Impact of foliar application of boron on yield and yield attributes, assimilate supply, production efficiency and fertilizers productivity of Indian mustard (*Brassica juncea*) in field experiments

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ABSTRACT:Field experiments were conducted for three consecutive *rabi* seasons from 2018 to 2020 to assess the impact of foliar application of boron fertilizer on yield and yield attributes, assimilate supply, production efficiency and fertilizers productivity of Indian mustard [*Brassica juncea*(L.) Czern. &Coss.]. The results showed that the number of primary branches/ plant(7.00 to 8.08), number of siliquae/plant (427.2 to 468.8), number of seeds/siliqua (13.03 to 14.01), test weight of seed (3.60 to 3.80 g) and plant dry matter production (38.10 to 41.20 g/plant) were significantly increased with T2 treatment (100% NPKS + foliar application of Boron @ 0.5 % Borax) as compared to farmer's practice T1 (100% NPKS + without boron) during three years of experiments. Significantly higher seed yield (22.5 to 24.7 q/ha) of the mustard crop was also reported with T2 (100% NPKS + foliar application of Boron @ 0.5 % Borax) as compared to farmers' practice T1 (100% NPKS + without boron) (seed yield 19 to 22.5 q/ha) during the studies. Similarly, Treatment T2 resulted in significantly higher production efficiency and assimilates supply of mustard crop than that of T1 (farmer's practice). The fertilizer productivity in the mustard crop that is directly related to seed yield and the partial factor of productivity of N, P, K and S fertilizers (PFP_{NPKS}) were also increased significantly with the T2 compared to farmers practiceT1(farmer's practice), during 3 years of studies. The highest gross return and net return and benefit-cost ratio were obtained with T2 (100% NPKS + foliar application of Boron @ 0.5 % Borax) treatment over T1 (100% NPKS + without boron).

Keywords: Assimilate supply, Economics, Fertilizers productivity, Production efficiency, and Seed yield

1. INTRODUCTION

Indian mustard (Brassica juncea) stands as one of the principal oilseed crops globally, revered for its nutritional value, adaptability, and economic significance. In agricultural landscapes, maximizing the yield and quality of mustard crops is imperative to meet the growing demands of food, feed, and industrial applications. Among the various factors influencing crop productivity, the availability and uptake of essential micronutrients play a pivotal role in determining plant growth, development, and ultimately, yield. Boron is an essential micronutrient for vascular plants and necessary for the growth of crop plants (Wimmer *et al.*2019). Low availability of boron in soils impairs the development of floral organs and the elongation of pollen tubes, which leads to a loss of crop yield (Zhao *et al.* 2021).Boron deficiency is the second most important micronutrient constraint in crop production after zinc (Rehman *et.al* 2022). Rapeseed–mustard is extremely sensitive to boron (B) deficiencies (Zhao *et al.* 2021).Boron deficiency in soil leads to the erratic growth of seedlings and reduced photosynthesis (Safdar *et al.* 2023).Boron is an important component for various biological processes in plants, including the growth and development of pollen tubes, the maintenance of membrane integrity, pollination and seed production (Ahmad *et al.* 2012). The primary roles of boron is include the breakdown of nucleic acids, carbohydrates, proteins, indole acetic acid, and phenol, which are involved in the synthesis of plant cell walls and the maintenance of membrane integrity (Goldbach *et al.* 2001). Additionally, boron plays a key role in cellular division and the control of carbohydrate and protein metabolism, and these processes influence the reproductive phase and development of seeds (Miwa *et al.* 2010). Boron is closely associated with plant growth and plays a vital role in cell division as well as synthesis of oil and protein. Flowering and pods formation is restricted due to boron deficiency and rapeseed-mustard crops are very responsive to boron fertilizer (Islam 2005, and Saha *et al*. 2003).Lu *et al.* (2000) and (Randhawa *et al.* 2021) found that boron fertilizer contributed 611 kg/ha (48.5%) yield advantage of the rapeseed.Yield reduction due to boron deficiency often occurs even if specific visual symptoms of leaves are not apparent.The majority of researchers have focused on foliar boron management in mustard in small experimental plots thus far; consequently, work needs to be done under field conditions to evaluate the influence at the field level.Keeping in mind the problem of low yield of mustard due to boron deficiency in the soil, an on farm trial was designed on foliar application of boron fertilizer in mustard to reduce the yield loss due to the deficiency of boron and to obtain higher yield and quality of mustard crop.

2. MATERIAL AND METHODS

2.1 Experimental details: On -farm trials on foliar application of boron on Indian mustard were carried out at the farmer's fields of Qazipur, Shikarpur and Jhatikara villages of NCT Delhi under similar agro climatic conditions during the *rabi* season from 2018 to 2020 (Figure 6). The rainfall and average temperature of the experimental area from 2018 to 2021 have been depicted in Figure 3,4,5. The experimental soil was a sandy loam in texture, low in organic carbon (0.31%), available nitrogen (225 Kg/ ha), phosphorous (21 Kg/ ha), potash (195 Kg/ha). The experiments were laid out on five farmer's fields with 5 replications in a 1000 m^2 plot area each and having 2 treatments *i.e* T1 Farmer's practice (100% NPKS + without boron) and T2 (100% NPKS + foliar application of Boron @ 0.5 % Borax).

2.2 Crop management: The recommended dose of fertilizer was 80:60:40: 30 kg N, P, K,S ha^{-1}, respectively, for Indian mustard. Nutrients were supplied through urea, single super phosphate, muriate of potash and bentonite sulphur. Boron was supplied through borax which contains 11% boron through foliar application. Whole of P, K and S and half of the N were supplied as basal dose and the remaining half of the nitrogen was applied 30 days after sowing. Proper weed management, insect- pest management and irrigation management was done in experimental fields. The Number of primary branches and total siliquae/ plant was counted from five randomly selected plants at harvest and the mean value was taken. The numbers of seeds per siliquae is also counted from randomly selected siliquae for the selected plants. Four plants were selected randomly from the observational rows of each plot and dug out with the help of *khurpi* at 60 DAS, 90 DAS and at harvest. These plants were sun-dried for 48 hours. After sun drying, these plants were dried in the oven at 65±5˚C temperature for 48-72 hours or till the samples attained a constant weight, and weighed. The dry matter was expressed ing $plant^{-1}$.The data output was collected from experimental fields as well as farmer's and cost of cultivation, net income, and benefit -cost ratio were also worked out.

2.3Crop efficiency parameters:Partial factor productivity of nitrogen (PFP_N), phosphorus (PFP_P) and Potash (PFP) fertilizer was calculated as per the following formula (Singh *et al.* 2021).

$$\text{Partial factor of productivity (PFPnpk)} = \frac{\text{Seed yield (kg)}}{\text{Rate of fertilizer applied(kg)}}$$

Assimilate supply (AS) is the ratio of above ground dry matter of individual plant / number of siliquae. Production efficiency (PE), it represents the increase in seed yield on a daily basis and calculated by dividing total mustard seed production ha^{-1} in a sequence with total duration of the crops in a sequence(Premi *et al.* 2013).

2.4 Statistical analysis: The yield data were collected from both the experiment and farmers' practice and analyzed by using simple statistical tools. All data were analyzed were using ANOVA, and two sample test values at 5% level of significance were calculated and used to test significance difference between treatment means.

3. RESULTS AND DISCUSSION

3.1 Yield attributes

Foliar application of boron had a significant impact on yield attributes of the mustard crop such as number of primary branches per plant, number of siliquae/plant, and number of seeds/siliqua and 1000-seed weight during 3 years of studies (Table 1). Significantly higher number of primary branches/ plant (7 to 8.08), number of siliquae/plant (427.2 to 468.8), number of seeds/siliqua (13.03 to 14.01) were obtained with T_2treatment (100% NPKS + foliar application of Boron @ 0.5 % Borax) as compared to farmer's practice T1 (100% NPKS + without boron) during three years of experiments. Similarly, the higher test weight of seed (3.6 to 3.8 g) was reported with the with T_2 treatment (100% NPKS + foliar application of Boron @ 0.5 % Borax) in mustard crop, which was significantly higher over farmer's practice T1 (100% NPKS + without boron) in which test weight of seed was 3.2 to 3.3 g. The partial or complete failure of boron fertilization leads to pollen abortion, seed drop, deformed and shrunken seeds and partially filled pods resulting in lower test weight (Kapila *et al.* 2008) and (Kumararaja *et al.* 2015).Additionally, Jankowski et al. (2020) observed that foliar boron application in mustard crops resulted in considerably larger numbers of primary branches/ plant, siliquae /plant, seeds/ siliqua, and 1000-seed weight. The highest values of yield attributes in treatment T2 might be attributed to the involvement of boron in hormone synthesis and translocation, carbohydrate metabolism and the synthesis of DNA in plants (Verma *et al.* 2020). Identical results for plant growth parameters were reported by Shah *et al.* (2016) and Handiganoor*et al.* (2017).

3.2Plant dry matter production

Foliar application of boron had a notable impact on dry matter accumulation during 3 years of the studies (table 2). The dry matter production (38.1 to 41.2 g/plant) in mustard crop was significantly higher with T_2 treatment (100% NPKS + foliar application of Boron @ 0.5 % Borax) as compared to the farmer's practice T1 (100% NPKS + without boron), in which an increase of 36.4 to 38 g/plant dry matter was recorded. The dry matter production was found to be increased could be attributed to the increased number of branches per plant arising out of the better growth and development conditions facilitated by proper supply of photosynthates to the plants parts. Boron is needed in small quantity by plants for division and cell enlargement in meristem tissue, then the meristem generate new cells at the tip of the root or stem that resulted in increased plant growth or length. The increase growth of plant and number of leaf affects the light received by the plant so that it can improve the performance of photosynthesis and produce many photosynthatase in forms of starch, lipids, and proteins. Photosynthatase is translocated inside the plant which helps to increase the dry matter of the plant (Timotwu*et al.* 2018).

3.3 Seed yield

The seed yield of the mustard crop was influenced by foliar application of boron during 3 years of studies. The significantly higher seed yield (22.50 to 24.70

q/ha) of the mustard crop was reportedwithT_2 treatment (100% NPKS + foliar application of Boron @ 0.5 % Borax) as compared to the farmer's practice T1 (100% NPKS + without boron), in which the seed yield was 19.00 to 22.50 q/ha during the experiments (Table2).These results corroborated well with the studies conducted by Jankowski *et al.* 2020 and Zhao *et al.* (2021)in which they reported higher seed yield with boron in mustard field. Lu *et al.* (2000) and (Randhawa *et al.* 2021) found that boron fertilizer contributed 611 kg/ha (48.5%) yield advantage of the rapeseed. The increase in the seed yield can be ascribed to boron as it is directly linked with the process of fertilization, pollen producing capacity of anther, viability of pollen grains, pollen germination and pollen tube growth (Padhbhusan and Kumar, 2015) and (Jaiswal *et al.* 2015).Boron's involvement in maintaining the structural integrity of plasma membrane, metabolism of carbohydrates, and synthesis of DNA probably resulted in the additional growth in crops (Handiganoor*et al.* 2017). The reason for the lowest seed yield under farmers practice, might be the higher pollen infertility and lower seed filling as they play an extremely crucial role in both the processes (Hussain *et al.* 2012).Correlation analysis showed that seed yield had a significant positive correlation with number of siliquae, seeds/ siliqua, test weight, dry matter accumulation, assimilate supply, however, negative correlation was observed with primary branches(table 4).

3.4 Production efficiency

The production efficiency of a crop refers to the daily increase in seed yield. Foliar application of boron exerted significant effects on the production efficiency of mustard crop during 3 years of studies (referencing Table 2). Specifically, as a result of foliar application of boron (T_2 treatment), the production efficiency of the mustard crop became significantly higher (16.67 to 18.31) than that of the farmer's practice T1 (100% NPKS + without boron), whose production potential was found to be 14.07 to 16.67. Foliar application of boron helps in proper translocation of photosynthates toward the seeds and siliquae formation, which enhances in the seeds and siliquae production in mustard. Whereas, the seeds and siliquae development was poor under farmers practices in which boron fertilizer was not applied. The translocation of food material from source to sink was better in boron spray treatment as compared to farmer's practices.

3.5 Assimilate Supply

Assimilate supply was influenced significantly with the application of boron fertilizer has been depicted in table 2. Assimilate supply refers to a plant's ability to mobilize photosynthates once again and it is the ratio of above ground dry matter of individual plant to the number of siliquae formation. During the 3 years studies, assimilate supply of the mustard crop was increased significantly (11 to 11.76) with T_2 treatment (100% NPKS + foliar application of Boron @ 0.5 % Borax) over farmer's practice T1 (100% NPKS + without boron) in which it was increased up from 10.33 to 11.17. At the time of the peak flowering period, the nutrients and carbohydrates begin to remobilize toward seed setting and siliquae formation. Similar finding were also confirmed by Shekhawat *et al.*(2016). Application of boron might be involved in the synthesis of protein, chloroplast pigments, and electron transfer system that led to the increased photosynthetic activity as well as assimilate supply of mustard crop (Srinivasan *et al.* 2019). The positive effect of boron application has been reported on assimilate supply by Haque *et al.* (2000) and Islam (2005).

3.6 Fertilizer productivity

Foliar spray of boron had a significant impact on NPK & S fertilizers productivity during 3 years of studies. Fertilizer productivity was evaluated in terms of partial factor of productivity (PFP) and calculated based on the yield of the mustard crop (Table 3).Over the course of study years, the PFP of N, P, K and S fertilizers (PFP_{NPKS}) were increased significantly (28.13 to 30.9, 37.5 to 41.19, 56.25 to 61.79, 75 to 82.39 kg kg^{-1}) with T_2 treatment (100% NPKS + foliar application of Boron @ 0.5 % Borax) as compared to the farmer's practice T1 (100% NPKS + No use of boron).It was observed that the PFP of S was found to be higher followed by PFP of K over of PFP of N and

P. It means boron had a positive interaction with other nutrients like N, P, K and S, and plays an important role to increase the fertilizer productivity of NPK&S. Higher PFP of NPK&S with a foliar application of boron might be ascribed for higher seed yield production and better translocation of food materials toward seeds development than without boron application field. All these are in accordance with the findings reported by Singh *et al.* (2021) and (Zhao *et al.* 2021).

3.7 Economics

The economics of the treatments was calculated depending on the prevailing market prices of the inputs and outputs for the particular year. During 3 years of studies, the higher gross return of Rs. 85500 to 111600/ha, net return of Rs.63210 to 72828/ha and B: C ratio 2.83 to 4were obtained with T_2 treatment (100% NPKS + foliar application of Boron @ 0.5 % Borax) as compared to farmer's practice T1 (100% NPKS + without boron) has been illustrated in figure 1. The higher benefit- cost ratio with T2 treatment was found due to the higher yield obtained under T2 treatment as compared to T1 (farmer's practice) (figure 2). Hence, higher benefit- cost ratio proved the economic viability of the technology intervention and convinced the farmers about the utility of improved technologies. Similar economic benefits owing to adoption of foliar application of boron in mustard were also reported by Dubey *et. al* (2018).

4. CONCLUSION

Based on the results of on-farm trials conducted in real farming conditions, it can be concluded that the foliar application of boron, specifically at a concentration of 0.5% borax alongside 100% recommended NPKS fertilizers, enhances the yield attributes of the mustard crop. Additionally, the foliar application of boron has been shown to improve the production efficiency and assimilate supply of the mustard crop. Moreover, the fertilizer productivity of N, P, K, and S fertilizers was observed to increase with the foliar application of boron at the mentioned concentration over the course of three years of studies. Consequently, foliar application of boron at 0.5% borax concentration was identified as optimal for achieving higher seed yields in boron-deficient soils. The adoption of foliar application of boron has the potential to significantly augment both the income and livelihoods of farming communities.

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Table:1 Effect of foliar application of boron on number of primary branches, number of siliquae /plant, number of seeds / siliqua, test weight (g) of the mustard crop during 2018 -2020

Treatment	Number of primary branches /plant			Number of siliquae / plant			Number of seeds/ siliqua			Test weight(g)		
	2018	2019	2020	2018	2019	2020	2018	2019	2020	2018	2019	2020
T1- Farmer's Practice (100%NPK+ without boron)	5.00±0.8	5.50±1.1	5.5±1.1	402.5±8.2	398.0±8.6	400.8±12.4	11.75±0.47	10.95±0.72	12.01±0.88	3.2±0.23	3.37±0.30	3.25±0.35
T2- (100% NPKS + foliar application of Boron @ 0.5 % Borax)	7.75±0.5	7.00±0.7	8.08±0.8	468.8±26.9	427.2±26.6	451.3±36.4	13.53±0.76	13.03±0.65	14.01±0.48	3.6±0.28	3.70±0.63	3.85±0.33
P(T<=t)	0.001	0.020	0.016	0.002	0.022	0.024	0.001	0.005	0.001	0.005	0.027	0.028

Table: 2 Effect of foliar application of boron on dry matter production (g/plant) seed yield (q/ha), assimilate supply and production efficiency of the mustard crop during 2018 -2020

Treatment	Dry matter production/plant (g)			Seed yield (q/ha)			Assimilate Supply (g siliqua^{-1})			Production efficiency (kg ha^{-1} day^{-1})		
	2018	2019	2020	2018	2019	2020	2018	2019	2020	2018	2019	2020
T1- Farmer's Practice (100%NPK+	38.4±1.8	36.4 ±4.6	38.9±1.7	22.5±0.9b	19.0±2.0b	20.0±1.7b	10.51±0.79	11.17±0.61	10.33±1.11	16.67±0.70	14.07±1.49	14.81±1.30

without boron)												
T2- (100% NPKS + foliar application of Boron @ 0.5 % Borax)	39.9±1.2	38.1±1.1	41.2±1.4	24.7±0.6a	22.5±0.9a	24.0±0.7a	11.76±1.8	11.22±0.66	11±0.60	18.31±0.51	16.67±0.70	17.78±0.64
P(T<=t)	0.108	0.221	0.044	0.007	0.021	0.001	0.026	0.480	0.203	0.001	0.041	0.001

Table: 3 Effect of foliar application of boron on partial factor of productivity of N,P, K and S of the mustard crop during 2018 - 2020

Treatment	N Partial factor productivity (kg kg^{-1})			P Partial factor productivity (kg kg^{-1})			K Partial factor productivity (kg kg^{-1})			S Partial factor productivity (kg kg^{-1})		
	2018	2019	2020	2018	2019	2020	2018	2019	2020	2018	2019	2020
T1- Farmer's Practice (100%NPK+ without boron)	28.13±1.19	23.75±2.5	25±2.19	37.50±1.5	31.67±3.3	33.3±2.92	56.25±2.39	47.50±5.5	50±4.38	75.00±3.19	63.33±6.73	66.67±5.85
T2- (100% NPKS + foliar application of Boron @ 0.5 % Borax)	30.90±0.87	28.13±1.1	30±1.08	41.19±1.1	37.50±1.4	40.0±1.44	61.79±1.74	56.25±2.40	60±2.16	82.39±2.32	75.00±2.28	80±2.88
P(T<=t)	0.007	0.021	0.001	0.027	0.001	0.005	0.007	0.021	0.001	0.002	0.011	0.005

Table:4 Relationship between yield and yield attributes of mustard as influced by boron spary (mean data of three years)

X-axis	**Y-a**xis	Correlation coefficient R²	**Regression equation**
Grain yield	sehcnarB yramirP	0.57	y = 0.447x - 3.4144
Grain yield	Number of siliquae/ plant	0.77	y = 11.739x + 165.11
Grain yield	Number of seeds/ siliqua^{-}	0.75	y = 0.4563x + 2.4576
Grain yield	Test weight (1000 seed weight)	0.39	y = 0.0736x + 1.8658

Grain yield	noitlaumcca rettamyrD	0.60	y = 0.5695x + 26.223
Grain yield	Assimilate supply	0.22	y = 0.1108x + 8.5482

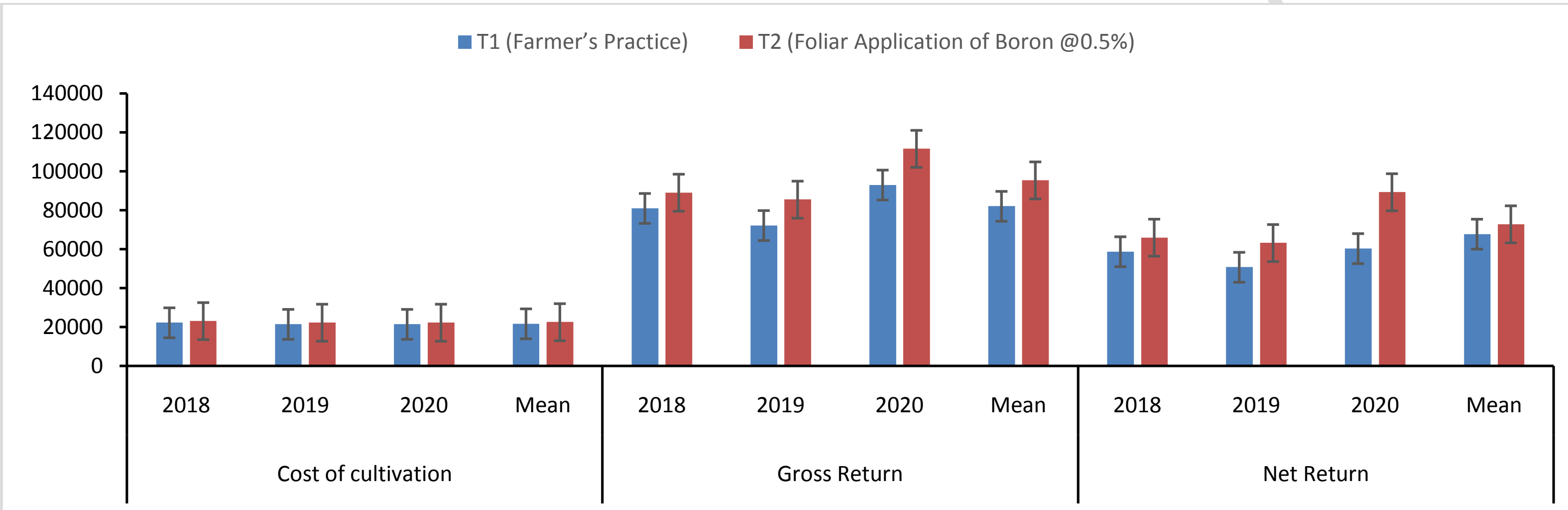


Figure: 1 Effect of foliar application of boron on cost of cultivation, gross return and net return of the mustard crop during 2018 - 2020

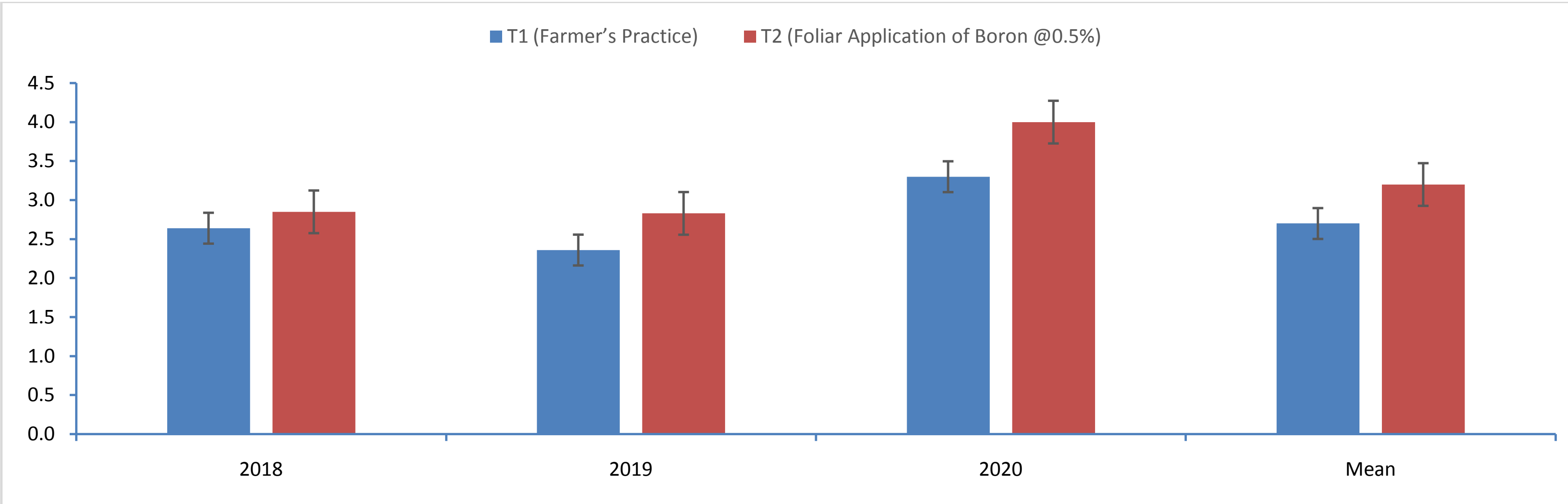
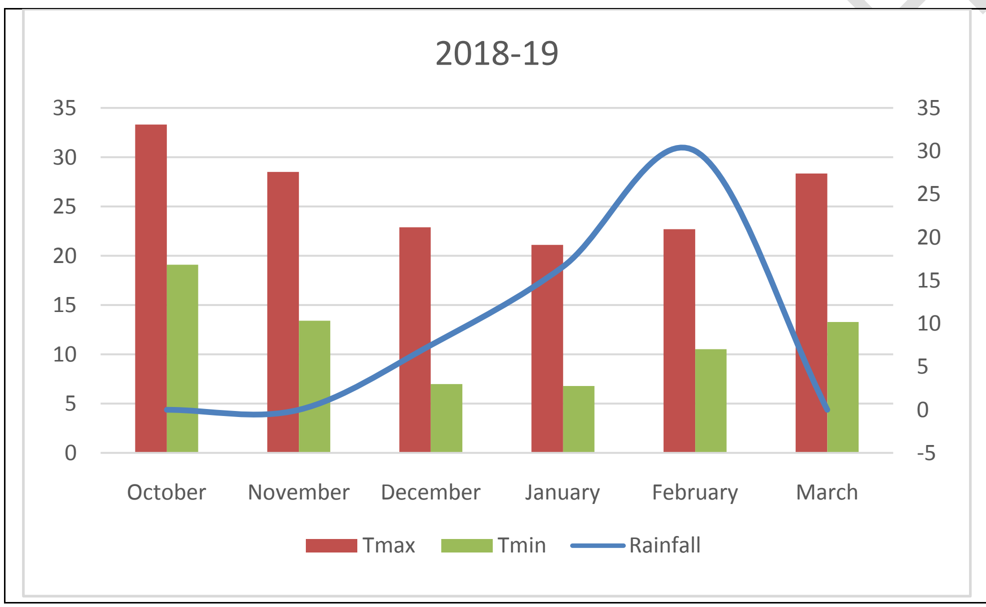
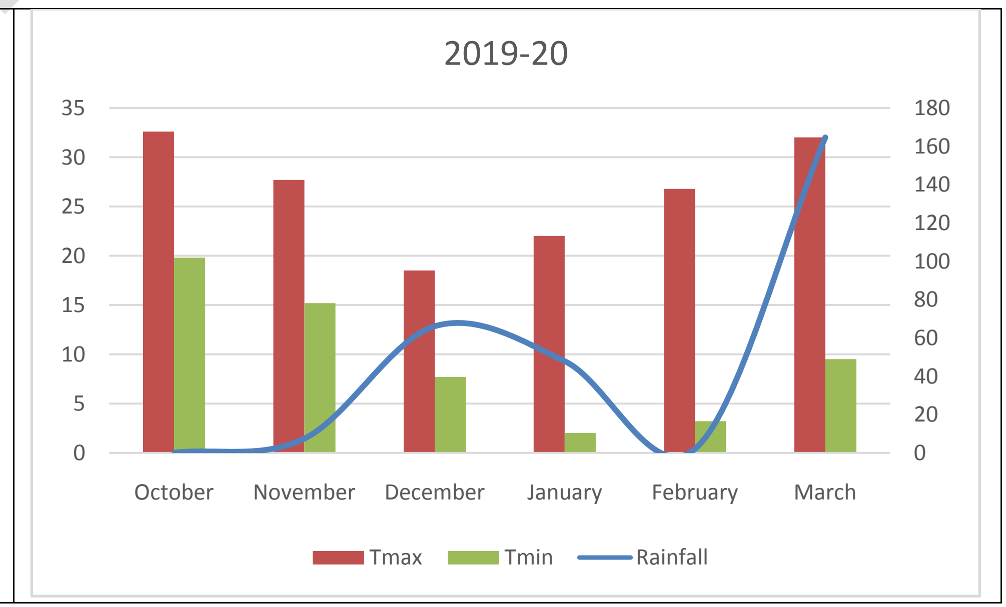


Figure: 2 Effect of foliar application of boron on benefit- cost ratio of the mustard crop during 2018 -2020





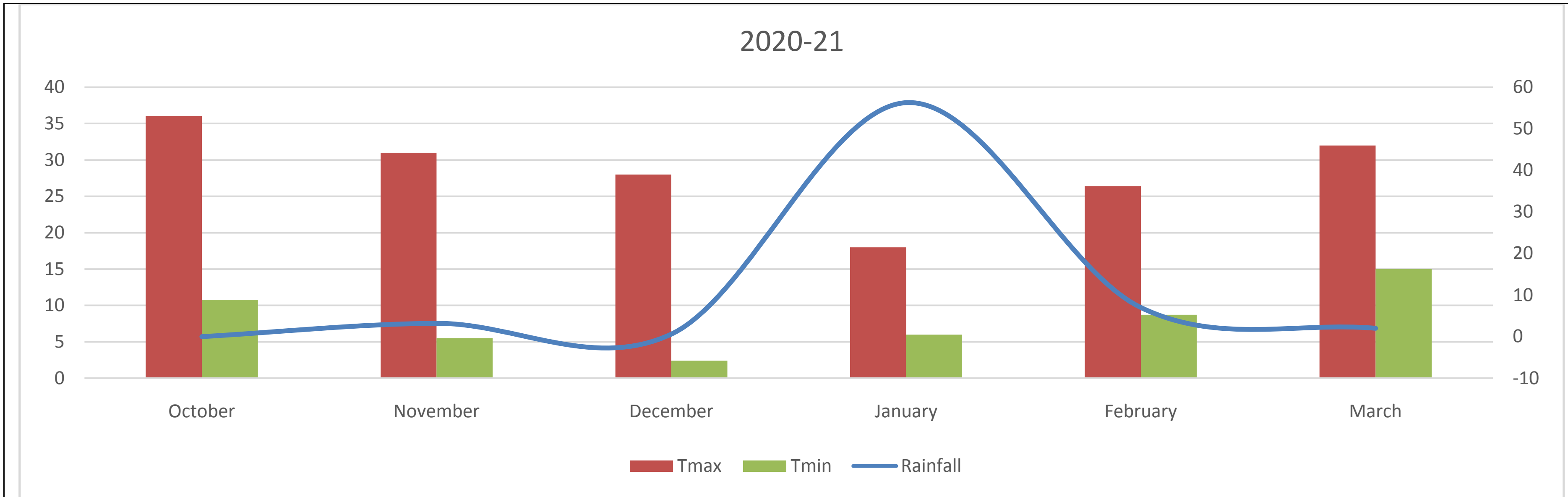


Figure: 3,4,5 Rainfall distributions (mm) during crop growing *rabi* season 2018 -21

Figure: 6 Site of Krishi Vigyan Kendra in NCT Delhi and its working area