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Role of silica and nitrogen interaction in submergence tolerance of rice

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ABSTRACT

Submergence is an intensifying problem in major rice producing areas, when intolerant cultivars are submerged, they show a number of morpho-physiological changes such as elongation and chlorosis which is markedly developed after desubmergence probably due to oxidative damage. We studied the effects of submergence on survival, photosynthesis, nonstructural carbohydrate content, enzymatic activities, growth and yield of Sub1 and non-Sub1 cultivars. The interaction effect of nitrogen (N) and silica (Si) application was also examined for the submergence tolerance in rice. The photosynthetic rate, survival, growth of all the cultivars decreased during submergence but to a greater extent in IR64 and Swarna. After desubmergence, both the type of cultivars experienced oxidative damage, however, the oxidation of lipids was maintain at lower levels in Sub1 cultivars and anti-oxidants activities was increased more than intolerant cultivars. Application of basal Si was beneficial whereas, pre- and post-submergence Si spray was detrimental in relation to submergence tolerance. Basal Si resulted in significantly reduced elongation, lodging, leaf senescence, and chlorosis; when combined with post-flood N application either as broadcasting or spray, it led to significantly highest survival, photosynthesis, anti-oxidant activity and ultimately yields. Interaction of basal Si and post-flood N spray was the most promising method of nutrient application which not only resisted the damage during submergence but also enhanced the survival, growth after recovery in terms of number of green leaves emergence, leaf area and photosynthetic rate leading to significantly higher yield. The findings of the investigation propounds that a simple alteration in the time and method of nutrient application can significantly contribute to higher survival, crop establishment and yield in flash-flood prone areas.

1. Introduction

Crop yield reduction as an outcome of increasingly severe climatic events threatens world food security. Crop losses due to extremes in the environment have risen progressively over the past several decades (Bailey-Serres et al., 2012), and climate models predict an increased phenomenon of floods and droughts. Complete submergence or flash flood is a common phenomenon mainly in lowland areas, subject to monsoon rains, seriously affecting survival as well as crop establishment, leading to severe yield losses. Rice, by nature, is tolerant to waterlogging, flash flood and associated anoxia which makes its cultivation possible under flood prone lowland ecosystem. More than 16% of lowland rice is adversely affected by excess water stress globally, causing either flash flood with complete submergence for a relatively short duration, ranging from a few days to 2 weeks. More than 22 million ha of rainfed lowlands in Asia are affected by flash floods (Khush, 1984; Bailey-Serres et al., 2010) including 5 million ha of deepwater rice (Khush, 1984) and these floods are highly unpredictable.

Submergence obliges a complex abiotic stress in flood-prone areas of rice, because it substantially reduces crop stand, especially if it occurs during initial crop growth stages and lasts for more than a week. A number of environmental and plant factors are associated with damage due to flooding namely low light, siltation on the leaves, mechanical damage, solute leakage, limitation to gas diffusion, accumulation of toxic metabolites inside the plant resulting in yield losses from 10–100% (Setter et al., 1997). Additional adverse effects may be associated with desubmergence and post hypoxic injury. During floods, plants endure environmental perturbations such as hampered outward diffusion of plant

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released ethylene (Voesenek and Sasidharan, 2013), electrochemical soil changes resulting in higher concentrations of toxic elements including manganese, iron and sulfides (Bailey-Serres and Voesenek, 2008). As a result, cells and tissues of plants are exposed to marked internal variations in oxygen and carbon dioxide, and rise in ethylene as well as reactive oxygen species (ROS). ROS are produced at the onset of flooding-induced O_2 deficiency as a consequence of the inhibition of mitochondrial electron transport and production of superoxide that is converted to hydrogen peroxide by dismutation (Santosa et al., 2007).

In areas, where flash floods cause momentary inundation during the seedling and crop establishment stage, rice varieties tolerant to flooding are needed that can survive submergence with least elongation. Varieties having Sub1 gene can survive during complete submergence for around 15 days because they resists elongation during submergence, conserving energy for survival and quick recovery after de-submergence. These cultivars also experience slower sugar and starch depletion and higher levels of alcoholic fermentation as a way of providing energy for maintenance processes in the absence of adequate oxygen underwater (Sarkar et al., 2006). Along with varietal improvement, agronomic management practices like nutrient management will also be helpful for plants adapted to these areas.

Nitrogen (N) is the important and primary element in determining rice grain yield, and N fertilizer is one of the key inputs to paddy fields, with favorable effect in stimulating tillering and increasing spikelet number per panicle (Qiao et al., 2011). Semi-dwarf rice cultivars having submergence tolerance developed in the recent years have been found to respond to nitrogen fertilization and withstand flooding stress better (Reddy et al., 1986). Basal fertilization of nitrogen (Reddy et al., 1985) and nitrogen and phosphorus (Gautam et al., 2014a) provides initial vigor to rice plants for higher tolerance to submergence at later crop growth stages. Post-submergence nutrient application can also contribute considerably towards increasing production in flood-prone areas (Gautam et al., 2014b).

Silicon (Si) is the most abundant element in the earth's crust only after oxygen, and in agronomy, Si is generally not considered an essential element. The effect of Si has been traditionally accredited to its role in decelerating abiotic and biotic stresses, as well as in imparting resistance to lodging and enhancing the erectness of leaves; these effects allow higher light transmittance in and above plant canopies and thus obliquely improve photosynthesis (Tamai and Ma, 2008). Application of nitrogenous fertilizers is a significant exercise for increasing rice production. However, when N is applied in excess, it may limit yield because of higher lodging, promote shading and susceptibility to insects and diseases. These effects can be curtailed by the use of silica (Ma et al., 1989; Munir et al., 2003), as Si plays a critical role in preventing the lodging in the cereal crops (Munir et al., 2003) especially rice, it provide culm sturdiness and increases leaf erectness. Due to a synergistic effect, the application of Si has the potential to raise the optimum N rate, resulting in enhancing productivity of lowland rice fields (Ho et al., 1980) of Eastern India. In a study, Lal et al. (2015a) studied the combined effects of Si, P and N in rice nursery but the interaction of Si and N in respect to their application time and methods is unknown to the rice crop when flooding occurs in the main field. Keeping the above facts in mind the experiment is designed to study the interaction effect of N and Si, with respect to their application time and method. The study is conducted with submergence tolerant rice varieties for harnessing the productivity potentials and minimizing flood damages in rice production through interaction of N × Si.

2. Materials and methods

2.1. Experimental setup

In order to accomplish the aforesaid objectives, an experiment was conducted at National Rice Research Institute, Cuttack (20° 45′N, 85° 93′E; elevation 24 m above mean sea level) during 2014–15. 15 days old seedlings of uniform appearance of IR64, Swarna, IR64-Sub1 and Swarna-Sub1 were selected and transplanted to plastic pots containing 10 kg of alluvial soil (Sandy clay loam, pH 6.7, EC-0.073 dS/m, available N, P and K—56.8, 4.7 and 64.2 mg/kg of soil, respectively) with 2 seedlings per pot. 0.89 g urea, 1.24 g SSP, 0.37 g MoP and 120 gm of Si were applied to each pot as per the treatments (application time of N and Si is given in Table 1). Nitrogen was applied as basal and post-submergence urea foliar spray, Si as basal (Na_2SiO_3) and pre/post submergence spray (H_4SiO_4) whereas; P and K were applied as basal at the time of transplanting. Leaves of rice seedlings were sprayed after 48 h of desubmergence on their adaxial surface with 2.0% (w/v) urea or Si solution through a back-pack sprayer in a water carrier until they were completely wetted. The turbidity was created by mixing silt into the tank water at a concentration of 0.4%, as in the survey silt concentration of Mahanadi river was found 0.4% (Das et al., 2009). The silt particles remained suspended in the water; to prevent the settling of silt particles in flood water, the water was stirred manually twice a day for 10 min. Plants were completely submerged at maximum tillering stage for 14 days in concrete tanks (plants were approximately 30 cm below the water surface) under following conditions: (i) water temperatures of 27.2–30.8 °C; (ii) dissolved oxygen (DO) of 2.5–5.39 mg l^{-1}; (iii) pH

Table 1
Details of nutrient application followed in the experiment.

Nutrient	Treatment symbols	Method of nutrient application				
		N			Si	P and K
		1st split	2nd split	3rd split		
Nitrogen	N_B	Urea broadcasting	Urea broadcasting after desubmergence	Urea broadcasting	–	Basal
	N_S	Urea broadcasting	Urea spray after desubmergence	Urea broadcasting	–	Basal
Silica	Si_B	–	–	–	Basal; broadcasting	Basal
	Si_S	–	–	–	Pre and post submergence spray	Basal
Nitrogen × Silica	$N_B \times Si_B$	Urea broadcasting	Urea broadcasting after desubmergence	Urea broadcasting	Basal; broadcasting	Basal
	$N_S \times Si_S$	Urea broadcasting	Urea spray after desubmergence	Urea broadcasting	Pre and post submergence spray	Basal
	$N_B \times Si_S$	Urea broadcasting	Urea broadcasting after desubmergence	Urea broadcasting	Pre and post submergence spray	Basal
	$N_S \times Si_B$	Urea broadcasting	Urea spray after desubmergence	Urea broadcasting	Basal; broadcasting	Basal