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Influence of boron nutrition on the rice productivity, kernel quality and biofortification in different production systems

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ABSTRACT

Boron (B) deficiency is becoming a common problem in water-saving rice production systems of South Asia. Boron nutrition can potentially improve the crop performance. This two-year field study was conducted to evaluate the potential of pre-optimized B application through various methods in improving the performance of rice grown in aerobic culture, alternate wetting and drying and flooded systems. Boron was delivered as seed priming (0.1 mM B), foliar spray (200 mM B), and soil application (1 kg B ha^{-1}); no B application and hydropriming were taken as control. Boron nutrition by either method improved the plant water relations, total chlorophyll contents, morphological and yield related traits in different rice production systems. In addition to improvement in kernel yield, boron application also improved the kernel quality. Foliar application of boron in flooded rice and alternate wetting and drying gave maximum net returns than all other treatment combinations. In crux, B application through foliar spary or seed priming may be an economically viable option to reduce panicle sterility, improve kernel quality, rice growth and yield. Improvement in rice yield by B application is attributed to increase in kernel size and decrease in panicle sterility.

1. Introduction

Rice is an important cereal crop being consumed as staple food by millions across the globe. Conventionally, rice nursery seedlings are transplanted in the paddy fields, which need more water and labor inputs. On the eve of decreasing water resources and increasing labor cost, water and labor-saving rice production systems may replace the conventional production system. Several water-saving rice production systems, such as alternate wetting and drying (AWD), and aerobic rice are being propagated worldwide (Castañeda et al., 2002), however certain factors like weed and pest pressure, panicle sterility and lodging are hindering the wide scale adoption and potential benefits of these systems (Farooq et al., 2011). Among these factors, panicle sterility is of vital importance (Ikehashi and Araki, 1986; Maheswari et al., 2007), which reduces the grains per panicle (Nieuwenhuis et al., 2002) leading towards less rice yields (Gowri, 2005). Any moisture deficit during flowering and grain filling increases the panicle sterility (Ekanayake et al., 1989; Bouman and Tuong, 2001; Mazid et al., 2002), which severely affects the rice yields.

Like other nutrients, boron (B) is an essential nutrient for plant growth and development. In plants, B takes part in nucleic acid, carbohydrate, protein, phenol and indole acetic acid metabolisms, cell wall synthesis, membrane integrity and function (Goldbach et al., 2001). Boron is also considered to be associated with one or more of the processes of calcium utilization, cell division, flowering/fruiting, carbohydrate and nitrogen metabolism, disease resistance, water relations, and catalyst for certain reactions (Sprague, 1951). However, B deficiency is spreading in most of rice growing soils. Although considered tolerant, rice suffers with B deficiency resulting in substantial yield loss (Cakmak and Römheld, 1997; Rashid et al., 2004, 2009). Several factors including drought,

Abbreviations: AWD, alternate wetting and drying; B, boron; Chl, chlorophyll; cm, centimeter; dS m^{-1}, desi siemen per meter; E, East; FAO, Food and Agriculture Organization; FW, fresh weight; h, hour; kg m^{-3}, kilogram per cubic meter; LSD, least significant difference; m, meter; m^3, cubic meter; masl, meter above see level; mM, milli molar; N, north; nm, nanometer; ppm, parts per million; RWC, relative water contents; USA, United State of America; USDA, United State Department of Agriculture; W_d, dry weight; W_f, fresh weight; W_s, saturated weight; WUE, water use efficiency; Zn, zinc.

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Table 1
Weather data at the experimental station during course of experimentation.

Months	Rainfall (mm)		Relative humidity (%)		Temperature (°C)						Sunshine (h)	
					Daily maximum		Daily minimum		Daily mean			
	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
June	1.0	78.3	40.0	55	40.1	38.6	27.7	26.0	33.9	32.3	9.4	9.4
July	277.8	118.1	63.6	70.3	36.0	34.7	27.9	26.0	31.9	30.4	9.0	9.0
August	22.6	92.6	74.6	74.7	34.9	34.1	26.1	25.5	30.5	29.8	6.0	5.4
September	86.5	155.1	66.8	75.8	33.9	32.9	23.3	23.6	28.6	28.3	7.9	6.9
October	0.0	0.4	59.6	61.0	32.9	32.2	19.7	17.2	26.3	17.2	7.6	7.6
November	0.0	0.0	62.3	61.2	27.1	27.6	10.5	13.3	18.8	20.4	8.5	8.5

Source: Agro-meteorology Cell, Department of Crop Physiology, University of Agriculture, Faisalabad, Pakistan

low soil pH, calcareous nature of soil, and B leaching and fixation have been considered as the possible reasons of B deficiency (Goldberg, 1997; Shorrocks, 1997; Rashid et al., 2009). Boron application to rice fields increased rice growth and grain yields in soils low in B (Rashid et al., 2004, 2009; Dunn et al., 2005; Hussain et al., 2012); however, some problems with uptake of B in conditions of low moisture in soil and/or application of B only upon evident B deficiency symptoms have been found (Rashid et al., 2004; Dunn et al., 2005).

Boron availability is often associated with soil moisture conditions and limited soil water often limits B availability because its release from organic complexes is restricted and ability of plants to extract it from the soil is impaired (Tisdale et al., 1985). Rashid et al. (2002) reported that B deficiency not only causes severe reduction in paddy yield, but also deteriorates its kernel quality (Rashid et al., 2004). Thus B application may substantially increase the paddy yield (Rashid et al., 2002).

Boron deficiency has been identified as one of the most important factors causing sterility in cereals because of poor development of anthers and pollen and failure of pollen germination (Cheng and Rerkasem, 1993), especially in low moisture conditions. Improved pollen vitality of rice with application of B has been known since long (Garg et al., 1979).

For efficient uptake of B by the plant, application method plays a vital role. Among different practices, soil application is the most prevalent method of B addition in the developed world. However, seed priming can be used as an attractive and easy physiological strategy (Farooq et al., 2007, 2012), for applying micronutrients. For instance in oats (*Avena sativa* L.), seed priming with B had no marked effect on seed germination, but tillering was increased substantially (Saric and Saciragic, 1969). Moreover, nutrient application through foliar sprays helps to cope with deficiency rapidly. In a study, Mohsen and Magda (2004) found that application of zinc (Zn) through foliar application in wheat increased the yield significantly.

As B is important for humans as well, grain biofortification is a pragmatic and easy option to enhance the level of micronutrients in grains. Biofortification may be achieved through conventional breeding (genetic biofortification), transgenic approaches and agronomic means (Cakmak, 2008). Agronomic biofortification is safe, cost-effective and short term approach of grain nutrient enrichment (Mayer et al., 2008). Agronomic biofortification includes micronutrient delivery as soil, foliar fertilizers and micronutrient enriched NPK fertilizers (Cakmak, 2008) and seed priming.

Previously, we found that pre-optimized B application in rice through seed priming, seed coating, foliar and soil application in lab and pot experiments significantly improved germination, early seedling growth, tillering, leaf expansion, water relations, chlorophyll contents and kernel yield in different rice cultivars (Farooq et al., 2011; Rehman et al., 2011; Rehman and Farooq, 2012). However, these B application strategies were not evaluated under field conditions. So this study was conducted to investigate the influence of B nutrition on the rice productivity, kernel quality and biofortification in different production systems.

2. Materials and methods

This two-year study was conducted at Agronomic Research Area, University of Agriculture, Faisalabad (31.25°N, 73.06°E and 183 masl), Pakistan during kharif season of 2010 and 2011. The experiment was laid out in randomized complete block design in split-plot arrangement randomizing rice production systems in main plots and B application methods in sub plots with net plot size of 8 m × 2.2 m. Before sowing of nursery and direct seeding of aerobic rice, soil samples with the help of auger were collected from 0 to 30 cm depth at different locations of the experimental site. Composite samples were air dried, grinded and passed through 2 mm sieve to remove clods and material other than soil. Soil was sandy loam having pH (8.2, 8.2), electrical conductivity (0.35, 0.36 dS m^{-1}), organic matter (0.92, 0.99%), total nitrogen (0.06, 0.04%), available phosphorous (4.88, 4.80 ppm), exchangeable potassium (167, 177 ppm), zinc (0.80, 0.78 ppm) and boron (0.56, 0.48 ppm) during both years, respectively. The experimental soil belongs to Lyallpur soil series (aridisol-fine-silty, mixed, hyperthermic Ustalfic), Haplarged in USDA classification and Haplic Yermosols in FAO classification. Meterological data during the experimental period are given in Table 1.

The experiment consisted of three different rice production systems (aerobic rice, alternate wetting and drying (AWD) system and flooded rice) and three boron application methods viz. seed priming with 0. 1 mM B, soil application at 1 kg B ha^{-1} and foliar application of 200 mM B. Hydropriming and no B application were taken as control. Soil application of B was done as basal dose; while B was foliage applied one week after sowing/transplanting. Boric acid (10.65% B) was used as the source of B. In aerobic rice, land was prepared by four cultivations followed by two plankings. The detail of land preparation, sowing time, seed rate, and other crop husbandry practices is given in Table 2. The whole quantity of phosphorous, potassium and zinc was applied as basal dose while half quantity of nitrogen was applied as basal and other half was applied in two splits at tillering and panicle initiation stage. Super Basmati was used as test cultivar in all the rice production systems.

In aerobic rice, aerobic conditions were maintained throughout the crop growth period. After the seedling emergence, first irrigation was applied one and a half week after sowing. After that supplementary irrigations were given as per requirement of the crop. In total, 16 irrigations (52 acre inches) were given to reach the crop at maturity stage. In AWD, nursery seedlings were transplanted in standing water (5–7 cm). Water was remained standing for 30 days after transplanting; afterwards field was allowed to dry for some days. The irrigation was applied according to the