Original Research Article

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

Abstract

~~Understand~~ 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 investigate the effect of different levels of boron and lime on boron fractions (viz., readily soluble, specifically adsorbed, oxide bound, organically bound, residual, and total boron), uptake and yield of green gram (*Vigna radiata* L.) as a test crop. The plant growth parameters were recorded at a regular interval of 15 days after sowing and at harvest. All the experiments were conducted with three replicates following factorial randomized block design (FRBD). The result revealed that the changes in different fractions of boron, its plant uptake and yield of green gram are significantly affected by the application of boron and lime. All the fractions contribute towards plant-available boron form. Interconversion between boron fractions was also observed. The application of boron and lime significantly influenced different boron pools, boron uptake, and yield of green gram.

Keywords: *lime, boron, boron fraction, uptake, and yield.*

Introduction

Micronutrients such as B play an important role in achieving the potential yield of green grams. Boron has a close relationship with calcium both in soil and in plants. Ca increases the B requirement of plants due to similarity in function (Golakya and Patel, 1986). Boron exists in the soil in five fractions. They are ~~easily~~ soluble, with specific adsorbed, oxide-bound, organically bound, and residual boron properties (Padbhushan and Kumar 2017). 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 (Raina *et al.*, 2006; Anitha *et al.*, 2013; Patra *et al.*, 2018).

Among the micronutrients, the ~~deficiency of~~ boron (B) deficiency is most widespread in acid soils. ~~As~~ Under acid soil conditions, boron is more water soluble, ~~and therefore leaches~~ it, 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 ~~to achieve~~ on achieving the potential yield of green grams. Thus, ~~the application of~~ applying B not only enhanced the boron concentration and dry matter yield of green grams but also improved the quality of green grams (Das *et al.*, 2020). 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, ~~which~~ reduces soil acidity, ~~also reduces~~ B availability due to adsorption on freshly precipitated Al and Fe hydroxides (Tsadilas and Kassioti, 2005). However~~, there is little information~~ 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 (Quaggio *et al.*, 2004). 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 (Bhupalraj *et al.*, 2005). 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 micronutrient forms are available to plants and their determination is important for estimation of its availability to plants. ~~An attempt has been made in this study~~ This study has attempted to estimate the application of boron and lime on different ~~forms~~ 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 ~~total of~~ ten treatments replicated three times. The general characteristics are presented in **Table 1**.

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

Soil Characteristics	Results	Methods
Textural Class	Clayey soil	Bouyoucos, 1962
Sand (%)	24.32	
Silt (%)	21.01	
Clay (%)	54.67	
pH (1:2.5 Soil: water ratio)	5.2	Jackson, 1973
EC (1:2.5 Soil: water ratio, dSm^{-1})	0.15	Jackson, 1973
CEC [cmol(p^{+}) kg^{-1}]	17.2	Borah et al., 1987
Lime requirement (ton/ha)	4.62	Shoemaker *et al.*, 1961
Organic carbon (%)	1.18	Walkley and Black, 1934
Available nitrogen (kg ha^{-1})	274.59	Subbiah and Asija, 1956
Available phosphorus (kg ha^{-1})	19.20	Bray and Kurtz, 1945
Available potassium (kg ha^{-1})	208.37	Jackson, 1973
Calcium (mg kg^{-1})	215.6	Jackson, 1973
Magnesium (mg kg^{-1})	34.10	Jackson, 1973
Sulfur (mg kg^{-1})	17.48	Jackson, 1973
Boron (mg kg^{-1})	0.18	John *et al.*, 1975
Readily soluble boron (mg kg^{-1})	0.62	Datta *et al.*, 2002
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	

3.2. 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 ~~in accordance with~~ 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 ~~while~~ 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.

Laboratory procedures

Different B fractions in soil samples were determined according to Datta *et al.* (2002). 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 (John *et al.*, 1975), 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.

Statistical analysis

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

Results and Discussion

Readily soluble boron

Among all the fractions, readily soluble boron (RS-B) is the first and most easily accessible form for plant uptake, as it is in soil solution or is weakly adsorbed by soil particles (Jin *et al.*, 1988). When lime was added to the soil, there was a significant decrease in readily soluble boron content in the soil however, there was no effect to boron content in unlimed soil **(Figure 1)**. According to Barman *et al.* (2017), readily soluble boron decreases with lime application due to increased B sorption caused by elevated levels of calcite in the soil. Application of lime raises soil pH; boron fixation generally increases in soils (Goldberg 1997). ~~In comparison~~ 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, 1.5, and 2 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.

Specifically adsorbed boron (SA-B)

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 (Jin *et al.*, 1987). It is primarily determined by the clay content of the soil. This fraction is in plant-available form after RS-B. (Tsalidas *et al.*, 1994). Unlimed soil had a significantly higher content of SA-B fraction than limed soil **(Figure 2)**. Kanprath (1971) 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 ~~found to be~~ significantly higher than other treatments except soil treated with 1.5 kg B ha^{-1} throughout the crop growth period. This is in corroboration with the findings of Karthikeyan and Shukla (2011); Sathya *et al.* (2013); Padbhushan and Kumar (2015b). An interaction study revealed that liming and boron did not affect this fraction at different crop growth stages.

Oxide-bound boron

The oxide-bound boron (Ox-B) fraction is associated with Fe and Al oxides and hydroxides. Manganese (Mn) is incorporated into the structure via isomorphous substitution (McLaren and Crawford 1973; Tessier *et al.*, 1979; Shuman 1985). It is a less labile form of B i.e. it is in inaccessible forms (Jin *et al.*, 1988). **Figure 3** showed ~~that during the entire crop growth stages,~~ 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 (2011), Barman *et al.* (2017), and Sidhu and Kumar (2018). Regardless of liming, boron application positively affected 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. According to an interaction study, the effect of liming with applied boron on the oxide-bound boron fraction in soil was found to be significant throughout the entire growth stages. On the 60th DAS and at harvest, limed soil ~~applied~~ with B_5 (2 kg B ha^{-1}) had statistically higher oxide-bound boron than limed soil ~~applied~~ with B_4 (1.5 kg B ha^{-1}).

Organically bound boron

Organic matter adsorbs boron (Goldberg, 1997), thus reducing its availability for plant uptake, accounting for 2-8 % of total-B content in soil (Padbhushan and Kumar, 2015a). The conversion of other boron fractions to this boron fraction is responsible for the increase in organically bound boron (Karthikeyan and Shukla, 2011) from **Figure 4**, it was evident that the addition of lime to the soil significantly lowers the organically bound boron content in soil compared to a no lime applied system. Among the various boron applications, B_2 (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.*, (1994) and Barman et al. (2017) 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.

Residual boron

This is the largest fraction among all the other fractions of B, which has nothing to do with plant available B (Jin *et al.*, 1987; Tsalidas *et al.*, 1994; Padbhushan and Kumar, 2015b). 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. 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 ~~entire~~ 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} (B_5L_2) 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 (**Figure 5**).

Total boron

The total boron concentration (T-B) ~~in the soil~~ varies depending on its parent material and degree of weathering (Barber, 1995). A decreasing pattern of total boron with crop growth was observed until crop harvest (Sathya *et al.*, 2013). As shown in **Figure 6**. Adding lime resulted in a statistically higher ~~amount of~~ 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).

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 crop growth stages absorbed significantly more boron than the control **(Figure 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 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 (Tsadilas and Kassioti 2005). 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.

Seed yield of Green gram

Green gram yield (seed weight, g plant-1) was higher in the boron and lime-treated system than in control. The seed yield of green gram increased significantly as the boron level increased up to 2 kg B ha^{-1} **(Figure 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.* (2017) and Kamboj and Malik (2018) reported similar findings.

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 ~~in combination~~ with lime.

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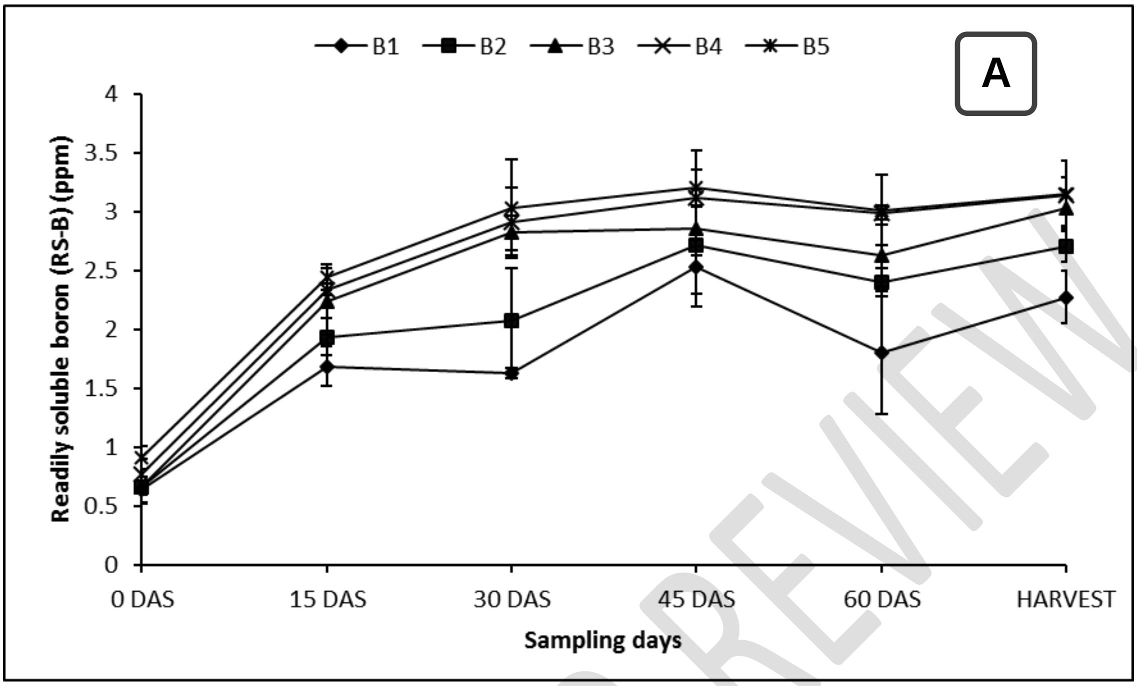
FIGURES



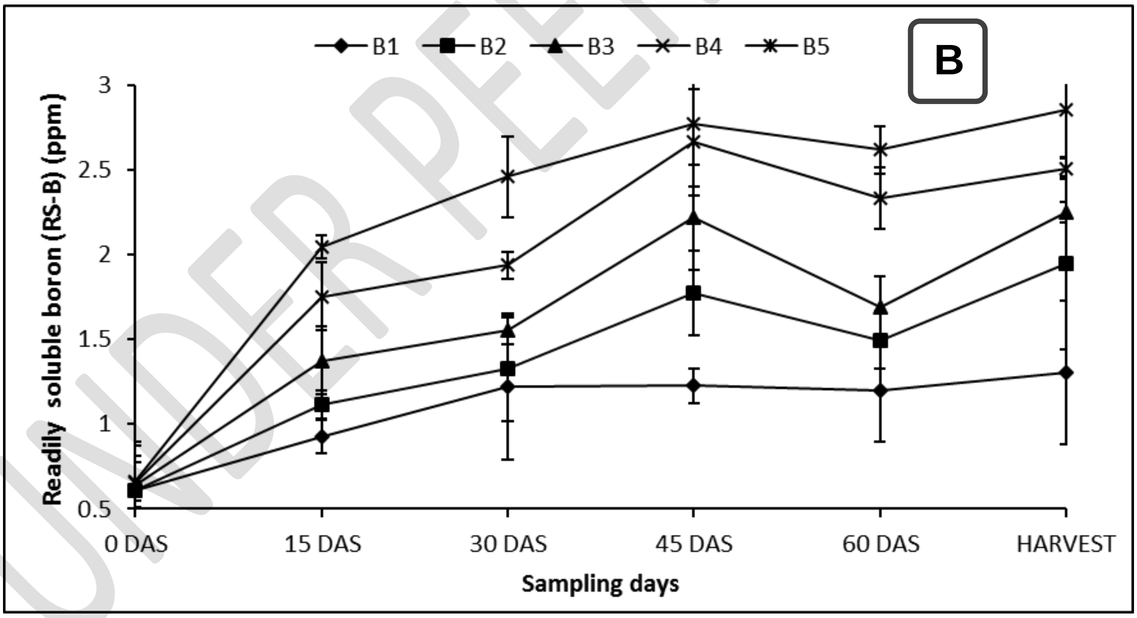


Figure 1. Effect of boron and lime on readily soluble boron (ppm) content in soil grown with green gram (Error bar showing Standard Error of Mean)

(A) Unlimed

(B) Limed

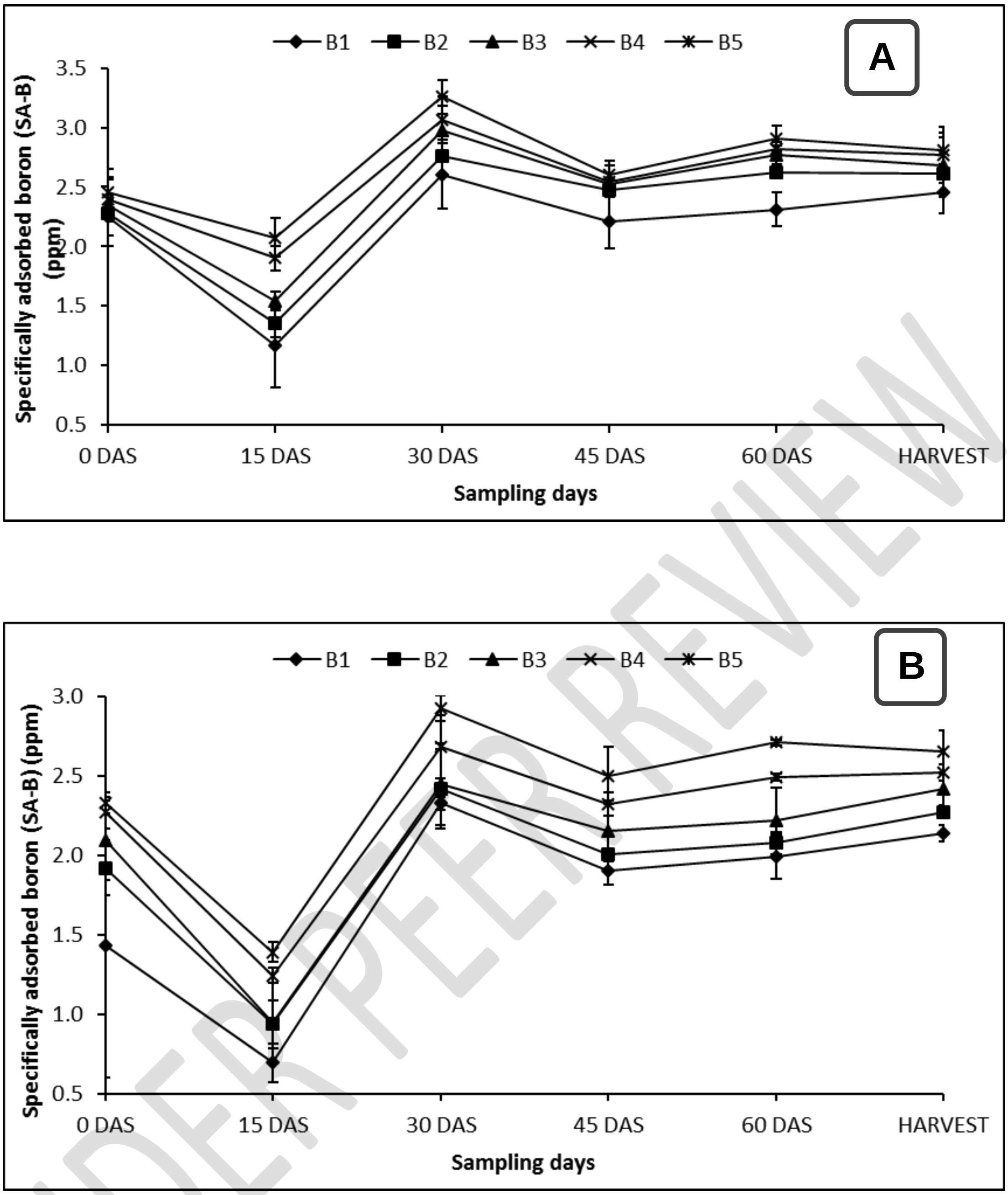
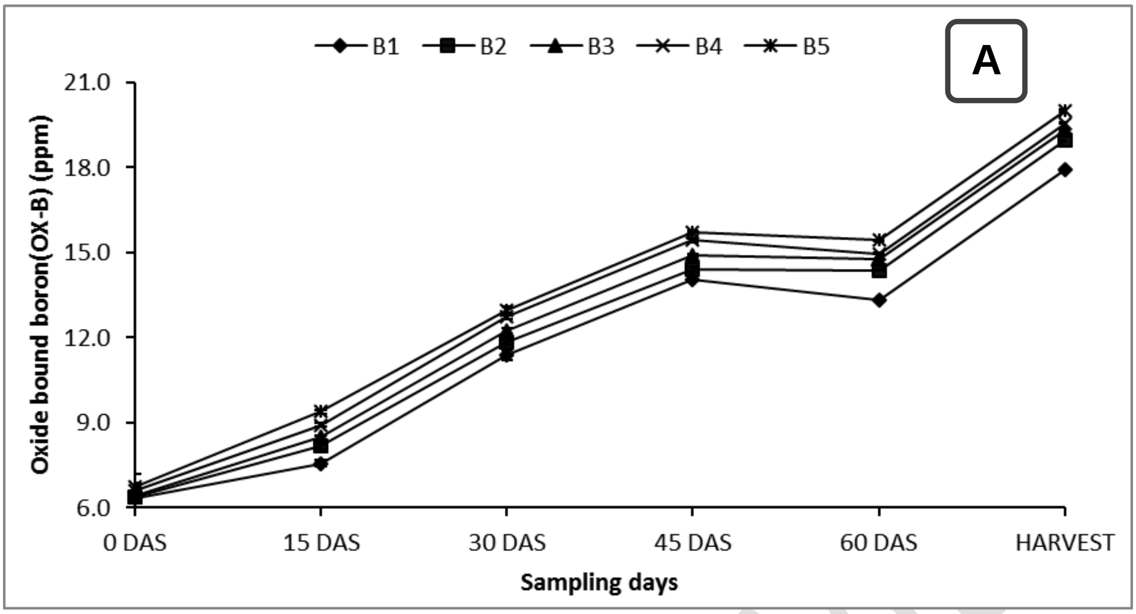


Figure 2. Effect of boron and lime on specifically adsorbed boron (ppm) content in soil grown with green gram (Error bar showing Standard Error of Mean)

(A) Unlimed

(B) Limed



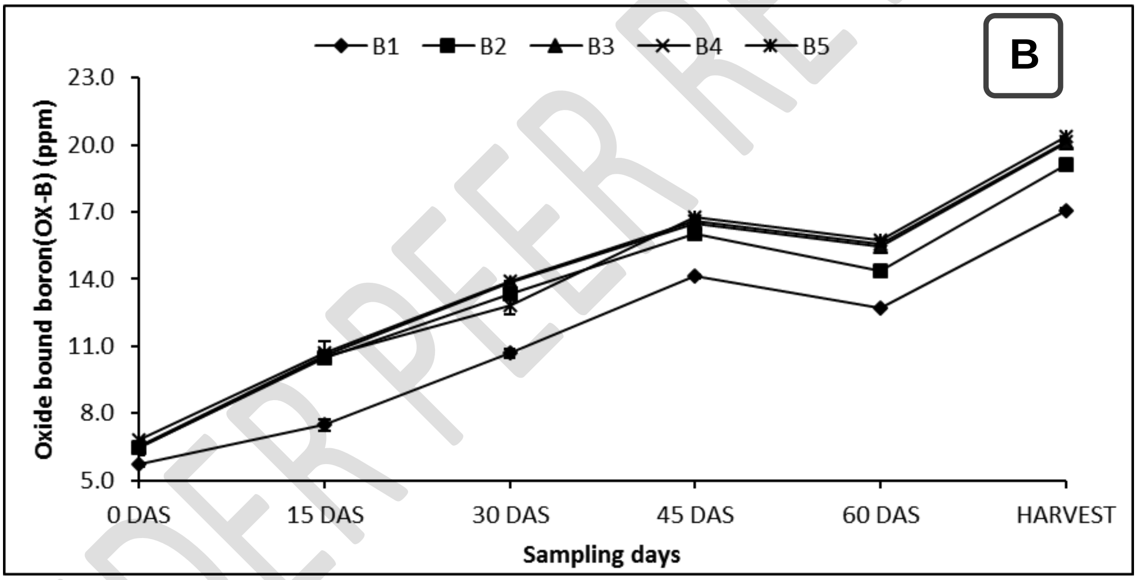


Figure 3. Effect of boron and lime on oxide bound boron (ppm) content in soil grown with green gram (Error bar showing Standard Error of Mean)

(A) Unlimed

(B) Limed

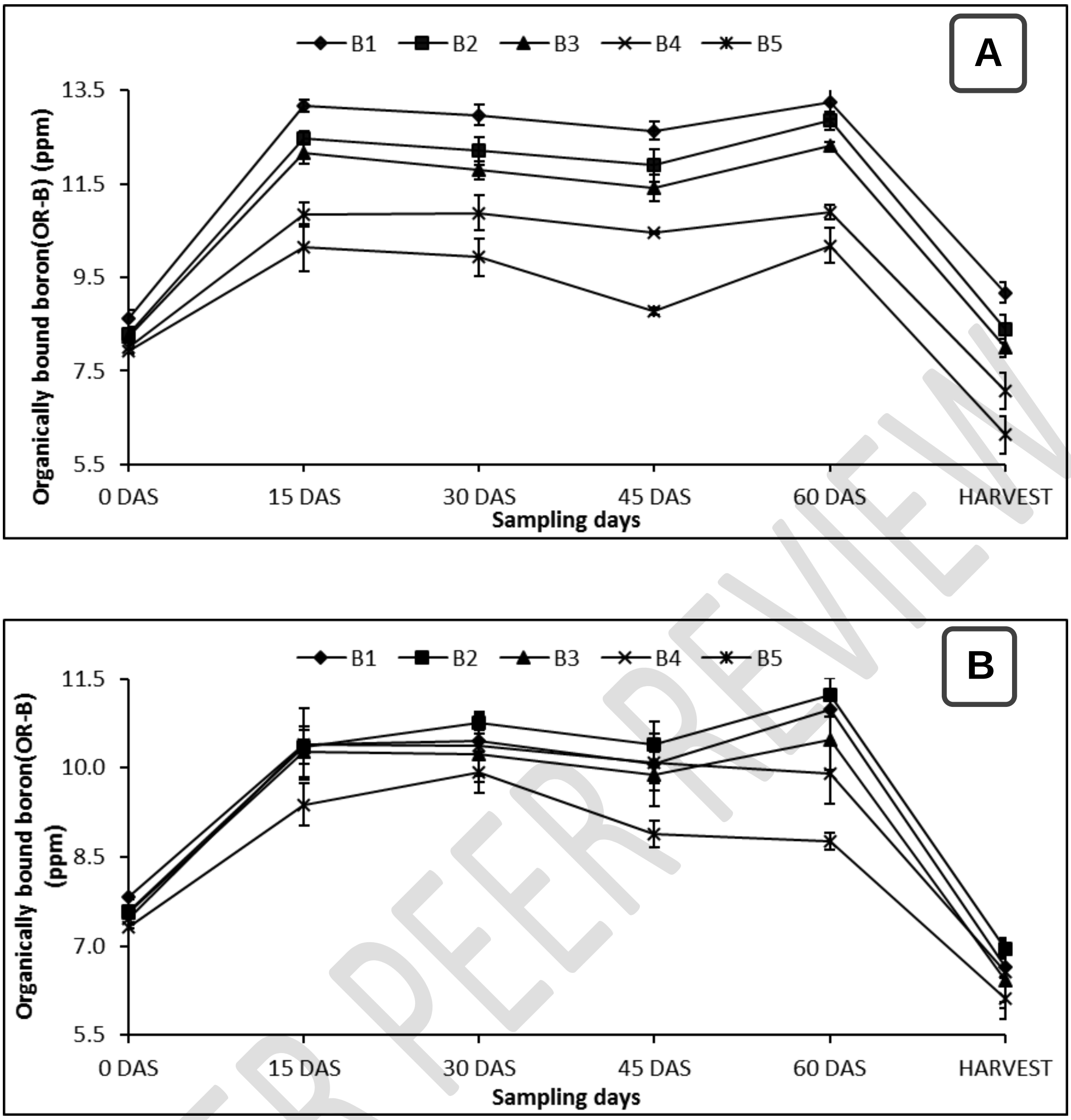


Figure 4. Effect of boron and lime on organically bound boron (ppm) content in soil grown with green gram (Error bar showing Standard Error of Mean)

(A) Unlimed

(B) Limed

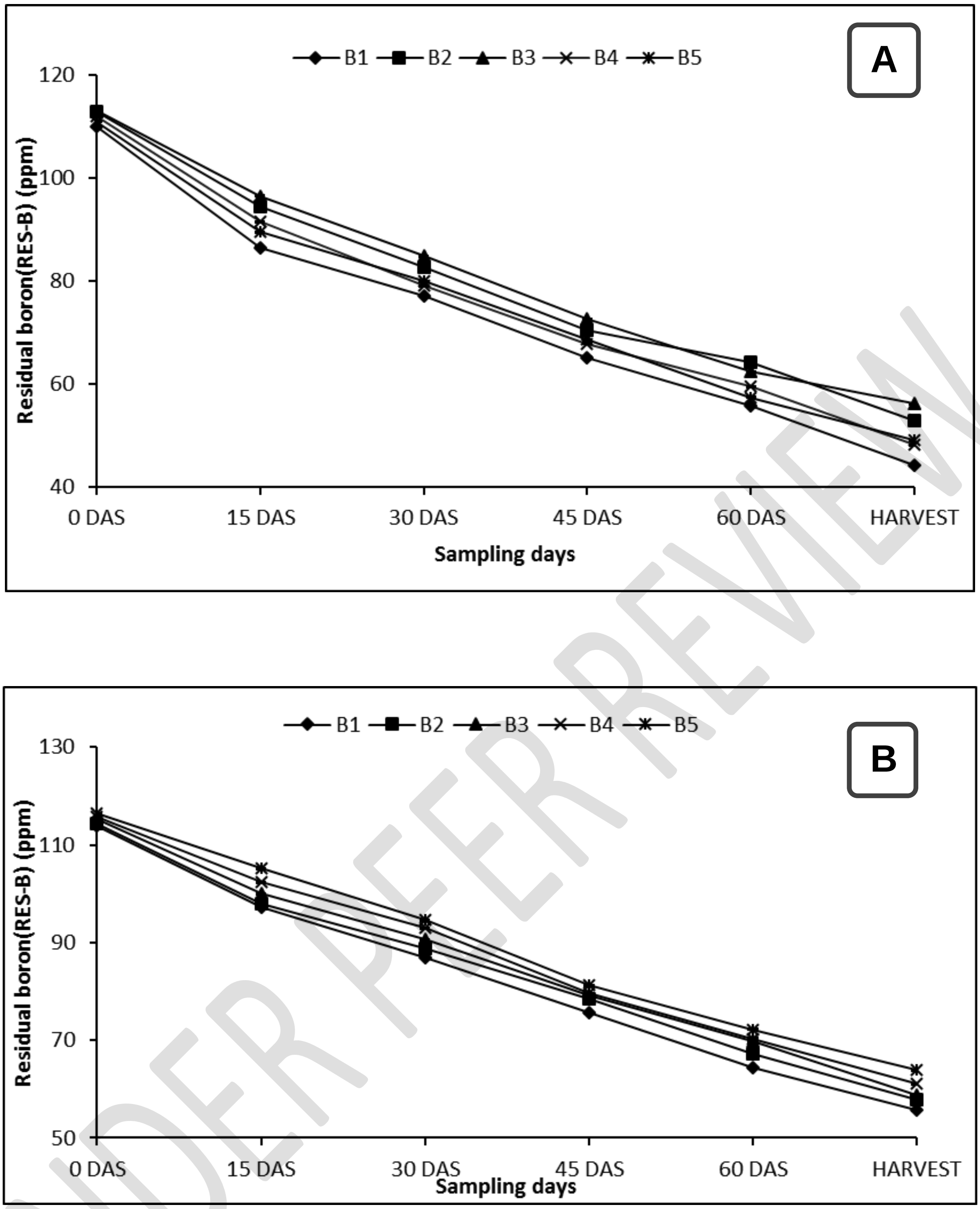


Figure 5. Effect of boron and lime on residual boron (ppm) content in soil grown with green gram (Error bar showing Standard Error of Mean)

(A) Unlimed

(B) Limed

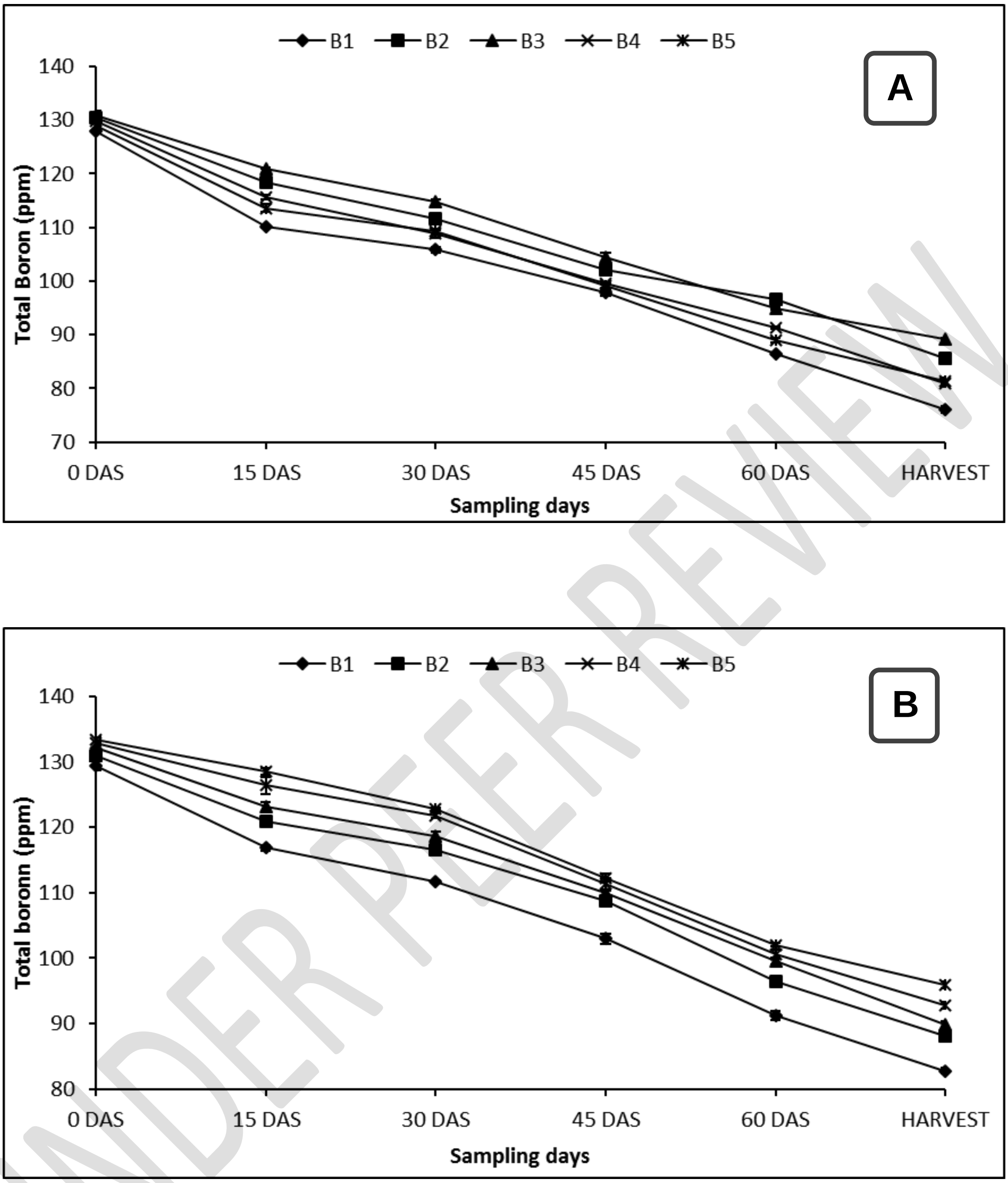


Figure: 6. Effect of boron and lime on total boron (ppm) content in soil grown with green gram (Error bar showing Standard Error of Mean)

(A) Unlimed

(B) Limed

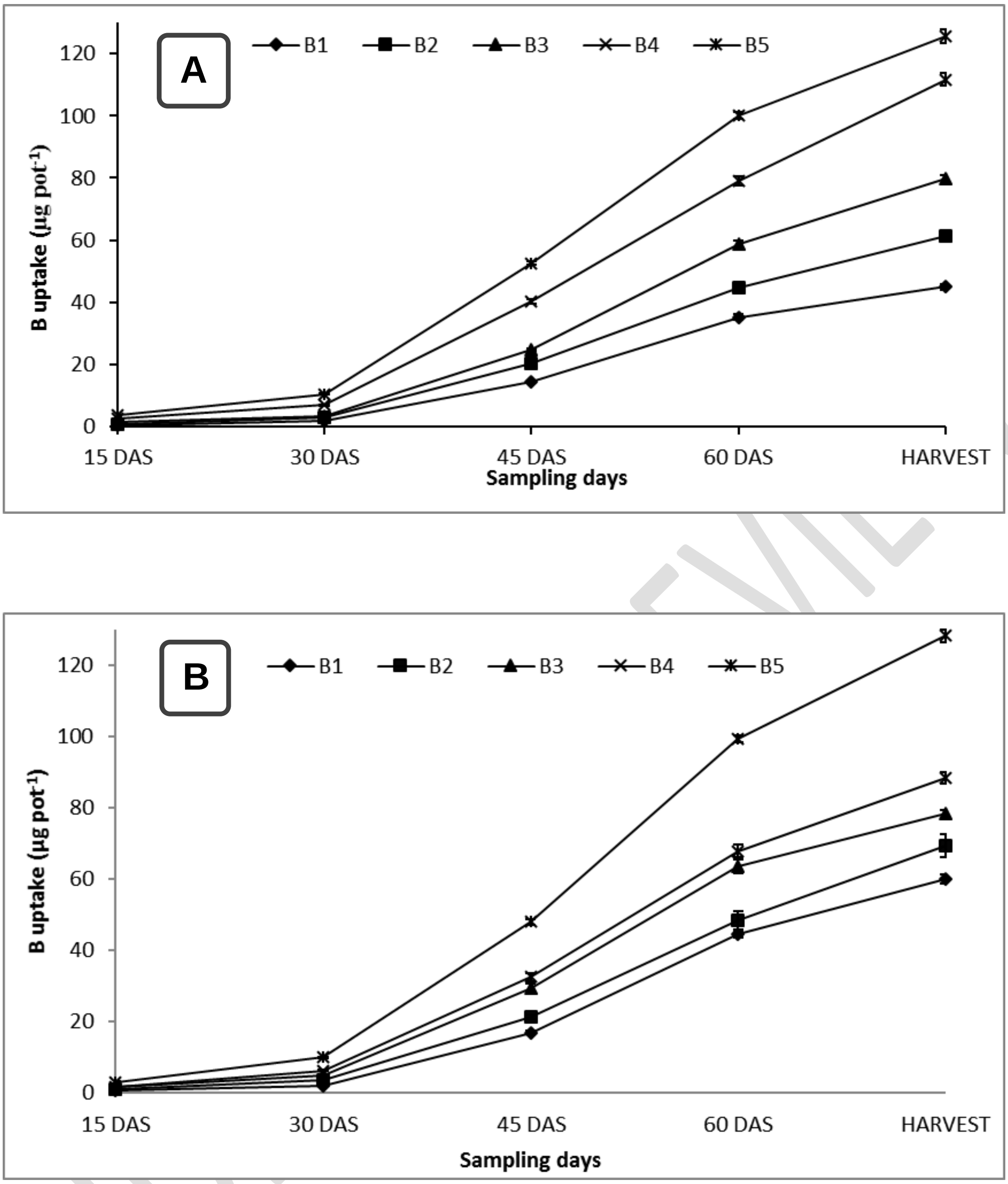


Figure: 7. Effect of boron and lime on boron uptake (µg pot^{-1}) by green gram (Error bar showing Standard Error of Mean)

(A) Unlimed

(B) Limed

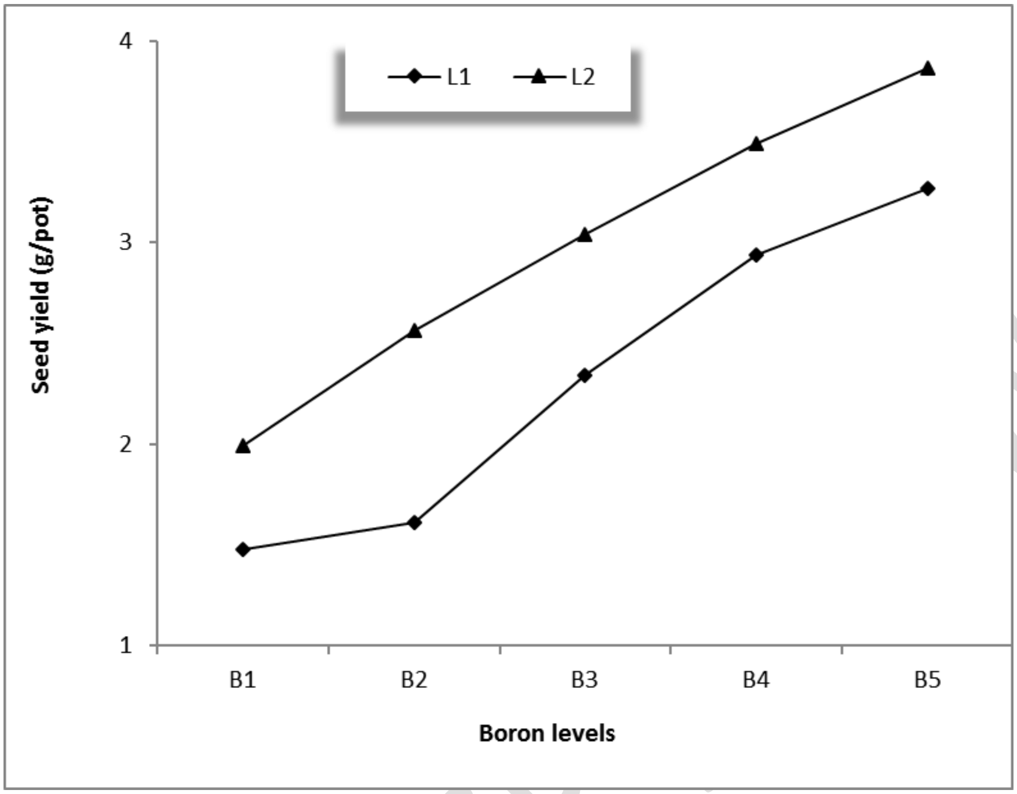


Figure 8. Effect of boron and lime on seed yield of green gram (g pot^{-1}):

L1 - Unlimed

L2 – Limed

<u>Boron levels:</u>

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}

<u>Liming:</u>

L_1= Unlimed

L_2= Limed