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Effects of Silicon-Based Fertilizer on Growth, Yield and Nutrient Uptake of Rice in Tropical Zone of Vietnam

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Abstract: Application of silicon (Si) could greatly boost rice yield and mitigate abiotic stress, especially drought. A field experiment was conducted during 2015 at the research farm of Hong Duc University, Thanh Hoa City, Vietnam, to evaluate the effects of five different combined doses of standard fertilizer practice and Si fertilizer on growth, yield and yield components, as well as nutrient uptake of rice. The treatments consisted of the recommended dose of fertilizer (RDF, 110 kg/hm^2 N + 90 kg/hm^2 P_2O_5 + 80 kg/hm^2 K_2O) as the control, RDF + 100 kg/hm^2 SiO_2, RDF + 200 kg/hm^2 SiO_2, RDF + 300 kg/hm^2 SiO_2 and RDF + 400 kg/hm^2 SiO_2. The results showed that the growth, grain and straw yields as well as yield components (number of grains per panicle, seed-setting rate and 1000-grain weight) were significantly affected by Si application. The highest grain yield of 3 705 kg/hm^2 was obtained with the highest level of Si fertilizer in combination with RDF (RDF + 400 kg/hm^2 SiO_2), however, it was statistically at par with the yields obtained with RDF + 300 kg/hm^2 SiO_2 (3 664 kg/hm^2) and RDF + 200 kg/hm^2 SiO_2 (3 621 kg/hm^2). The optimum dose of Si fertilizer with maximized grain yield (3 716 kg/hm^2) was 329 kg/hm^2 SiO_2. The nutrient (Si, N, P and K) uptakes of rice were also significantly enhanced by Si application. Si application at the level of 329 kg/hm^2 along with RDF would help in the sustainable production of rice in the tropical zone of Vietnam.

Key words: silicon; yield; nutrient uptake; standard fertilizer practice; rice; fertilizer

Silicon (Si) is ranked as the second-most abundant element (after oxygen) in the earth's crust with nearly 29% mean content (Sommer et al, 2006). Si content (mostly 1%–45%) in soil ranges depending on soil types (Sommer et al, 2006). Liang et al (2015) reported that Si content in latosols or latosolic red soils (highly weathered soil) in the tropical zone can be less than 1% due to the presence of extremely active desilification and fersialitization processes. In soil, Si mainly presents in various categories of aluminosilicates and quartz (SiO_2), which consist of up to 75%–95% of soil inorganic constituents (Liang et al, 2015; Meharg and Meharg, 2015).

The potential of Si in improving crop yield has been demonstrated in many studies, especially under abiotic and biotic stress conditions (drought, heavy metals, salinity and pathogens) (Epstein, 2009; Keeping and Reynolds, 2009; Meena et al, 2014; Farooq and Dietz, 2015). Si is known for its role in alleviating the negative stress effects on many plant species. Monocotyledons in general and *Poaceae* species such as rice (*Oryza sativa* L.) in particular are clearly favored due to an enhanced supply of Si (Epstein, 1999; Ma et al, 2007). Despite these benefits, Si is still not classified as an essential element, but considered as a beneficial element.

With nearly 154 million hectares harvested each

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year, rice is one of the most important cereal crops in the world. It is the major source of calorie intake and the staple food for more than three billion people in the world (Datta et al, 2017; Ullah et al, 2017). The demand for rice is steadily increasing due to an increase in global population. However, certain constraints such as water scarcity, pest infestation, inadequate fertilizer use and growing of low-yielding traditional varieties restrict yield increase (Datta et al, 2017). Asian countries are the largest consumer of rice where more than 1.3 billion people consider rice as the staple food. Rice plays a pivotal role in Vietnam's agriculture with a cultivated area of 82% of the total arable land. Rice yield has been significantly increased over the recent decades. However, due to low profitability of crop production, limited access to new agricultural technologies and poor soil and crop management by farmers with the recent added concern of climate change, the objective of increasing rice yield per unit area with less harmful impact to the environment has become a major global concern (Lobell et al, 2009).

Rice is known as Si accumulator and a high Si demanding crop (Ma and Takahashi, 2002). Increasing rice yield per unit area is associated with Si depletion, which is a matter of concern (Savant et al, 1997). Plant available Si in the soils of tropical and subtropical areas including Vietnam is generally low (Meena et al, 2014). Si fertilizer has been used in many countries for improving rice yield (Guntzer et al, 2012). About 20 kg/hm^2 SiO_2 is being removed from the soil to produce every 100 kg brown rice (Ma and Takahashi, 2002). Many Vietnamese farmers export Si from fields by removing straw residues with the harvest and the exogenous application of Si in rice cultivation is often overlooked. This suggests that Si may become a yield-limiting element for rice production, therefore, application of exogenous Si fertilizer may be necessary for an economic and sustainable rice production system (Ning et al, 2014). The objective of this study was to evaluate the effects of different combined doses of standard fertilizer practice and Si fertilizer on growth, yield and yield components, and nutrient uptake of rice.

MATERIALS AND METHODS

Experimental setup and treatments

The study was conducted at the research farm, Hong Duc University (20º8′28″ N, 105º18′34″ E), Thanh Hoa City, Vietnam during July–November in 2015. The experimental site was primarily used to produce annual crops. It receives a mean annual rainfall of 1 750 mm with mean annual minimum and maximum temperatures of 21 ºC and 27 ºC, respectively.

The experiment was set up as a randomized complete block design with five treatments and four replications. The five treatments consisted of the recommended dose of fertilizer (RDF, 110 kg/hm^2 N + 90 kg/hm^2 P_2O_5 + 80 kg/hm^2 K_2O), RDF + 100 kg/hm^2 SiO_2, RDF + 200 kg/hm^2 SiO_2, RDF + 300 kg/hm^2 SiO_2 and RDF + 400 kg/hm^2 SiO_2. Each experimental plot was 20 m^2 (5 m × 4 m). RDF was selected based on the National Technical Regulation on Testing for Value of Cultivation and Use of Rice Varieties of Vietnam. Orthosilicic acid (H_4SiO_4) was used as a source of Si. The percentage of available SiO_2 in Si fertilizer was 60%. The product in powder form was obtained from the Tien Nong Industrial & Agricultural Joint Stock Company, Vietnam. All Si fertilizer was applied before transplanting stage. Nitrogen (N as urea) was applied in three split doses (30% before transplanting, 40% at 7 d after transplanting and 30% at 17 d after transplanting), while P (as single superphosphate) was applied as 100% basal and K (as muriate of potash) was applied in two split doses (50% at 7 d after transplanting and 50% at 17 d after transplanting).

Seeds of rice variety BC15 were used. The wet-bed method was used to raise the seedlings. Seedlings of 20-day-old were transplanted at the rate of 38–42 hills/m^2 and 2–3 seedlings per hill. From transplanting to tillering stages, standing water level at the field was maintained between 3 and 5 cm. After this stage, less than 10 cm standing water was maintained at the field until two weeks before harvesting. All plots were kept weed-free for the entire growing season by hand hoeing as weeds appeared.

Data collection

Soil analysis

Soil samples (0–20 cm depth) were collected before the initiation of the experiment. The samples were air-dried, ground and passed through a 2 mm mesh sieve, and analyzed for pH (electrometric method), organic carbon (Walkley and Black procedure), cation exchange capacity (Kappen's method) (Kappen, 1929), total N (Micro-Kjeldahl method) (Jackson, 1973), available P (Bray No. 1 Extract method) (Bray and