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Research Article

IMPACT OF BORON ADDITIONS IN MARGINAL SOILS FOR GROWTH OF CORN, WHEAT, SOYBEAN, AND SWITCHGRASS¬

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A R T I C L E I N F O

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A B S T R A C T

Expansion of agricultural production in marginal or poor nutrient status soils would necessitate calibration of the various nutrients to support plant growth. Boron (B) is an important micronutrient required by plants for regulating many functions including seed and fruit development. Few studies have compared the effectiveness of different types (refined vs crushed ore) of B source on the growth of plants. We hypothesize that addition of refined granulated B fertilizer as well as granulated ores will increase plant available Ca and B in the marginal and sandy soils. A greenhouse experiment was carried out to mimic a poor soil condition, using potting media created by mixing 20 % potting mix and 80% sand. Nitrogen was applied at recommended rates. Pots were watered evenly throughout the growing season. Plant tissues were harvested, biomass recorded, dried and ground for analysis. There was no significant difference on biomass yield due to either rate or source. The four B sources showed different rates of availability to corn, soybean, wheat and switchgrass. Highly soluble B source seems to be the effective among B sources. Etigran-21 was found to be toxic to soybean plants, most likely due to its high solubility.

INTRODUCTION

Boron (B) is one of the seven essential micronutrients vital for the normal growth of most plants and most regularly deficient micronutrient for crop production (Keren and Bingham 1985).B is the only essential nutrient that is present in the soil solution in an available form for plant growth in the neutral pH range (Khurana and Arora, 2012). The primary functions of B include seed production, root elongation, sugar metabolism, regulation of the use of other nutrients and its role in membrane integrity (Goldbach 2001; Gupta *et al*., 2011). The level of soil B is "low" when extractable B is less than 0.1 kg ha^{-1} and is "excessive" when extractable B is greater than 1.4 kg ha^{-1}. Soil B is found in both organic and inorganic forms that are made available to plants as either or both soil organic matter is decomposed and/or boron-containing minerals dissolve. Boron deficiency can result in poor blossoming, reduced fruit and seed setting, chlorosis, and other physiological deficiency symptoms (Shorrocks, 1997; Dell *et al*. 2006). Deficiency of B has been reported in over 80 countries and on 132 crops over the last 60 years (Shorrocks, 1997) and is by far the most widely reported micronutrient deficiency across a range of soil type and crop (Yan 2006).At the same time, planting of high yielding crop varieties under intensive agricultural management is causing B deficiency in traditionally boron sufficient soils. In plants, deficiency symptoms include brittle, dead spots on leaves, lessening in upper internodes and reduction and absence of tassels and ear shoots (Iowa Extention 2004) while B toxicity symptoms are characterized by tip and marginal burn of the leaves.

Management of B in soils can often become a challenge due to the narrow range between plant deficiency and toxicity symptoms (Keren and Bingham 1985). In an ideal circumstance, a steady and slow supply of B from the applied fertilizer would result in best yields. Boron deficiency can occur in coarse textured soil in comparison with fine textured soil(Malhi *et al*. 2003) and also during drought conditions (Chang, 1993; Barber, 1995).Farming sandy soils is not viable due to high leaching losses of nutrients and insufficient soil water content in the plant root zone. Several studies have also documented that levels of organic matter in soil is positively correlated with available soil B (Niaz *et al*., 2002; Shafiq *et al*., 2008).Various other factors such as calcium (Ca), potassium (K), and nitrogen (N) concentrations in both the soil and plant can affect B availability and plant function, the calcium: boron (Ca:B) ratio relationship being the most important.

In order to achieve best management of B in soils, various types of boron fertilizers have been evaluated under various conditions (Byers *et al*., 2001; Khurana and Arora 2012; Saleem

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et al., 2016).There are mainly three types of Bfertilizer sources - highly soluble refined materials, granulated refined materials of controlled solubility, and granulated ores that have varying degrees of solubility in response to physical and chemical properties (Bell and Dell 2008). With refined source materials, the B is readily dissolved in soil solution and is available for plant uptake. Whereas with granules of controlled solubility and granulated ores, the amount and rate of release for B is slow and such applications can provide optimum supply of B throughout the growing season (Bell and Dell, 2008).Their solubility depends on particle size, proportions of sodium, magnesium, and calcium present in the mineral (Mortvedt, 1994). Sodium borate ($Na_2B_4O_7.5H_2O$) is the most common B fertilizer and it is a soluble product (Martens and Westermann, 1991) while colemanite ($CaB_3O_4(OH)_3{\cdot}H_2O$), is a calcium borate is moderately soluble (Eaton, 1932). Ulexite ($NaCaB_5O_6(OH)_6{\cdot}5H_2O$) and Hydroboracite ($CaMgB_6O_{11}.6H_2O$) have solubility that is intermediate between the sodium and calcium borates.Thus it is evident that the availability and rate of uptake of B will depend on numerous factors including soil physicochemical characteristics, boron sources, and other environmental factors. Marginal soils, primarily coarse textured soil resulting from flood deposited sand, can be brought under cultivation of perineal grasses, bioenergy crops or for the purpose of land reclamation. However, since such soils have poor nutrient conditions it will be necessary to actively manage and supplement nutrients. The objective of this study was to evaluate the solubility and plant uptake of boron in marginal soils in response to different rates of application in four plant species (switchgrass, wheat, corn, and soybean) under greenhouse conditions.

MATERIALS AND METHODS

Boron sources

Various types of B fertilizers were obtained from Etimine USA Inc., a wholly owned subsidiary of Eti Maden of Turkey, the largest producer of boron products in the world. For this study, we obtained four different forms of B fertilizers. Among them, two two belonged to refined boron category while the two were of granulated ore category.The two refined B sources were Etigran-21 granulated form of sodium octaborate tetrahydrate ($Na_2B_8O_{13}.4H_2O$), commercially known as Etigran-21 (21% B); and Etigran (15% B), granular (2-4mm) form of disodium tetraborate pentahydrate ($Na_2B_4O_7.5H_2O$). The two granulated ores were granular colemanite ($CaB_3O_4(OH)_3{\cdot}H_2O$)(13%) (2-4mm) and Granular Ulexite ($NaCaB_5O_6(OH)_6{\cdot}5H_2O$) (11%) (2-4mm).

Experimental design

The study was conducted at Green house complex, Horticulture and Agroforestry Research Center, University of Missouri-Columbia in New Franklin, MO. The light and temperature were maintained at 45% sunlight and 75-90 °F respectively. The potting media wasprepared by homogenously mixing Promix® and white sand at a ratio of 3:1 v/v. Mixing was done using the automatic rotary and prepared media was filled into three gallon pots leaving about 1 inch from the rim. The pots were arranged in a randomized complete block design (RCBD) with four replicatesin the greenhouse benches. The four B sources were added at rates of 0.5, 1.0 and 1.5 mg kg^{-1} of B. No B was added in the control pots (Table 1). Seedlings of switchgrass, corn, soybean, and we were planted at a depth of about 4 -5 cminside the pot. Approximately one week after planting, the pots were fertilized with NH_4NO_3 will at the rate of 30 kg ha^{-1} for switchgrass, wheat, and soybeanwhile for corn the rate was 90 kg ha^{-1}. All pots were watered evenly depending on the moisture status of the media. The plants were harvested above the soil after75 days of planting. Plants were dried in a drying oven at 65°C until constant weight and aboveground biomass was measured. The roots were separated from soil carefully and cleaned using a gentle water flow to remove any remaining debris and soil particles. The roots were also dried similarly as the aboveground plant tissues. The dried plant tissues were ground and dry-ashed prior to B analysis using an inductively coupled plasma atomic emission spectrophotometer (ICP-AES) at the STAR laboratory located at the Ohio State University.

Table. 1 Treatment combinations followed in the experiment. Boron level 0 did not receive any B amount.

	Boron Sources (mg kg^{-1} soil)				
	Level	0	0.5	1	1.5
Fertilizer types	Etigran-21	*	*	*	*
	Etigran	*	*	*	*
	G.Colemanite	*	*	*	*
	G. Ulexite	*	*	*	*

Statistics

Differences in plant aboveground biomass and plant tissue concentration of B were determined using ANOVAin JMP by SAS Institute. Graphs were generated using Sigma Plot 11.0. Assumption of homogeneity of variance was tested using the Levene test. Comparison of means, at a predetermined level of significance ($P < 0.05$), was done using the least significant difference (LSD) method (SAS Institute) after first confirming that treatment effects were statistically significant ($P < 0.05$).

RESULTS AND DISCUSSION

Biomass production

B uptake is greatly influenced by various factors such as plant type, soil type, and other physical, chemical, and environmental conditions. Some of the important factors include pH, moisture, temperature, and available sunlight. In this experiment, the different set of plants were exposed to the same conditions except for variable rates of B application. There was no significant effect of the different B sources on the biomass yields of switchgrass (Figure 1).

Similar trend was observed for other plant species also (data not shown). All crops showed relatively higher biomass production where Etigran-21 was applied. Byers *et al*. 2001 also observed that there was no significant impact of the different B sources on biomass yield of alfalfa (*Medicago sativa*). However, Khurana and Arora (2012) observed 25% increases in seed yield of lentil with the application of B over control samples.

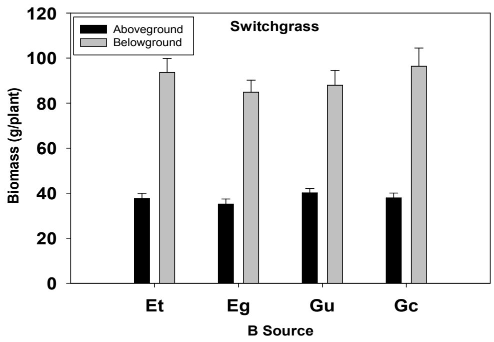

Figure 1 Above and belowground biomass production in switchgrass in response to various sources of B fertilizers. Et-Etigran-21, Eg-Etigran, Gu-Granular Ulexite, Gc-Granular colemanite

Nonetheless, it is important to mention that the lentil experiment was conducted in a field rather than in a greenhouse situation as in this study. B is a micronutrient necessary for various plant physiological functions but not necessarily for increased production of biomass. Above and belowground biomass production was comparable among the control and treatment samples.

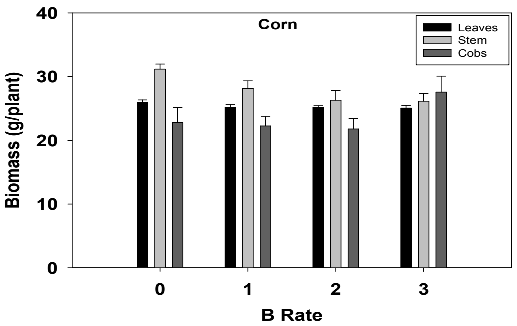

Figure 2 Corn leaf, stem, and cob biomass with different rates of fertilizer application. The different rates are as follows: 0-Control, 1-0.5 mg kg-1, 2-1.0 mg kg-1, and 3-1.5 mg kg-1

Different rate of B application was also insignificant in influencing growth of different plant parts, for example corn leaf, stem, and cobs (Figure 2). Growth of wheat was stunted most likely because of the greenhouse temperature, wheat being a winter crop.

Tissue concentrations

Tissue concentration of B was higher with the refined boron products compared to the boron ores. Amongst the two refined boron products studied, Etigran-21 demonstrated faster uptake by all plants evaluated. Compared to the control, with the highest rate of Etigran-21 corn and soybean leaves recorded almost 770% and 630% increase in B tissue concentration. For the three other sources of B, the increase in tissue concentration was much lower between 260% and 370%. This was probably because Etigran-21 is much more soluble and the B is available to the plants immediately for uptake. Between colemanite and ulexite, although the initial concentrations of B in the materials are slightly different, no significant difference in uptake was observed among the plants.Similar findings were observed by other researchers where application of boron increased the tissue concentration (Byers, 2001; Khurana and Arora 2012)

Overall the data showed increment in tissue B concentration when the application rate increased. Etigran-21 at 1.5 $mgkg^{-1}$ application rate showed highest tissue B concentration in corn, switchgrass and soybean roots (Table 2). Corn and soybean leaves had the highest concentration of B among all plants and tissue types. The mean tissue concentration of B was significantly different in plants with the application of Etigran-21, while the other three B sources were not significantly different among themselves (Figure 4). Soybean leaves showed indications of B toxicity which suggests that soybean is sensitive for high rates of B (Figure 3) in the marginal soils. In marginal soils, such as flood deposited sandy soils, it may not be feasible to grow corn or soybean crops with a decent economic return.

Table. 2 Tissue B concentrations in different parts of the crops selected for the study. Note: Sw stands for swithgrass.

	Corn Leaf	Corn Stem	Corn Cob	Corn Roots	Sw Stem	Sw Root	Wheat Leaves	Wheat Roots	Soy Leaves	Soy Roots
					$\mu g\ g^{-1}$					
Et-0	27.0	0.0	0.0	0.0	0.0	0.0	13.0	0.0	22.2	13.2
Et-1	101.0	8.4	9.0	8.3	9.2	0.0	73.2	14.0	77.6	19.0
Et-2	160.2	8.4	13.6	10.0	17.8	8.9	105.0	23.4	145.7	34.5
Et-3	210.2	10.7	14.8	16.7	27.9	11.4	87.5	17.5	140.6	37.3
Eg-0	27.3	0.0	0.0	0.0	0.0	0.0	9.3	0.0	28.6	8.4
Eg-1	40.4	0.0	0.0	0.0	0.0	0.0	17.4	0.0	39.9	16.8
Eg-2	70.8	18.9	9.2	7.5	6.5	0.0	34.3	8.3	46.7	12.9
Eg-3	99.4	9.3	10.4	7.4	6.6	0.0	40.3	8.3	86.9	18.8
Gu-0	26.4	0.0	0.0	0.0	0.0	0.0	13.1	0.0	23.2	8.0
Gu-1	44.0	0.0	0.0	0.0	0.0	0.0	36.1	0.0	46.6	12.9
Gu-2	66.9	7.7	10.8	7.2	0.0	0.0	21.5	9.1	70.3	14.2
Gu-3	78.9	8.2	13.4	7.8	7.9	0.0	38.2	8.8	60.5	17.5
Gc-0	26.6	0.0	0.0	0.0	0.0	0.0	12.8	0.0	22.9	0.0
Gc-1	41.3	7.1	14.4	0.0	0.0	0.0	20.5	0.0	45.1	18.1
Gc-2	65.6	0.0	8.2	0.0	6.4	0.0	31.3	9.3	60.8	11.1
Gc-3	81.3	7.3	9.0	7.2	6.9	0.0	34.1	9.9	64.6	22.9

Figure 3 B toxicity as observed on soybean leaf with application of Etigran-21.

corn, soybean, wheat and switchgrass. Highly soluble B source seems to be the effective among B sources. Etigran-21 was found to be toxic to soybean plants, most likely due to its high solubility. Corn and switchgrass grew without showing any visible toxicity with all forms of applied B sources.Etigran, granular colemanite, and ulexite showed slow release potential and thus can be applied for slow continuous release throughout the season.While soybeans showed indications of toxicity at higher rates, especially with Etigran-21, no visible toxicity was observed in switchgrass for any applied B source and for all rates.Future research to evaluate agronomic efficiency, physiological efficiency, and nutrient recovery of B has to be conducted under field conditions by carrying the plants to full maturity.

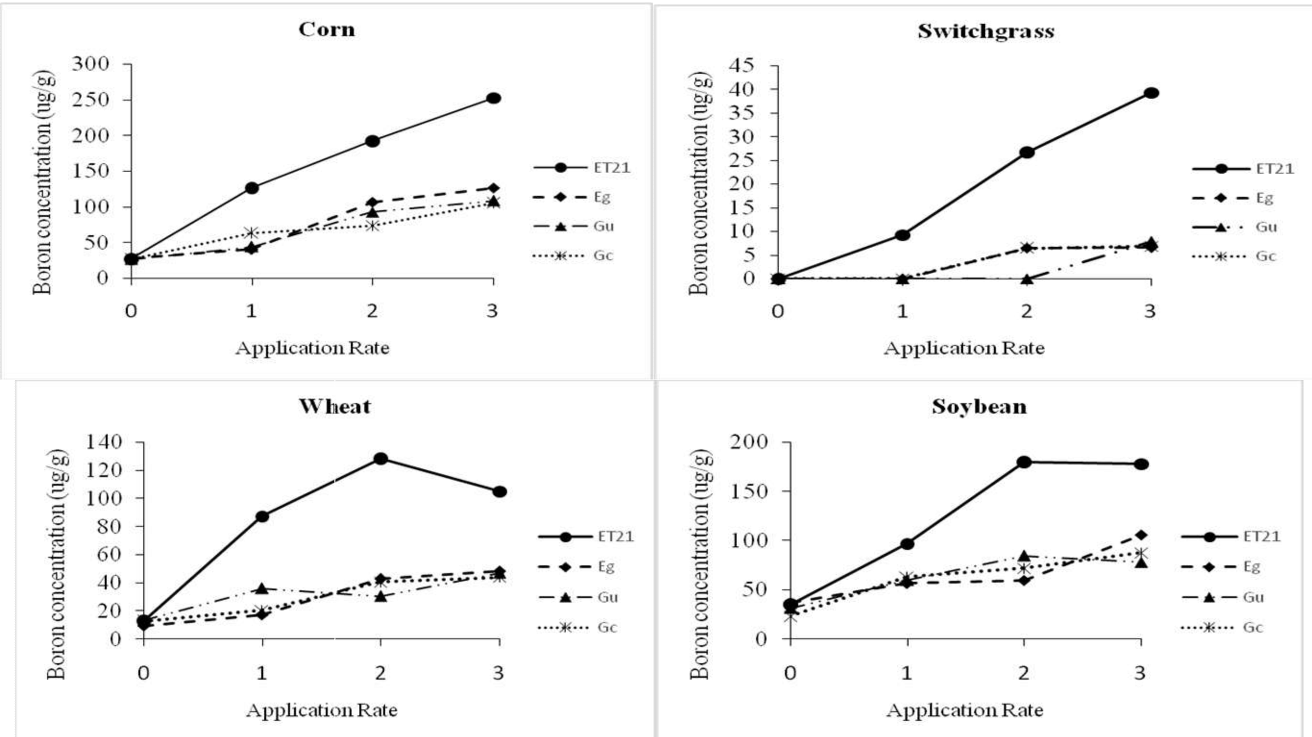

Figure 4 Tissue B concentrations of corn, switchgrass, wheat and soybean leaves for four different B sources having three levels of application rates.

However, with little manipulation of nutrient status it may be feasible to grow bioenergy crops such as switchgrass. Although, soybean in general is considered fairly insensitive to B deficiency, recently in many areas B deficiency was reported for soybean (Ross *et al*. 2006). However, higher rates of B can result in boron toxicity as observed in our experiment. Therefore proper rates of B application and evaluation of B sources would be critical in managing B fertilization in such crops.

CONCLUSION

In the greenhouse study, neither the source nor the rate of B resulted in increased biomass production for any plant species. The four B sources showed different rates of availability to

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