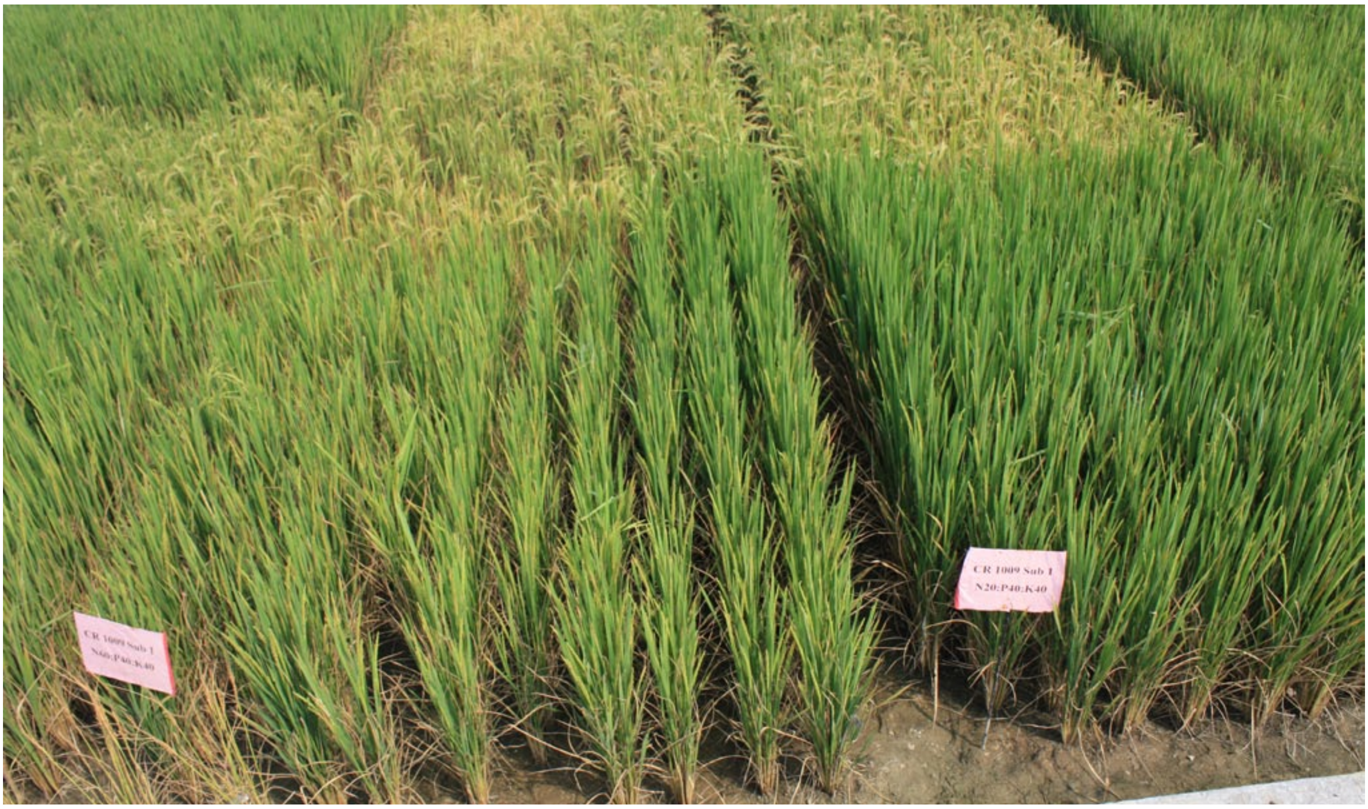
Research Findings



The experimental plot at Narendra Deva University of Agriculture and Technology (NDUAT), Kumarganj, Faizabad, UP, India. Photo by E. Sokolowski.

The Beneficial Effects of Applying Potassium Alone or with Phosphorus During Nursery Management in Enhancing the Survival and Yield of the Rice Variety Swarna-Sub1 in a Flood-Prone Ecosystem

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Abstract

The introduction of submergence-tolerant SUB1 rice varieties has enhanced productivity of average lowland rice yields by over 2 t ha^{-1}. Considering the benefit of these varieties the government of Uttar Pradesh has launched a large-scale seed production program to greatly increase the cultivation of the Swarna-Sub1 variety in the flood-prone, rainfed lowlands of eastern UP. However, relatively little is known concerning nutrient management, especially that of potassium (K), phosphorus (P) and nitrogen (N), to provide the best potential for the growth of SUB1 rice varieties. This question is investigated in nursery applications in a study carried out at the Instructional Farm of Narendra Deva University of Agriculture and Technology,

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Kumarganj, Faizabad, India during the 2010 and 2011 *kharif* seasons. Seven nutrient treatments, representing nursery nutrient management were applied 10 days after seed sowing with various combinations of fertilizers, with N supplied as urea, P as single superphosphate and K as muriate of potash. The 25-day old seedlings obtained were transplanted in an outdoor submergence pond. Fifteen days after transplanting, plants were submerged for a period of 13 days. Survival and recovery were recorded five and 15 days after desubmergence, respectively. Growth observations and nutrient analyses were carried out at different stages of crop growth, i.e. just before transplanting, before submergence, just after desubmergence and at the recovery stage. A significantly higher survival rate after desubmergence was recorded in treatment T_5 when K was applied alone (0-0-40 kg N-P_2O_5-K_2O ha^{-1}) and in T_6, when K was applied together with a higher dose of P in the nursery treatment (0-60-40 kg N-P_2O_5-K_2O ha^{-1}). Maximum underwater shoot elongation (25.4%) was recorded in T_1 (40-40-40 kg N-P_2O_5-K_2O ha^{-1}) when K and P were supplied with N, whereas at recovery, greater plant heights were recorded in T_6 (0-60-40 kg N-P_2O_5-K_2O ha^{-1}) and T_5 (0-0-40 kg N-P_2O_5-K_2O ha^{-1}). Reduction in N, P and K concentrations and their uptakes were recorded after desubmergence. The highest grain yield (t ha^{-1}) was recorded in T_5 (0-0-40 kg N-P_2O_5-K_2O ha^{-1}), which was significantly superior to all other treatments except T_6 (0-60-40 kg N-P_2O_5-K_2O ha^{-1}). A high positive correlation was recorded between K concentration and its uptake at the nursery stage and survival and yield. The present study revealed that K alone or in combination with P during rice nursery management significantly improved crop survival and regeneration after desubmergence to ensure faster recovery and a better crop stand.

Introduction

Flooding affects about 20 million ha in Asia each year and estimates indicate that submergence stress in rice causes corresponding annual losses of US$650 million to US$1 billion (Herdt, 1991; Dey and Upadhyaya, 1996). In India, about 16.1 million ha of rainfed lowland rice are grown each year, of which 4.4 million ha are highly submergence-prone (intermediate rainfed lowlands; Haefele and Hijmans, 2007). In addition, submergence might also occur in shallow rainfed lowlands and irrigated lowlands. Recent research has identified the SUB1 gene as the main gene controlling submergence tolerance in rice. The cloning of the gene underlying tolerance (Xu *et al.*, 2006) has enabled the development of precise marker targeted transfer of this gene into widely accepted "mega varieties" (Neeraja *et al.*, 2007; Septiningsih *et al.*, 2009) through a marker-assisted backcrossing approach. The effects of SUB1 on plant survival under submergence are dramatic, and the gene has no yield penalty under non-submerged conditions. Results of research carried out by the International Rice Research Institute (IRRI) showed that SUB1 varieties gave an average of 1-3.8 t ha^{-1} higher yield than non SUB1 types under 12-17 days of complete submergence (Singh *et al.*, 2009). Similar results were also obtained on farmers' fields in several states in India, namely Uttar Pradesh (UP), Bihar, West Bengal and Orissa. In some cases, SUB1 varieties gave a near normal yield under submergence while intolerant varieties were irretrievably damaged (Mackill *et al.*, 2012). In India, Swarna-Sub1 was released by the states of UP and Orissa in 2012 and this variety has enhanced the productivity of rice by 1-2 t ha^{-1} compared to the average lowland yield.

Considering the benefit of the Swarna-Sub1 variety, the UP government has launched a large-scale seed production program for Swarna-Sub1, increasing its cultivation extensively. However, limited progress has been made in the development of accompanying crop and nutrient management options to harness the potential of the newly developed SUB1 introgressed rice varieties. Recent research has shown that leaf N concentration is negatively correlated with plant survival under flooded conditions, and addition of P seems to enhance tolerance of plants grown on P deficient soils (Ella and Ismail, 2006). Furthermore, unpublished results indicate that low as well as high leaf nitrogen (N) concentrations reduce survival, whereas zinc (Zn) application on Zn deficient soils increases survival. Interestingly Wade *et al.* (1999) reported that slow release N fertilizer was the most beneficial fertilizer in submergence-prone rainfed lowlands. Additionally, balanced nutrition (N-P-K-Zn) with farm yard manure (FYM) together with lower seed density in the seed bed, and the transplanting of older seedlings, also significantly enhanced survival following flooding after transplanting (Bhowmick *et al.*, 2014).

Very little work has been conducted on the effect of potassium (K) nutrition on yield improvement under flood prone situations. However, available information on nutrient management after flooding (recovery) shows that a significant increase in yield can be achieved through application of nutrients, particularly N, because of its effects in stimulating recovery growth and early tillering (Ram *et al.*, 2009). Thus, there are clear indications that crop and nutrient management may have a major impact on the performance of these SUB1 varieties. Given the fact that Swarna-Sub1 has already been released in India and Bangladesh, and its release is pending in several other countries, there is an urgent need to obtain more information on the effects of nursery nutrient management. The purpose of this work was therefore to investigate the influence of nutrient management, especially that of K, in relation to the high potential of Swarna-Sub1 to withstand submergence induced by flooding.

Materials and methods

Site description

The investigation was carried out during the 2010 and 2011 *kharif* seasons at the Instructional Farm, Department of Crop Physiology, Narendra Deva University of Agriculture and Technology (NDUAT), Kumarganj, Faizabad, UP, India. This site lies in the

Gangetic alluvium of eastern UP, situated at latitude 26°47' North and longitude 82°12' East and at an altitude of 113 m above sea level. This is in a semi-arid zone receiving a mean annual rainfall of above 1,100 mm, of which about 80% is precipitated during the monsoon season (July to end of September) with the remainder falling mainly as showers in winter. The pooled nursery physico-chemical soil test results of the experimental site in 2010 and 2011 were as follows: sand 35.20%, silt 48.60%, clay 16.20%, field-capacity 39.60%, bulk density 1.3 g cm^{-2}, pH 7.6, EC 0.2 dS m^{-1}, organic carbon 0.3%, available N 57 ppm, available P_2O_5 7 ppm ($NaHCO_3$ pH 8.5) and available K 218 ppm. Nitrogen, phosphorus (P) and K content were estimated and calculated according to the methods given by Subbiah and Asiza (1956), Jackson (1969), and Olsen *et al.* (1954), respectively.

Experimental layout and crop management

Nursery raising

The experiments were conducted using a randomized complete block design with three replications using Swarna-Sub1. Seeds (at 50 g m^{-2}) were sown in the nursery at NDUAT's instructional farm using the wet method in a 2 x 2 m^2 plot size on 7th June of both years of the experiment. Seven nursery nutrient treatment combination doses of N, P_2O_5 and K_2O were applied after 10 days of seed sowing. These treatments are referred to throughout the text as N-P-K (Table 1).

Nitrogen, P and K were applied as urea, single superphosphate and muriate of potash, respectively. Phosphorus and K were applied in one dose as a basal dressing whereas N was applied in two equally split doses, the first at 10 days after seeding and the second 20 days after seeding.

Main field experiment (in side pond)

The 25-day old seedlings were transplanted into a newly constructed submergence pond covered with plastic sheets (size: 20 x 17 x 1.5 m^3) at NDUAT's Crop Physiology research field and were retained there until the end of experiment. FYM (cow dung) was applied at 6 t ha^{-1} one week before transplanting. 80-40-40 kg N-P_2O_5-K_2O ha^{-1} was applied in the side pond. The P and K was applied as a basal dressing whereas N was applied in three split doses: the first in the form of a top-dressing of 40 kg N ha^{-1} five days after desubmergence, and the second and third top-dressings of 20 kg N ha^{-1} were made at 60 and 90 days after transplanting.

The seedlings were transplanted at 20 x 15 cm spacing using single seedlings per hill in plot size 2.5 x 2 m^2 on 2nd July in both years. Fifteen days after transplanting, the plants were completely submerged for 13 days by filling the pond with turbid stream water. Water was not released into the ponds until noon thus allowing the plants enough time to have accumulated carbohydrates from photosynthesis in the morning. A 70-75 cm water depth was maintained by adding water regularly to the ponds. Survival and recovery respectively, were recorded at days 5 and 15 after desubmergence. Recommended conventional agronomic treatments and protective measures were applied throughout the experiment.

Observations and statistical analysis

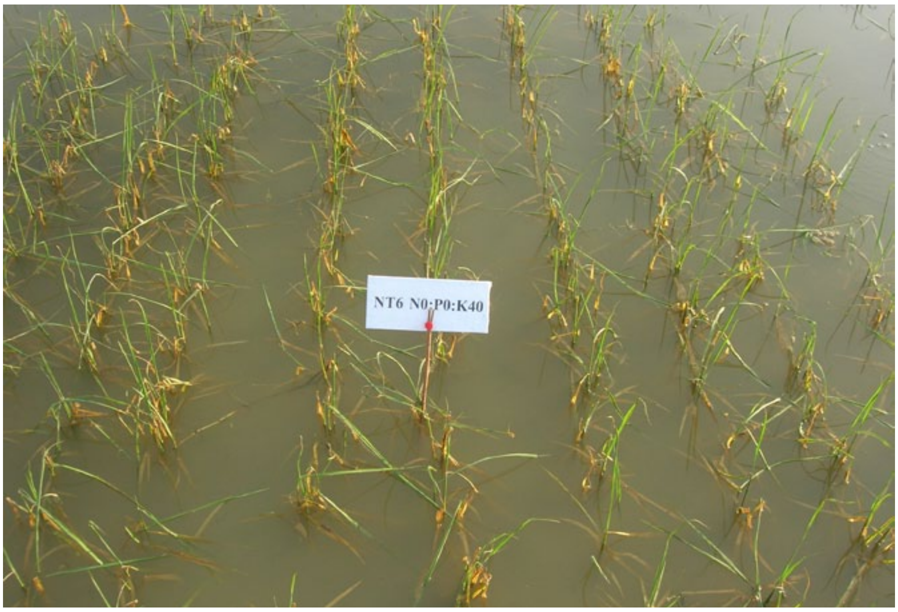
Observations on various growth parameters - plant height (cm), dry shoot biomass (g), plant numbers $plot^{-1}$ and yield (t ha^{-1}) - were recorded. Plant numbers $plot^{-1}$ were counted before, and at recovery, while plant height was recorded before transplanting, before submergence, after desubmergence and at recovery. Dry shoot biomass per plant was determined before transplanting,

Table 1. N-P-K treatments applied at the experiment.

Treatment	N-P-K	N, P_2O_5, K_2O
		------*kg ha^{-1}*------
T_1	N-P-K	40-40-40
T_2	N	40-0-0
T_3	P-K	0-40-40
T_4	P	0-40-0
T_5	K	0-0-40
T_6	P-K	0-60-40
T_7	P	0-60-0

Artificial newly constructed submergence pond covered with plastic sheets for the experimental setup. Photo by E. Sokolowski.

before submergence and after de-submergence, while grain yields were recorded at maturity of all treatments on a per plot basis which was converted into t ha^{-1}. The samples were oven dried at 70˚C to obtain constant weight. All these observations were recorded on 10 initially tagged hills from each plot. Grains were harvested, dried, and weighed. Concentrations of N, P and K in the dried shoot material were determined in plants obtained before transplanting, before submergence and after desubmergence using methods described by Lindner (1944) and Jackson (1973). Nutrient uptakes were calculated as the product of concentration and biomass. Collected data were analyzed statistically following the method of Gomez and Gomez (1984).



Submerged rice seedlings. Photo by E. Sokolowski.

Results and discussion

Survival and growth parameters

A higher percentage of plant survival was recorded with a nursery application of 40 kg K_2O ha^{-1} alone (T_5) or together with 60 kg P_2O_5 ha^{-1} (T_6). Minimum survival was recorded when 40 kg N ha^{-1} (T_2) or 40 kg P_2O_5 ha^{-1} (T_4) were applied (Table 2). The increased mortality in T_2 and T_4 treatments suggests that application of only N or P fertilizers were unable to maintain normal growth and biochemical processes during submergence to support a rapid detoxification of oxygen free radicals which cause damage to plants after desubmergence. We suggest that the beneficial role of K fertilizer alone during nursery application or with a higher dose of P might have resulted for two reasons. The first could be due to the greater capability of these plants to maintain internal gas diffusion or energy levels to sustain normal growth and developmental processes during submergence, and the second might be due to the ability of the this SUB1 gene introgressed variety to enable quick responses of anti-oxidative defense mechanisms after desubmergence. According to Shabala and Pottosin (2014), reactive oxygen species (ROS) production is a major reason for excessive K losses from the shoots of rice plants during submergence. This occurs because unsaturated triglycerides of the membrane lipid bilayer are attacked primarily by ROS leading to destruction of membrane integrity and a leakage of K from the plant. Higher K concentrations in the shoot may thus be an important trait for increasing survival under lowland conditions where flooding is common during the early stage of crop establishment. Moreover, plants supplied with additional K (and P) are better able to avoid K deficiency than those not supplied. Potassium plays a major role in photosynthesis and, when K is deficient, ROS production and their detrimental effect is increased intensely (Cakmak, 2005). In practical terms in the field, avoidance of K deficiency is a major reason for K application.

Table 2. Effect of nursery nutrient management on survival, regeneration and new leaf emergence of Swarna-Sub1 rice variety.

Treatment	N, P_2O_5, K_2O application	Plant no. plot^{-1}			Survival(1)	New leaf emergence (DAD)
		BS	AS	AR		
	kg ha^{-1}	----------------*No.*----------------			*%*	
T_1	40-40-40	134.3	108.7	129.6	80.9	3rd
T_2	40-0-0	135.0	96.3	129.0	71.3	3rd
T_3	0-40-40	132.0	115.0	121.0	87.1	3rd
T_4	0-40-0	122.6	92.0	119.0	75.0	3rd
T_5	0-0-40	128.6	116.7	125.3	90.8	3rd
T_6	0-60-40	127.6	114.7	126.0	89.9	3rd
T_7	0-60-0	125.0	106.3	125.0	85.0	3rd
LSD at 5%		2.98	6.35	6.99	2.83	-

Note: BS: Before submergence; AS: After desubmergence (after 13 days of complete submergence); AR: At recovery (15 days after desubmergence); DAD: Days after desubmergence.

(1)Survival was recorded five days after desubmergence.

15 days after transplanting, plants were completely submerged for 13 days in an outdoor pond under natural conditions.

Nitrogen appears to play a major role in determining plant population, particularly when applied after desubmergence

Table 3. Effect of nursery nutrient management on plant height and elongation rates (%) of Swarna-Sub1.

Treatment	N, P_2O_5, K_2O application	Plant height			
		BT	BS	AS	AR
	kg ha^{-1}	-----------------------------------*cm*-----------------------------------			
T_1	40-40-40	17.67	25.73	32.27 (25.4)$^{(1)}$	46.33 (43.6)$^{(2)}$
T_2	40-0-0	15.93	27.22	32.83 (20.6)	45.77 (39.4)
T_3	0-40-40	14.67	26.97	33.00 (22.4)	43.80 (32.7)
T_4	0-40-0	13.90	28.70	33.83 (17.9)	42.47 (25.5)
T_5	0-0-40	14.07	27.73	33.97 (22.5)	48.83 (43.7)
T_6	0-60-40	16.77	25.80	31.40 (21.7)	47.03 (49.8)
T_7	0-60-0	14.13	28.73	32.80 (14.2)	46.23 (40.9)
LSD at 5%		0.86	0.87	1.14	1.23

$^{(1)}$Figures in parenthesis are percent increase at AS over corresponding values of BS.

$^{(2)}$Figures in parenthesis are percent increase at AR over corresponding values of AS.

Note: BT: Before transplanting; BS: Before submergence; AS: After desubmergence (after 13 days of complete submergence); AR: At recovery (15 days after desubmergence).

15 days after transplanting, plants were completely submerged for 13 days in an outdoor pond under natural conditions.

(Table 2). The maximum plant population of all treatments at recovery - 15 days after desubmergence - was recorded in T_1 (40-40-40 kg N-P-K ha^{-1}) which had also received a supplementary application of 40 kg N ha^{-1} at day five of desubmergence. A somewhat lower population at recovery and survival was obtained for T_2 (40-0-0 kg N-P-K ha^{-1}) (without P and K), which also received the supplementary N application. The minimum plant population of all treatments at recovery was obtained in T_4 (0-40-0 kg N-P-K ha^{-1}), which was deprived of N (and K). This beneficial effect of N is in agreement with the findings of Bhowmick *et al.* (2014) who reported that an additional N dose after seven days of desubmergence improved survival and post submergence recovery and increased grain yields for the same waterlogging resistant rice variety as used in our experiment (Swarna-Sub1). In our experiment, new leaf emergence was observed on the third day after desubmergence in all treatments (Table 2).

The various nutrient combinations applied during nursery management induced significant differences in plant height of the seedlings measured before uprooting for transplanting (Table 3). Heights ranged from 13.9 to 17.7 cm with maximum height recorded in T_1 (17.7 cm) (40-40-40 kg N-P-K ha^{-1}), followed by T_6 (16.8 cm) (0-60-40 kg N-P-K ha^{-1}) with a minimum height being observed in T_4 (13.9 cm) (0-40-0 kg N-P-K ha^{-1}). According to Yoshida (1981), "Plant height is an important plant trait that is controlled by the genetic makeup of the plant as well as the growing conditions, seedling vigour and nutrient status." The greater plant height in T_1 seems likely be associated with the more balanced nursery nutrient supply. Phosphate supplied alone at the lower rate (T_4) resulted in the lowest plant height but when associated with K (and no N) (T_6) it produced a significantly greater plant height (16.8 cm) (Table 3). Before submergence, 15 days after transplanting, maximum plant height was recorded in T_7 (0-60-0 kg N-P_2O_5-K_2O ha^{-1}), which was significantly superior to all treatments except T_4; a minimum height was recorded in T_1. Immediately after desubmergence shoot heights were again measured and shoot percentage elongation during the period of submergence was recorded in all treatments. These ranged from the lowest at 14.2% (T_7) to the highest at 25.4% (T_1). Unlike deep water and other aquatic plants, the importance of slow growth in rainfed lowland rice during submergence has been suggested to be beneficial in that it prevents damage due to lodging once water recedes following a flash flood (Singh, 2001; Jackson and Ram, 2003; Srivastava, 2007). Elongation rates ranged from a maximum of 0.54 cm day^{-1} (T_1) closely followed by 0.52 cm day^{-1} (T_5) to a minimum of 0.34 cm day^{-1} (T_7) (Fig. 1). At recovery, maximum plant height was recorded in T_5 (48.83 cm) followed by T_6

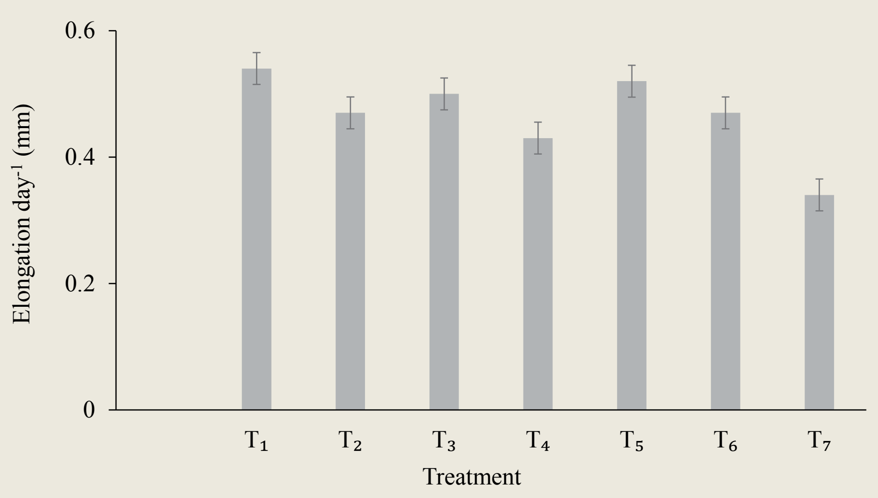


Fig. 1. Effect of different nursery nutrient treatments on underwater shoot elongation day^{-1} (mm) of Swarna-Sub1 during 13 days of complete submergence. Bars represent the corresponding SD values.

Note: T_1: 40-40-40 kg N-P-K ha^{-1}, T_2: 40-0-0 kg N-P-K ha^{-1}, T_3: 0-40-40 kg N-P-K ha^{-1}, T_4: 0-40-0 kg N-P-K ha^{-1}, T_5: 0-0-40 kg N-P-K ha^{-1}, T_6: 0-60-40 kg N-P-K ha^{-1}, T_7: 0-60-0 kg N-P-K ha^{-1}.

15 days after transplanting, plants were completely submerged for 13 days in an outdoor pond under natural conditions.

Table 4. Effect of nursery nutrient management on the dry weight of Swarna-Sub1.

Treatment	N, P_2O_5, K_2O application	Plant dry wt.		
		BT	BS	AS
	kg ha⁻¹	*mg plant⁻¹*		
T_1	40-40-40	0.53	0.60	0.64 (6.67)(1)
T_2	40-0-0	0.51	0.59	0.61 (3.39)
T_3	0-40-40	0.53	0.61	0.63 (3.28)
T_4	0-40-0	0.52	0.59	0.61 (3.39)
T_5	0-0-40	0.53	0.58	0.69 (18.97)
T_6	0-60-40	0.57	0.58	0.69 (18.97)
T_7	0-60-0	0.55	0.56	0.66 (17.86)
LSD at 5%		0.001	0.005	0.003

(1)Figures in parenthesis are percent increase at AS over corresponding values of BS.

Note: BT: Before transplanting; BS: Before submergence; AS: After desubmergence (after 13 days of complete submergence).

15 days after transplanting, plants were completely submerged for 13 days in an outdoor pond under natural conditions.

(47.03 cm) and was lowest in T_4 (42.47 cm). During the 15 day period, from immediately after desubmergence to recovery, maximum increase in height was recorded in T_6 (49.8%) followed by T_5 (43.7%) with a minimum (25.5%) in T_4 (Table 3).

Seedling dry weights (Table 4) varied significantly from 0.51-0.57 mg, at transplanting, the maximum being recorded in T_6 (0.57 mg) and minimum in T_2 (0.51 mg). Singh *et al.* (2005) reported that various features of seedling growth were significantly dependent on nursery nutrient management, which is in agreement with our findings. Before submergence, maximum seedling dry weight was recorded in T_3 (0.61 mg) followed by T_1 (0.60 mg) and minimum in T_7 (0.57 mg) (Table 4). After desubmergence, higher seedling dry weights were recorded for all treatments, with a maximum increase of 18.97% recorded in T_5 (K) and T_6 (P-K) compared with a minimum (3.39%) in T_2 (N) and T_4 (P) (Table 4). Winkel *et al.* (2013) and Winkel *et al.* (2014) reported that rice leaves have gas films that aid O_2 and CO_2 exchange and that underwater photosynthesis can take place supported by high irradiance at depth during submergence, resulting in biomass production after desubmergence. However, much depends on the floodwater characteristics. During submergence a balance may occur between normal metabolic activities consuming reserve food material (RFM) and underwater photosynthesis, compensating for this loss by newly synthesized assimilates. In this respect, genotypes are likely to show differences in photosynthetic activity as confirmed in a recent study by Winkel *et al.* (2014) who compared four contrasting rice genotypes growing submerged for 13 days. Swarna-Sub1 (carrying the SUB1 gene) was shown to decline in photosynthetic activity during submergence and gas film retention was not linked to SUB1.

Nutrient analysis, uptake and yield

Before transplanting and before submergence maximum N concentration was recorded in T_2 (40-0-0 kg N-P-K ha^{-1}), whereas after desubmergence, it was recorded in T_1 (40-40-40 kg N-P-K ha^{-1}), probably as a consequence of N application in both these treatments (Table 5). Maximum P concentrations (before transplanting and before submergence) were recorded in T_6 (0-60-40 kg N-P-K ha^{-1}), whereas after desubmergence these were recorded in T_7 (0-60-0 kg N-P-K ha^{-1}), which had the same P status as T_6 (0-60-40 kg N-P-K ha^{-1}). Maximum K concentration before transplanting was recorded in T_3 (0-40-40 kg N-P-K ha^{-1}) whereas before submergence and after desubmergence maximum K concentrations were recorded in T_5 (0-0-40 kg N-P-K ha^{-1}) and T_6 (0-60-40 kg N-P-K ha^{-1}), respectively.

Table 5. Effect of nursery nutrient management on N, P and K shoot concentrations of Swarna-Sub1 exposed to early stage submergence (5 days).

Treatment	N, P_2O_5, K_2O application	BT			BS			AS		
		N	P	K	N	P	K	N	P	K
	kg ha⁻¹	%								
T_1	40-40-40	4.02	0.77	1.66	3.83	0.94	2.29	3.83	0.08	1.68
T_2	40-0-0	4.20	0.66	1.63	3.93	0.44	2.08	3.84	0.09	1.14
T_3	0-40-40	3.02	0.75	1.86	3.81	0.98	2.26	3.42	0.14	1.62
T_4	0-40-0	3.21	0.78	1.64	3.24	0.96	2.12	3.14	0.13	1.22
T_5	0-0-40	3.30	0.74	1.84	3.42	0.45	2.38	3.23	0.10	1.47
T_6	0-60-40	3.43	1.05	1.83	3.71	1.25	2.36	3.49	0.16	1.70
T_7	0-60-0	3.35	1.04	1.66	3.53	1.02	2.28	3.41	0.17	1.46
LSD at 5%		0.11	0.03	0.05	0.07	0.01	0.06	0.08	0.01	0.12

Note: BT: Before transplanting; BS: Before submergence; AS: After desubmergence (after 13 days of complete submergence).

15 days after transplanting, plants were completely submerged for 13 days in an outdoor pond under natural conditions.

Ella and Ismail (2006) reported that a high N concentration of rice leaves was not beneficial when rice was subjected to flash flooding at an early stage and also that application of N alone was prejudicial to survival. Reserves of shoot carbohydrates were very quickly exhausted and severe post-oxidative damage occurred. However, N accompanied by P and K substantially improved survival of the SUB1 introgressed cultivar Swarna-Sub1. In this regard, Singh (2011) has reported

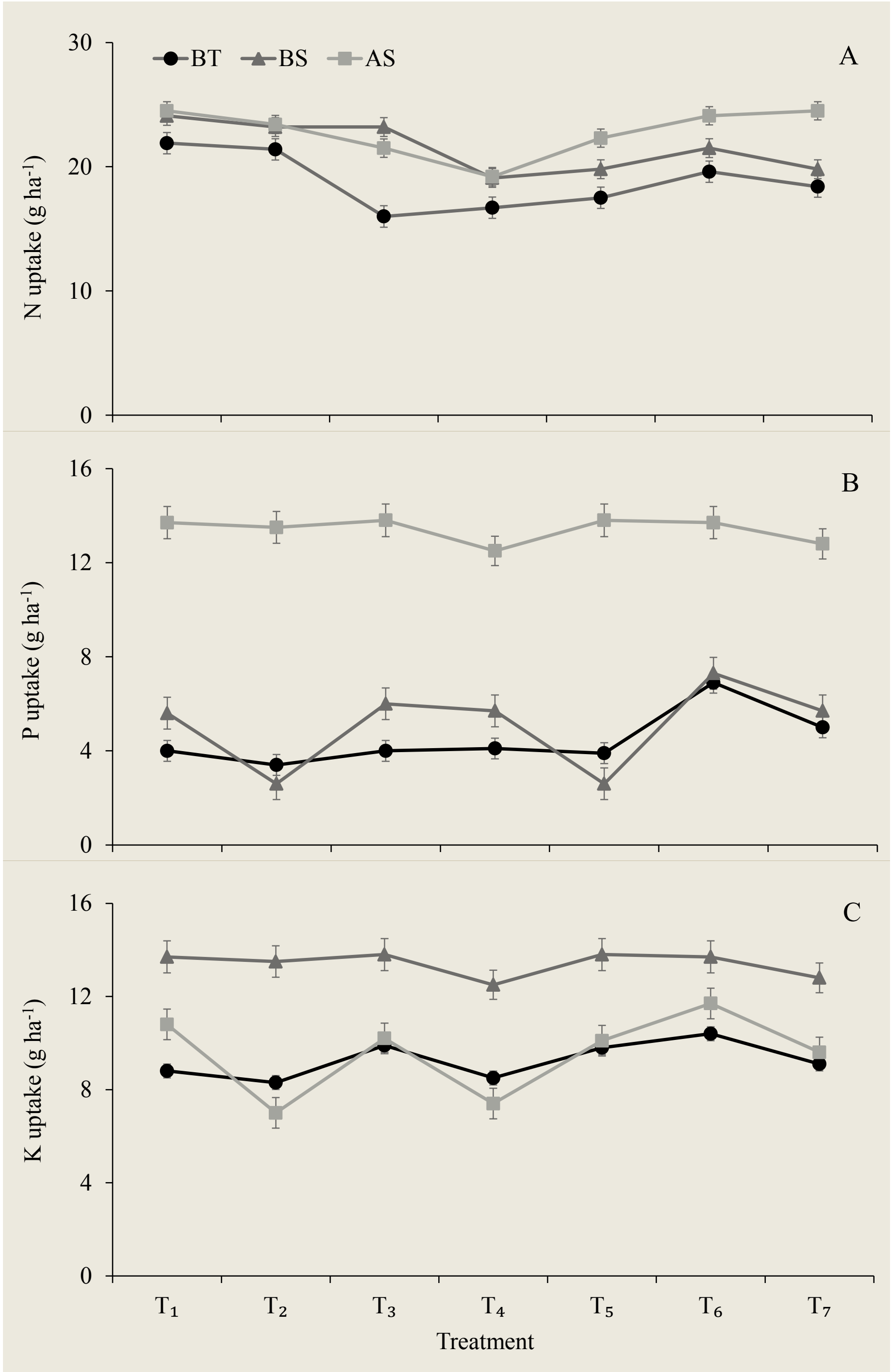


Fig. 2. Effect of different nursery nutrient treatments on nutrient uptake; A) N uptake (g ha^{-1}), B) P uptake (g ha^{-1}), C) K uptake (g ha^{-1}). Bars represent the corresponding SD values.

Note: BT: Before transplanting; BS: Before submergence; AS: After desubmergence (after 13 days of complete submergence).

T_1: 40-40-40 kg N-P-K ha^{-1}, T_2: 40-0-0 kg N-P-K ha^{-1}, T_3: 0-40-40 kg N-P-K ha^{-1}, T_4: 0-40-0 kg N-P-K ha^{-1}, T_5: 0-0-40 kg N-P-K ha^{-1}, T_6: 0-60-40 kg N-P-K ha^{-1}, T_7: 0-60-0 kg N-P-K ha^{-1}.

15 days after transplanting, plants were completely submerged for 13 days in an outdoor pond under natural conditions.

that higher regeneration of plants after desubmergence in treatments (applied with doses of N, P and K during nursery management) was associated with the first dose of N applied in the field (five days after desubmergence) rather than the N applied in the nursery, with P and K.

Nitrogen, P, and K uptakes (g ha^{-1}) before transplanting, before submergence and after desubmergence are shown in Fig. 2 (A-C). The pattern of N uptake was similar in all stages, showing higher uptake in treatments supplied with higher N (T_1 and T_2). After desubmergence, a sharp decrease in N uptake was noticed in T_4 (0-40-0 kg N-P-K ha^{-1}), probably due to an interaction between P and N uptake during submergence (Fig. 2A). A higher uptake of P before transplanting was recorded in T_6 and T_7 treatments due to higher P doses (40 and 60 kg ha^{-1}), however T_7 recorded lower P uptake than T_6. Lower P uptake was recorded in T_2 and T_5 (solely applied N and K fertilizers respectively) than the rest of the treatments before submergence. After desubmergence, higher P uptake was recorded in all treatments presumably due to increased availability of P in the submerged soil (Singh, 2011) (Fig. 2B). Higher uptake of K before transplanting was recorded in treatments supplied with K doses. Interestingly, the higher dose of P along with K (T_6; 0-60-40 kg N-P-K ha^{-1}) produced a significantly higher K uptake than a lower dose of P (T_3; 0-40-40 kg N-P-K ha^{-1}). Higher K uptake before submergence was recorded in all treatments compared to their respective values before transplanting. After desubmergence a drastic reductive K uptake pattern was recorded in all treatments (Fig. 2C) with higher reduction in treatments with N and P alone (T_2, T_4 and T_7).

Maximum grain yield (t ha^{-1}) was recorded in T_5 (0-0-40 kg N-P-K ha^{-1}), which was significantly superior to all other treatments except T_6 (0-60-40 kg N-P-K ha^{-1}). Higher P

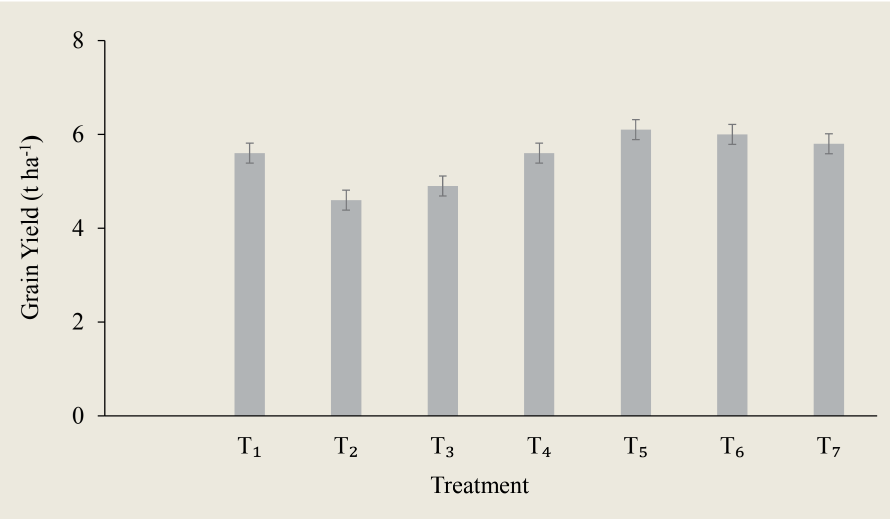


Fig. 3. Effect of different nursery nutrient treatments on grain yield of Swarna-Sub1 (grain was harvested 93-97 days after desubmergence). Bars represent the corresponding SD values.

Note: T_1: 40-40-40 kg N-P-K ha^{-1}, T_2: 40-0-0 kg N-P-K ha^{-1}, T_3: 0-40-40 kg N-P-K ha^{-1}, T_4: 0-40-0 kg N-P-K ha^{-1}, T_5: 0-0-40 kg N-P-K ha^{-1}, T_6: 0-60-40 kg N-P-K ha^{-1}, T_7: 0-60-0 kg N-P-K ha^{-1}.

15 days after transplanting, plants were completely submerged for 13 days in an outdoor pond under natural conditions.

doses alone, or together with K, (T_7; 0-60-0 kg N-P-K ha^{-1} and T_6; 0-60-40 kg N-P-K ha^{-1}) produced higher yields than lower doses of P (T_4; 0-40-0 kg N-P-K ha^{-1} and T_3; 0-40-40 kg N-P-K ha^{-1}). Difference in yield due only to a higher P dose, however, was not significant whereas yield differences resulting from different K doses were significant (Fig. 3). Lowest grain yield was recorded in T_2 (40-0-0 kg N-P-K ha^{-1}). These findings clearly indicate that nursery application of N fertilizer alone produced a detrimental effect after desubmergence, by decreasing the survival and/or initial crop stand (Table 2). This was associated with a slower recovery and growth, which might have influenced the yield attributing traits (data not shown), ultimately affecting yield. The influence of K supply during seeding growth before transplanting was shown to have a major positive impact on subsequent plant development. The K concentration of the seedlings and K uptake showed correlation coefficients with survival (0.95 and 0.92 respectively) and with grain yield (0.60 and 0.45 respectively). By contrast, the N concentration of the seedlings and N uptake were negatively correlated with survival (-0.58 and -0.36 respectively).

Conclusions

The results of the experiment indicated that 40 kg K_2O ha^{-1} alone or supplied together with 60 kg ha^{-1} P_2O_5 fertilizer produced significantly higher survival rates, and thereafter helped in rapid regeneration, which was reflected in the form of higher yield. Proper nursery nutrient management using K can contribute considerably to maximizing submergence tolerance and grain yield of the rice crop in the field. A slightly higher dose of P, along with the normal K dose, also produced a higher yield than the normal P dose used in nursery management. These results, however, need further validation on farmers' fields applying lower N doses with K and P.

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The paper "The Beneficial Effects of Applying Potassium Alone or with Phosphorus During Nursery Management in Enhancing the Survival and Yield of the Rice Variety Swarna-Sub1 in a Flood-Prone Ecosystem" also appears on the IPI website at:

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