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Effect of Boron and Lime on Boron Transformation in a Fluvaquentic Humaquepts Soil Concerning Uptake and Yield of Green Gram

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Understanding different fractions and availability of boron (B) is essential while studying the response of crops towards B. Fractionation provides information about the chemistry of B and quantifies its bioavailability. Therefore, a pot experiment was performed during the 2019 pre-*kharif* season in acid soil to study soil B fractions and response of green gram (*Vigna radiata* L.) to B application. Lime is applied to such soils with the primary objective of increasing the productivity of crops by enhancing the availability of native and applied plant nutrients. On the contrary, availability of B in soil was increase due to liming. The treatments comprised of five levels of soil applied B (0, 0.5, 1.0, 1.5 and 2.0 mg B kg^{-1}) and two levels of lime, lime and no lime was used. The experiment

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was laid out in factorial randomized block design (FRBD) with three replications. The soil and pant growth parameters were recorded at a regular interval of 15 days after sowing, and at harvest. All the result revealed that the changes in different fractions of B (viz., readily soluble, specifically adsorbed, oxide bound, organically bound, residual and total B), its plant uptake and yield of green gram are significantly affected by the application of B and lime. All the fractions contribute towards plant available boron form. Inter conversion between B fractions was also observed. The application of B and lime significantly influenced different B pools, boron uptake and yield of green gram.

Keywords: Lime; boron; boron fraction; uptake and yield.

1. INTRODUCTION

"Micronutrients such as B play an important role in achieving the potential yield of green grams. Boron exists in the soil in five fractions. They are soluble, with specific adsorbed, oxide bound, organically bound, and residual boron properties" [1]. "The proportions of boron in soil are as follows: residual boron > organically bound boron > specifically adsorbed boron > readily soluble boron > oxide bound boron. The relative proportion of boron in the fractions and the transformation among these fractions are affected by a variety of factors such as soil pH, clay mineral, Fe and Al oxide, $CaCO_3$ content, and so on" [2,3,4].

"Among the micronutrients, the B is most widespread in acid soils. Under acid soil conditions, boron is more water soluble therefore leaches below the root-zones of plants by rainfall, coupled with adsorption by aluminium (Al) and iron (Fe) oxide minerals. The difference between deficiency and toxicity is very narrow and, therefore, boron requires careful fertility management. Depending on the crop, it has a relatively low quantitative need. Micronutrients like B also have a significant effect on achieving the potential yield of green gram. Thus, applying B not only enhanced the boron concentration and dry matter yield of green gram but also improved the quality of green gram" [5]. The effect of liming on the availability of boron in soil is usually assessed by plant uptake data, which requires elaborate experimentation involving plants.

"Liming, reduces soil acidity, B availability due to adsorption on freshly precipitated Al and Fe hydroxides" [6]. "Boron has a close relationship with calcium both in soil and in plant. Ca increases the B requirement of plants due to similarity in function" [7]. "However, little information available on the effect of liming, particularly at lower levels, on nutrient availability in acid soils. Liming has been shown to have both negative and positive effects on nutrient availability in acid soils and subsequent crop uptake" [8]. The transformation of added B in lime-amended acid soils is poorly understood. A better understanding of the distribution of B in various soil fractions and their relationships with plant response, particularly in lime-amended soils, would provide a foundation for assessing soil B availability to plants and developing appropriate management strategies to combat B deficiency in acid soils.

"Depending on the crop, its quantitative requirement is very low. Thus, the use of B not only increased yield but also improved green gram quality. The effect of liming on boron availability in soil is typically assessed using plant uptake data, which necessitates extensive plant experimentation. Proper micronutrient management in acid soils has been discovered to be extremely important in sustaining higher crop yields" [9]. The present investigation was undertaken to study the effect of boron and lime on born fractions, its uptake, and yield of green gram (variety DGGS-4) in a Fluvaquentic Humaquepts soil. However, only a few Micronutrients forms are available to plants and their determination is important for estimation of its availability to plants. This study has attempted to estimate the application of boron and lime on different levels of boron. With this preview, the present investigation was programmed to quantify the different forms of B in soil.

2. MATERIALS AND METHODS

2.1 Sampling Location and Soil Characteristic

A pot experiment was conducted during pre-*Kharif* 2019, at the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Iroisemba, Central Agricultural

University, Imphal. The experiment was carried out under factorial randomized block design (FRBD) with ten treatments replicated three times. The general characteristics were presented in Table 1.

2.2 Incubation Experiment

Five kg each of air-dried soil was taken in a series of pots. The required quantity of N @ 20 kg ha^{-1}, P_2O_5 @ 40 kg ha^{-1}, and K_2O @ 20 kg ha^{-1} was applied to all the pots as basal dose through urea, SSP, and MOP and also mixed with the soil. Lime was added 7 days before sowing and boron with borax (B-11%) as source material for basal application. The lime requirement was determined by the method described by Shoemaker *et al.,* (1961). For the current study five boron levels i.e. B_1=0 kg ha^{-1}, B_2=0.5 kg ha^{-1}, B_3=1.0 kg ha^{-1}, B_4=1.5 kg ha^{-1}, B_5=2.0 kg ha^{-1} and two levels of lime L_1= unlime, L_2= lime. A stock solution of the known concentration was prepared using mineralized water. From the stock solution, a series of working solutions were prepared and sprayed on the soil by the different treatment levels and mixed thoroughly the green gram *var*. DGGS-4 was sowing in each pot. The pots were irrigated with water throughout the crop growth period maintaining 60 % water-holding capacity (WHC). The whole plants were collected on the 15th, 30th, 45th, and 60th days after sowing (DAS) and at harvest by destructive sampling.

2.3 Laboratory Procedures

Different B fractions in soil samples were determined according to Datta *et al.,* [17]. Readily soluble B was extracted by 0.01 M $CaCl_2$, specifically adsorbed B with 0.05 M KH_2PO_4, oxide bound B with 0.175 M ammonium oxalate (pH 3.25), organically bound B with 0.5 M NaOH, and residual B with soil digestion in H_2SO_4, HF, and $HClO_4$. Boron in the extracts was determined colorimetrically by the azomethine-H method [16] depending on the extraction medium. All above fractions i.e., readily soluble B to residual B were summed- up to get the total B content of the soil. Green gram yield data were collected as per the standard method.

The processed plant samples were subjected to dry ashing at 550 – 600°C in a muffle furnace for (time) followed by the addition of 0.1 N HCl, and the total B in the extracts was determined colorimetrically by using the azomethine-H method at 420 nm wavelengths.

Table 1. General characteristics of the soil used in the experiment

Soil Characteristics	Results	Methods
Textural Class	Clayey soil	Bouyoucos, [10]
Sand (%)	24.32	
Silt (%)	21.01	
Clay (%)	54.67	
pH (1:2.5 Soil: water ratio)	5.2	Jackson, [11]
EC (1:2.5 Soil: water ratio, dSm^{-1})	0.15	Jackson, [11]
CEC [cmol(p^+) kg^{-1}]	17.2	Borah et al., 1987
Lime requirement (ton/ha)	4.62	Shoemaker *et al.,* [12]
Organic carbon (%)	1.18	Walkley and Black, [13]
Available nitrogen (kg ha^{-1})	274.59	Subbiah and Asija, [14]
Available phosphorus (kg ha^{-1})	19.20	Bray and Kurtz, [15]
Available potassium (kg ha^{-1})	208.37	Jackson, [11]
Calcium (mg kg^{-1})	215.6	Jackson, [11]
Magnesium (mg kg^{-1})	34.10	Jackson, [11]
Sulfur (mg kg^{-1})	17.48	Jackson, [11]
Boron (mg kg^{-1})	0.18	John *et al.,* [16]
Readily soluble boron (mg kg^{-1})	0.62	Datta *et al.,* [17]
Specifically adsorbed boron (mg kg^{-1})	2.21	
Oxide-bound boron (mg kg^{-1})	6.32	
Organically bound boron (mg kg^{-1})	8.55	
Residual boron (mg kg^{-1})	110.04	
Total boron (mg kg^{-1})	127.71	

2.4 Statistical Analysis

ANOVA was performed on all the data to test the statistical significance of the effects of the treatment. The significance of various effects was tested at 5% level of probability.

3. RESULTS AND DISCUSSION

3.1 Readily Soluble Boron

Readily soluble B fraction in soil significantly decreased with increasing levels of applied lime (Fig. 1). Application of lime raises soil pH; boron fixation generally increases in soils [18]. Compared to the control, the B applied system had a higher RS-B in soil. When comparing different B applications, soil applied with B_5 (2 kg B ha^{-1}) had significantly higher Readily Soluble-B, which was comparable to B_4 (1.5 kg B ha^{-1}) and B_3 (1 kg B ha^{-1}) at different stages of crop growth. According to an interaction study, the application of boron at 0, 0.5, 1.0, 1.5, and 2.0 kg B ha^{-1} with or without lime had no significant effect on readily soluble boron accumulation in the soil at different crop growth stages. Application of B had a positive impact on this fraction. "Application of lime generally increased the B fixation in soils because it raised the soil pH. In addition to its effect on soil pH, $CaCO_3$ also acts as an important B adsorbing surface in soil" [18]. Reduction in readily soluble B fraction may be responsible for severe reduction in dry matter yield in lime treated pot, particularly where no B was applied. According to Barman *et al.,* [19], readily soluble boron decreases with lime application due to increased B sorption caused by elevated levels of calcite in the soil.

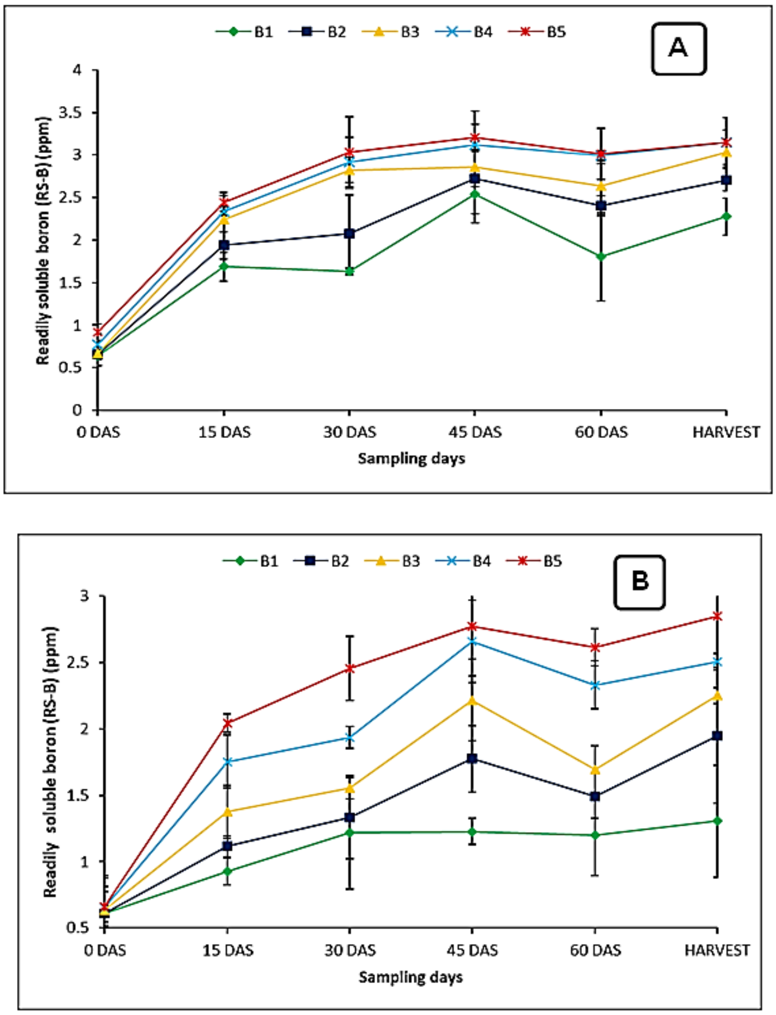


Fig. 1. Effect of boron and lime on readily soluble boron (ppm) content in soil grown with green gram (Error bar showing Standard Error of Mean)
(A) Unlimed; (B) Limed

3.2 Specifically Adsorbed Boron (SA-B)

There was no significant relationship of specifically adsorbed B with lime application, while this fraction of B was positively and significantly affected by the application of B (Fig. 2). These fractions of boron are referred to as so due to their specificity to get adsorbed may be specifically adsorbed onto clay surfaces or associated with organic matter in the soil [20]. It is primarily determined by the clay content of the soil. This fraction is in plant available form after RS-B. [21]. Unlimed soil had significantly higher content of SA-B fraction than limed soil (Fig. 2). Kanprath [22] reported that limed soils with high oxide coatings increased B by clays and decreased B availability. As a result, liming reduces the availability of B in soils. SA-B content in soil treated with 2 kg B ha^{-1} was significantly higher than other treatment except soil treated with 1.5 kg B ha^{-1} throughout the crop growth period. Datta *et al.* [17] inferred that "specifically adsorbed B originates from the weakly binding sites of both organic and inorganic constituents of soil and none of these constituents contributes exclusively towards this B fraction. This may partially explain the non-significant effect of liming on specifically adsorbed B in soil".

3.3 Oxide-bound Boron

Effect of liming on oxide bound fraction of B was irregular. Whereas, effect of B application had a positive effect on oxide bound B fraction in soil. It is a less labile form of B i.e. it is in inaccessible forms [23]. Fig. 3 showed, soil treated with boron had significantly higher oxide bound boron than the control. On the 45th and 60th DAS and at harvest, soil applied with B_5 (2 kg B ha^{-1}) had a statistically higher oxide bound boron content than soil applied with B_4 (1.5 kg B ha^{-1}) followed by B_3 (1 kg B ha^{-1}) and B_2 (0.5 kg B ha^{-1}). Similar reports on increased oxide bound boron with increasing levels of boron were presented by Karthikeyan and Shukla [24], Barman *et al.,* [19], and Sidhu and Kumar (2018). On the 60th DAS and at harvest, limed soil with B_5 (2 kg B ha^{-1}) had statistically higher oxide bound boron than limed soil with B_4 (1.5 kg B ha^{-1}). It appears that substantial amount of applied B goes to oxide bound fraction as a result of liming. Regardless of liming, boron application positively affect the oxide bound boron fraction in soil. Lime addition increased the oxide bound boron content in soil significantly more than no lime addition during the entire study period.

3.4 Organically Bound Boron

There was no significant relation of organically bound B fraction in soil with both lime and B application (Fig. 4). Among the various boron applications, B2 (0.5 kg B ha^{-1}) had statistically higher organically bound boron, compared to B_5 (2 kg B ha^{-1}) during the entire growth period. Hou *et al.* [25] and Barman *et al.* [19] made similar observations regarding the decline in organically bound boron with increasing boron levels. An interaction study revealed that boron and lime application had a significant effect on organically bound boron at different growth stages, with the exception of the 60th DAS, where no significant difference was observed. Organic matter adsorbs boron [19] thus reducing its availability for plant uptake, accounting for 2-8 % of total-B content in soil [26]. The conversion of other boron fractions to this boron fraction is responsible for the increase in organically bound boron [24].

3.5 Residual Boron

Effect of lime and B application residual fraction of B in soil was not statistically significant. The interactive effect of lime on this fraction was also not significant. It was observed that throughout the experimental period soil treated with lime had significantly elevated levels of residual boron in soil compared to unlimed soil. During the growth stages of green gram, a significant interaction effect of boron and lime application on residual boron content was observed. Among the various treatment combinations, limed soil with 2 kg B ha^{-1} (B5L2) had a statistically higher residual boron content than limed soil with 1.5 kg B ha^{-1} (B_4L_2) and 1 kg B ha^{-1} (B_3L_2) throughout the entire stages of green gram growth (Fig. 5). This is the largest fraction among all the other fractions of B, which has nothing to do with plant available B [20,21,27]. Residual boron gradually decreased until harvest. At different stages of green gram growth, the boron-treated system had significantly higher residual boron concentrations than the untreated control.

3.6 Total Boron

A decreasing pattern of total boron with crop growth was observed until crop harvest [28]. As shown in Fig. 6. Adding lime resulted in a statistically higher total boron in the soil. Again, a significant interaction effect of boron and lime addition levels on total boron concentration was observed. On the 60th DAS and at harvest, interaction data revealed that total boron concentration was comparatively higher in limed soil applied with 2 kg B ha^{-1} (B_5L_2), followed by the same limed soil applied with 1.5 kg B ha^{-1} (B_4L_2). The total boron concentration (T-B) varies depending on its parent material and degree of weathering [29].

3.7 Uptake

Boron uptake in green gram increased until harvest. A critical examination of the results revealed that green gram grown in boron-applied systems at various stages of crop growth absorbed significantly more boron than the control (Fig. 7). Among the various B applications, soil applied with B_5 (2 kg B ha^{-1}) had the highest boron uptake, followed by B_4 (1.5 kg B ha^{-1}), B_3 (1kg B ha^{-1}) and B_2 (0.5 kg B ha^{-1}) at different sampling stages, with a significant difference. The results of the 15th and 45th DAS, the results show that lime application significantly reduced boron uptake by green gram compared to the no lime applied system. This is supported by the finding that liming acid soil reduced available soil boron and its uptake by green gram, resulting in B deficiency [6]. On the 30th and 60th DAS, as well as at the harvest, limed soil had statistically higher boron uptake than unlimed soil. The interaction effect revealed significant differences in plant boron uptake across all growth stages when combining boron and lime. On the 15th, 30th, and 45th DAS, soil treated with B_5L_1 had significantly higher boron uptake.

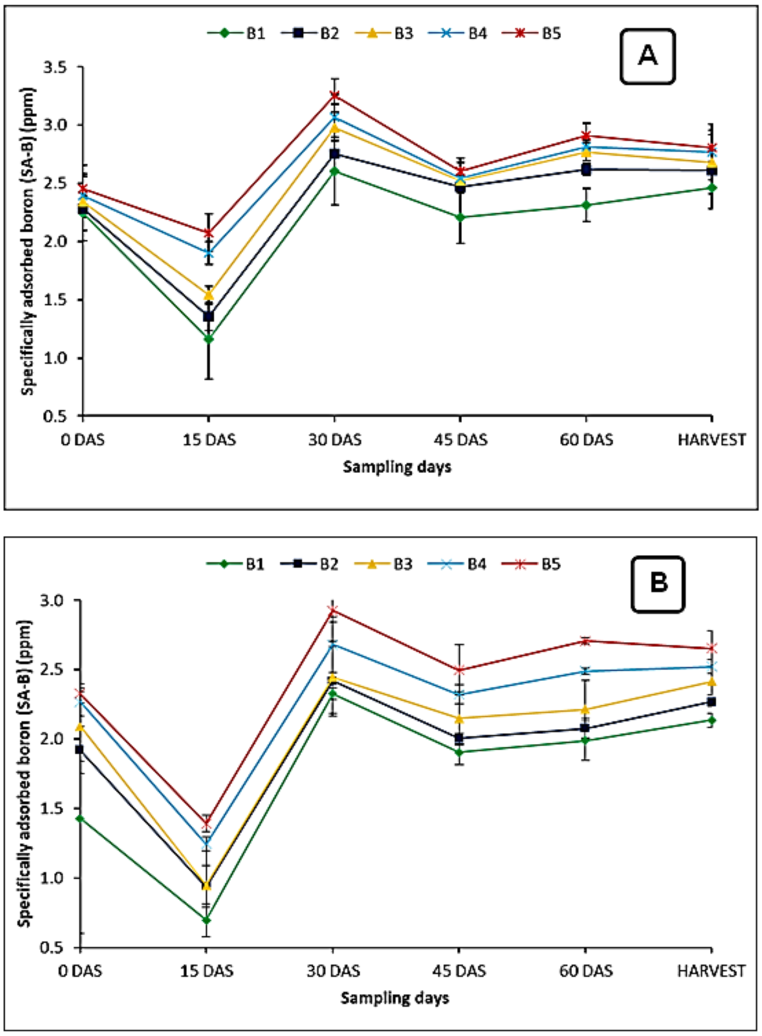


Fig. 2. Effect of boron and lime on specifically adsorbed boron (ppm) content in soil grown with green gram (Error bar showing Standard Error of Mean)
(A) Unlimed; (B) Limed

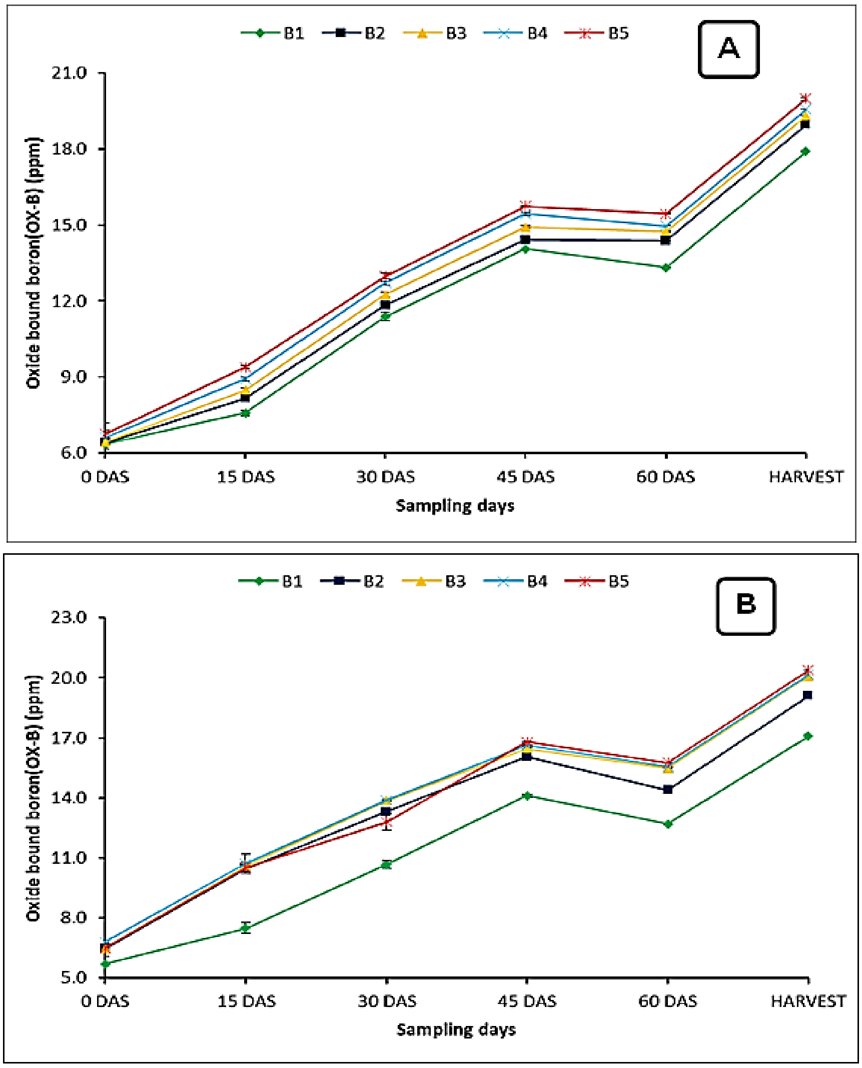
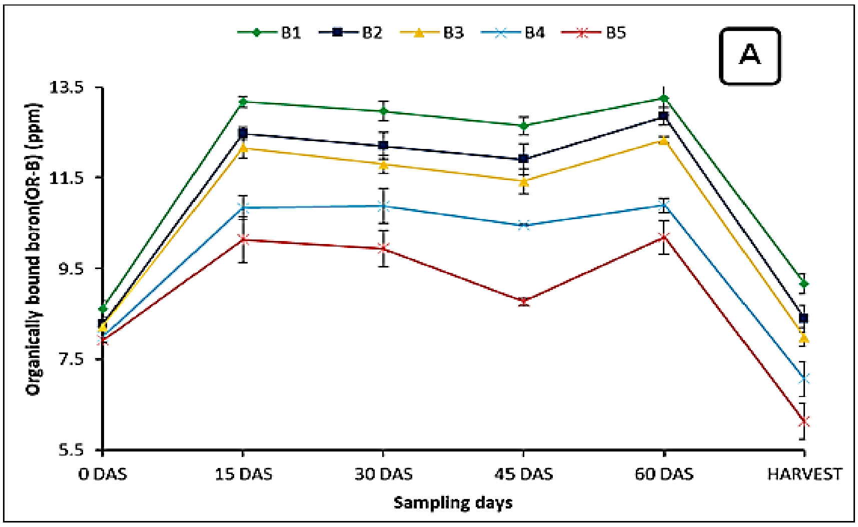


Fig. 3. Effect of boron and lime on oxide bound boron (ppm) content in soil grown with green gram (Error bar showing Standard Error of Mean)
(A) Unlimed; (B) Limed



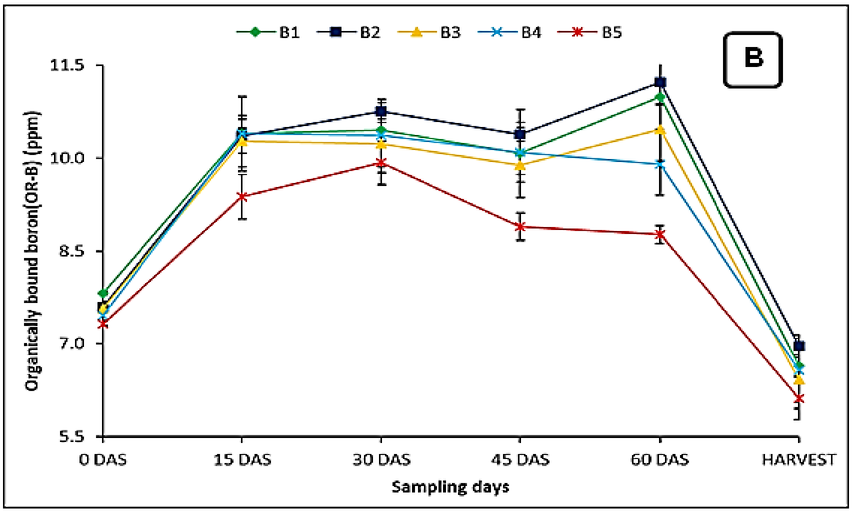


Fig. 4. Effect of boron and lime on organically bound boron (ppm) content in soil grown with green gram (Error bar showing Standard Error of Mean) (A) Unlimed; (B) Limed

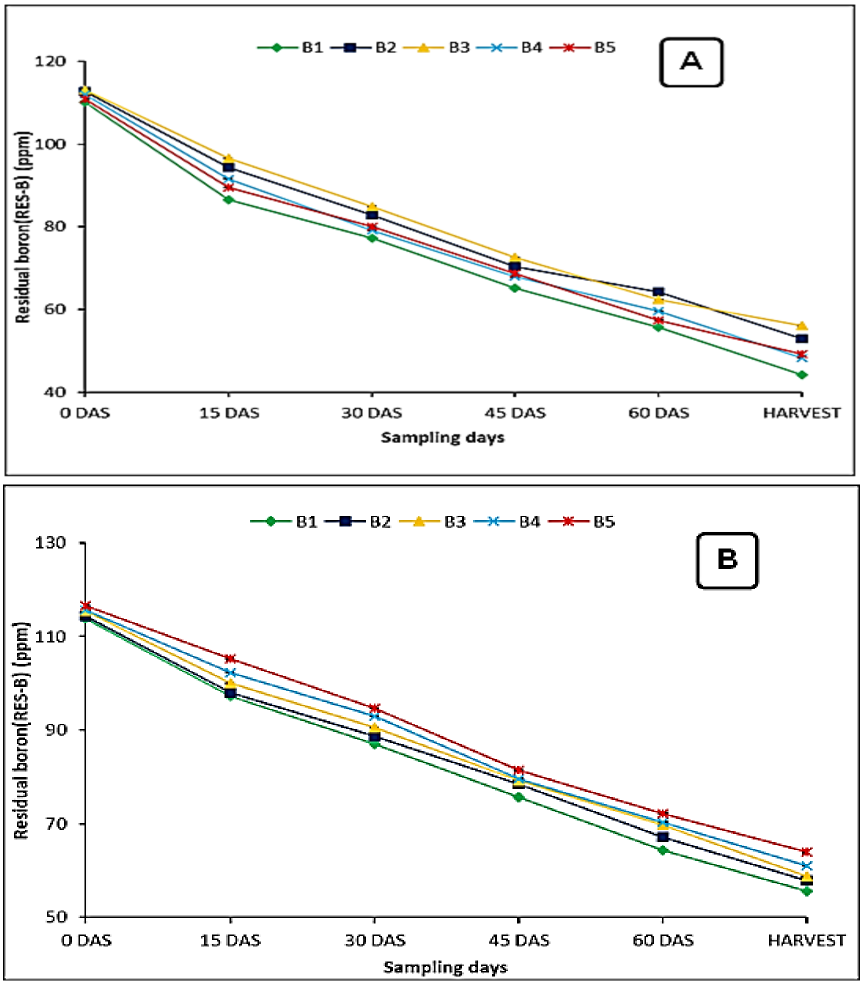


Fig. 5. Effect of boron and lime on residual boron (ppm) content in soil grown with green gram (Error bar showing Standard Error of Mean) (A) Unlimed; (B) Limed

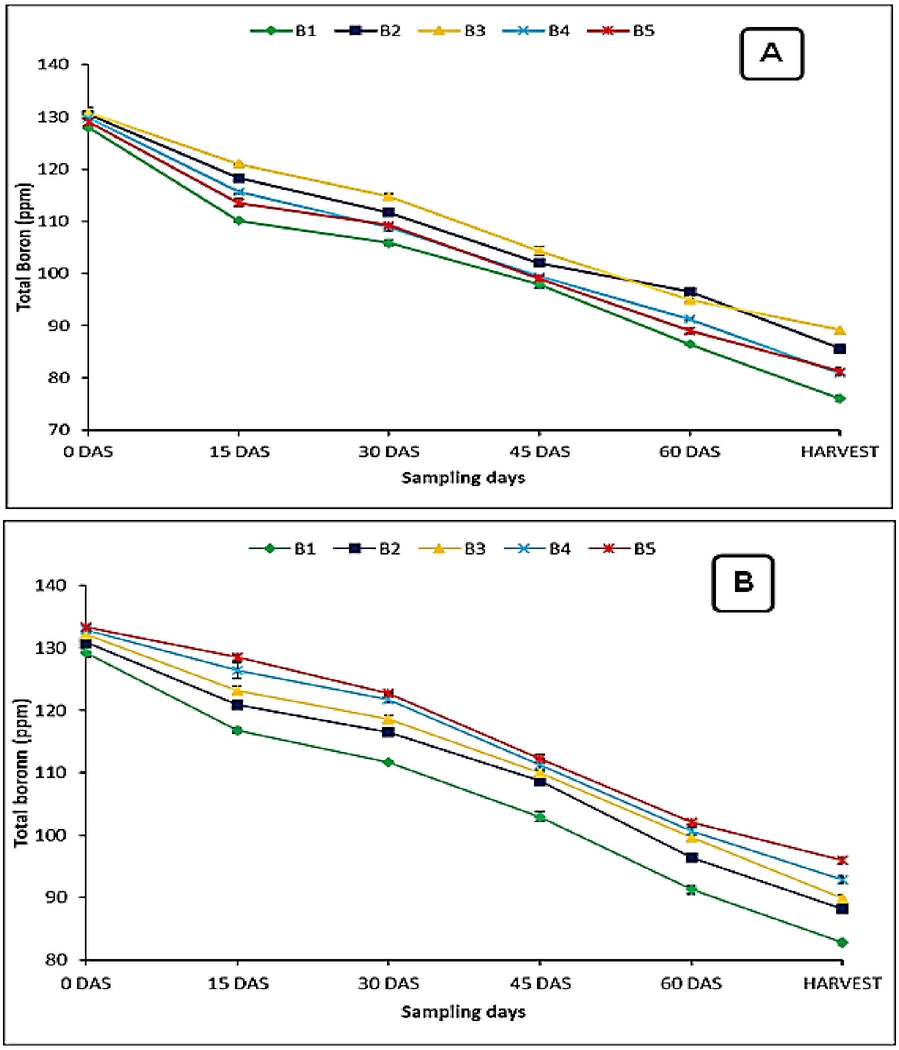
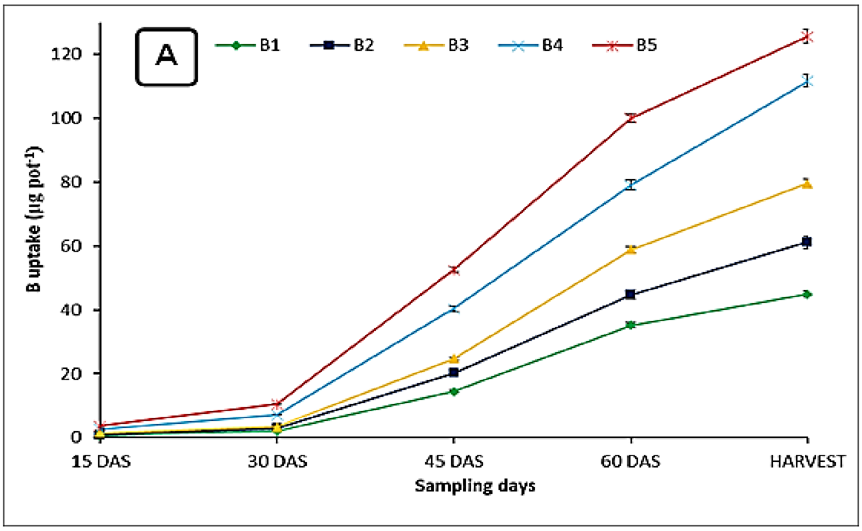


Fig. 6. Effect of boron and lime on total boron (ppm) content in soil grown with green gram (Error bar showing Standard Error of Mean)
(A) Unlimed; (B) Limed



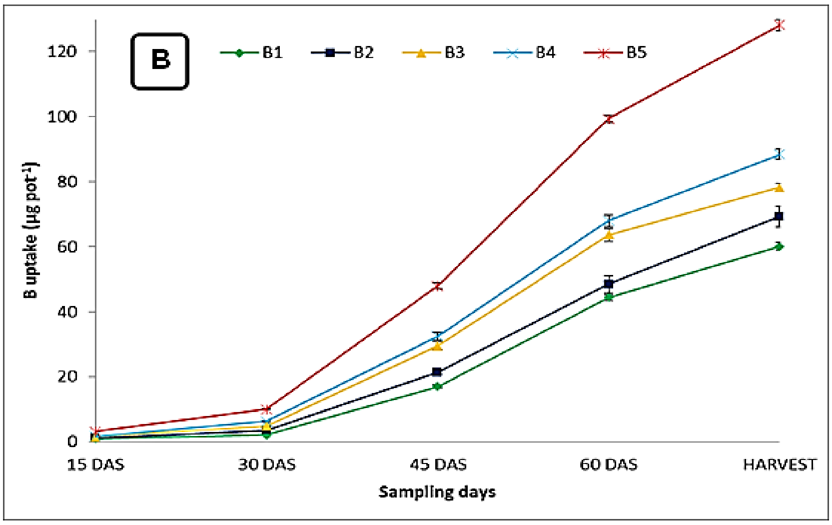


Fig. 7. Effect of boron and lime on boron uptake (µg pot-1) by green gram (Error bar showing Standard Error of Mean)
(A) Unlimed; (B) Limed

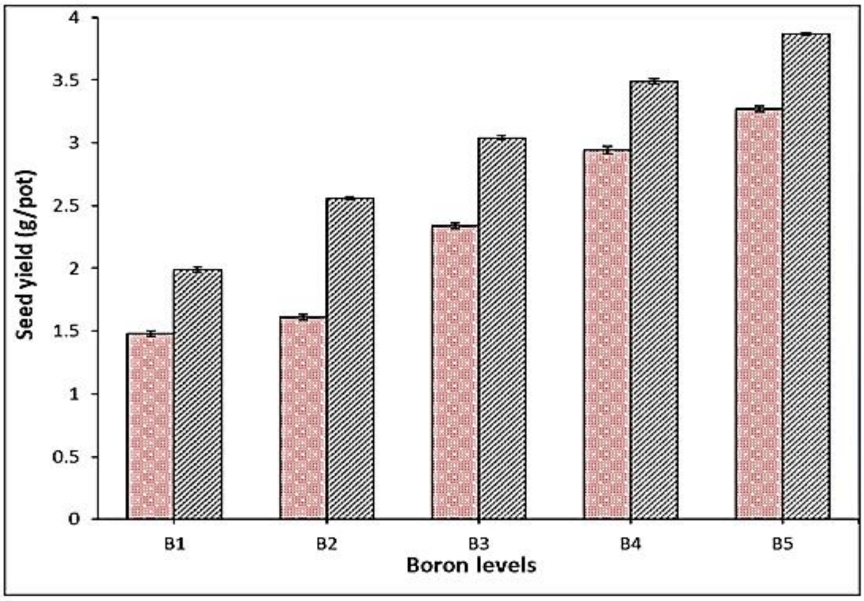


Fig. 8. Effect of boron and lime on seed yield of green gram (g pot-1):
Unlimed
Limed

Boron levels: B_1 = B @ 0 Kg ha^{-1} ; B_2 = B @ 0.5 Kg ha^{-1}; B_3 = B @ 1.0 Kg ha^{-1}; B_4 = B @ 1.5 Kg ha^{-1} ; B_5 = B @ 2.0 Kg ha^{-1}
Liming: L_1= Unlimed; L_2= Limed

3.8 Seed Yield of Green Gram

Green gram seed yield (seed weight, g plant^{-1}) was higher in the boron and lime-treated system than in the control. The seed yield of green gram increased significantly as the boron level increased up to 2 kg B ha^{-1} (Fig. 8). The yield in the boron-treated soil was significantly higher at 2 kg ha^{-1}, followed by 1.5 kg ha^{-1}, 1 kg ha^{-1}, and 0.5 kg ha^{-1}. It was also discovered that, regardless of boron application, the incorporation of lime increased seed yield significantly more than without lime. A detailed analysis of the interaction effect revealed that limed soil applied with 2 kg B ha^{-1} (B_5L_2) produced significantly higher seed yield than 1.5 kg B ha^{-1} + lime (B_4L_2), which was statistically equivalent to 2 kg B ha^{-1} + unlime (B_5L_1). Boron-treated soil combined with lime produced a higher seed yield. Hirpara *et al.,* [30] and Kamboj and Malik [31] reported similar findings [32-35].

4. CONCLUSION

Liming significantly reduced the fraction of readily soluble B, specifically adsorbed B, and organically bound B in soil. However, the use of B had a positive effect on various fractions. Soil residual and total boron content decreased gradually as growth stages progressed until harvest. Regarding plant boron uptake, the interaction effect revealed significant differences between boron and lime combinations. Green gram (variety DGGS-4) seed yield was significantly higher in limed soil applied with 2 kg B ha^{-1} than in acid soil. Boron's agronomic effectiveness increased when applied at a higher dose with lime.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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