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Post-submergence Nitrogen Fertilizer Management for Enhancing Rainfed Lowland Rice Productivity in Eastern India

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Abstract

Flashflood in rainfed lowlands seriously affect rice crop establishment and cause severe yield losses. Survival of new flood tolerant rice varieties (Swarna-Sub1, Samba Mahsuri-Sub1, IR64-Sub1, etc.) developed through introgressing the submergence tolerance gene SUB1into mega rice varieties of South Asia is substantially higher than that of non-Sub1 varieties under flooding stress. This has been consistently reflected in a yield advantage of 1 to 3 t ha^{-1}. Submergence tolerance and productivity of these Sub1 varieties can be further enhanced through adoption of appropriate crop and nutrient management practices. Post-flood nitrogen application plays an important role in helping rice plants to resume quick growth after flood water recession. On station experiments conducted during the wet seasons (*Kharif*) of 2011 and 2012 at the college of agriculture, Chiplima, Sambalpur, Odisha, to study the effect of 3 post-flood nitrogen doses (N_1: 10 kg ha^{-1}; N_2: 20 kg ha^{-1}; N_3: 30 kg ha^{-1}) and 3 application times (% plants started showing at least one green leaf after de-submergence) viz. T_1: 10-15%; T_2: 30-35% and T_3: 65-70% on survival, growth and yield performance of the rice variety Swarna-Sub1. Treatments N_3 (91.4%) and T_2 (96.3%) produced significantly higher survival than other treatments. Additional N increased the yield attributes and finally grain yield. Mean maximum grain yield was recorded with N_3 (3485 kg ha^{-1}) and T_2 (3623 kg ha^{-1}). When the additional N dose was applied earlier (T_1) or late (T_3), the average yield reduction was 19 and 12%, respectively, compared to T_2.

Keywords: Flash flood, rice, eastern india, nitrogen, swarna-sub1

1. Introduction

Flooding is the third most important abiotic stress affecting rice productivity in Asia, surpassed only by drought and weeds (Ella et al., 2011). Rice is the major staple food for more than half of the World population and 90% of rice is being produced and consumed in Asia. It is the major crop in most flood prone areas of South and Southeast Asia (Ismail, 2013). Flash-flood or submergence is a common phenomenon in lowland areas, seriously affecting crop establishment as well as survival, leading to severe yield losses. It imposes severe abiotic stress in flood prone ecosystems, reducing crop stand especially if it occurs during the early vegetative stage and continues for more than a week (Bailey-Serres et al., 2010).

Eastern India is a traditional rice growing region in India, occupying 60% of the total rice cropped area in the country. Approximately 80% of the rice growing area in eastern India is rainfed and exposed to abiotic stress, such as drought, salinity and flood. In recent years, due to changing climate scenario, rainfall is becoming more erratic and heavy rainfall during the cropping season results in floods and crop submergence in low lying areas. This type of stress is widespread and reduces the productivity of rice in the region. Consequently, the average rice productivity of submergence prone areas in eastern India is 0.5-0.8 t ha^{-1}, whereas it is about 2.0 t ha^{-1} in favorable rainfed lowlands. However, flood-prone ecosystems have enormous potential for higher food production to meet the ever-increasing demands for rice supply (Ismail et al., 2013; Singh et al., 2013).

Abiotic stresses have a strong role in increasing food insecurity in rural areas of the country due to low production and low purchasing power. Because farmers in rainfed areas are mostly poor, crop losses caused by abiotic stresses, can have a devastating impact, potentially exacerbating poverty in the region. Eastern India alone has approximately 10 million hectares of rice lands affected by flash flood and complete submergence (Reddy and Sharma, 1992). Water accumulate in these lands to varying depth and duration, at various crop growth stages, rendering rice cultivation highly risky and difficult; and drainage of excess water is not feasible. In Uttar Pradesh, Bihar, West Bengal and Odisha, approximately 8, 40, 40 and 27% rice growing area, respectively, are prone to submergence.

Traditional rice varieties in flood prone regions are long duration, photosensitive varieties, often producing low yields (<1.5 t ha^{-1}) due to poor crop stand caused by excessive flooding. These tall varieties elongate with the rising water level and avoid complete submergence. In contrast, submergence tolerant modern semi-dwarf varieties stop growing when submerged and recover better in the post-flood period. Damage to plants caused by submergence has several causes linked to flood water conditions, particularly the interference in normal gas exchange and light interception. The adverse effects of submergence on rice vary by genotype, the developmental stage at which flooding occurs, duration and depth, and the level of turbidity and turbulence of floodwater (Das et al., 2005; Van Eck et al., 2005; Colmer and Pedersen, 2008; Singh et al., 2014b). Of particular importance is the carbohydrate status of the plant before and after submergence.

Higher yielding modern rice varieties die within a week of complete submergence, making them unsuitable alternatives of traditional rice landraces. However, because of their predominantly fertile soils and huge freshwater resources, flood prone ecosystems have enormous potential for enhancing food production. Furthermore, rice is the only agricultural crop able to survive these frequently flooded environments. Developing high yielding, stress tolerant varieties is thus a strategic imperative that aims to provide farmers with cost effective options in flood affected areas (Mackill et al., 2012; Ismail, 2013; Singh et al., 2013). Modern varieties containing the Sub1 gene are identical to the original varieties in nearly all traits (Sarkar et al., 2009; Singh et al., 2009; Mackill et al., 2012). But submergence survival of the Sub1 lines is substantially higher than that of non-Sub1 varieties. This has been consistently reflected in a yield advantage of 1 to >3 t ha^{-1}, and is depending on the stage at which submergence occurred, the duration of submergence and the condition of the floodwater (Das et al., 2009; Mackill et al., 2012; Ismail et al., 2013). Moreover, Sub1 varieties flowered and matured earlier and had better grain filling than non-Sub1 genotypes following submergence (Sarkar et al., 2009; Singh et al., 2009; Manzanilla et al., 2011). Thus, the availability of tolerant varieties provides new opportunities for developing and validating proper management options effective in flood prone areas, which can further boost and stabilize the productivity of these varieties (Ella and Ismail, 2006; Ella et al., 2011; Ram et al., 2009, Singh et al., 2013). And by reducing risk for the use of nutrients and others inputs, these varieties provide new opportunities for farmers in submergence prone areas to secure higher annual productivity (Ismail, 2013). However, nutrient recommendations have not been fully developed for flood prone areas and farmers do need better advice. For example, improved post-submergence nutrient management can be one component contributing towards increasing productivity in flood prone areas. In particular, Nitrogen (N) has been reported to be the most limiting nutrient for rice production in flood prone areas (Haefele et al., 2010). Generally, it is advised that fertilizers can be applied at any time 1 week after the flood subsides. Farmers' usually apply small amounts of N after receding of flood water, but doses and timing are still not standardized. Thus, there is an urgent need to standardize fertilizer schedules for newly developed Sub1 varieties, as the optimal practice may vary depending on the severity of the stress and tolerance limit of genotypes. In the present investigation an attempt was made to study the effect of application of additional doses of nitrogen and timing of its application after de-submergence on yield performance of Swarna-Sub1 in the field.

2. Materials and Methods

2.1. Site characterization

The field experiments were conducted at the instructional research farm of the College of Agriculture, Chiplima, Odisha, India during the wet seasons (May to December) of 2011 and 2012. The experimental site is situated at latitude 21° 52′ North and longitude 84° 16′ East, at an altitude of 179 m above mean sea level. It has a sub-humid climate, receiving a mean annual rainfall of 1450 mm mostly in the months of

June to October. The intensity and frequency of rain varied during both years of experimentation, which led to a variable pattern of flood water accumulation in the field (Figure 1). During 2011, the maximum monthly rainfall of 450 mm was recorded in September, followed by 289 mm in July and 270 mm in August. Similarly, during 2012, the maximum monthly rainfall of 632 mm was recorded in August, followed by 318 mm in September and 278 mm in July. Because of the uneven rainfall distribution, the crop experienced natural submergence conditions for 2 to 3 months. During this time, water from surrounding hilly terrains, upland and medium land is released as percolation and surface runoff, and accumulates causing subsequent flooding and submergence of lowland crops. The physical and chemical properties of the soil at the experimental site are given in Table 1. The soil has formed in a lateritic sandy loam with pH 6.8, organic carbon concentration of 0.5-0.6%, total Kjeldahl N of 0.07%, 22 kg ha^{-1} Olsen's P and 140 kg ha^{-1} NH_4Ac-K.

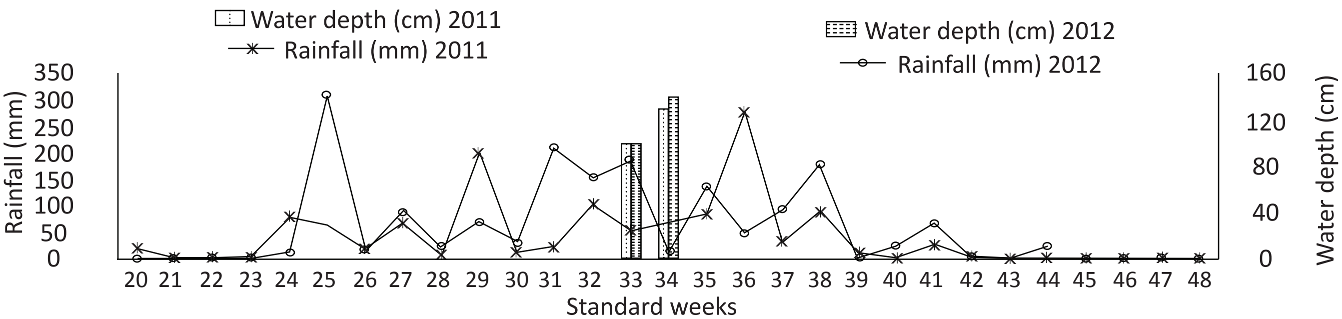

Figure 1: Average weekly rainfall receipt and water depth imposed in the experimental plots during the crop growing season

Table 1: Soil physical and chemical parameters of the experimental site

Parameter	Profile depth		
	0-15 cm	15-30 cm	30-45 cm
Soil texture (%)			
Sand	76.8	66.3	64.5
Silt	11.5	12.2	13.5
Clay	11.7	21.5	22.0
Texture Class	Sandy loam	Clay loam	Clay loam
Bulk density (g ml^{-1})	1.52	1.58	1.56
Field capacity (%)	17.5	19.4	19.5
Wilting point (%)	7.7	9.0	9.4
Soil pH (1:2.5)	6.8	6.5	6.4
EC_e (dS m^{-1})	0.028	0.031	0.035
Organic carbon (%)	0.53	0.32	0.22

2.2. Experimental details

The field experiment was laid out in a factorial randomized complete block design with three replications using the rice variety Swarna-Sub1. It was situated in lowland fields at the instructional research farm of the College of Agriculture, Chiplima, Odisha. The experiment had nine treatment combinations, combined from three post flood nitrogen doses, N_1: 10 kg ha^{-1}, N_2: 20 kg ha^{-1} and N_3: 30 kg ha^{-1}; and three different application times, T_1: when 10-15% plants started showing at least one green leaf after de-submergence (4 days after de-submergence; DAD), T_2: when 30-35% plants started showing at least one green leaf after de-submergence (7 DAD), and T_3: when 65-70% plants started showing at least one green leaf after de-submergence (10 DAD). The recommended rate of 80-40-40 kg N, P_2O_5 and K_2O ha^{-1} were applied in the form of urea, single super phosphate and muriate of potash. Full dose of P, K and 1/3rd N was applied as a basal dressing, whereas the remaining 2/3rd N were applied in equal rates at active tillering and panicle initiation stages, respectively. Twenty five day old seedlings were transplanted in subplots of 5×4 m^2, with a spacing of 20×15 cm^2 and 2 seedlings $hill^{-1}$. Ten days after transplanting, the plants were completely submerged for 14 days with natural flood water at a depth of 90-100 cm. Normal recommended cultural practices (Table 2) and plant protection measures were applied throughout the experiment.

2.3. Observations and data analysis

The survival percentage of hills was recorded 21 days after de-submergence. Observations on other growth parameters like number of hills m^{-2}, number of tillers $hill^{-1}$, leaf number $hill^{-1}$, dry biomass of leaf and stem, and root length were recorded at the vegetative stage whereas yield attributing characters like panicle $hill^{-1}$, grains $panicle^{-1}$, panicle weight $hill^{-1}$, panicle length, filled and unfilled grains $panicle^{-1}$, grain and straw yield, and harvest index (HI) were recorded at maturity. All these observations were recorded on 10 initially tagged hills from each plot. Number of hills m^{-2}, number of tillers $hill^{-1}$, and leaf number $hill^{-1}$ were counted before submergence (BS) and at 20 DAD. Plant height from the base of the stem to the tip of the longest leaf or of the panicle if longer was recorded at 30, 60, 90 DAD and maturity. Dry biomass of leaf and stem (g), and root length (cm) were recorded at 60 DAD. Shoot and leaves were oven dried at 70 °C and weighed. The whole root system was washed carefully, separated, and length of the longest root (cm) was determined. Longest panicles of each treatment were selected for height and

Table 2: Calendar of field operations during 2011 and 2012		
Cultural operation	2011	2012
Land preparation	15.05. 2011	14.05.2012
Nursery raising	05.07.2011	07.07.2012
Seedling uprooting	31.07.2011	02.08.2012
Puddling	31.07.2011	02.08.2012
Transplanting	01.08.2011	03.08.2012
Starting of submergence	11.08.2011	13.08.2012
De-submergence	25.08.2011	27.08.2012
Fertilizer application		
i. Basal-Full dose of P, K; and 1/3rd N	31.07.2011	02.08.2012
ii. 2nd Split dose of 1/3rd N at AT	18.09.2011	20.09.2012
iii. 3rd Split dose of 1/3rd N at PI	08.10.2011	10.10.2012
Harvesting	23.12. 2011	25.12.2012

AT: Active tillering; PI: Panicle initiation

weight measurements. Panicles were hand-threshed and the fertile and sterile grains were separated by submerging threshed grains in tap water. The samples were oven dried at 70 ˚C to constant weight, and then the 1000 grain weight was computed. Grains and straw were harvested, dried, weighed and HI was computed. Chlorophyll (Chl) concentration was determined calorimetrically (Porra, 2002) BS and 20 days after de-submergence (20 DAD). Chopped fresh leaf tissue of 0.1 g was transferred to a capped measuring tube containing 25 ml of 80% acetone, and kept in a refrigerator (4 °C) for 48 h before measurements were made using a spectrophotometer (SICAN 2301Double Beam Spectrophotometer, USA). The chlorophyll a and chlorophyll b concentrations were calculated using the standard equations1) Chla (μg ml^{-1})=12.25 ($A_{663.6}$) - 2.55 ($A_{646.6}$) and 2) Chl b(μg ml^{-1})=20.31 ($A_{646.6}$) -2.55 ($A_{663.6}$). Collected data were analyzed by analysis of variance (ANOVA) using MSTAT-C statistical computer package and treatment comparisons were made using t-test at p≤0.05 level of significance following Gomez and Gomez (1984). The interactions of factors monitored in this study were found to be non-significant and were not reported.

3. Results and Discussion

3.1. Survival and growth parameters

The survival percentage varied significantly from 86.6 to 92.3% and 88.5 to 96.1% for additional N doses and application time, respectively (Figure 2). N application of 20 (N_2) and 30 (N_3) kg N ha^{-1} after de-submergence produced significantly higher survival than 10 kg N ha^{-1} (N_1), though, N_2 and N_3 were statistically similar. However, best application time resulted in higher survival than additional N doses. Post flood N application when 30-35% plants started showing at least one green leaf after de-submergence (7 DAD; T_2) recorded significantly higher survival (96.1%) than all other treatments except T_3 (post flood N application at 10 DAD). Earlier application at 4 DAD (T_1) resulted in the lowest survival of 88.5% (Figure 2). These results clearly indicate that additional N applied 7 and 10 DAD had more pronounced effect on crop reestablishment, recovery and growth, which was reflected in a higher survival rate than earlier applications at 4 DAD.

Higher N doses (N_2 and N_3) produced higher plant height at all stages but in both seasons, differences were not significant except at maturity (Figure 3a). Additional N applied at 7 DAD (T_2) produced tallest plants at all stages, with significant

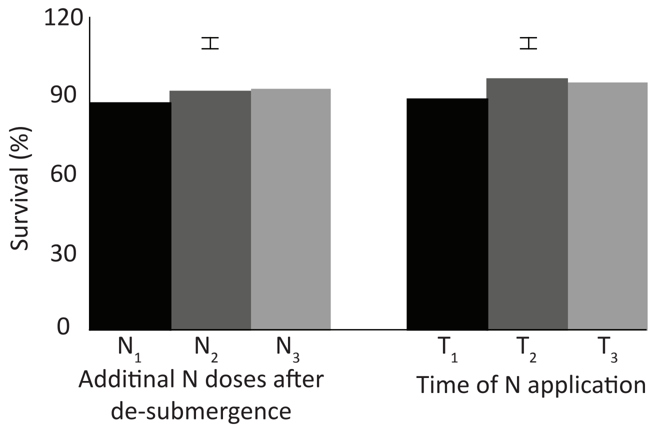

Figure 2: Survival (%) as influenced by different doses and time of post-flood N application

differences among treatments in both seasons except at 30 DAD in 2012. Additional N applied at 4 DAD produced significantly smaller plants at all stages (Figure 3b). Higher N doses (N_2 and N_3) caused significantly lower reduction in number of hills m^{-2} (8.6 and 7.7%, respectively) than N_1 (13.5%). Additional N in T_2 had a pronounced effect on quick recovery and growth, resulting in a higher number of shoots hill^{-1} at 20 DAD than in T_3 and T_1 (Table 3). N_2 and T_3 produced the maximum number of shoots hill^{-1} after de-submergence (7.9 and 8.3, respectively), whereas N_1 and T_1 had the lowest number (6.8 and 6.2, respectively). N_2 produced a 146.6% increase in number of leaves hill^{-1} in comparison with pre-submergence values, compared with N_3 (141.5%) and N_1 (119.8). Similarly, T_2 exhibited 150.9% increase in number of leaves hill^{-1} after de-submergence over pre-submergence values, which was statistically similar to T_3 (147.6) and significantly higher than N_1 (109.0) (Table 3).

The highest post-flood N dose (N_3; 30 kg ha^{-1}) produced significantly higher leaf and stem dry weight plant^{-1} (0.65 g and 0.91 g, respectively) than other treatments except N_2 (0.63 and 0.88 g, respectively). With respect to application timing, additional N applied at 7 DAD (T_2) produced significantly higher leaf and stem dry weight plant^{-1} (0.67 g and 1.00 g, respectively) than the other treatments (Table 3). Leaf-stem

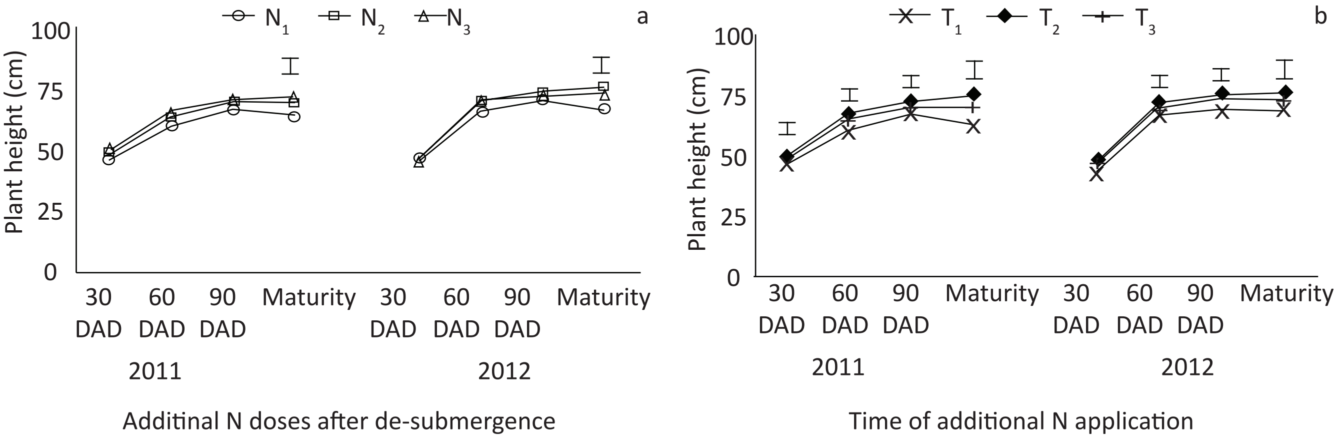

Figure 3: Plant height of Swarna-Sub1 as influenced by (a) different post flood N doses and (b) application time during 2011 and 2012

Table 3: Growth parameters before submergence, at 20 and 60 days after de-submergence of Swarna-Sub1 as influenced by different doses and time of post-flood N application during 2011 and 2012 (pooled data)

Treatment	No. of hills m^{-2} (BS)	No. of hills m^{-2} (20 DAD)	No. of shoot $hill^{-1}$ (BS)	No. of shoot $hill^{-1}$ (20 DAD)	No. of leaves $hill^{-1}$ (BS)	No. of leaves $hill^{-1}$ (20 DAD)	Leaf dry wt. $plant^{-1}$ (g)	Stem dry wt. $plant^{-1}$ (g)	Leaf-stem ratio	Root dry wt. $plant^{-1}$ (g)	Root length (cm)
N level											
N_1	34.7	30.0	3.3	6.8	13.5	29.7	0.56	0.81	0.69	0.22	14.8
N_2	35.0	32.0	3.3	7.9	13.3	32.7	0.63	0.88	0.72	0.26	15.2
N_3	34.7	32.0	3.5	7.4	13.8	33.3	0.65	0.91	0.72	0.25	15.0
SEm±	0.78	0.57	0.07	0.28	0.25	0.71	0.012	0.236	-	0.003	0.48
LSD (p=0.05)	ns	1.97	ns	0.97	ns	2.46	0.042	0.082	-	0.01	ns
Time of N application											
T_1	34.7	31.7	3.3	6.2	13.4	28.0	0.57	0.77	0.75	0.20	14.4
T_2	34.7	33.0	3.4	8.3	13.6	34.0	0.67	1.00	0.67	0.28	14.8
T_3	35.0	32.3	3.4	7.6	13.6	33.7	0.60	0.84	0.71	0.25	15.7
SEm±	0.62	0.51	0.06	0.54	0.20	0.70	0.010	0.270	-	0.013	0.36
LSD (p=0.05)	ns	ns	ns	1.60	ns	2.10	0.032	0.080	-	0.039	1.07

ns: non-significant; N_1: 10 kg N ha^{-1}; N_2: 20 kg N ha^{-1}; N3: 30 kg N ha^{-1}; T_1: when 10-15% plants started showing at least one green leaf after de-submergence (4 days after de-submergence; DAD); T_2: When 30-35% plants started showing at least one green leaf after de-submergence (7 DAD); T_3: When 65-70% plants started showing at least one green leaf after de-submergence (10 DAD)

ratios varied from 0.69 to 0.72 for additional N doses and from 0.67 to 0.75 for different application times. Treatment N_2 produced significantly higher root dry weight $plant^{-1}$ than N_1 but was statistically similar to N_3 (0.25 g). Post flood application time of additional N significantly affected the root dry weight $plant^{-1}$, the maximum being recorded in T_2 and minimum in T_1. Additional N application did not have a significant effect on root length; highest length was recorded in N_2 (15.2 cm), followed by N_3 (15.0 cm) and minimum in N_1 (14.8 cm) (Table 3).

Submergence tolerance in rice is highly dependent on several environmental conditions including temperature, irradiance during submergence, submergence depth (Palada and Vergara, 1972; Adkins et al., 1990; Singh et al., 2009), flood water CO_2 concentrations (Setter et al., 1987), as well as the physiological condition of the plant material such as age (Adkins et al., 1990, Sarangi et al., 2015), carbohydrate content and nutrient status (Jackson and Ram 2003; Singh et al., 2014a; Gautam et al., 2014a, 2014b). Additional doses of 20 and 30 kg post-flood N ha^{-1} applied 7-10 DAD significantly increased crop survival as compared to application of 10 kg N ha^{-1}, indicating that higher N doses (>10 kg ha^{-1}) applied around 7 DAD helped in better survival (Figure 2), quick crop recovery and resumption of faster growth. According to Crawford (2003), a plant's ability to survive for long periods under submergence is related to the storage organs able to survive and regenerate new shoots and roots after the flood water recedes. Basal application of P and post-flood N application ensured less shoot elongation, plant mortality and ultimately higher plant survival (Gautam et al., 2014a). Singh et al. (2014a) and Bhowmik et al. (2014) also reported that N applied 5-7 DAD improved survival, maintained higher plant population at recovery and thus increased grain yield of Swarna-Sub1.

Complete submergence enhances the accumulation of ethylene due to increased synthesis which triggers chlorophyll degradation and leaf senescence of the submerged plants through suppression of abscisic acid synthesis but enhanced synthesis and sensitivity to gibberellins (Fukao and Bailey-Serres, 2008), resulting in a lower photosynthetic rate. Singh et al. (2014*b*) reported that chlorophyll retention during and after submergence is critical for survival because it ensures underwater photosynthesis and faster recovery after the water recedes (Sarkar et al., 1996; Krishnan et al., 1999; Ella and Ismail, 2006). Post-submergence N application ensured lower reduction in Chl a & b contents after de-submergence, and higher N treatments showed less reduction in our study (Figure 4). Basal application of P accompanied with post-flood N application maintained higher level of Chl a and b contents, nonstructural carbohydrate and photosynthetic rate with encouraging effects in plants submerged with clear and turbid water (Gautam et al., 2014a).

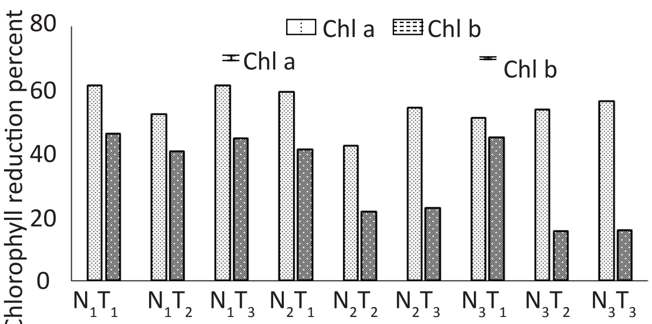

Figure 4: Relative decrease in Chlorophyll a and b concentrations as influenced by different doses and time of post-flood N application

The number of hills m^{-2}, tillers $hill^{-1}$ and number of leaves $hill^{-1}$ were higher with 20 and 30 kg N ha^{-1} than with a rate of 10 kg N ha^{-1} (Table 3). Leaves, stem and root dry weight, and root length also differed due to different N levels and application time (Table 3). The plant height increased with the additional dose of fertilizer, which remained statistically similar at initial stages, however, at maturity the differences were significant (Figure 3 a and b). Similarly, the plant height was also influenced by the time of application of the nitrogen. The maximum plant height was recorded when the additional dose of nitrogen was applied when 30-35% plants start showing at least one green leaf after de-submergence. The leaf and stem dry-matter accumulations exhibited a steady increase with increase in N level when applied after de-submergence. However, the ratio between leaf and stem did not maintain the same trend indicating that the stem growth was more in proportion than the leaf. Ram et al. (2009) reported that plant growth and yield might not only depend on carbohydrate production through photosynthesis, but also on mineral absorption and assimilation by the roots. Since a part of applied N might be lost through gaseous emission, percolation and runoff if not rapidly absorbed by the plants, the lowest N dose was not enough to meet the crop's demand after de-submergence (Pandey, 2013; Bhowmick et al., 2014). Singh et al. (2014a) reported that higher regeneration of plants after de-submergence was associated with the N applied after de-submergence rather than pre-submergence application. After de-submergence, a sharp decrease in N uptake was recorded due to P and N interaction during submergence. Higher N doses compensated interaction effects and provided optimal N required for regeneration and growth. Similarly, Gautam et al. (2015) found that N application after de-submergence produced higher number of green leaves, photosynthetic rate, biomass and yield. This could indicate that leaf sheath N has a major accumulative and supportive role during submergence, perhaps by containing proteins acting as respirable reserves.

3.2. Chlorophyll concentration

Variation in reduction of Chlorophyll a & b concentrations were recorded due to additional post-flood N applied at different times after de-submergence (Figure 4). Treatments receiving a low dose of N (10 kg ha^{-1}) applied early (4 DAD) recorded the highest and significant reduction (N_1T_1) in chl a (61.4%) and Chl b (46.1%) content. The smallest significant reduction in Chl a was recorded in N_2T_2 (42.4%), followed by N_3T_1 (51.2%) and N_3T_2 (53.8%), whereas for Chl b it was in N_3T_2 (15.5%) followed by N_3T_3 (15.8%) and N_2T_2 (21.5%). Least reduction in Chl contents enabled plants to regain their photosynthetic capacity more quickly, which helped in faster recovery and re-growth. Submergence or waterlogging imposes a complex abiotic stress on rice plants, and affects numerous physiological and metabolic processes, suppressing normal plant growth and development (Ella et al., 2003; Sarkar et al., 2006; Bailey-Serres and Voesenek, 2008; Ismail, 2013; Singh et al., 2014*b*). It is a common problem and challenge for enhancing rice productivity in eastern India. Developing submergence tolerant rice varieties has been an important breeding objective over the past few decades (HilleRisLambers and Vergara, 1982; Mackill, 1986, 1993; Mohanty and Chaudhary, 1986), however, progress has been slow because newly developed varieties were mostly inferior in some traits, such as grain quality, that made them not acceptable to farmers. Cloning of the SUB1A gene and its introgression into popular rice varieties using marker assisted back crossing made it possible for development of flood tolerant varieties that can withstand 2 weeks of complete submergence. These varieties are being adopted on a large scale in South Asia, given that they retain their other main agronomic and quality traits (Xu et al., 2006; Neeraja et al., 2007; Singh et al., 2009, 2011, 2014*b*; Septiningsih et al., 2009). However, tolerance level and productive potential of such newly released varieties can be further enhanced through matching crop and nutrient management (Ismail et al., 2013; Bhowmick et al., 2014; Singh et al., 2014*a*, Sarangi et al., 2015).

3.3. Phenology, yield attributes and yield

Significantly later 50% flowering and maturity were recorded in treatments receiving higher doses of N application (N_3; 121 and 149 days, respectively) than treatments receiving less N (N_2 and N_1). However, application time had non-significant effect on 50% flowering and days to maturity (Figure 5 a and b). The responses of Swarna-Sub1 to different additional doses of N and different application times were clearly illustrated by variation in yield and yield attributes. The effect of the treatments was non-significant on hills m^{-2} at maturity (Table 4). However, treatment N_2, N_3 and T_2 had significantly more panicles $hill^{-1}$, whereas N_2 produced significantly more grains $panicle^{-1}$; less panicles $hill^{-1}$ and grains $panicle^{-1}$ were recorded in N_1. Panicle weight was also significantly affected, being higher in N_2, T_2 and T_3. Additional doses of N and application time did not affect panicle length significantly. Additional application of 20 and 30 kg N ha^{-1} caused significantly more grains $panicle^{-1}$ compared with N_1 which had most chaffs $panicle^{-1}$. Additional N application 7 DAD produced the most grains $panicle^{-1}$, followed by T_3, and most chaffs $panicle^{-1}$ were recorded in T_1 (Table 4).

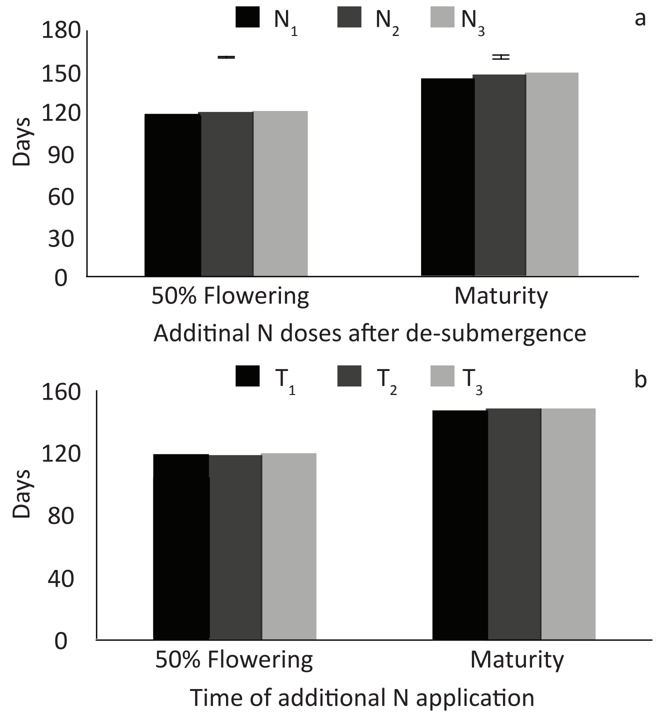

Figure 5: Days to 50% flowering and maturity as influenced by (a) different post-flood N doses and (b) application time

Treatments with additional nitrogen doses of 20 (N_2) and 30 (N_3) kg N ha^{-1} did achieve significantly higher grain yields than N_1 (10 kg N ha^{-1}), however, the straw yield was highest with N_3. The highest grain yields of 3485 kg ha^{-1} was recorded with the additional dose of 30 kg N ha^{-1} (N_3), but the treatment was not significantly different from N_2 (20 kg N ha^{-1}). Application of additional N when 30-35% plants started showing at least

Table 4: Yield and yield attributes of Swarna-Sub1 as influenced by different doses and time of post-flood N application during 2011 and 2012 (pooled data of 2 years)

Treatment	Hill m^{-2}	Panicles $hill^{-1}$	Panicle weight $hill^{-1}$ (g)	Panicle length (cm)	Grains $panicle^{-1}$	Chaffs $panicle^{-1}$	1000-grain wt. (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index
N levels										
N_1	31.0	9.4	9.5	18.5	105.3	53.9	18.58	3007	5386	0.36
N_2	31.9	10.9	10.8	20.1	127.2	37.8	19.26	3261	5439	0.37
N_3	31.3	11.0	10.5	19.8	124.1	51.1	18.86	3485	5947	0.37
SEm±	1.10	0.38	0.35	1.52	5.02	3.52	0.16	67.4	131	-
LSD (*p*=0.05)	ns	1.31	1.21	ns	17.3	12.18	0.57	233	452	-
Time of N application										
T_1	31.0	9.9	9.2	19.3	106.2	57.5	18.15	2932	5420	0.35
T_2	32.0	11.0	10.7	19.6	127.2	43.4	19.43	3623	5840	0.38
T_3	31.2	10.4	10.8	19.4	122.8	49.3	19.17	3199	5512	0.37
SEm±	0.67	0.22	0.19	1.41	4.73	3.38	0.15	73.9	119	-
LSD (*p*=0.05)	ns	0.65	0.56	ns	14.05	10.05	0.46	219	353	-

one green leaf (T_2, 7 DAD) recorded maximum grain yields of 3623 kg ha^{-1}. Straw yield was significantly higher in T_2 (5840 kg ha^{-1}), however it was at par with T_3 (5512 kg ha^{-1}). Additional N applied after de-submergence improved HI, with highest values in N_2 and N_3, and lowest value in N_1. Regarding N application timing, T_2 (N application7 DAD) resulted in the highest HI, followed by T_3 and T_1 (Table 4).

A general delay in flowering and maturity occurred after de-submergence as it takes the surviving plants time to recover and resume normal vegetative growth, and to overcome damage caused during and after submergence (Figure 5a and b). Higher post-flood nitrogen rates (30 kg ha^{-1}) caused a greater delay in comparison to the lower doses, but the values were not significantly different. Nitrogen application time had no effect on flowering and maturity. This could be explained by additional N application maintaining healthier plants that can recover and produce more tillers and prolonged vegetative growth as N is known to enhance photosynthetic rate due to maintaining higher chlorophyll concentration (Jackson and Ram, 2003; Ella et al., 2003; Das et al., 2005; Fukao et al., 2006; Singh et al., 2014a; Gautam et al., 2014a, 2014b; Lal et al., 2014). The apparent delay in maturity was mostly because of the delay in flowering (Figure 5 a and b).

Higher N doses after de-submergence significantly improved grain yield. The highest grain yield was recorded with the additional dose of 30 kg N ha^{-1} (N_3) (Table 4). The ability for faster recovery and early tiller formation following post-submergence application of higher N-doses might be the reason for higher grain yields. Significant decreases in grain and straw yields were recorded with the lowest N-dose (N_1) because the lowest N-dose was not enough to meet the crop demand after submergence (Pandey, 2013).

Application of additional N dose at 7 DAD, when 30-35% plants started showing at least one green leaf (T_2), recorded the maximum grain yield which was significantly higher than the earlier and later applications (Table 4). Appropriate application time of higher N doses led to highest values of hills m^{-2}, panicles $hill^{-2}$, grains $panicle^{-1}$, and 1000 grain weight along with minimum spikelet sterility (Table 4). Rice plants could rapidly absorb the additional dose of fertilizer N applied at 7 DAD which obviously matched best with crop demand after recovery and regrowth. Second best was N application at 10 DAD (T_3), when 60-65% plants started showing at least one green leaf. The average grain yield reduction was 19 and 12% when additional N was applied at 4 DAD (T_1) and 10 DAD (T_3), respectively, compared to 7 DAD (T_2) (Table 4). This yield decline was mainly attributed to the reductions in grain filling, number of panicle m^{-2} and 1000-grain weight. Similar results were reported by Bhowmick et al. (2014) who found that an additional N dose after 7 DAD improved survival, post-submergence recovery, yield contributing characters and yield. Gautam et al. (2014a and 2015) also noticed that foliar application of post-submergence N with basal P resulted in higher survival, better post oxidative damage control, higher yield attributing characters and yield in clear as well as in turbid water submergence conditions with Sub1 varieties.

Although the flooded soil might supply some N, rice plants were so stressed after de-submergence that they could not exploit the nutrients from the flooded soil, probably due to their poor establishment and growth. Therefore, time of N fertilization during the post emergence period might be a crucial factor for determining the recovery growth, which would be especially important when stand establishment was completely destroyed by submergence (Ella and Ismail, 2006; Bhowmick et al., 2014; Gautam et al., 2015). Good recovery growth after this period could be considered a re-establishment of the crop after flash-flood damage (Ram et al, 2009). Gomosta (2001) found that re-growth and consequently grain yield were much better with N fertilization at 15 days after the drainage of water than N application immediately after the drainage of water. Similarly, Pandey (2013) and Mackill et al. (2012) recommended that small additional amount of N might be applied preferably at one week after the recession of floods.

4. Conclusion

Additional 20 to 30 kg N ha^{-1}, applied when 30-35% plants started showing at least one green leaf, resulted in significantly higher survival, helped in rapid regeneration, leading to higher yield in flash flood situations. Such practice considerably increase submergence tolerance and grain yield of rice in the flood-prone rainfed lowlands. These findings can effectively be replicated in other Indian states as well as in Bangladesh and the Terai of Nepal with similar ecologies.

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