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A review on zinc and boron nutrition in rice

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Abstract
Micronutrients, though needed in smaller amounts, play a major role in the production and productivity of rice. Zn is the fourth most deficient nutrient element in Indian soils and its deficiency causes severe yield reduction in rice. Application of Zn either as foliar spray or soil application caused significant improvement in growth and yield attributes and yield of rice. Similar to that of Zn, B nutrition also caused significant improvement in growth and yield attributes and yield of rice. The review elaborates the effect of Zn and B nutrition on the growth, physiological parameters, yield attributes, yield and quality of rice.

Keywords: Growth attributes, Grain quality, Physiological parameters, Yield attributes, Yield

INTRODUCTION

Zinc (Zn) plays a major role in the growth and development of rice (Chaudhary *et al.,* 2007). Among the seventeen essential nutrient elements, Zn is the fourth most deficient nutrient element in Indian soils (Shukla and Behera, 2011). Zinc is one of the vital nutrients which is required for various biochemical and metabolic process in rice such as synthesis of cytochromes and nucleotides, auxin metabolism, production of chlorophyll, activation of several enzymes, membrane integrity, metabolism of carbohydrate, cell wall development, gene expression and respiration (IRRI, 2000; Broadley *et al*., 2007).

Cereals are more prone to Zn deficiency than legumes and resulted in substantial reduction in yield and quality (Cakmak *et al*., 1999). Rehman *et al*. (2012) reported that Zn deficiency is considered to be the most important nutritional stresses limiting rice production in Asia. The main factors which affect the Zn availability to the plants are soil pH, concentration of Zn, Fe, Mn and P in soil solution, high organic matter and bicarbonate content, high Ca to Mg ratio, prolonged submergence and low redox potential.

Zinc deficiency in rice causes a deficiency disorder called Khaira disease. Seedling stage of the crop is highly prone to Zn deficiency. Leaves develop brown blotches and streaks, the streaks and blotches may fuse to cover the entire leaf, plants remain stunted and in severe case of deficiency the plant may die. Zinc deficiency decreases the tillering, increases the spikelet sterility and delay the crop maturity (IRRI, 2000). Slaton *et al*. (2001) reported that Zn deficient rice plant show poor root respiration especially in submerged soils.

The deficiency of boron (B) is spreading and it is most common in rice growing soils. Though it is required in small amounts but proved essential for plant growth. Boron is associated with one or more process of calcium utilization, cell division, flowering/fruiting, disease resistance, water relations and act as catalyst for several reactions (Spraque, 1951). It is also very much essential for the metabolism of carbohydrate, transport of sugars, synthesis of nucleotide, respiration and pollen viability (Dell and Huang, 1997). Deficiency of B affects the cell wall biosynthesis, phenol metabolism, structure and plasma membrane integrity. It does not affect enzyme activities since it is not an enzyme constituent and it is comparatively immobile in rice plants (Yu and Bell, 1998). The factors contribute to B deficiency in rice are drought, low pH, calcareous nature of the soil, leaching and fixation (Mengel and Kirby, 2001; Niaz *et al*., 2002; Rashid and Rayan, 2004; Rashid *et al*., 2005; Niaz *et al*., 2007 and Rashid *et al*., 2009). By correcting the deficiency, B has the potential to enhance the rice production and foliar application is an easy and effective way to resolve the B deficiency.

Effect of zinc fertilization on growth attributes of rice: Zinc fertilization had significant effect on growth attributes. Khan *et al*. (2002) indicated that application of 10 kg $ZnSO_4$ ha^{-1} produced tallest plants and recorded a plant height of 82.5 cm. Rahman *et al*. (2008) reported that in boro rice, Zn applied @ 3 kg ha^{-1} along with recommended doses of NPK recorded taller plants. Shivay *et al*. (2008) conducted an experiment to study the effect of various concentrations of zinc enrichment of urea in aromatic rice–wheat cropping system for two consecutive years and pointed out that application of 3.5% Zn enriched urea recorded the tallest rice plants (105.2). Shivay *et al*. (2010) observed that with the incremental dose of zinc the plant height of aromatic rice cultivars was found to increase and the tallest plants of 103.1 cm was recorded with the application of 7.5 kg Zn ha^{-1}. Taller plants with higher LAI (4.29) at anthesis and higher DMP at harvest were recorded with 6 kg Zn ha^{-1} (Singh *et al*., 2012). Application of 1.5% Zn ($ZnSO_4$) coated prilled urea and 2% Zn ($ZnSO_4$) coated prilled urea in Pusa Sugandh 5, an aromatic semi dwarf rice variety produced taller plants (Shivay and Prasad, 2012). Tillers m^{-2} were significantly increased by the application of Zn @ 8 kg ha^{-1} along with B (Qadir *et al*., 2013). Zn fertilization along with NPK fertilizers significantly influenced the plant height in rice genotypes compared to NPK fertilization alone (Sudha and Stalin, 2015). Application of Zn @ 10 mg kg^{-1} soil enhanced the dry matter yield in rice (Kalala *et al.,* 2016). Soil application of 15 kg Zn ha^{-1} just after transplanting recorded maximum plant height of 100 cm and tillers (430 m^{-2}) (Ghoneim, 2016). Oahiduzzaman *et al*. (2016) reported that $ZnSO_4$ applied @ 4 kg ha^{-1} enhanced the plant height at harvest (88.3 cm) in rice variety, BRRI dhan-33. Foliar application of Zn along with Fe, B and S recorded taller plants with higher number of tillers, DMP and LAI (Mohan *et al.,* 2017b).

Zinc fertilization on physiological parameters of rice: Li *et al*. (1999) reported that chlorophyll content and net photosynthetic rate were significantly decreased due to Zn deficiency. Aravind and Prasad (2004) indicated that Zn is involved in chlorophyll formation through regulation of nutrients homeostasis in cytoplasm. Zinc plays a crucial role in triggering some of the chlorophyll biosynthetic pathway enzymes (Ayad *et al*., 2010). Mousavi (2011) reported that foliar or soil application of Zn increases the biosynthesis of chlorophyll which are important for the photosynthetic process. Zinc fertilization resulted in considerable increase in the chlorophyll content of rice leaves (Mathpal, 2015).

Mustafa *et al*. (2011) revealed that the CGR was significantly influenced by zinc nutrition. The maximum CGR and total chlorophyll content were registered with the combined application of borax (7.5 kg ha^{-1}) and zinc sulphate (12.5 kg ha^{-1}) (Sarwar *et al*., 2013). Ghasal *et al*. (2016) revealed that CGR, RGR and NAR was not significantly influenced by Zn fertilization, however, the highest values were recorded with soil application of Zn-EDTA @ 1.25 kg ha^{-1} + foliar spray of 0.5 per cent at maximum tillering and panicle initiation stage.

Zinc fertilization on yield attributes of rice: Yield attributes were significantly influenced by Zn fertilization. Soil application of zinc sulphate @ 15 kg ha^{-1} significantly influenced the yield components of rice under Faisalabad condition (Maqsood *et al*., 1999). Khan *et al*. (2002) reported that application of 10 kg $ZnSO_4$ ha^{-1} recorded the highest number of panicles $plant^{-1}$, spikelets $panicle^{-1}$ and 1000 grain weight. Naik and Das (2007) reported that adequate supply of Zn produced higher number of panicle m^{-2}. Application of 3.5% zinc enriched urea significantly influenced the yield attributes of aromatic rice *viz.,* fertile tillers $hill^{-1}$, panicle length and grains $panicle^{-1}$ in rice -wheat cropping system (Shivay *et al*., 2008). Application of Zn @ 7.5 kg ha^{-1} enhanced the yield attributes like panicles $hill^{-1}$ (9.7), panicle length (27.3) and grains $panicle^{-1}$ (113.4) in aromatic rice varieties when compared to control (Shivay *et al*., 2010). Application of 2% Zn coated ($ZnSO_4$) prilled urea in aromatic rice variety Pusa Sugandh -5 significantly influenced the yield attributes like panicle $hill^{-1}$ (11.1 and 11.3), panicle length (27.7 and 28.4), number of grains $panicle^{-1}$ (125.7 and 128.7) and 1000 grain weight (29.3 and 29.8) respectively, during two consecutive years of study (Shivay and Prasad, 2012). Singh *et al*. (2012) reported that panicles m^{-2} and grains $panicle^{-1}$ were significantly enhanced by the application of Zn @ 6 kg ha^{-1}. Soil application of $ZnSO_4$ @ 40 kg ha^{-1} increased the panicle m^{-2} and fertile grains $panicle^{-1}$ (Yadi *et al*., 2012). Qadir *et al*. (2013) reported that Zn applied @ 8 kg ha^{-1} increased the panicle m^{-2}, spikelets $panicle^{-1}$ and fertility percentage (73.90 per cent). Grains $panicle^{-1}$ and panicle length was enhanced by the application of Zn as basal and foliar spray at flowering, milk and dough stages of rice (Sudha and Stalin, 2015). The highest number of panicle m^{-2} (350), number of spikelets $panicle^{-1}$ (129), filled grains (82 per cent) and 1000 grain weight (27.1 g) were recorded with the soil application of 15 kg Zn ha^{-1} just after transplanting in rice (Ghoneim, 2016). Oahiduzzaman *et al.* (2016) opined that higher number of productive tillers $hill^{-1}$ and filled grains $panicle^{-1}$ were recorded with 4 kg Zn ha^{-1}. Foliar spray of $ZnSO_4$ @10 kg ha^{-1} along with recommended dose of NPK enhanced the yield attributing characters like productive tillers m^{-2}, grains $panicle^{-1}$ and test grain weight (Mohan *et al*., 2017b).

Zinc fertilization on rice yield: Zn fertilization had significant effect on the grain yield of rice and highest grain yield was recorded with the application of $ZnSO_4$ @ 10 kg ha^{-1} (Khan *et al*., 2002). Foliar nutrition of Zn enhanced the grain yield in rice (Potarzycki and Grzebisz, 2009). In an experiment conducted in rice-wheat cropping system, aromatic rice recorded the highest grain (4.12 and 5.45 t ha^{-1}) and straw yield (10.95 and 12.64 t ha^{-1}) with the application of 3.5% Zn enriched urea (Shivay *et al*., 2008). Shivay *et al.* (2010) reported that application of Zn @ 7.5 kg ha^{-1} recorded the highest straw yield of 10.99 t ha^{-1} in aromatic rice. Soil application of 25 kg $ZnSO_4$ ha^{-1} along with 120 kg ha^{-1} prilled urea recorded the highest grain yield of 5.18 t ha^{-1} in aromatic rice variety Pusa Sugandh-5 (Yadav *et al*., 2010). Fageria *et al*. (2011) reported that Zn fertilization resulted in 97 per cent increase in grain yield. Mustafa *et al*. (2011) opined that method and time of application of Zn significantly influenced the grain yield of rice. They also reported that soil application of $ZnSO_4$ (25 kg ha^{-1}) recorded higher grain yield compared to 0.5 per cent Zn foliar spray at 75 DAT. Application of 2% Zn coated ($ZnSO_4$) prilled urea in aromatic rice variety Pusa Sugandh-5 recorded the highest grain (5.26 and 5.29 t ha^{-1}) and straw yield (11.23 and 11.31 t ha^{-1}) respectively, during the consecutive years of study (Shivay and Prasad, 2012). The highest grain yield (7.63 t ha^{-1}) was recorded with Zn applied @ 6 kg ha^{-1} (Singh *et al.,* 2012). Yadi *et al*. (2012) pointed out that as the rate of application increased from 20 to 30 kg Zn ha^{-1}, corresponding increase in grain yield was observed in two rice varieties tested. Application of Zn and B @ 8 and 2 kg ha^{-1} along with recommended NPK recorded the highest grain and straw yield (Qadir *et al*., 2013). Rana and Khasif (2014) reported that foliar application of Zn resulted in higher grain yield than soil application. Shivay *et al*. (2015) reported that soil application (5 kg Zn ha^{-1}) plus foliar application (1 kg Zn ha^{-1}) recorded the highest grain and straw yield in rice. Application of Zn @ 5 mg kg^{-1} soil was found optimum for obtaining good yield in soils deficient in Zn (Kalala *et al.,* 2016). Oahiduzzaman *et al*. (2016) revealed that Zn applied @ 4 kg ha^{-1}recorded higher grain (5.1 t ha^{-1}) and straw (6.6 t ha^{-1}) yield in BRRI dhan-33 rice variety. Foliar spray of one per cent Zn salt at tillering and flag leaf stage significantly enhanced the grain and straw yield (Kulhare *et al*., 2017).

Zinc fertilization on Zn availability in soil and uptake by rice: Zinc fertilization had significant effect on Zn uptake by rice plant (Salam and Subramanian, 1988). Zinc levels and genotypes had significant effect on Zn content in shoot and grain (Fageria and Baligar, 2005). The total uptake of zinc was recorded the highest with the application of 3.5% Zn enriched urea in aromatic rice under rice-wheat cropping system (Shivay *et al*., 2008). Fageria *et al*. (2011) reported that application of 120 mg Zn kg^{-1} of soil recorded the highest uptake of Zn in shoot (20.01mg pot^{-1}) and grain (1.77 mg pot^{-1}), respectively. Zinc content and Zn uptake were significantly influenced by various levels of Zn. The highest Zn content and uptake was recorded with Zn @ 7.5 $mgkg^{-1}$ soil (Muthukumararaja and Sriramachandrasekharan, 2012). Zinc content of brown rice was increased significantly over the control by the foliar and soil application of Zn (Phattarakul *et al*., 2012). Shivay and Prasad (2012) reported that the highest zinc uptake (1346.3 and 1325.1 g ha^{-1} respectively) was recorded with the application of 2% Zn coated ($ZnSO_4$) prilled urea in aromatic rice variety Pusa Sugandh-5 during both the consecutive years of study. Foliar spray of 0.5% $ZnSO_4$ after flowering increased the Zn content in paddy (Boonchauay *et al.,* 2013). The highest uptake of Zn was registered with the soil application of 5 kg Zn ha^{-1} + foliar application of 1 kg Zn ha^{-1} (Shivay *et al*., 2015). Rana and Kashif (2014) reported that Zn content in the paddy and straw were increased with the application of Zn-EDTA @ 10 kg ha^{-1}. Zinc application enhanced the Zn content of whole grain by 30 to 53 per cent over control (Sudha and Stalin, 2015). Kumar *et al*. (2017) reported that soil application of $ZnSO_4$ @ 50 kg ha^{-1} recorded higher Zn content in grain which was statistically on par with foliar spray of Zn-EDTA equivalent to 0.2 per cent $ZnSO_4$. Kulhare *et al*. (2017) reported that foliar spray of one per cent Zn salt significantly increased the Zn uptake by grain.

Srivastava *et al*. (1999) pointed out that Zn fertilization significantly increased the available Zn content in the soil over control (no Zn). Khan *et al*. (2004) reported that soil application of 15 kg Zn ha^{-1} recorded the highest Zn content of 0.773 ppm. Zinc content in the soil was significantly influenced by different levels of Zn. Application of Zn @ 6 kg ha^{-1} recorded the highest available Zn content (0.98 ppm) (Singh *et al*., 2012). Comparing the different sources of Zn, Kulhare *et al*. (2017) found that available Zn content in the soil was highest with Zn-EDTA and $ZnSO_4$ compared to $ZnCl_2$, $Zn_3(PO_4)_2$ and ZnO.

Zinc fertilization on quality parameters of rice: Li *et al*. (1999) observed that quality of rice grain was enhanced by Zn fertilization. However, Khan *et al*. (2004) observed that Zn fertilization adversely affected the starch content of the paddy grain. Hossain *et al*. (2008) indicated that Zn levels did not have any significant effect on the protein content of grain, whereas the starch content significantly varied with the Zn levels and the highest starch content (73.15 per cent) was recorded with $ZnSO_4$ foliar spray at 0.5 per cent. Application of Zn along with N significantly enhanced the water absorption ratio and protein content of the grain (Khan *et al*., 2009). Application of Zn as basal and foliar application at flowering, milk and dough stages enhanced the crude protein and starch content in rice from 56.28 to 82.48 per cent and 5 to 19 per cent, respectively over control (Sudha and Stalin, 2015). Kumar *et al*. (2017) reported that the highest grain protein content was observed with soil application of $ZnSO_4$ @ 50 kg ha^{-1}. Mohan *et al*. (2017a) reported that foliar application of 10 kg zinc sulphate+ 5 kg ferrous sulphate +10 kg borax + 10 kg sulphur ha^{-1} along with recommended dose of NPK recorded the highest protein content (8.875 per cent).

Boron fertilization on growth attributes of rice: Application of B enhances the growth attributes due to its favourable influence on metabolic pathways involved in cell division and elongation (Hatwar *et al.,* 2003). Ahmad *et al*. (2012) pointed out that foliar spray of B and Si at 0.5 per cent and 1.5 per cent recorded the highest plant height (107.17 cm). Arif *et al*. (2012) revealed that foliar spray of B and Zn @ 3 and 6 kg $acre^{-1}$ enhanced the plant height (121 cm) and tillers $plant^{-1}$. Qadir *et al*. (2013) opined that higher number of tillers were recorded with the soil application of B and Zn @ 2 and 8 kg ha^{-1}. Rehman *et al*. (2014) also reported that foliar application of 0.24 M B had significant effect on tiller production in cultivars, Super basmati and Shaheen basmati. The dry matter production was also significantly influenced by foliar spray of B @ 20 mg L^{-1} (Ali *et al*., 2016). The highest DMP of 15.57 t ha^{-1} was recorded with the application of borax 10 kg ha^{-1} along with FYM 5t ha^{-1}, recommended NPK and lime 600 kg ha^{-1} in Kole lands of Kerala (Rani and Latha, 2017).

Boron fertilization on physiological parameters of rice: Soil application of B and Zn @ 3 and 6 kg $acre^{-1}$ enhanced the chlorophyll a, b and the total chlorophyll content (Arif *et al.,* 2012). Chlorophyll content is increased by the application of B and Zn (Pervaiz *et al.,* 2012). Rehman *et al*. (2014) reported that foliar spray of 0.16 M B and 0.24 M B recorded higher total chlorophyll contents in rice varieties Super basmati and Shaheen basmati.

Boron fertilization on yield attributes of rice: Boron fertilization had profound influence on the production of yield attributes. Ahmad *et al*. (2012) reported that foliar spray of one per cent B and 0.5 per cent Si produced panicles with more length. Soil application of B and Zn @ 1.5 and 3 kg $acre^{-1}$ enhanced the panicle length (30.40 cm) (Arif *et al*., 2012). Boron was applied along with Zn and Fe resulted in the production of higher number of spikelets $panicle^{-1}$ and grains with higher test grain weight (Qadir *et al*., 2013). Application of 0.24 M B recorded higher number of productive tillers and grain yield $plant^{-1}$, however, the lowest sterility percentage was recorded with the application of 0.32 M B (Rehman *et al*., 2014). Remesh and Rani (2017) found that grain weight $panicle^{-1}$ was enhanced by the soil application of B @ 1kg ha^{-1} and foliar application of B@ 250 mg L^{-1}. Ali *et al*. (2016) reported that higher number of filled grains $panicle^{-1}$ were recorded with the application of 20 mg B L^{-1}. Rani and Latha (2017) reported that higher number of spikelets $panicle^{-1}$ (96.41) and filled grains $panicle^{-1}$ (94.30) were recorded with application of borax 10 kg ha^{-1} along with FYM 5t ha^{-1}, recommended NPK and lime 600 kg ha^{-1} in Kole lands of Kerala which was 45% more than that of the control.

Boron fertilization on rice yield: The grain yield was increased with the application of B at heading or flowering stage of rice (Ramanathan *et al*., 2002). Grain yield was significantly improved by foliar spray of one per cent B and 1.5 per cent Si (Ahmad *et al*., 2012). Rice growth and grain yield were enhanced by the soil application of B in soils deficient in B (Hussain *et al.,* 2012). Soil application of B and Zn @ 3 and 6 kg $acre^{-1}$ recorded the highest grain and straw yield (4.18 and 13.84 t ha^{-1}, respectively) (Arif *et al*., 2012). Ali *et al.* (2016) observed that foliar application of B @ 20 mg L^{-1} recorded the highest grain yield. Remesh and Rani (2017) opined that soil application of B @ 1kg ha^{-1} recorded the highest grain yield (5502.85 kg ha^{-1}). Rani and Latha (2017) reported that application of borax @10 kg ha^{-1} along with recommended dose of NPK recorded the highest grain yield of 7.67 t ha^{-1}.

Boron fertilization on B availability in soil and uptake by rice: Application of B fertilizer enhances the uptake of B within the rice plant, but only less than 40 per cent is stored in grain and remaining portion is accumulated in leaves and stem (Katyal and Singh,1992). Arif *et al*. (2012) revealed that soil application of B and Zn @ 3 and 6 kg $acre^{-1}$ recorded higher B and Zn content in rice. Soil application of B and Zn @10 and 2 kg ha^{-1} increased the B and Zn content of rice grain (Bhutto *et al*., 2013). Boron content in leaves and kernels was found to enhance with the increasing concentration of foliar applied B in cultivars Super basmati and Shaheen basmati (Rehman *et al*., 2014).

Boron fertilization on quality parameters of rice: The quality of grain is enhanced by the application of B @ 0.75 kg ha^{-1} (Rashid *et al.,* 2009). Ahmad *et al*. (2012) reported that highest grain protein content (6.89%) was recorded with the application of 1 per cent B and highest grain starch content was obtained with the application of B and Si at 1 and 1.5 per cent, respectively.

Conclusion

It was concluded that the main factors affecting the Zn availability to the rice plant are soil pH, concentration of Zn, Fe, Mn and P in the soil solution, organic matter content, bicarbonate content, high Ca to Mg ratio, moisture content in the soil and redox potential of the soil. Zinc fertilization had significant effect on its growth, yield attributes and yield. It also had significant effect on total chlorophyll content and net photosynthetic rate due to active role in the biosynthesis of chlorophyll. Also, Zn fertilization significantly improved the Zn uptake by crop and Zn content in the rice grain. The quality of rice grain was also enhanced by Zn fertilization. Boron also plays a major role in the growth and development of rice due to its metabolic involvement in the metabolic pathways involved in cell division and cell elongation, calcium utilization, flowering/fruiting, disease resistance, water relations and act as catalyst for several reactions. It is also very much essential for the metabolism of carbohydrate, transport of sugars, synthesis of nucleotide, respiration and pollen viability. Deficiency of B affects the plant growth. The soil factors affected the B deficiency in soil are low moisture content, acidity, calcareous nature of soil, leaching and fixation. Boron fertilization had profound influence on the production of growth and yield attributes and finally resulted in higher grain yield. The grain protein and starch content were significantly improved with the foliar nutrition of B. Hence Zn and B are very vital for rice production and its deficiency in soil may cause significant reduction in rice grain yield.

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