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Nutrient management and submergence-tolerant varieties antecedently enhances the productivity and profitability of rice in flood-prone regions

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ABSTRACT

Poor productivity of rice in rainfed lowlands is due to complete submergence as it is a major abiotic stress of these regions. For enhancing the rice productivity of these areas, better nutrient management options are required and results may even better when combined with stress tolerant cultivars, even when tested under natural conditions of farmers' field. For supporting the above statement, the effect of nitrogen and phosphorus in graded doses was evaluated for submergence tolerance in controlled conditions and the results obtained were tested and validated at farmers' field in Cuttack, Odisha, India. Shoot elongation, leaf senescence and lodging were lowest with the application of higher phosphorus (60 kg ha^{-1}). Highest dose i.e. 100-60-40 NPK kg ha^{-1} resulted in higher plant survival of all the varieties by 90–170% over no nutrient application, it was also reflected in the higher growth after recovery, leaf greenness, leaf and stem growth, chlorophyll and carbohydrate concentrations and ultimately higher grain yield. At farmers' field, application of basal P, K and post-flood N management practice resulted in overall better performance of Swarna and Swarna-Sub1 showing higher yield attributes leading to 65.7 and 37.9% higher grain yield, over conventional practices followed by farmers. Apart from that results were more positive if post-flood nitrogen was applied as urea foliar spray might be due to quick absorption of N by plant leaves and also spraying helps in removing the silt of flood water sticking to the leaf surface and facilitated the plants to photosynthesize and survive after desubmergence. These cost-effective management options may enhance the productivity and profitability of rice in the flood-prone areas where farmers hesitate to apply nutrients.

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nutrient management; productivity; profitability; submergence; survival

Introduction

Globally, rainfed lowlands covers 54 mha area (Bouman et al. 2007), and accounts for about 19% of the world rice production, apart from that rice is the staple diet of India, grown in about 44 m ha area but productivity is low because India covers its largest rice area (39%) as rainfed lowland (Mandal et al. 2010). Extreme weather patterns due to climate change increases abiotic stresses like flood, drought, and salinity, which pretenses a critical challenge to rice production adversely in more than 50% of this area (Singh et al. 2016). The heavy and erratic

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precipitation during monsoon season leads to occurrence of flooding in rainfed lowlands and make flooding the major stress of the area, which can occur at any time of crop growth and also in variable severity. In South and Southeast Asia, approximately 22 million ha of rice lands are flood-prone and more than 100 million people primarily depend on this ecosystem for their livelihood (Sarkar et al. 2006; Ismail et al. 2013). Under such situation, floodwater may remain in the field for 1–2 days or may last up to few weeks, submerging the crop standing in the field. If crop submerges for 1–3 days it will recover after receding of floodwater, but if the crop is submerged for $>$ 5 days it will not recover and regenerate. The survival of rice plant after complete submergence and intensity of flooding stress largely relies on prevailing weather conditions, like temperature, turbidity of flood water, solar radiation available underwater etc. In rainfed lowlands, where flood is more common, farmers usually cultivate tall and moderately tolerant landraces but these are poor yielders, and sometimes when high-yielding rice varieties grown which are susceptible to submergence, farmers often suffer significant yield reduction or may be total crop failure caused by flashflood episodes because of high mortality, suppressed tillering, reduced panicle size, and high sterility (Wassmann et al. 2009). Rice submergence can result in leaf chlorosis, decrease in green leaves, reduced root absorption leading to impaired growth and development, with high lodging, which can bring about poor output or even loss of total crop failure (Lal et al. 2015). Submergence tolerant gene i.e. Sub1 was identified and incorporated in the popular rice varieties which were preferable to farmers and new developed varieties released in India like Swarna-Sub1, IR64-Sub1, Samba Masuri-Sub1, this step resulted in enhanced rice productivity in such flood-affected areas (Mackill et al. 2012). After inundation Sub1 rice cultivars slow down their growth, so, when flood water recedes the energy contributes to survival and fast recovery.

Further, if fields are prone to flooding, farmers did not want to invest on crop inputs like fertilizer as crop loss restricts the expected benefit from investments done by the farmer in crop raising (Gautam et al. 2014a). If farmers take risk of applying nutrients to crop, they only use small amount of nitrogenous fertilizers, as per availability without knowing and following standard recommendation. These practices leads to economic losses as even during seasons of average rainfall, crop may produce poor yields. Besides these facts and considerable area of rice cultivation is flood prone, nutrient application time, dose and methods as fertilizer recommendations have not been scientifically developed. Further, research opportunities are available for developing and validating appropriate crop management options even in tolerant cultivars like IR64-Sub 1, Swarna-Sub1, and Savitri-Sub1 which could further augment the productivity of these varieties and may give sustainability to rice production in these areas. According to Gautam et al. (2014b) and Bhowmick et al. (2014) productivity of flood-prone areas can be increased substantially by following post-submergence nutrient management, particularly nitrogen. In the light of above mentioned facts the objective of the present study are (i) to study the response of graded dose of N and P in submergence tolerance of rice, and (ii) to validate the results of our first study i.e. basal phosphorus and post-flood nitrogen enhances the submergence tolerance in rice at Farmers' field in Cuttack, Odisha.

Material and methods

Experiment 1

To fulfill the above said objectives, experiment was conducted during 2013–2014 in pots under natural conditions with graded dose of N and P, i.e., 100 and 150% P of recommended fertilizer dose (RDF), 100 and 125% N of RDF, at National Rice Research Institute, Cuttack (20° 27′N, 85° 56′E; elevation 24 m above mean sea level). Plastic pots were prepared with 10 kg of farm soil, which is sandy clay loam in texture, and having pH 6.6, EC-0.076 dSm^{-1}, available

Table 1. Details of locations, varieties, and plot sizes of on-station and on-farm trials conducted during 2014–2015 in the Cuttack, Odisha, India.

					Initial soil status			
						N	P	K
Location	Longitude	Latitude	Variety	Plot size	pH	Kg ha^{-1}		
On-station trial								
ICAR-NRRI, Cuttack	85° 56′4.10° E	20° 27′ 13.46°N	IR64, Swarna, IR64-Sub1, Swarna-Sub1	Pot experiment	6.4	212.5	10.8	118.7
On-Farm trial								
F1: Atoda, Salipur	86° 7′9.11° E	20° 29′ 3.66°N	Swarna, Swarna-Sub1	300 m^2	5.9	96	11.2	106.9
F2: Bahugram, Salipur	86° 7′9.12° E	20° 29′ 3.68°N	Swarna, Swarna-Sub1	300 m^2	5.6	105	11.5	109.8

nitrogen (N), phosphorus (P) and potassium (K)-51.2, 3.9 and 65.4 mg kg^{-1} of soil. Varieties which are popularly grown in the region but susceptible to flooding i.e. IR64 and Swarna and their Sub1s which can tolerate submergence were used in the study, 15 days old seedlings of each variety were transplanted in pots (2 seedlings per pot). A total of seven NPK combinations were used viz., control (no nutrient application), 0-40-40, 0-60-40, 80-40-40, 80-60-40, 100-40-40, 100-60-40 kg ha^{-1}, to meet the requirement of N, P and K, respectively. For P and K requirement, single super phosphate (SSP) @114 and 171 mg and muriate of potash (MOP) @30 mg was applied to each pot as per the treatments at the time of transplanting. To meet out the N requirement Urea @ 80 and 100 mg was applied in three splits, 1/3rd as basal, 1/3rd as panicle initiation stage and 1/3rd as post-flood (after 48 hrs of desubmergence as urea foliar spray) as per the treatments. Leaves of rice seedlings were sprayed with 2.0% (w/v) urea solution on their ad axial surface through a sprayer in a water carrier until they were completely wetted. For imposing complete submergence, in a concrete tank rice plants were submerged for 14 days and level of water was kept 30 cm above the canopy under following conditions (i) water temperatures of 26.5–27.8 °C; (ii) dissolved oxygen (DO) of 1.32–4.56 mg l^{-1}; (iii) pH ranged from 6.7 to 8.3; and (iv) photosynthetically active radiation (PAR) was 933.2 µ mol m^{-2}s^{-1} at surface and 489.7, 276.3, 41.8 µ mol m^{-2}s^{-1} at 10, 30 and 50 cm of water depth. For creating turbidity 0.4% concentration of silt was mixed into the water (Das et al. 2002). The turbid flood water was stirred manually for 10 mins twice a day to prevent the settling of silt at the base. The experiment was repeated in four replications under factorial randomized block design. After receding of flood water, the plants were permitted to recuperate for about 10 days, samples for different analysis were collected 48 hr before submergence and then 10 days after desubmergence.

Experiment II (on-farm trial)

Results of station trials (i.e. basal phosphorus and post-flood nitrogen improves submergence tolerance and yield of rice), was validated for commercial validity at Farmers field in Salipur block of Cuttack district (Table 1). This area is affected by complete submergence for 10–15 days during July-August, thereby adversely affecting crop establishment and productivity. The improved variety i.e. Swarna-Sub1 recently developed for coastal lowland areas were released in 2009, were used in the experiment along with its recurrent parent Swarna. The flash flood experienced during seedling stage for 11 days (main field). Randomized block design (RBD) was followed in each experiment with three treatments—T1: farmer's field practice (FFP); T2: basal P and K + urea broadcasting; and T3: Basal P and K + urea foliar spray (Table 2). Field was thoroughly puddled and 30 days old rice seedlings were transplanted at a spacing of 20 × 15 cm and nutrient was applied as per the treatments.

Table 2. Details of the nutrient treatments executed in on-farm trial conducted during 2014–2015 in the Cuttack, Odisha, India.

Symbols	Treatments	Details
T_1	Farmers' Field practices	Dose (kg ha^{-1}): 40:20:20, NPK, P and K applied as basal and N applied at PI stage only; it varies from field to field and farmer to farmer
T_2	Basal P and K + Urea broadcasting	P and K was applied@ 40 kg/ha as basal at the time of transplanting and N (100 kg/ha) in four equal splits, 25% as basal and remaining N in three equal splits (25%), one split as post-flood, whenever flood occurs; and at maximum tillering and panicle initiation stage. Urea broadcasting after complete receding of flood water.
T_3	Basal P and K + Urea foliar spray	P and K was applied@ 40 kg/ha as basal at the time of transplanting and N (85 kg/ha), 25 kg as basal and remaining N one as post-flood (Spray of urea (2% solution with knapsack sprayer) after desubmergence whenever flood occurs; and 25 kg each at maximum tillering and panicle initiation stage. Urea foliar spray if flood water not completely recedes from field.

Measurements

$$\text{Shoot elongation } (\%) = \frac{\text{Plant height after desubmergence} - \text{plant height before submergence}}{\text{plant height before submergence}} \times 100$$

$$\text{Plant survival } (\%) = \frac{\text{No.of green leaves after 10 days of desubmergnce}}{\text{Total no of leaves before submergence}} \times 100$$

For observing crop growth leaf area, leaf dry weight, biomass accumulation was recorded before submergence and after desubmergence, lodging and leaf senescence was recorded after 1 day of desubmergence from all the treatments. The degree of lodging and senescence was scored visually in the scale of 1 to 6 and 1 to 5, respectively. In the score 1 shows minimum damage and 5 or 6 represented mortality of plants by complete degenerated leaves and heavy lodging. Leaf senescence was confirmed with the SPAD reading taken up by chlorophyll meter, which measures the amount of chlorophyll or greenness of leaves. Different developmental stages like days to flowering and days to maturity was also recorded to find out the treatment differences. Prior to harvesting, different yield attributing characters and after harvest grain yield were recorded. Photosynthetic measurements were taken with infrared gas analyzer (LI-6400, LI-COR, Lincoln, NE, USA) around 11:00 AM. Third or fourth upper fully developed healthy leaf was selected for the measurement, and conditions maintained in assimilation chamber are air humidity, 68%; leaf temperature, 31 °C; light intensity (PAR), 1200 $\mu molm^{-2} s^{-1}$. Net photosynthetic rate was taken at the CO_2 concentration of 380 µmol CO_2 mol^{-1}. By following the procedures of Porra (2002) and Yoshida et al. (1976), chlorophyll and non-structural carbohydrate (NSC) concentration was calculated before and after submergence.

Economic and statistical analysis

Economics of treatments was calculated based on the cost and returns; cost included the expenditure on inputs like seed, Labor and agrichemicals. Quantity of produce was multiplied by its existing price for computing gross returns. The net returns and benefit cost ratio were calculated by subtracting the cost from gross returns, and dividing net returns by costs, respectively. All the data of differentiating treatments were analyzed in SAS 9.2 (SAS Inc., Chicago IL) and Microsoft Excel 2007 (http://www.microsoft.com/) software. Differences in plant growth, metabolic and physiological parameters, yield and its characters were compared using repeated measures of analysis of variance at 0.05 probability.

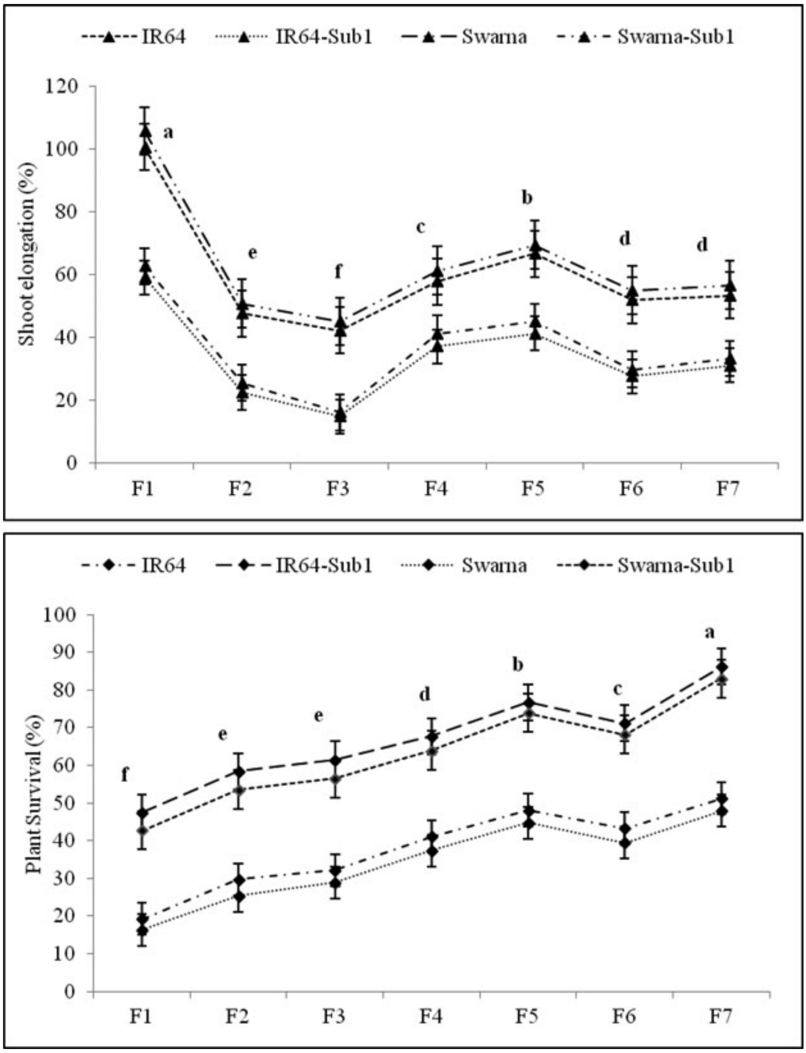

Figure 1. Effect of fertilizer application on shoot elongation and plant survival of IR-64, IR-64 Sub1, Swarna and Swarna (vertical bars in each line represents standard error). F1: control (0), F2: 0-40-40, F3: 0-60-40, F4: 80-40-40, F5: 80-60-40, F6: 100-40-40, F7:100-60-40 NPK kg ha^{-1}.

Results

On-station trial for evaluation of graded dose of nutrient application

Survival and shoot elongation

Average survival rates were 37.8, 34.3, 67.1 and 63.1% in IR 64, Swarna, IR 64-Sub1 and Swarna-Sub1 respectively (Figure 1). Higher dose of N and P contributed to better survival; regardless of the cultivars, higher N (100 kg ha^{-1}) and P (60 kg ha^{-1}) resulted in 18.5% and 7.9% higher plant survival as compared to their recommended doses i.e. 80 and 40 kg ha^{-1}, respectively. The gain in plant survival was highest with 100-60-40 kg NPK ha^{-1}, which was around 166.7, 192.1, 81.6 and 94.1% higher over control in IR 64, Swarna, IR 64-Sub1 and Swarna-Sub1 respectively. Complete submergence affected shoot elongation greatly; among the four cultivars, increase in shoot length was greater in Swarna (63.5%) and IR 64 (60.1%) as compared to Swarna-Sub1 (36.3%) and IR 64-Sub1 (33.4). Phosphorus substantially suppressed the shoot elongation of all

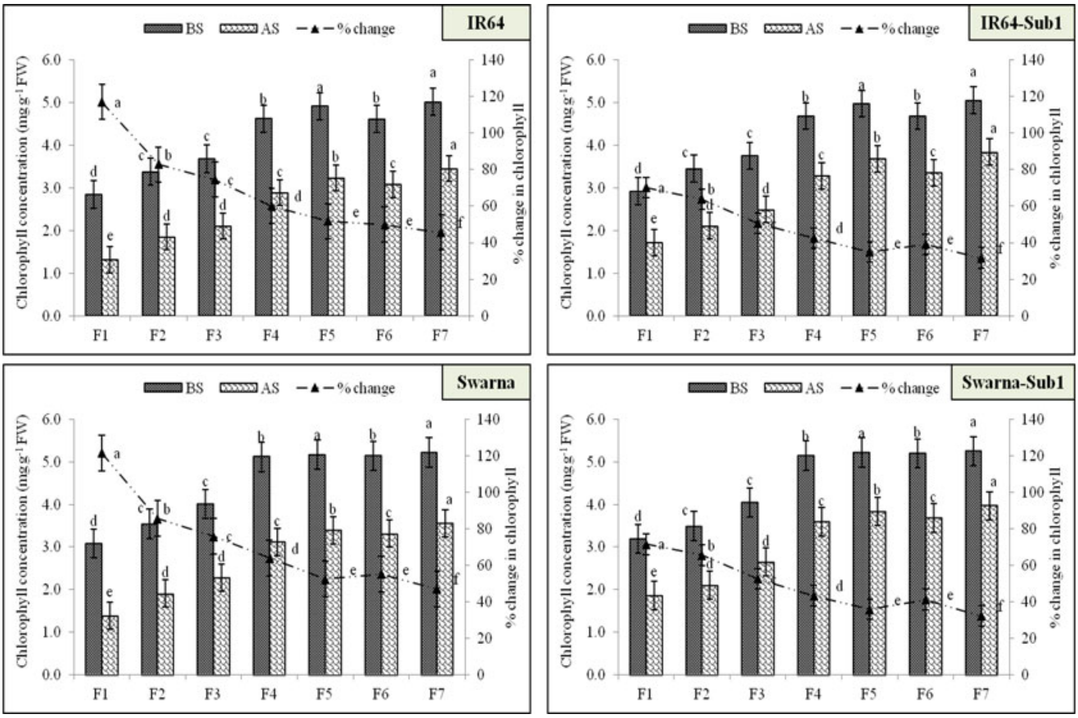

Figure 2. Effect of fertilizer application on chlorophyll concentration (mg g^{-1} FW) of IR-64, IR-64 Sub1, Swarna and Swarna Sub1 before submergence (BS), 10 days of desubmergence (AS) and % change in chlorophyll after desubmergence over before submergence (vertical bars in each column and line represents standard error). Column bars on primary axis represents chlorophyll concentration and lines on secondary axis represents % change in chlorophyll concentration. F1: control (0), F2: 0-40-40, F3: 0-60-40, F4: 80-40-40, F5: 80-60-40, F6: 100-40-40, F7:100-60-40 NPK kg ha^{-1}.

the cultivars and higher dose contributed to promising results (Figure 1). Lowest shoot elongation was recorded with 60 kg P (29.6%) alone followed by 40 kg P (36.7%), whereas, highest shoot elongation was recorded in the control (82%), irrespective of the cultivar.

Chlorophyll, non-structural carbohydrates (NSC) concentration and photosynthesis

The difference in total chlorophyll concentration before submergence (BS) was due to varietal characters i.e. higher in Swarna and Swarna-Sub1 and in the treatments receiving N (Figure 2). Submergence stress reduced the chlorophyll and the reduction was lower in Sub1 cultivars and chlorophyll recuperated faster in these cultivars after desubmergence. When post-flood N and basal P was applied, especially at higher doses resulted in higher regain in chlorophyll leading to least % change (39.2%) in chlorophyll over before submergence, whereas, it was highest in control (95.1%). A significant depletion in sugar and starch content was observed after submergence in all the cultivars, which was significantly higher in IR 64 and Swarna resulting in higher percent change over before submergence (Table 3). After 10 days of desubmergence, significant differences in carbohydrate levels were observed among control and graded dose of N and P application. Concentration of sugar and starch after desubmergence was 35.3 and 26.8% higher with 100-60-40 kg NPK ha^{-1} resulting in lowest percent change (around 50%) over control (87%), respectively. Interaction of genotype and nutrient was significant only in the concentrations after desubmergence, IR 64-Sub1 recorded highest sugar and starch content with the higher doses of N and P. Prior to submergence, all the cultivars performed almost similar photosynthesis as in normal conditions, only small effect of nutrients was evident. After desubmergence, photosynthesis was

Table 3. Effect of fertilizer application on sugar and starch concentration of IR-64, IR-64 Sub1, Swarna and Swarna Sub1 measured before submergence, 10 days after desubmergence and % change in sugar and starch after desubmergence over before submergence in experiment 1.

	Sugar content (mg g^{-1} DW)			Starch content (mg g^{-1} DW)		
	BS	AS	%change	BS	AS	% change
Variety (V)						
IR 64	32.8	19.6	69.3	36.9	20.3	82.3
IR 64-Sub1	33.1	21.1	58.6	37.2	24.7	51.3
Swarna	32.0	17.6	83.4	35.9	19.3	86.7
Swarna-Sub1	32.3	21.9	48.8	36.1	24.1	51.1
$LSD_{P=0.05}$	ns	0.91	10.82	ns	0.86	6.51
Fertilizer application (NPK, kg ha^{-1})						
Control	31.0	16.7	87.6	35.1	19.0	87.0
0-40-40	32.1	18.8	71.9	36.0	21.3	71.3
0-60-40	32.5	19.7	66.3	36.1	21.7	68.1
80-40-40	32.8	20.3	63.2	36.8	22.4	66.4
100-40-40	33.1	20.9	60.1	37.0	22.7	64.5
80-60-40	33.0	21.4	55.4	37.1	23.5	60.3
100-60-40	33.6	22.6	50.5	37.5	24.1	57.4
$LSD_{P = 0.05}$	ns	1.21	14.32	ns	1.13	8.61
$LSD_{P = 0.05}$ (VxF)	ns	1.70	ns	ns	1.61	12.17

BS: Before submergence; AS: After desubmergence.

reduced in all the cultivars and effects were more detrimental in Swarna (18.1 µmol $CO_2 m^{-2} s^{-1}$) and IR 64 (16.9 µmol $CO_2 m^{-2} s^{-1}$). Phosphorus defied the decrement in photosynthetic (Pn) rate and post-flood N led to plodding augmentation in Pn rate and stomatal conductance during the recovery period (Figure 3). Application of 100-60-40 kg NPK ha^{-1} resulted in highest photosynthesis after desubmergence, which was around 118.4, 110.3, 108.2 and 95.3% higher in IR 64, Swarna, IR 64-Sub1 and Swarna-Sub1 respectively over control.

Growth attributes and yield

Leaf senescence and lodging score was assessed 48 hrs of desubmergence and score was appreciably higher in Swarna and IR 64. Application of P notably helped in occluding the leaf greenness and provides lodging resistance resulting in low score of leaf senescence and lodging in all the cultivars. It is also evident from the score that higher dose of P (60 kg ha^{-1}) resulted in reduced lodging and senescence. Dry matter weight and leaf area was measured during the recovery after 10 days of desubmergence; as evident in survival, dry matter weight (DMW) or biomass accumulation, leaf area and leaf greenness measured in terms of SPAD value was also higher in Sub1 cultivars as compared to non-Sub1. Nitrogen and phosphorus ensured the higher growth characters especially at higher doses i.e. 100-60-40 kg NPK ha^{-1} resulted in 114.9, 69.8 and 58.9% higher DMW, leaf area and SPAD value, respectively over control (Table 4). Tolerant cultivars took around 15 days more and intolerant cultivars took around 25 days to flower (Table 5). Supply of N and P reduced the flowering time from 8 to 21 days over no nutrition. Similar to plant survival, all the yield attributes were better in Sub1 cultivars compared to their recurrent parents (Table 5). Application of 100 and 60 kg ha^{-1} N and P also contributed significantly to the higher number of panicles, grains per panicle and fertility percentage. Swarna-Sub1 produced maximum grain yield as it is having high yield potential followed by IR 64-Sub1 but the difference in their yield was around 13.8% (Figure 4). Swarna-Sub 1 and IR 64-Sub1 recorded 61.5 and 65.2% higher grain yield over Swarna and IR 64, respectively. 100-60-40 kg NPK ha^{-1} produced around 143 and 30.1% greater yield over control and 80-40-40 kg NPK ha^{-1}, respectively.

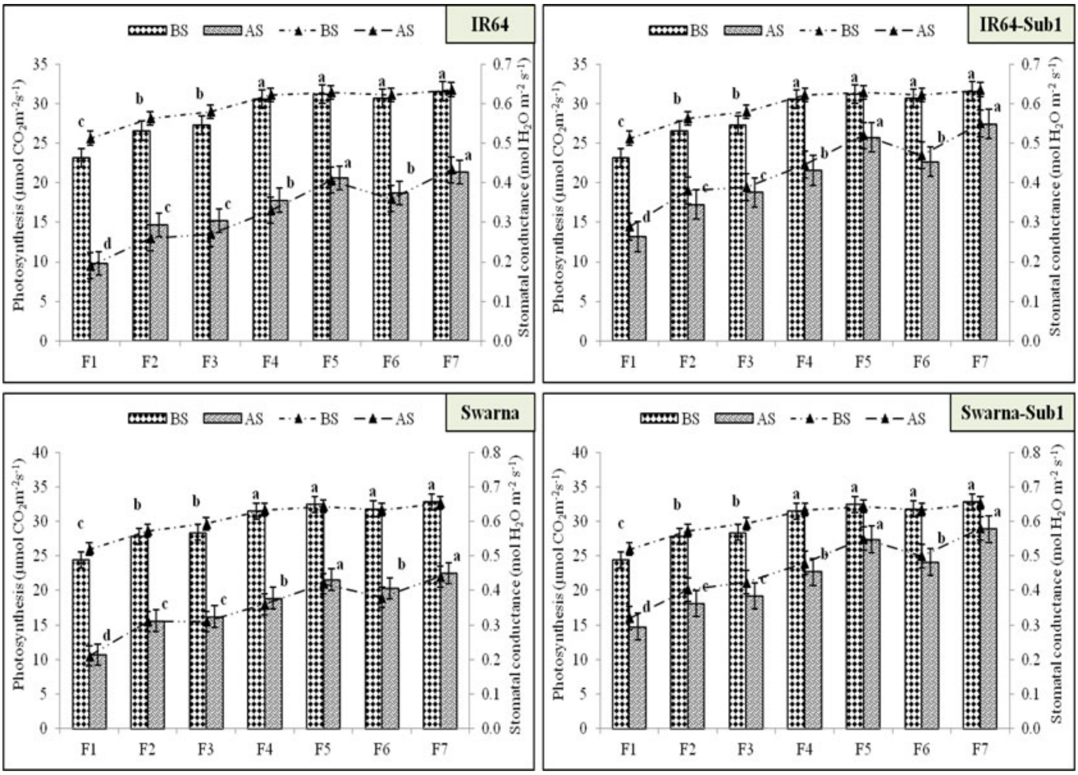

Figure 3. Effect of fertilizer application on photosynthetic rate (Pn rate) and stomatal conductance of IR-64, IR-64 Sub1, Swarna and Swarna Sub1 before submergence (BS) and 10 days of desubmergence (AS) (vertical bars in each column and line represents standard error). Column bars on primary axis represents photosynthetic rate and lines on secondary axis represents stomatal conductance. F1: control (0), F2: 0-40-40, F3: 0-60-40, F4: 80-40-40, F5: 80-60-40, F6: 100-40-40, F7:100-60-40 NPK kg ha^{-1}.

Table 4. Effect of fertilizer application on allometric characters of IR-64, IR-64 Sub1, Swarna and Swarna Sub1 in experiment 1.

	DMW (mg $plant^{-1}$)	Leaf area (cm^2 $plant^{-1}$)	Leaf senescence score	Lodging score	SPAD
Variety (V)					
IR 64	224.3	192.3	4.8	5.3	24.9
IR 64-Sub1	354.8	388.7	1.1	1.4	28.0
Swarna	261.2	256.1	4.6	5.4	25.7
Swarna-Sub1	378.5	476.5	1.2	1.5	30.5
$LSD_{P=0.05}$	26.5	32.6	0.68	0.72	1.54
Fertilizer application (NPK, kg ha^{-1})					
Control	181.4	233.6	4.9	5.8	19.7
0-40-40	241.2	271.2	2.1	2.5	25.2
0-60-40	257.3	290.0	1.9	2.2	26.2
80-40-40	333.4	351.1	3.1	3.5	29.3
100-40-40	377.6	383.0	3.4	3.7	29.8
80-60-40	352.1	372.9	2.3	2.8	29.4
100-60-40	389.9	396.8	2.6	3.1	31.3
$LSD_{P = 0.05}$	31.4	38.5	0.84	0.93	2.04
$LSD_{P = 0.05}$ (VxF)	38.7	42.1	1.02	1.07	2.88

Leaf senescence and lodging score was measured 1 day after desubmergence and dry matter weight (DMW), leaf area and SPAD value was measured after 10 days of desubmergence.

On-farm validation

In the on-farm trial, nutrient management practices reduced the elongation and improved the plant survival of both the cultivars and locations with greater effects in Swarna-Sub1 (Table 6).

Table 5. Effect of fertilizer application on yield attributes of IR-64, IR-64 Sub1, Swarna and Swarna Sub1 measured in experiment 1.

	Days to flowering	No. of Panicles hill^{-1}	Panicle weight	No. of grains panicle^{-1}	Spikelet fertility %age	1000 grain weight (g)
Variety (V)						
IR 64	117.9	6.1	1.49	74.6	59.5	22.5
IR 64-Sub1	108.1	12.7	1.96	123.4	77.4	23.2
Swarna	142.5	7.5	1.68	89.5	61.2	19.1
Swarna-Sub1	132.2	15.8	2.09	131.2	79.8	19.6
$LSD_{P=0.05}$	8.74	1.14	0.11	5.42	3.36	ns
Fertilizer application (NPK, kg ha^{-1})						
Control	137.5	5.9	1.33	65.9	50.4	19.1
0-40-40	129.3	8.7	1.71	89.7	60.5	20.2
0-60-40	128.8	9.1	1.76	92.5	62.0	20.6
80-40-40	123.4	11.2	1.84	112.8	76.1	21.2
100-40-40	119.3	12.9	2.05	126.8	79.8	22.5
80-60-40	121.9	11.6	1.89	115.5	77.4	21.6
100-60-40	116.5	13.8	2.11	128.5	80.5	22.8
$LSD_{P\ =\ 0.05}$	9.13	1.56	0.24	6.32	5.14	ns
$LSD_{P\ =\ 0.05}$ (VxF)	11.45	2.12	0.37	8.16	6.68	ns

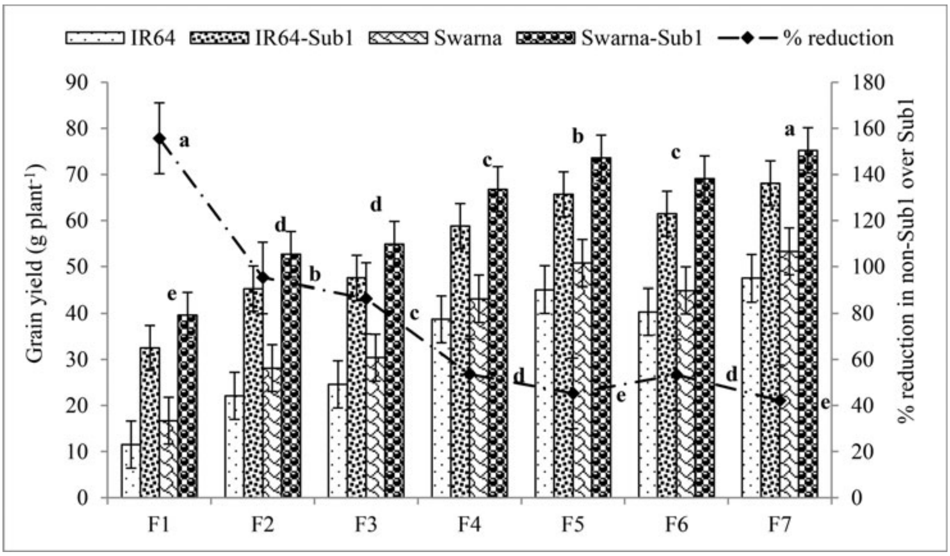

Figure 4. Effect of fertilizer application on grain yield (grain plant^{-1}) of IR-64, IR-64 Sub1, Swarna and Swarna Sub1 and % reduction in yield of non-Sub1 cultivars over Sub1 cultivars (vertical bars in each column and line represents standard error). Column bars on primary axis represents grain yield and lines on secondary axis represents % reduction in yield of non-Sub1 cultivars over Sub1 cultivars. F1: control (0), F2: 0-40-40, F3: 0-60-40, F4: 80-40-40, F5: 80-60-40, F6: 100-40-40, F7:100-60-40 NPK kg ha^{-1}.

Table 6. Shoot elongation and plant survival of Swarna and Swarna-Sub1 influenced by nutrient management practices at farmers' field experiment.

Treatments	Shoot elongation (%)				Plant survival (%)			
	Swarna		Swarna-Sub1		Swarna		Swarna-Sub1	
	F1	F2	F1	F2	F1	F2	F1	F2
Farmers' Field practices	79.2	74.6	48.8	44.6	38.5	39.6	62.8	65.3
Basal P and K + Urea broadcasting	60.4	57.3	31.2	30.5	51.3	52.1	87.2	87.9
Basal P and K + Urea foliar spray	60.2	57.6	30.9	29.7	53.4	54.9	91.1	92.6

F1: Farmer 1; F2: Farmer 2.

Table 7. Yield attributes of Swarna and Swarna-Sub1 influenced by nutrient management practices at farmers' field experiment.

			Effective tillers m^{-2}	Panicles per hill	Filled grains per panicle	Spikelet fertility %age	Panicle length (cm)	Panicle weight (g)	1000-grain weight (g)
F1	**Swarna**	**T1**	215	6.2	61.4	67.2	20.3	1.58	19.1
		T2	299	8.9	69.8	70.6	20.8	1.71	19.2
		T3	317	9.1	72.6	71.5	20.9	1.75	19.2
	Swarna-Sub1	**T1**	288	8.5	119.2	85.5	21.3	2.01	19.4
		T2	389	12.1	126.9	88.1	21.6	2.08	19.5
		T3	407	12.4	128.1	88.2	21.6	2.11	19.5
F2	**Swarna**	**T1**	229	6.5	62.5	69.1	20.5	1.61	19.2
		T2	305	9.1	71.7	72.6	20.9	1.73	19.3
		T3	326	9.6	74.2	73.3	21.1	1.78	19.3
	Swarna-Sub1	**T1**	302	8.8	121.1	86.3	21.5	2.04	19.6
		T2	401	12.5	128.5	89.5	21.7	2.12	19.7
		T3	412	12.9	130.3	89.6	21.8	2.14	19.7

Application of basal P and K + post-flood N improved the survival by 35.5 and 40.1% in Swarna and Swarna-Sub1 over farmers' field practices (FFP), respectively. Number of tillers, panicles, filled grains and panicle weight were higher in Swarna-Sub1 as compared to Swarna (Table 7). Besides that, application of basal P and K + post-flood N resulted in 38.1, 44.0, 10.2 and 6.6% higher number of tillers, panicles, filled grains and panicle weight, respectively as compared to FFP. Similar to yield attributes and plant survival, grain yield was also affected by cultivars grown and nutrient management options (Figure 5). Swarna-Sub1 recorded 50.3 and 51.5% higher grain yield over Swarna at F1 and F2 locations, respectively. Farmers' field practice obtained the lowest grain yield at both the locations, which was 65.7 and 37.9% lower in Swarna and Swarna-Sub1. Both productivity and profitability in terms of annual net return and B: C ratio must be considered for choosing suitable cultivars and their management options. The cost of production was lower when FFP was followed but the net returns and (benefit: cost) B: C ratio were higher when basal P, K and post-flood N management options were adopted because of higher grain yield under the treatment (Table 8). Net returns were around 355 USD higher in basal P, K and post-flood N management over FFP, irrespective of the cultivar and locations. Further, net returns were increased by 4.4% and 2.9% in Swarna and Swarna-Sub1 when urea foliar spray was applied over N supply through urea broadcasting as post-flood.

Discussion

Complete submergence of rice enhanced anaerobic respirations, resulting in increasing consumption of accumulated carbohydrates leading to decreased photosynthesis which reduced plant growth and development (Das, Sarkar, and Ismail 2005). Under submergence reduction in dry weights of leaf and shoot due to their degeneration also reduced the endowment of carbohydrates through simultaneous under-water photosynthesis. In temporal flooding, extensive plant growth is deleterious since it quickens vitality exhaustion and builds mortality and when flood water recedes, large growth in plant height lodged easily and its consequence led to loss in crop productivity and quality (Ella et al. 2003; Jackson and Ram 2003). Reduction in soluble sugars and starch during submergence is presumably crucial metabolic reaction that affects plant survival and post survival growth. The limited high-yielding flood tolerant variety was major factor for enhancing rice yield in flood-prone regions. A major factor for submergence tolerance is suppressed cell elongation and carbohydrate metabolism was got with the inclusion of *Sub1* gene to popular rice varieties (Xu et al. 2006) which may enhance survival without causing substantial

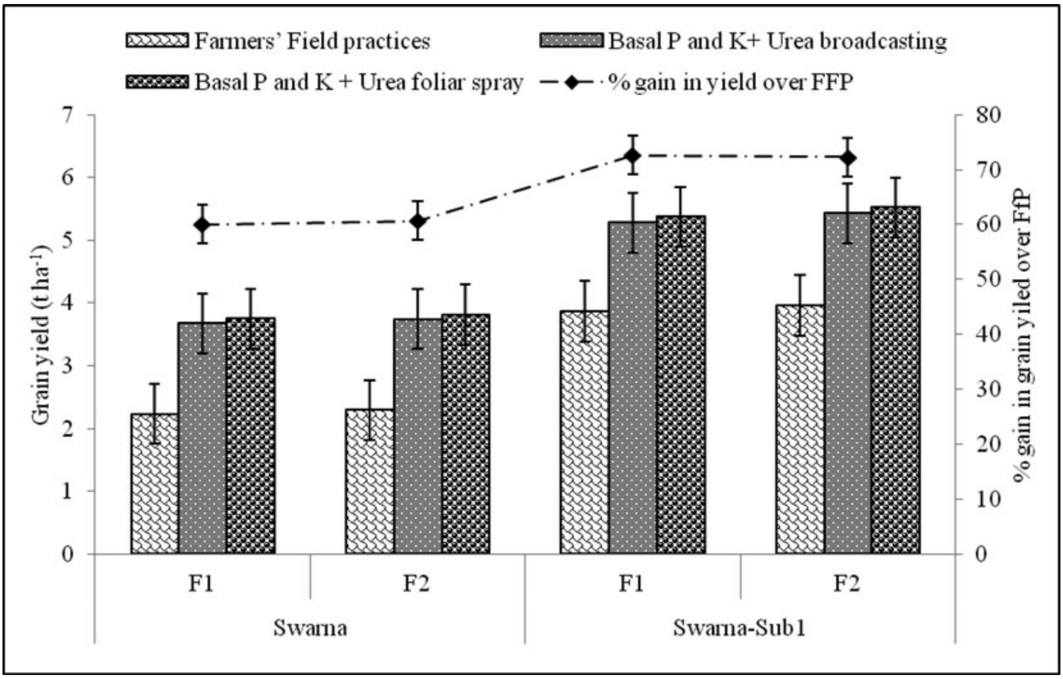

Figure 5. Effect of fertilizer application on grain yield (t ha^{-1}) of Swarna and Swarna Sub1 in on-farm trial conducted at farmers' field (vertical bars in each column and line represents standard error). Column bars on primary axis represents grain yield and lines on secondary axis represents % gain in grain yield over farmers' field practices (FFP).

Table 8. Economics of Swarna and Swarna-Sub1 influenced by nutrient management practices at farmers' field experiment.

			Gross returns (USD ha^{-1})	Net returns (USD ha^{-1})	B:C ratio
F1	**Swarna**	**T1**	599.9	171.2	0.40
		T2	989.9	516.0	1.09
		T3	1008.7	538.9	1.15
	Swarna-Sub1	**T1**	1041.0	612.4	1.43
		T2	1420.3	946.4	2.00
		T3	1444.5	974.7	2.07
F2	**Swarna**	**T1**	616.0	187.4	0.44
		T2	1006.0	532.2	1.12
		T3	1024.9	555.0	1.18
	Swarna-Sub1	**T1**	1065.2	636.6	1.49
		T2	1460.6	986.8	2.08
		T3	1484.8	1015.0	2.16

USD: US dollar; B:C ratio- Benefit: cost ratio.

yield penalty (Singh, Mackill, and Ismail 2009). Under non-submerged control conditions no significant differences in agronomic performance, grain yield and grain quality between Swarna and Swarna-Sub1 were observed indicating complete restoration of the Swarna background in Swarna-Sub1 (Sarkar et al. 2006; Neeraja et al. 2007), but Swarna-Sub1 showed a twofold or higher yield advantage over Swarna after submergence for 10 d or more during the vegetative stage (Septiningsih et al. 2009). Internal aeration or O_2 concentrations were important for survival after submergence but in tolerant cultivars higher survival is also correlated with a better maintenance of carbohydrates in plant after receding flood water (Sauter 2000), as these are essential for delivering energy and forming new cells (Ella and Ismail 2006). Cultivars with the tolerant *Sub1* locus (Xu et al. 2006) enter into a "quiescent" state that preserves carbohydrate reserves and limits anaerobic metabolism (Barding et al. 2012; Fukao, Yeung, and Bailey-Serres 2012) and halting chlorophyll degradation (Colmer et al. 2013). This tolerance strategy limits the energy crisis caused by carbohydrate starvation or reduced mitochondrial ATP generation under flooded condition, that is, low-oxygen conditions. The whole mechanism seems to be regulated uniquely by the *Sub1A* gene, an ERF factor, which is expressed only under submergence, causing reduction in ethylene synthesis and sensitivity, suppressing gibberellic, acid synthesis, and halting elongation (Bailey-Serres et al. 2010). In our study, stress affected shoot elongation, plant survival, leaf growth, dry matter weight and ultimately yield with more efficacious results in sensitive cultivars. Tolerant cultivars having Sub1 gene proved their supremacy in compliance with relatively less elongation, lodging, senescence and greater survival due to chlorophyll and NSC retention. Leaf growth, development and greenness were also higher in Swarna-Sub1 and IR64-Sub1. Several studies showed that initial carbohydrate content is not, on its own, a good indicator for submergence tolerance, though post submergence non-structural carbohydrates (NSC), which is the outcome of both elongation ability and the initial carbohydrate contents, is a better indicator of tolerance (Das, Sarkar, and Ismail 2005). Tolerant varieties were also found to have greater ability to retain their chlorophyll content during and after submergence. This is found in studies where chlorophyll degradation was prevented by blocking the action of ethylene that accumulates during submergence (Ella et al. 2003).

Farmers neither grow the tolerant varieties, nor did they follow any nutrient schedule lead to meager survival of rice after submergence. The traditional varieties they used to cultivate resulted in low crop establishment, patchy growth, and when plant survives did not show healthy growth might be due to poor management especially nutrient. Nutrient management activities are mainly done after the recession of the floods because of the inherent risks of crop loss if submergence is severe. Farmers mostly apply N after the floods for rapid recovery growth of surviving rice plants. Therefore, time of N fertilization during the post-flood period might be a deciding factor for post survival plant growth; it may be more useful when stand establishment is poor due to floods (Ella and Ismail 2006). The on-farm trial was conducted to appraise the fertilizer schedules at farmers' field, because with submergence tolerant varieties following proper nutrient management schedules are also necessary for better crop establishment and higher yield in the areas inclined to submergence. Gautam et al. (2014a) documented that nitrogen application before occurrence of floods led to decrease in plant tolerance level. According to Panda, Reddy, and Sharma (1991) boosted dose of N upto 100 kg N ha^{-1}, in the rice nursery a 20% more yield can be achieved. Phosphorus and nitrogen either alone or together sublimed plant survival in P-deficient soils (Lal et al. 2015). Submergence-induced membrane damage is one of the most serious threats to plant survival and plants need a large amount of energy for repair and maintenance processes under anaerobic stress. Supply of sufficient P might thus have positive impacts on submergence tolerance of rice plants, presumably through the maintenance of a high level of energy. Application of P at sowing enhanced initial seedling vigor and NSC content before submergence. Plant survival after 7–10 d of complete submergence and regeneration growth during recovery were better in P-treated plants of several lowland rice varieties (Gautam et al. 2014a; Lal et al. 2015). However, P application 24 h prior to submergence did not show any beneficial effect on plant survival and recovery growth. Ramakrishnayya et al (1999) reported that addition of P to floodwater during submergence reduced rice plant survival by 35%. The adverse effects of high P concentration in floodwater were mainly attributed to enhanced growth of algae that competed with the submerged plants for CO_2 and light. Application of P should therefore be considered both in the nursery and as basal rather than in floodwater. Bhowmick et al. (2014) accounted that 80-40-40, N- P_2O_5-K_2O kg ha^{-1} in nursery resulted in 93.8% survival and improved crop stand. In on-station trial of our study, graded dose of nutrient application resulted in higher grain yield as compared to control; significantly highest grain yield was recorded with 100-60-40 kg NPK ha^{-1} in the control, grain yield was lowest and therefore % reduction in yield of non-Sub1 cultivars over Sub1 cultivars was highest. However, in On-farm trial basal P, K and post-flood N management enhanced the grain yield of Swarna and Swarna-Sub1 by 65.7 and 37.9% over popular FFPs.

Yamada (1959) and Ella and Ismail (2006) reported that seedling enrichment with N before submergence adversely affected plant survival, later on Gautam et al. (2014a) confirmed that pre-submergence N application enhanced succulence of plants resulted in poor survival. In a study, Gautam et al. (2014c) foliar spray of post-submergence N resulted in higher plant survival, and maintained higher level of chl a & b content and NSC with encouraging effects in plants submerged under turbid water might be due to the fact that urea spray removed the adhering silt from the leaf surface and enable the plants to photosynthesize and survive. Urea foliar spray as post-flood N management was given the more positive results in terms of growth and yield over broadcasting because urea spray resulted in quick absorption of N by plant leaves and also removed the adhering silt from the leaf surface (silt load in flood water deposited to leaves) and enabled the plants to photosynthesize and survive. Rice can quickly take up the extra N supplied after desubmergence which perhaps coordinated with the crop's requirement after stress for gaining growth (Lal et al. 2015; Bhowmick et al. 2014). According to Lal et al. (2018), addition of 20% more phosphorus to the recommended N-P-K improved crop establishment and grain yield by up to 20% suggesting the use of appropriate agro techniques at right time as cost effective investments that could lead to better crop establishment and productivity of rice in flood-affected environment.

Conclusion

It can be adduced from the study that rice production in rainfed lowlands of Eastern India can be augmented by altering the field practices followed by farmers, especially in stress prone regions. Further, reformation of fertilizer application time, method and requirement with tolerant cultivar may be a source of increased productivity and income. The graded dose of both nitrogen and phosphorus helped in tolerating submergence of rice due to better maintenance of carbohydrate content, chlorophyll and reduced chlorosis, senescence, elongation and lodging. These factors were reflected in the higher survival, crop establishment and yield of cultivars. Combining these nutrient management options with submergence tolerant cultivars like Swarna-Sub1 enhanced their productivity and providing more revenues to resource-poor farmers of the area.

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