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EFFICACY OF CRUSHED ORE COLEMANITE AS BORON FERTILIZER FOR RICE GROWN UNDER CALCAREOUS SOIL CONDITIONS

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Boron (B) deficiencies occur over a wider range of soils and crops in the world. Different sources of fertilizers are used to supply sufficient amounts of B for healthier plant growth. The effectiveness of crushed ore colemanite as B source for rice crop under flooded calcareous soil was evaluated in a glass house study. We studied the effects of powder colemanite (PC) and granular colemanite (GC) at the rates of 0, 1, 2, and 3 kg B ha^{-1} on growth and yield parameters of rice crop. Powder colemanite application at 2 and 3 kg B ha^{-1} significantly increased plant height, number of tillers and panicles $plant^{-1}$, number of grains $panicle^{-1}$, weight of 1000 grains and B concentration in grain compared to those observed due to application of 0 and 1 kg B ha^{-1}. Rice crop applied B at 3 kg ha^{-1} in the form of PC produced significantly (18% increase over control) higher grain yield than 0 kg B ha^{-1} treatment. The effectiveness of PC was higher in terms of yield and yield parameters of rice than the GC, The B source of PC was very effective in supplying B to rice crop, however GC applied pots produced significantly lower yields because of its larger particle size which was the controlling factor in B release from the fertilizer.
Key words: Boron, rice, colemanite, calcareous soil, rice grain

INTRODUCTION

Rice is a vital food crop and occupies a position of over whelming importance in the global food system. It belongs to the Gramineae family and the half world population eats it as a main part of their daily diets (Benton, 2003). Irrigated and lowland rainfed rice systems account for about 80% of the worldwide harvested rice area and 92% of the total production (Dobermann 2000). To keep pace with population growth, rice yields in both the irrigated and rainfed lowland environments must increase by 25% over the next 20 years (IRRI, 2008). Fertilizer use in rice predominantly pertains to only macro nutrients thus one major cause of low rice productivity is imbalanced nutrient management (Rashid, 2002). Micronutrient deficiency is one of the major causes of the declining productivity trends in rice growing countries (Mohanty, 1999).

Boron deficiencies occur over a much wider range of soils and crops in comparison to deficiencies of any other micronutrient elements (Yan, 2006). Boron is essential for plant physiological functions such as nucleic acid metabolism, carbohydrate and protein metabolism, indole acetic acid metabolism, cell wall synthesis, cell wall structure, membrane integrity and function, sugar translocation and phenol metabolism (Goldbach, 2001). Boron seed coating has also been tested in rice (Rehman *et al*., 2012). There are two types of B fertilizer sources, the refined completely soluble materials which can be conveniently applied either in solution or as solids, and the crushed ores which have variable chemical and physical properties (Bell, 2008). The refined products are Sodium tetra borate, ($Na_2B_4O_7 \cdot 5H_2O$) borax ($Na_2B_4O_7 \cdot 10H_2O$), sodium penta-borate ($Na_2B_{10}O_{16} \cdot 10H_2O$), solubor ($Na_2B_8O_{13} \cdot 4H_2O$) and boric acid ($H_3BO_3$). The crushed ores are colemanite ($Ca_2B_6O_{11} \cdot 5H_2O$), ulexite ($Na_2O.2CaO.5B_2O_3.16H_2O$), datolite ($2CaO.B_2O_3.2SiO_2.H_2O$), hydroboracite ($CaO.MgO.3B_2O_3.6H_2O$) and ascharite ($2MgO.B_2O_3.H_2O$). Sodium pentaborates and boric acid are easily dissolved in soils and are quickly available for plant uptake, but at the same time B can be leached from the soil root zone. Only two crushed ores ulexite and colemanite are used for soil application (Bell, 2008). These two crushed ores can be satisfactorily applied to the soil to provide season long B supply for a crop.

Crushed ore colemanite is a cheap and slow release source of B in comparison to refined products but this B source is not widely used as fertilizer. Byers et al., (2001) conducted a grlass house experiment on alfalfa to evaluate the effectiveness of four B fertilizers; Granubor, Hydroboracite, Ulexite and Colemanite. He found that in the first cutting of the crop there was difference in B sources, however by the third and fourth cuttings, there was no significant difference among the four fertilizer sources. Very few studies on crushed ores as B fertilizers for crops had been reported. Most studies on ores have been carried out in pots with toxicity and leaching in mind rather than crop response (Shorrocks, 1997). The objective of this study was to evaluate the efficacy of crushed borate ore colemanite as B source for rice under flooded calcareous soil condition.

MATERIALS AND METHODS

Soil analysis: A glass house experiment was conducted at University Putra Malaysia. Calcareous soil used was collected from Perlis, Malaysia. The laboratory analysis of soil samples showed that it was deficient in plant available B. Boron in the soil was determined by hot water extraction method (Bingham, 1982) and in the plant tissue was determined by the dry ashing followed by azomethine-H colorimetric method (Benton, 2001). Soil pH was measured in soil; water (1:2.5) extract using PHM210 Standard pH meter at 30^0C (Benton, 2001). Phosphorus was extracted using Bray and Kurtz #2 extractants (Bray and Kurtz, 1945). Samples were analyzed for organic carbon using the Carbon Analyzer (Benton, 2001). Soil texture, total N and cation exchange capacity (CEC) were determined using the pipette method (Gee and Bauder, 1986), Kjeldahl digestion method (Bremner and Mulvane, 1982) and leaching method (Thomas, 1982), respectively.

***Rice sowing*:** Healthy seeds of variety MR220 were selected for planting. These seeds were soaked in a beaker with water for 24 hours and then placed on soaked filter paper in Petri dishes for 48 hours for pre germination and on the third day when the radicle emerged, the seeds were sown into pots. The number of seeds needed per pot was calculated on the basis of surface area of pot at sowing rate of 140 kg ha^{-1}. The level of water in each pot was maintained at 5 cm above the soil surface.

***Fertilizer sources and rates*:** Experiment was conducted by adding 6 kg calcareous soil into each plastic pot. Each pot received either powder colemanite (PC) with particle size of 75µm or granular colemanite (GC) with particle size 0.3 mm and the rates were 0, 1, 2 and 3 kg B ha^{-1}. The fertilizer was applied at the time of planting by surface application. Macronutrients nitrogen, phosphorus and potassium were also applied according to the rates-recommended by Malaysian Agriculture Development Authority, a government owned research organization. Nitrogen was applied as urea at the rate of 140 kg N ha^{-1} in three split doses at 15, 40 and 60 days after planting while P and K were applied after 15 days of planting at the rate of 70 kg (P_2O_5 or K_2O) ha^{-1} in the form of triple super phosphate and muriate of potash, respectively. Pots were arranged in randomized complete block design with three replications.

***Crop and soil parameters*:** The crop parameters determined were number of tillers and panicles $plant^{-1}$, plant height, panicle height, fresh and dry weight of straw with and without grain, weight of panicle, grains $panicle^{-1}$, empty grains $panicle^{-1}$, weight of grain from each pot, weight of 1000 grains, chlorophyll content of leaf (measured with a SPAD meter), and B concentration in plant straw and grain. Tillers and panicles were counted at maturity stage; plant height and seed yield were measured at harvest. Panicles were harvested and threshed by hand. The filled grains were separated from unfilled ones by using salt solution of 1.06 specific gravity (Seizo, 1980). The 20 grams representative grain and straw samples were ground to pass through a 1 mm sieve and were kept in plastic containers for chemical analysis.

Statistical analysis: The data were analyzed using Statistical Analysis System (SAS) software package version 8.2 and mean comparisons between treatments were determined using analysis of variance (ANOVA) procedure and Tukeys' Honestly Significant Difference at 95% level of confidence.

RESULTS AND DISCUSSION

***Classification of Soil Used in Experiment*:** The calcareous soil used in this experiment belongs to Bukit Temiang series and classified as a Typic Hapludult under the USDA Soil Taxonomy classification (Paramananthan 2000). The soil was deficient in B (0.32 mg kg^{-1}) with high pH (8.1). Soil textural class was silty clay with 2% organic carbon, 9.1 cmol kg^{-1} CEC, 20 mg kg^{-1} phosphorus and 0.16% total nitrogen.

Effects of B fertilizer rates and sources on rice yield and growth parameters

***Number of panicles per plant*:** Boron fertilizers PC and GC application on rice crop increased the production of panicles $plant^{-1}$ (Table 1). Boron source PC significantly increased the number of panicles $plant^{-1}$ and there was significant difference in number of panicles $plant^{-1}$ between PC and GC applied pots. Although the pots treated with GC also increased the number of panicles but the numbers were significantly lower than the PC. The interaction between fertilizers and B rates was significant.

Table 1. Effect of B fertilizer rates and sources on number of panicles per plant

B levels (kg ha^{-1})	PC	GC	Mean of B levels
0	2.1 d	2.1 b	2.1 B
1	2.6 c	2.1 b	2.3 B
2	3.3 b	2.5 a	2.9 A
3	3.9 a	3.0 a	3.4 A
Mean of B source	2.9 A	2.4 B	

The values with same capital letter within columns and rows and the values with same non-capital letter within B source at different levels are not significantly different at p=0.05.
PC= Powder Colemanite and GC= Granular Colemanite

The results further indicated that application of 2 and 3 kg B ha^{-1} produced the higher number of panicles compared to the control and 1 kg B ha^{-1} rate. However, there was no significant difference in panicles $plant^{-1}$ between 2 and 3 kg B ha^{-1}. Powder colemanite applied pots produced more panicles because B from these fertilizers was readily available for plant uptake, and on the other hand GC solubility was low due to its larger particle size. This increase in the number of panicles was due to the role of B in the reproduction of plants and germination of pollen as B promotes pollen tube growth (Bolanos *et al*., 2004). Sodium pentaborate and PC had shown similar pattern of B release for plant uptake as was observed in the field experiments. Our results are consistent with the results of Ashraf *et al*. (2004) who reported that the number of productive tillers and panicle hill^{-1} of paddy cultivars increased with B application.

***Percentage of empty grains*:** Comparison of means of empty grains for different fertilizers showed that the difference between PC and GC was significant (Table 2). Under calcareous soil conditions, PC was found to be effective B source; similar results were observed in acidic soils.

Table 2. Effect of B fertilizer rates and sources on percentage of empty grains per panicles

B levels (kg ha^{-1})	PC	GC	Mean of B levels
0	22.4 a	22.4 a	22.4 A
1	21.5 a	21.0 a	21.2 A
2	19.2 b	19.0 b	19.1 B
3	17.0 c	18.6 b	17.8 C
Mean of B source	19.6 B	20.3 A	

The values with same capital letter within columns and rows and the values with same non-capital letter within B source at different levels are not significantly different at p=0.05.
PC= Powder Colemanite and GC= Granular Colemanite.

Application of B at the rate of 3 kg B ha^{-1} significantly decreased the percentage of empty grains compared to the other B levels. Application of 2 kg B ha^{-1} significantly decreased the non-fertilized grains in comparison to 0 and 1 kg B ha^{-1} and the control. This decrease in unfilled spikelets was pragmatic because B hinders the abortion of the ovaries, produce functional flowers and its deficiency can result in the sterility of pollen (O'Niell *et al.,* 2004). Boron application decreased the plant empty grains because it is essential for normal development of reproductive tissues and deficiency is responsible for creating male sterility and inducing floral abnormalities results in low grain set or poor seed quality (Dell and Bell, 2002). Ehsan *et al.* (2009) reported that B fertilization improved rice tillering capacity, weight of grain, seed setting and decreased empty grains.

***Weight of 1000 Grains*:** The PC applied pots recorded significantly higher 1000 grain weight compared to that of GC applied ones (Table 3). There was also significant interaction between fertilizer sources and rates. As B has a role in many plant physiological functions, spikelet quality and weight were positively affected. The highest weight of 1000 grains was recorded at 3 kg B ha^{-1} but there was no significant difference in the weight of 1000 grains for pots applied with 1 and 2 kg B ha^{-1}. However, weight of grains for any B applied pot was higher than the control. Boron plays an important part in the fertilization, flowering, and seed-setting process of plants so improvement in grain weight may be due to its role in the synthesis of ethylene and flower buds (Dell and Bell, 2002). These results are in agreement with the findings of Aslam *et al.* (2002) who conducted a glass house experiment under saline and saline-sodic soils and reported that B application increased the weight of rice grain and decreased the spikelet sterility.

Table 3. Effect of B fertilizer rates and sources on weight of 1000 rice grains

B levels (kg ha^{-1})	PC (g)	GC (g)	Mean of B levels
0	15.5 b	15.5 a	15.5 C
1	17.0 ab	16.1 a	16.5 B
2	17.7 a	17.0 a	17.3 B
3	19.2 a	17.1 a	18.15 A
Mean	17.5 A	16.6 A	

The values with same capital letter within columns and rows and the values with same non-capital letter within B source at different levels are not significantly different at p=0.05.
PC= Powder Colemanite and GC= Granular Colemanite

***Boron concentration*:** Powder colemanite and GC significantly affected B concentrations of rice grain and rice straw (Tables 4 and 5). There was significant difference in grain B concentration between PC and GC applied pots but plants from both pots had higher grain B concentration than pots where B was not applied. In case of B concentration in plant straw similar trend was observed. The interaction between fertilizers and rates was significant. Plant B uptake is a passive process so its continuous supply is necessary for normal plant growth, its uptake from PC was according to plant needs as PC was slow release source so whatever B quantity was released with the passage of time, proved to be enough for plant requirement. Therefore, at the end of plant life cycle PC fertilizer were sufficient enough for healthy crop growth.

Table 4. Effect of B rates and sources on B concentration of grain

B levels (kg ha^{-1})	PC (mg kg^{-1})	GC (mg kg^{-1})	Mean of B levels
0	6.0 b	6.0 a	6.0 C
1	7.0 b	6.0 a	6.5 C
2	8.4 a	6.7 a	7.5 B
3	10.0 a	7.3 a	8.6 A
Mean of B sources	7.9 A	6.5 B	

The values with same capital letter within columns and rows and the values with same non-capital letter within B source at different levels are not significantly different at p=0.05.
PC= Powder Colemanite and GC= Granular Colemanite

Table 5. Effect of B rates and sources on B concentration in plant straw

B levels (kg ha^{-1})	PC (mg kg^{-1})	GC (mg kg^{-1})	Mean of B levels
0	6.6 c	6.6 a	6.6 C
1	8.0 b	6.6 a	7.3 C
2	10.3 a	6.7 a	8.5 B
3	13.0 a	7.3 a	10.2 A
Mean of B sources	9.4 A	6.8 B	

The values with same capital letter within columns and rows and the values with same non-capital letter within B source at different levels are not significantly different at p=0.05.
PC= Powder Colemanite and GC= Granular Colemanite

The highest B concentrations were measured in 3 kg B ha^{-1} applied plants compared to those found in other treatments. Boron application at 2 kg ha^{-1} showed higher rice grain B concentration over 0 and 1 kg B ha^{-1}. Boron concentration in rice straw showed the same trend as of the grain. The highest B concentration was measured in plants which received 3 kg B ha^{-1} followed by 2 kg B ha^{-1}**.** These results are in agreement with the findings of Rashid *et al.* (2007) and Yang *et al.* (2000) which they reported that B application increased the leaf and grain B concentration of rice plant.

Boron recovery efficiency and B use efficiency**:** Boron recovery and use efficiency were affected by B rates (Table 6). Based on calculations it was observed that the quantity of B taken up by the crop or B recovery efficiency increased with the increasing rate of B application. The highest recovery efficiency was calculated from 3 kg B ha^{-1} followed by 2 kg B ha^{-1}. The highest recovery efficiency percentage was 6.0% at 3 kg B ha^{-1} PC. Boron utilization efficiency also showed the same trend. Agronomic efficiency in B use (AEB) was higher at 3 kg B ha^{-1}. Colemanite powder exhibited higher AEB than GC.

Grain yield of rice**:** Fertilization of rice plants using crushed ore colemanite as B source had positive effects on all growth parameters of the crop so ultimately grain yield per pot increased significantly (Table 7). The powder colemanite fertilized pots had significantly higher yield than the GC applied pots. The interaction between fertilizers and rate was significant. Boron application as PC produced higher yields at 2 and 3 kg B ha^{-1} levels. The PC had very small particles (75 µm diameters) was proved to be highly soluble B source so it was readily available for plant uptake and showed significant effect on all growth parameters. It is apparent from this study that particle size had significant effect on B release from colemanite. The results of this glasshouse experiment are similar to the results of field experiments conducted on same fertilizers under acidic soil condition. Our earlier study on B dissolution kinetics, showed that soil pH had no effect on solubility of PC and GC fertilizers (Saleem *et al.,* 2009).

Boron fertilizer application at 3 kg B ha^{-1} rate increased 18% rice grain yield over the 0 kg B ha^{-1}. Boron application at the rate of 3 kg ha^{-1} produced significantly higher yield than the other treatments. The yield of 2 kg B ha^{-1} applied pots was significantly higher than 1 kg B ha^{-1} but there was no significant difference between the yields in 1 kg B ha^{-1} applied pots and the control. Rice yield responded to B application due to its positive effect on the number of tillers, panicles, weight of grain and filled grains. These results suggests that B addition improves seed setting due to its major role in many plant physiological functions such as it promotes cell growth and development of the rice panicle (Garg *et al.,* 1979). These findings are consistent with those of Rashid *et al.* (2002) and Dunn *et al.* (2005). They found that soil-applied B produced significantly higher yields and up-to 26% increase has been reported.

Table 6. Effect of B rate and source on B recovery efficiency and B use efficiency

B fertilizers and rates	B recovery efficiency (%)	AEB (g) spikelet kg^{-1} B applied
PC		
1 kg B ha^{-1}	4.4 b	1.0
2 kg B ha^{-1}	4.5 b	1.2
3 kg B ha^{-1}	5.3 a	1.5
GC		
1 kg B ha^{-1}	1.6 b	0.5
2 kg B ha^{-1}	1.0 b	0.7
3 kg B ha^{-1}	2.2 a	0.6

The values within same fertilizer at different levels are not significantly different at p= 0.05. AEB = Agronomic efficiency in B use, PC= Powder Colemanite and GC= Granular Colemanite

Table 7. Effect of B rates and sources on the rice grain yield per pot

B levels (kg ha^{-1})	PC (g)	GC (g)	Mean of B levels
0	21.5 b	21.5 a	21.5 C
1	22.5 b	22.0 a	22.2 C
2	24.0 ab	23.0 a	23.5 B
3	26.0 a	23.5 a	24.7 A
Mean	23.5 A	22 B	

The values with same capital letter within columns and rows and the values with same non-capital letter within B source at different levels are not significantly different at p=0.05.
PC= Powder Colemanite and GC= Granular Colemanite

Since B is immobile in plants, once utilized in the actively growing tissues, it cannot be retranslocated to other tissues. Therefore, it is necessary to have a continuous supply of available B for plant uptake throughout its growth cycle. Boron source PC is a slow release B as our previous studies on B dissolution kinetics, soil incubation and soil column leaching indicated (Saleem *et al.*, 2009) so rice plant received adequate B during its growth period. It is apparent from this study that particle size had significant effect on B release from colemanite. The results indicated that PC was effective in improving all plant growth parameters when used as a B fertilizer. However GC with its larger particle size (0.3 mm diameter) was less efficient in supplying B during the growth of the rice plant.

Conclusion**:** The results of this study showed strong evidence of the positive effects of PC as a B fertilizer for rice crop. The growth and yield of rice plants depended on the B fertilizer properties especially the particle size. Crushed ore colemanite in the powder form was the effective B source. In most of the plant parameters studied, the PC was successful B source. Granular colemanite however was ineffective as a B source over the rice growing period most probably because the amount of B released during crop growth was inadequate for healthy rice plant. This can be attributed to the large particle size of GC which caused its low solubility.

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