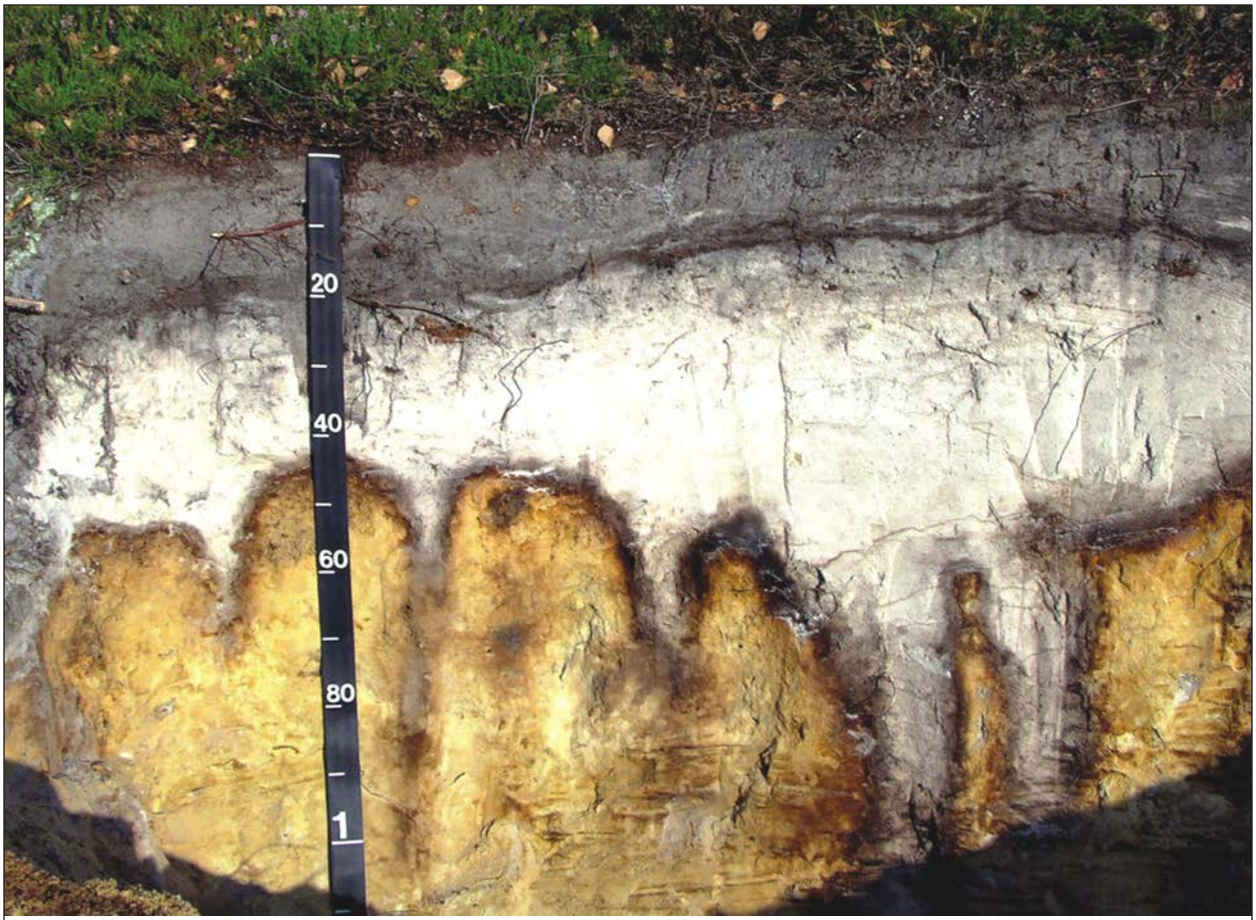

International Journal of

Soil Science

ISSN 1816-4978

Academic
Journals Inc.

www.academicjournals.com

OPEN ACCESS International Journal of Soil Science

ISSN 1816-4978
DOI: 10.3923/ijss.2018.28.34

Research Article
Performance of Rainfed Lowland Rice Genotypes under Different Levels of Boron Application

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Abstract

Background and Objective: Soil available boron can be the limiting factor for rice production in rainfed lowland condition. This study aimed to identify the external boron requirement of the rainfed lowland rice varieties. **Materials and Methods:** A field experiment was conducted during June-October, 2016 at Purkot, Tanahun, Nepal to assess the performance of rice varieties grown under rainfed condition. Using split plot design, three replicates of four rice varieties (Sukkhadhan-2, Sukkhadhan-4, DRR-44 and Ciherang sub-1) under four levels of soil boron (B) application (0, 1, 2 and 3 kg ha^{-1}) were cultivated. **Results:** We found that the significant effects of B application among rice varieties on yield and its associated traits; the genotypic differences, however, varied. On average, B application at the upper level -as compared to the control of no B application- increased the plant height, effective tiller numbers and effective grain numbers by 7, 3 and 5%, respectively. Similarly, it increased grain yield and straw yield by 38% and 12%, respectively. While, Sukkhadhan-2 appeared to be the highest grain yielding variety, the straw yield was the premier for Ciherang sub-1. Such B induced grain yield increment corresponded to the decline in unfilled grains proportion (43%)-the highest for Sukkhadhan-2. B also induced the 1000 grains weight (12%) and harvest index (15%). **Conclusion:** Hence, not only the genetic makeup but also the soil B application controls rice production under rainfed condition.

Key words: Boron, lowland rice, rainfed, unfilled grains, yield

Citation: Ram Kumar Shrestha, Sita Paudel, Samjhana Wagle, Salikram Ghimire and Deepak Yadav, 2018. Performance of rainfed lowland rice genotypes under different levels of boron application. Int. J. Soil Sci., 13: 28-34.

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Boron (B) deficiency is considered as a common problem of rice production[1]. Most of the Nepalese soils are deficient in available B[2,3]. In plants, B regulates carbohydrate metabolism, sugar transport, lignification, nucleotide synthesis and respiration as well as pollen viability[4]. Rice yield is severely affected when the soil available B falls below 0.5 mg kg^{-1} soil[5] and the symptoms are manifested as white and rolled young leaf tips, death of growing points and failure of flowers to set seed[6]. Since reproductive stage of plants is more sensitive to B deficiency, yield as well as quality of the grain is severely affected[7]. Rice in the mid-hills of Nepal are commonly grown under rainfed condition[8] and about 0.7 million ha rainfed lowland rice is prone to the prolong drought[9]. Soil conditions in these areas strongly favor the low available B to the rice. Low moisture regimes not only reduce the B mobility toward rice root via mass flow[10,11] but also induces the B fixation[5]. Further, soils are acidic and coarse textured[12-15], which are not only inherently poor in B[16] but also favor its leaching loss[1,17,18].

Many researchers have investigated the effect of application of B on rice in B deficit soils and revealed that its input has potential to increase rice yield from 14-75% through improving the chlorophyll content, leaf emergence and elongation and tillering in rice plant[19-21]. Those studies were conducted at irrigated lowland fields and the effects of B application on rainfed condition-in which the low moisture greatly reduces the B availability through impeding mass flow-was yet to be studied. In Nepal, though the decrease in panicle sterility and associated yield increase of the wheat crop through the application of B in low available B soils in Nepal is well identified[22], its effect on the rice yield was unknown. The objective of the study was to study the responses of the rainfed lowland rice varieties to the soil addition of B through an experiment at farmer's field condition.

MATERIALS AND METHODS

A research experiment was conducted at a farmer field of Purkot, Tanahun, Nepal N (27°74"N to 28°13"N and 83°94"E to 88° 53" E) from June-October, 2016. This experiment consisted of two factors- B level and rice varieties. The rice varieties included were Sukhha-2, Sukkhadhan-4, DRR-44 and Ciherang sub-1. Sukkhadhan-2 and Sukkhadhan-4, recommended for the rainfed conditions[23] and were commonly grown by farmers in the study area. DRR-44 has proven its ability to tolerate low soil moisture condition[24,25]. Ciherang sub-1 is considered as well adapted to both submerged as well as low soil moisture condition[24]. The seeds were obtained from National Rice Research Program, Hardinath, Nepal. Dry bed nurseries of these rice varieties were established on June 23, 2016 (bed size 2×1 m; seed rate 0.5 kg each plot). Firstly, the soils representing all corners of the experimental site were sampled and analyzed for various physical and chemical properties at the Soil Testing Laboratory, Soil Management Directorate, Lalitpur. The method employed and the soil test values have been presented in Table 1.

Then, field was divided into three blocks (replications) against fertility gradient. Each block was divided into four main plots with random assignment of B. Then each plot was further divided into four subplots to which rice varieties were randomly assigned. The area of each sub-plot was 5 m^2. After laying out the experimental plot, common farm yard manure (20 t ha^{-1}), nitrogen (N) (11.7 kg ha^{-1}; Urea), phosphorus (P_2O_5) (30 kg ha^{-1}, Diammonium Phosphate) and potassium (K_2O) (20 kg ha^{-1}, muriate of potash) were applied. Those fertilizers were supplied in the local market by Agriculture Input Company Limited, Nepal. After applying four levels of B [0, 1, 2 and 3 kg ha^{-1}; Agri-Borax (10% B); AGRICARE Bharatpur Chitwan, Nepal], 26 days old rice seedlings were transplanted at the spacing of 20×10 cm. After first and second weeding (at 28 and 50 days after transplanting, respectively), N top dressings (30 kg ha^{-1} in each application; urea) was carried out. A day before plant harvesting on October 17, 2016, plant height, effective tiller numbers and effective grains per panicle were measured. After threshing, the filled, unfilled grains and straw were separated and were weighed and sundried.

Table 1: Soil properties of the experimental plot

Soil characteristics	Standard method	Value	Rating
Soil texture	Feel method (at field)	-	Sandy clay loam
Soil pH	Electronic pH meter (1:1 soil water suspension method)	5.90	Slightly acidic
Soil organic matter (%)	Wakley-Black method	2.95	Medium
Soil Total Nitrogen (%)	Microjeldahl method	0.15	Medium
Soil available Phosphorus (kg ha^{-1})	Modified Olsen's bicarbonate method	105.80	High
Soil available Potassium (kg ha^{-1})	Neutral normal ammonium acetate extraction by flame photometer Method	120.16	Medium

All the data collected from the experimental plots were compiled and arranged using Microsoft Office Excel 2010. Grain sterility percentage was calculated as the percentage of weight of unfilled grains in the total grain weight. Analysis of variance and mean separation was done using R version 3.4.3. Duncan's Multiple Range Test (DMRT) at 0.05 probability level. Figures were developed using Microsoft Office Excel and Microsoft word 2013 was used for the word processing.

RESULTS AND DISCUSSION

Plant height and effective tiller numbers: Effect of B and rice varieties on various yield parameters has been presented in Table 2 and 3. Plant height significantly increased at higher levels of B application ($p\leq 0.001$). Hence, rice varieties expressed maximum height at 3 kg ha^{-1} B application (110 cm) as compared to 103.5 cm at control of 0 kg ha^{-1} B application. Response of the rice varieties was also very highly significant ($p\leq 0.001$). DRR-44 expressed maximum plant height (117 cm) followed by Ciherang sub-1. The plants height of Ciherang sub-1 appeared to be genetically controlled as the effect on this tallest variety seems B irresponsive. Sukkhadhan-2 and Sukkhadhan-4 showed the lowest plant height. The interaction between B levels and rice varieties was non-significant. B helps in cell wall elongation and division[1]. Similar observation was reported by Dobermann and Fairhurst[5].

Irrespective of the varieties, B application significantly increased the effective tiller numbers ($p\leq 0.05$). The tiller numbers ranged from 226 at 0 kg B ha^{-1} application to 234 at 3 kg B ha^{-1} input. The effective tiller numbers, however, remain unaffected among the treatments that receive addition of B. Among varieties, Ciherang sub-1 produced significantly highest number of tillers (265) and other varieties did not significantly differ each other and produced around 219 tillers m^{-2}. This finding agreed with the finding of Khan *et al.*[19] who reported the increase number of tillers with application of B.

Effective grain, grain sterility and thousand grains weight: Both the effects of B input and rice varieties for the production of number of effective grains in the panicle were very highly significant ($p\leq 0.001$). Compared to the control of no B application, input of 1 kg B ha^{-1} did not significantly increase the effective grains. Application of 3 kg ha^{-1} B increased 5% effective grain numbers when compared with control treatment and it was not differ with 2 kg B ha^{-1}.

Table 2: Plant height, effective tiller numbers and effective grain numbers of rice varieties under different levels of soil boron application

	Boron levels (kg ha^{-1})					
	0	1	2	3	Significant	LSD
Plant height (cm)						
Sukkhadhan-2	97.20c(C)	104.77c(B)	105.17c(B)	107.50c(A)	0	0.814
Sukkhadhan-4	97.03c(B)	101.80c(A)	104.33c(A)	105.17c(A)	0	1.412
DRR-44	114.20a(A)	116.50a(A)	117.27a(A)	117.80a(A)	ns	1.512
Ciherang sub-1	105.53b(B)	109.23ab(AB)	110.07b(AB)	111.27b(A)	0	1.642
Mean	103.49(A)	108.08(A)	109.21(B)	110.43(A)	***	0.684
Significant	0	0	0	0		
LSD	1.725	0.787	0.862	1.292		
Effective tiller numbers m^{-2}						
Sukkhadhan-2	212.00b(C)	218.33b(B)	221.00b(AB)	222.67b(A)	0	1.386
Sukkhadhan-4	213.33b(A)	217.67b(A)	219.00b(A)	221.33b(A)	ns	6.137
DRR-44	217.67b(A)	221.00b(A)	222.67b(A)	223.33b(A)	ns	5.263
Ciherang sub-1	262.00a(A)	263.67a(A)	268.67a(A)	269.00a(A)	ns	5.192
Mean	226.25(B)	230.17(AB)	232.83(A)	234(A)	0	5.20
Significant	0	0	0	0		
LSD	6.992	2.134	2.338	4.515		
Effective grain numbers panicle^{-1}						
Sukkhadhan-2	133.50b(B)	135.57b(B)	141.53a(A)	143.53a(A)	0	2.070
Sukkhadhan-4	134.97b(B)	137.09b(AB)	138.08a(AB)	141.33ab(A)	0	2.105
DRR-44	141.20a(A)	142.20a(A)	142.85a(A)	144.23a(A)	ns	1.275
Ciherang sub-1	133.20b(B)	134.83b(AB)	138.67a(AB)	139.13b(A)	0	1.895
Mean	135.72(B)	137.42(B)	140.28(A)	142.06(A)	***	1.939
Significant	0	0	0	0		
LSD	1.386	2.554	2.798	1.386		

Value followed by the same lowercase letter in column and the uppercase letter in rows are not significantly different by Duncan's Multiple Range Test (α = 0.05; n = 3), ns: Non-significant, *Significant at $p\leq 0.05$, **Highly significant ($p\leq 0.01$), ***Very highly significant ($p\leq 0.001$)

Table 3:Thousand grains weight and harvest index of rice varieties under different levels of soil boron application

	Boron levels (kg ha^{-1})					
	0	1	2	3	Significant	LSD
1000 grain weight (g)						
Sukkhadhan-2	26.59a(A)	27.55a(A)	27.89a(A)	28.21a(A)	ns	1.444
Sukkhadhan-4	23.89a(B)	27.89a(A)	28.56a(A)	29.22a(A)	0	1.005
DRR-44	26.23a(A)	27.21a(A)	27.94a(A)	28.34a(A)	ns	1.699
Ciherang sub-1	26.56a(A)	26.89a(A)	29.23a(A)	29.84a(A)	ns	2.195
Mean	25.82	27.39	28.41	28.90	Mean	
Significant	ns	ns	ns	ns		
LSD	1.894	0.970	1.063	1.335		
Harvest Index						
Sukkhadhan-2	30.85a(C)	33.56d(B)	35.84a(A)	36.67a(A)	0	0.769
Sukkhadhan-4	26.24b(B)	27.94c(AB)	29.95c(AB)	30.11c(A)	0	1.245
DRR-44	32.49a(B)	36.18b(A)	36.97a(A)	37.12a(A)	0	1.053
Ciherang sub-1	29.98ab(C)	31.01a(BC)	33.08b(AB)	33.87b(A)	0	0.859
Mean	29.89	32.17	33.96	34.44	Mean	
Significant	0	0	0	0		
LSD	1.464	0.496	0.543	0.941		

Value followed by the same lowercase letter in column and the uppercase letter in rows are not significantly different by Tukey test (α = 0.05; n = 3), ns: Non-significant, *Significant at $p\leq0.05$, **Highly significant ($p\leq0.01$), ***Very highly significant ($p\leq0.001$)

At varietal level, while DRR-44 produced significantly highest number of the effective grains panicle^{-1} (143), the tallest variety Ciherang sub-1 expressed least number (136). The commonly grown Sukkhadhan-2 and Sukkhadhan-4 produced 138 and 137 unfilled grains panicle^{-1} and were not significantly differed each other. Rashid[26] and Ramanathan *et al.*[27] reported higher level of effective grain panicle^{-1} with the application of B. The increase in effective grain per panicle is due the role of B in the growth of pollen tubes by rapid synthesis of cell wall and plasma membrane that results better grain setting[28].

B application reduced the grain sterility in rice varieties (R^2 = 0.44, $p\leq0.001$, LSD = 0.410), however, the varietal responses differed (Fig. 1). Irrespective of the rice varieties, proportion of unfilled grains was highest when B was not applied and was least at 2.0 and 3.0 kg B ha^{-1} application. Hence, the grain sterility of 6.3% at no B application reduced to 3.35% at 3 kg B ha^{-1} application. At varietal level, proportion of unfilled grain was lowest for Sukkhadhan-2 (3.04%) and highest for Ciherang sub-1 (5.5%). When compared between 0 and 3 kg ha^{-1} B application, the reduction in the grain sterility ranged from 32-63%-the highest for the Sukkhadhan-2 and the lowest for Ciherang sub-1. Decreased grain sterility by increased B level might be due to growth of pollen tube resulting grain setting by rapid synthesis of cell wall and plasma membrane. Similar results were also reported by various researchers Dixit *et al.*[29], Farooq *et al.*[30] and Rehman *et al.*[31].

There was corresponding increase in the thousand grains weight with the application of the soil B ($p\leq0.001$, LSD = 1.459), effect of rice varieties on the same, however, remained unaffected. Among the rice varieties, the effect of different levels of B appeared to be significant only in DRR-44 but was insignificant when compared among the added levels of B. Irrespective of the rice varieties, thousand grains weight was highest at 3 kg B ha^{-1} (28.9 g) but it was significantly at par with 2 kg B ha^{-1}. Compared to 0 kg ha^{-1} B application, the increase in thousand grain weight at 3 kg B ha^{-1} level was highest for Sukkhadhan-4 (22%) followed by Ciherang sub-1 (12%) and least for the Sukkhadhan-2. It might be due to the role of B in fruit setting through the transport of the sugar to the grains as well as role in the pollen tube growth and viability. This result was also supported by Rehman *et al.*[31], Ashraf[32] and Yu and Bell[33].

Grain yield, Straw yield and harvest index: B application significantly increased the grain yield in rice varieties. Irrespective of rice varieties, the highest grain yield (3.14 t ha^{-1}) was observed when soil was applied with 3 kg ha^{-1} B-nearly 38% higher as compared to the control of 0 kg B ha^{-1}. Similarly, Sukkhadhan-4 produced lowest grain yield (2.17 t ha^{-1}) as compared to the DRR-44 that yielded 3.1 t ha^{-1} grains which was not significantly different with Ciherang sub-1 and Sukkhadhan-2. Sukkhadhan-2 appeared to be more responsive towards soil B application which increased grain yield by 43% as compared to the 2.37 t ha^{-1} at 0 kg ha^{-1} B application. Even for DRR-44, which was least responsive to the soil B application, the grain yield increment was by 36% at 3 kg B ha^{-1} as compared to the control

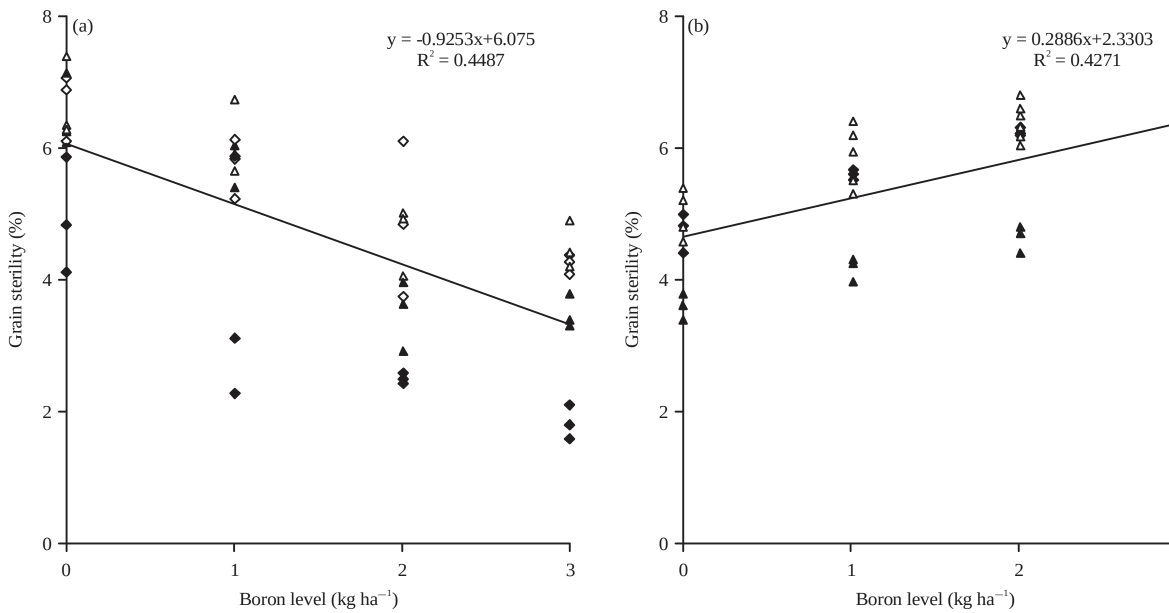

Fig. 1(a-b): (a) Grain sterility and (b) Grain yield in rice varieties as affected by soil boron application

treatment. The B and variety interaction in terms of grain yield appeared to be significant (Fig. 2). B helps to improve the membrane function which directly affects the transport all metabolites require for growth and development and also activates the activities of membrane bound enzymes. Similar results were reported by Saleem *et al.*[6], Ashraf *et al.*[32], Yu and Bell[33] and Shah *et al.*[34].

Result revealed the significant effect of B on straw yield in rice varieties ($p\leq 0.05$). Irrespective of the rice varieties, the highest straw yield was recorded at 3 kg B ha^{-1} but it did not differ with 1 and 2 kg ha^{-1} B application. The straw yield at 3 kg B ha^{-1} application was 12% higher than at B omitted plot (5.31 t ha^{-1}). Similarly, Ciherang sub-1 produced the highest straw yield (6.04 t ha^{-1}) but other varieties were significantly at par. At 3 kg B ha^{-1} , as compared to no B application, the highest straw yield increase was observed at Ciherang sub-1 (14%) followed by Sukkhadhan-4 (13%) and the least at Sukkhadhan-2 (10%). B helps to improve the membrane function which directly affects the transport all metabolites required for growth and development and also activates the activities of membrane bound enzymes. Similar results were reported by Saleem *et al.*[6], Shah *et al.*[34] and Rashid *et al.*[35].

Soil application of B significantly increased the harvest index (HI) in rice varieties (($p\leq 0.001$; LSD = 0.884). Hence, it was highest at 3 kg B ha^{-1} and was 15% higher as compared to that at control of 0 kg B ha^{-1} , this result, however, was significantly at par with at 2 kg B ha^{-1} . Effect of varieties on the HI also appeared to be highly significant ($p\leq 0.001$; LSD = 0.952). Hence, highest HI was obtained in DRR-44

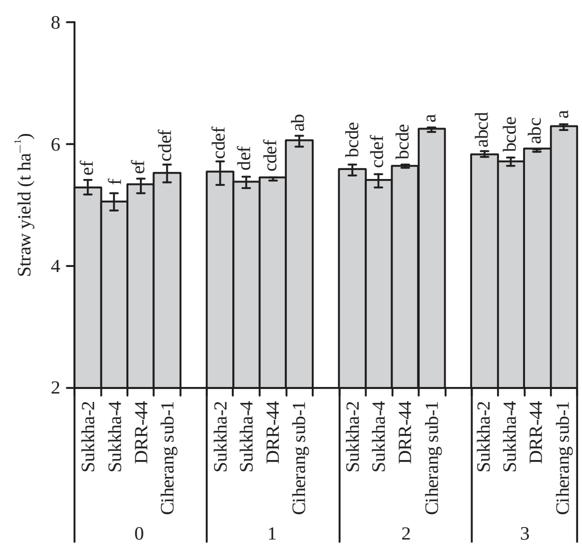

Fig. 2: Straw yield in rice varieties due to the soil application of different levels boron

Value followed by the same lowercase letter in the bars are not significantly different by Tukey test ($\alpha = 0.05$, n = 3) at $p\leq 0.05$

(37.12%) at 3 Kg B ha^{-1} which was at par with the application of 2 kg B ha^{-1} (36.97%) for the same variety and lowest HI was obtained in Sukkhadhan-4 (26.24%) at 0 kg B ha^{-1}. Irrespective of the B, the DRR-44 expressed highest HI followed by Sukkhadhan-2 and Ciherang sub-1. The interaction effect of the B and varieties on the HI, however, appeared to be insignificant. Improvement in HI with the application of B might be due to better starch utilization that results in higher seed setting and translocation of assimilates to developing grains. This finding was supported by Hussain *et al.*[20] and Hussain and Yasin[36].

Since this study was carried out at natural state of moisture at field condition and included only four levels of the B, further study including the different levels of the soil moisture and higher levels of the B may help to have a better understanding of the role of boron inputs on the rainfed lowland rice production system.

CONCLUSION

It can be concluded that soil application of B induces plant height, effective grain numbers, grain and straw yield and harvest index and tends to reduce the proportion of un-filled grains and such responses varies among the rice varieties. While DRR-44 is superior over other varieties in terms of producing plant height, effective grains and harvest index, Sukkhadhan-2 tends to be highly responsive to the addition of soil B for reducing grain sterility and grain yield increment-indicates the role of plant genotypes for this trait. On contrast, Ciherang sub-1 has potential to produce the higher straw yield at various levels of soil B application. Hence, B application is crucial for the rice production.

SIGNIFICANCE OF THE STUDY

This study discovered the effect of soil B application on rainfed lowland rice genotypes and found that B application enhances the plant height, effective grain numbers, grain and straw yield and harvest index and tends to reduce the proportion of un-filled grains in different varieties. This study would help the farmers in increasing the rice yield with respective B application as mentioned. Thus, best theory regarding the soil B management in rice production system with limited moisture availability may be arrived at.

ACKNOWLEDGMENTS

Funding from the Institute of Agriculture and Animal Science (IAAS) - International Rice Research Institute (IRRI) collaborative Stress Tolerant Rice for Africa and South Asia (STRASA) Project to carry out this study is highly acknowledged.

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