon in submerged conditions. It may also be due to less supply of Si and may be inadequate in attaining the Si requirement by the crop for producing higher grain yield.

In the present investigation, the LCC critical value three (aerobic) or four (wetland) based N (30 kg N ha^{-1} as basal and three splits of 15 kg N ha^{-1} each time) matched the crop demand at different physiological stages and might have reduced the losses through nitrification, leaching and volatilization and resulted in the highest grain yield. It was also on par with 100 kg N ha^{-1} (Table 5). Tran et al. (2002) reported that the N application method based on the leaf colour diagnosis helped in saving on the N fertilizers applied and increased grain yield. The N rate of 60 to 80 kg ha^{-1} for the dry season and 40 to 60 kg ha^{-1} for the wet season was recommended. N split application at early tillering and at panicle initiation or booting stage was optimum for early and late maturing cultivars.

Increase in straw yield was mainly attributed to higher tiller numbers, biomass observed in the treatment with calcium silicate at 2 t ha^{-1} under both aerobic and wetland situations (Table 4). The enhanced straw yield with calcium silicate at higher N levels may be attributed to leaf erectness which facilitated better penetration of sunlight leading to higher photosynthetic activity of plant and higher production of carbohydrates (Ma et al., 1989; Korndorfer et al., 2001). Agarie et al. (1998) reported that maintenance of photosynthetic activity due to Si fertilization could be one of the reasons for increased dry matter production in rice crop. Savant et al. (1997) noted beneficial effects of Si on plant growth in terms of increased number of leaves. Ma et al. (1989) observed that addition of 100 ppm SiO_2 as silicic acid during the reproductive stage markedly increased straw yield of rice.

N Uptake (kg ha^{-1})

N uptake of both grain and straw was higher when silicon

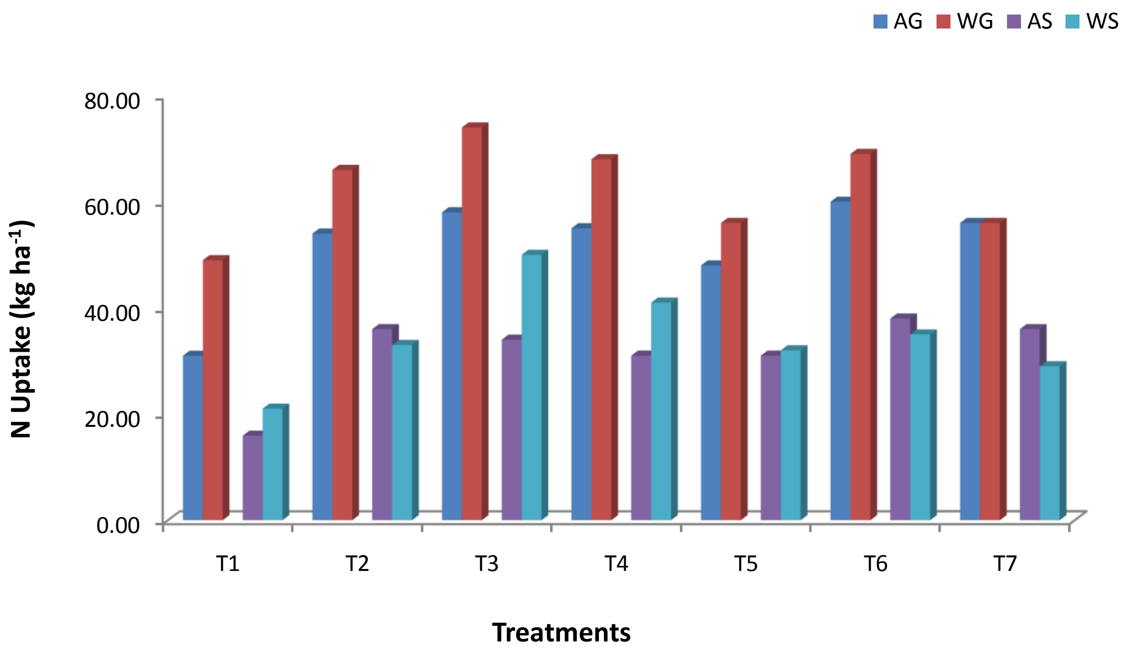

Figure 1. Effect of Si and N on N uptake (kg ha^{-1}) of grain and straw in aerobic and wetland rice. AG, Aerobic rice grain; WG, Wetland rice grain; AS, aerobic rice straw; WS, wetland rice straw. AEN, Agronomic efficiency; REN, apparent recovery efficiency; PFPN, partial factor productivity

applied along with RDF of N (100 kg ha^{-1}) compared with LCC based N application (75 kg ha^{-1}) (Figure 1). However, N application along with silicon recorded higher N content than RDF of N alone. This might be due to the possibility of dilution effect when Si fertilized with less application of N. Due to a synergistic effect, the application of Si has the potential to raise the optimum N rate, thus enhancing productivity of existing lowland rice fields (Ho et al., 1980). Silicon has been reported to raise the optimum level of N in rice. Snyder et al. (1986) reported that a decline in N concentration in Histosol grown rice and attributed it to the possibility of dilution in the larger Si fertilized plants. In greater biomass where N is limiting, the plants will show lower N concentration due to dilution. The mean total N content in the Si fertilized treatments were statistically non significant when silicon applied along with LCC based N application (75 kg ha^{-1}) than recommended N (100 kg ha^{-1}). However, Beyrouty et al. (1994) recorded no difference in total plant N content between alternately submerged, non submerged and flooded rice.

Nitrogen use efficiency (NUE)

Application of N based on LCC in combination with silicon sources significantly affected the NUE of aerobic rice. The AE_N, RE_N and PFP_N values were higher for LCC based N application along with calcium silicate at 2 t ha^{-1} and silica gel at 500 kg ha^{-1} (Figure 2). Generally AE_N, RE_N and PFP_N are greater when less N fertilizer was used, but this was achieved with the use of the LCC without sacrificing yield. The AE_N for LCC based N management treatments was the same or higher as in fixed schedule recommended N treatment. The AE_N, RE_N, PFP_N values ranged from 10.95 to 24.43 and 42.81 to 68.15, 38.07 to 60.59 in aerobic rice and 9.10 to 17.0, 18.0 to 72.0, 48.5 to 62.56 in wet land rice respectively (Figures 1 to 3). The AE_N is a function of both physiological efficiency and RE_N of applied N. Application of N using LCC resulted in increased leaf N concentration. The AE_N was greater when less N fertilizer was applied, but this was achieved with LCC without sacrificing the yield under both aerobic and wetland conditions. Basal application of 30 kg N ha^{-1} compared to 50 kg N ha^{-1} (RDF) efficiently utilized the applied N, whereas at later stages of the crop growth N was applied based on the crop requirement which was measured through LCC based on critical values. Spilt application of N at 15 kg N ha^{-1} was applied at each time against the recommended fixed dose of 25 kg N ha^{-1}. Cassman and Pingali (1985) reported AE_N values of 24 to 30 in rice by improved timing and further revealed that crop demand of applied N could improve the AE_N to some extent.

Application of N based on LCC achieved higher PFP_N values against RDF of fixed N spilt application under both

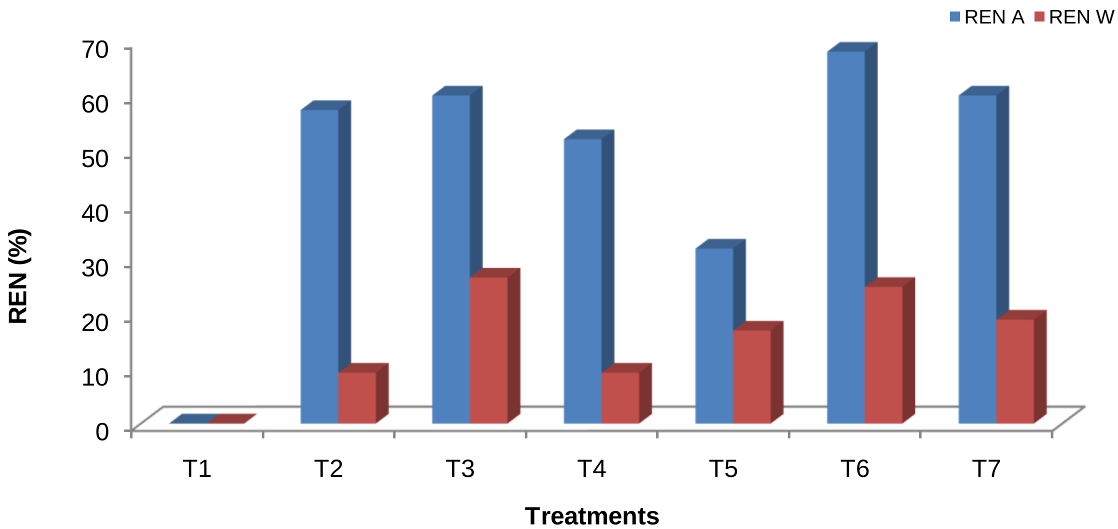

Figure 2. Effect of SI and N on RE_N in aerobic rice.

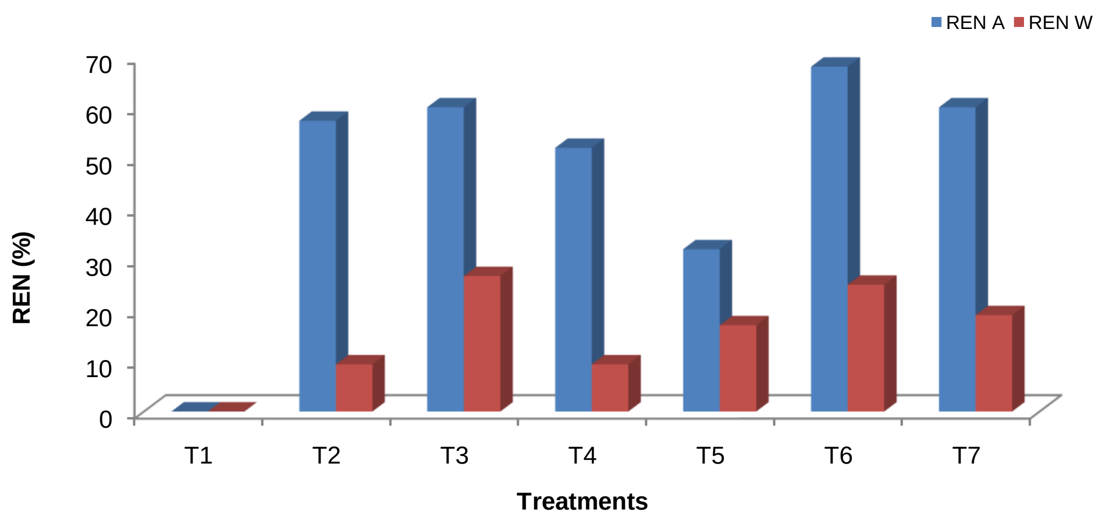

Figure 3. Effect of silicon and nitrogen on AE_N and PFP_N in aerobic and wetland rice.

aerobic and wetland rice. Half of the 100 kg N ha^{-1} (RDF) was recommended as basal application. As rice seeds take about 5 to 7 days to germinate and 2 to 3 leaf seedlings in fields, it is very likely that most of N applied as basal immediately after sowing is not used by plants and is subjected to lose by many ways. Rice seedlings need about 7 to 10 days to recover from transplanting shock and hence, N uptake within two weeks of transplanting could be very small. The usefulness of applying a lower dose of N is sufficient or at later stages of crop, that is, 30 days after sowing in aerobic rice, and 14 days after transplanting in wetland rice need to be examined. Shulka et al. (2004) and Alam et al. (2004) observed not only higher NUE, but also higher yields through LCC based management. Yogendra et al. (2011) reported that basal application of low dosage of N fertilizer (30 kg ha^{-1}) along with calcium silicate as a source of Si was effective for aerobic rice. Application of calcium silicate along with LCC based N application has achieved high N and Si use efficiency in aerobic rice. Yogendra et al. (2013) reported a significant increase in the grain yield of wetland rice and nitrogen use efficiency was noticed with the application of calcium silicate at 2 t ha-1 in eastern dry zone soils of Karnataka. This result indicate that the current recommendation of fixed time split N applications at specified growth time is not adequate to synchronize N supply with actual crop N demand due to poorly designed N splitting and variations in crop N demand (Bijay et al., 2002; Nachimuthu et al., 2007). Furthermore, N application in recommended splits are not based on the indigenous N supply (INS) (Shukla et al., 2004). The INS is defined as total plant N uptake at physiological maturity in zero N plots, which represents all sources of N (soil, organic materials, rhizosphere N fixation, crop residues, rainfall, irrigation water, etc.) available to crops during the growing season (Dobermann et al., 2003). This varies with crop, soil and cropping season (Stalin et al., 1996).

Conclusion

It is evident from our results that the use of LCC with reduced the basal N application (30 kg N ha^{-1}) along with calcium silicate at 2 t ha^{-1} as a source of silicon resulted on par grain yield as compared to the recommended N treatments under both aerobic and wetland rice. Monitoring rice plant N status and N requirement is an important subject with improving the balance between crop N demand and N supply from soil and applied fertilizer. In many field situations in Karnataka, more than 50% (50% of total N is supplied as basal application) of applied N is lost due in part to the lack of synchrony of plant N demand with N supply. The LCC is simple and easy-to-use tool that can help farmers avoid over application of N in rice plant. The LCC based management in rice suggests that N application can be saved with no yield lose by appropriately revising the fertilizer recommendation. Thus, there is considerable opportunity to increase farmers yield and N recovery efficiency levels through improved N management with the LCC. In the situation of using fixed-time split N recommendations, refining fixed time split N recommendations periodically will be needed with the real-time N management to tackle high spatial and temporal variability in INS.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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