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Assessing the impact of graded level of boron fertilization on plant physiological and quality parameters and its relationship with crop yield in cauliflower-cowpea-okra sequence in an Inceptisol of North East India

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Abstract
A field investigation was conducted at Horticultural Experimental Farm, Assam Agricultural University, Jorhat during the year 2015-17 to assess the impact of boron fertilization on plant physiological and quality parameters in cauliflower–cowpea- okra cropping sequence in an *inceptisol* of North East India. Five levels of boron were applied (0, 0.5, 1.0, 1.5 & 2.0 kg ha^{-1}) along with recommended dose of NPK fertilizer once in both the years in only cauliflower to assess the direct effect of boron fertilization in soil while cowpea and okra were grown as a test crop to study the succeeding residual effects of boron fertilization in cauliflower–cowpea- okra cropping sequence. Among the different levels of boron, the assessed fate of the experimental findings revealed that application of 2 kg B ha^{-1} was found significant and the highest in augmenting positively the plant physiological parameters *viz,* total chlorophyll content and nitrate reductase activities in plant leaves and quality parameters *viz.*, ascorbic acid and protein in edible portion in all crops as compared to other lower boron levels while the lowest were recorded in control plots which shows an incremental trend plant in physiological and quality parameters corresponding to the escalating boron level. Excepting, starch which recorded the lowest content corresponding to the highest boron application of 2 kg B ha^{-1} thereby exhibiting an inverse relationship between starch content and applied boron level in crops in cropping sequence.

Keywords: Graded level, fertilization, physiological and quality parameters

Introduction
Boron (B) is an essential micronutrient that plays a major role in crop production and crop quality. It is supposed to be involved in a wide variety of metabolic functions. Some of the postulated functions of B in plant physiological and biochemical processes include cell wall structure and membrane integrity, sugar transport, lignification, carbohydrate metabolism, phenol metabolism, protein metabolism, nucleic acid metabolism and indole acetic acid (IAA) metabolism (Marschner, 1995; Loomis and Durst, 1992) [23, 20]. Boron (B) is required for normal growth and development of all higher plants (Brown *et al*. 2002) [2]. B is involved in cell wall intactness and synthesis (Hu *et al*. 1997) [15] and in plasma membrane integrity (Marschner 1995, O'Neil *et al*. 2001) [23, 27]. Kastori *et al*. (1995) [18] observed a reduction in the leaf area and chlorophyll contents under B deficiency. A reduced nitrate reductase (NR) activity and enhanced accumulation of nitrate have been described in B-deficient plants (Kastori and Petrovic 1989; Ramon *et al*. 1989; Shen *et al*. 1993) [28, 33], Moreover, B deficiency reduces chlorophyll and soluble protein (largely photosynthetic enzymes) contents of leaves, which in turn affect Hill reaction activity and photosynthetic rate (Sharma and Ramchandra, 1990) [32]. Boron application increases growth, yield, protein and ascorbic acid content of vegetables and improved its quality by increasing protein and ascorbic acid content of roots considerably (Maurya and Bineeta, 2016) [25]. B deficiency causes different effects on very diverse processes in vascular plants such as root elongation, indole acetic acid (IAA) oxidase activity, sugar translocation, carbohydrate metabolism, nucleic acid synthesis, and pollen tube growth (Blevins and Lukaszewski 1998; Goldbach and Wimmer 2007) [11]. Short-

term B deficiency led to a decline in root and, particularly leaf nitrate contents without affecting NR activity (Camacho Cristobal and Gonzalez-Fontes 2007) [5] or the concentrations of other macronutrients such as magnesium, calcium, potassium or phosphate (Camacho-Cristobal *et al*. 2005) [6]. Moreover, B deficiency caused a drop in leaf nitrate reductase (NR) activity throughout the day (Camacho-Cristóbal and González-Fontes 1999) [8]. This is a very interesting result because it points out a possible relationship between B and N metabolism in vascular plants. In addition, B deficiency may also promote ammonium assimilation via asparagine synthetase in tobacco roots (Camacho-Cristobal and Gonzalez- Fontes 2007) [5]. Among the vegetable crops, especially cauliflower, cowpea and okra need micronutrient boron for normal plant growth and development and quality aspects. But till date, proper recommendation of boron for vegetable cropping sequence has not been formulated and popularized. Further recommendation of boron for cauliflower based cropping system is not yet available in the soils of Assam for making boron application more rationale and efficient. Therefore, a field experiment was undertaken to work on effect of graded levels of boron on plant physiological and quality parameters in cauliflower-cowpea-okra sequence.

Materials and Methods

Field experiments were conducted in the experimental Farm, Department of Horticulture, Assam Agricultural University, Jorhat during 2015-2017. The soil of the experimental area is *Inceptisol* having sandy clay loam texture and acidic in reaction (pH 4.80). The experimental site was located at 26°47′N latitude, 94°12′E longitude and at an altitude of 86.6 m above mean sea level. The climatic condition of this region is characterized by a sub-tropical environment with hot humid summer and relatively dry and cool winter. The average annual rainfall varies from 1500 to 2000 mm, unevenly distributed throughout the year. Normally rain starts from June and continues up to September with the pre-monsoon showers commencing from the mid March. In general, the maximum temperature being about 34° during summer and the minimum about 7° during winter.

Experimental Details

The field experiment was laid out in a randomized block design with four replications. Boron was applied at 0, 0.5, 1.0, 1.5 and 2.0 kg ha^{-1} to cauliflower only to assess the direct effect of boron fertilization while boron fertilization was curtailed off in cowpea and okra to assess the residual effect of boron fertilization. The recommended dose of N: P_2O_5:K_2O: 80:60:60, 15:35:10 and 50:50:50 kg ha^{-1} were applied to cauliflower, cowpea and okra, respectively at the time of sowing through urea, single super phosphate and muriate of potash. Farmyard manure at a rate of 10, 9 and 10 tonne ha^{-1} were also applied before 10 days of sowing to cauliflower, cowpea and okra, respectively. Crop yields were recorded at maturity stage

Chemical analysis

Total chlorophyll content

Leaf chlorophyll in fresh leaf was estimated by non-maceration method using dimethyl sulphoxide (DMSO) (Hiscox and Israelstam, 1979). Leaf chlorophyll was estimated by non-maceration method using Dimethyl Sulphoxide (DMSO) (Hiscox and Israelstam, 1979) and light absorption at 663 nm and 645 nm was read in a spectrophotometer. The amount of chlorophyll content was calculated using absorption coefficients.

The fresh leaf material (0.5 g) in a test tube containing 5 ml of DMSO was kept in an oven at 65°C for about 4 hours. Chlorophyll was extracted in a test tube and the volume was made 10 ml by using DMSO. The optimal density (OD) of the extract was read at 663 nm and 645 nm using spectrophotometer. The chlorophyll content was determined by using the following formula and expressed as mg g^{-1} leaf fresh weight.

$$\text{Chlorophyll a} = [12.7\,(A_{663}) - 2.69\,(A_{645})] \times \frac{V}{1000 \times W}$$

$$\text{Chlorophyll b} = [22.9\,(A_{645}) - 4.68\,(A_{663})] \times \frac{V}{1000 \times W}$$

$$\text{Total chlorophyll} = [20.2\,(A_{645}) + 8.02\,(A_{663})] \times \frac{V}{1000 \times W}$$

Where, A = Absorbance at specific wavelength

V = Final volume of chlorophyll extract in 80% acetone

W = Fresh weight of the tissue extracted

In vivo nitrate reductase activity

The *in vivo* assay of NR activity in leaf was done according to the procedure of Hageman and Flesher (1960) with slight modifications.

Quality parameters

Protein

Protein in samples of known weight was extracted with tricholoro acetic acid. Colours in the aliquots of diluted protein extract was developed after 30 minutes by alkaline copper solution prepared from 2 per cent sodium carbonate, 1 per cent copper sulphate, 1 per cent sodium – potassium tartarate and 1 N Folin Ciocalteau reagent according to Lowry *et al.* (1951).

Ascorbic acid

Ascorbic acid in fresh leaf was determined using 2,6-Dichlorophenol – Indophenol Visual Titration method given by A.O.A.C. (2001).

$$\text{mg ascorbic acid per 100 g} = \frac{T.V \times D.F \times V}{A \times W} \times 100$$

Where, T.V.= Titre value

D.F. = Dye factor

V = Volume made up

A = Aliquot of extract taken for estimation

W = Weight of volume of sample taken for estimation.

Starch

Starch content was determined by Anthrone method (Mcready *et al*., 1950) [26]. The dry residue left after sugar extraction was powdered and a known amount of it was hydrolyzed by boiling with 10 ml of 1N HCl in a glycerin bath at 112-115°C for 30 minutes. The residue was repeatedly washed with distilled water until a negative test of starch by iodine was obtained. The extract was collected and final volume was made up to 100 ml. An aliquot (0.5-1.0 ml) of the above extract was made to uniform of 2.5 ml with distilled water. It was then mixed thoroughly with 10 ml of freshly prepared anthrone reagent (100 mg of anthrone in 100 ml of chilled concentrated sulphuric acid) in a cold water bath. The tubes then kept in a boiling water bath for 15 minutes and cooled in running tap water. Absorbance was measured at 620 nm in a spectrophotometer. A blank and two freshly prepared glucose standards were also included with each set of samples. Starch content was calculated by multiplying the glucose values by 0.9 (Pucher *et al*., 1948) and expressed in mg g^{-1} DW.

Statistical Analysis

The experimental data obtained from various observations were analyzed statistically by using Fisher's method of analysis of variance in Randomized Block Design as described by Panse and Sukhatme (1985). Significance or non significance of the variance due to various treatment effect was determined by calculating respective 'F' values.

Results and Discussion

Physiological parameters

Chlorophyll content in plant leaves

The pooled data (Table 1) showed that the total chlorophyll content of fresh plant leaves responded significantly to application of graded levels of boron.

The assessed fate of direct response of boron fertilization marked an increase in total chlorophyll content with the application of 2 kg B ha^{-1} as observed at the vegetative stage of crop growth in cropping sequence. In respect of cauliflower, the total chlorophyll content of 7.17 mg g^{-1} was recorded at the same stage with same level. Further, its content declined by 7.04 mg g^{-1} at the curd initiation stage and 4.97 mg g^{-1} at the maturity stage.

In cowpea and okra also, a prominent residual effect of boron fertilization was observed with the application of 2 kg B ha^{-1}. In cowpea, the highest total chlorophyll content of 6.95 mg g^{-1} was recorded at vegetative stage and then its content decreased to 6.35 mg g^{-1} at the flowering stage and 4.65 mg g^{-1} at maturity stage. Similarly, same trend was replicated in okra with the highest total chlorophyll content of 9.42 mg g^{-1}, 7.66 mg g^{-1} and 6.03 mg g^{-1} at the vegetative, fruiting and maturity stage, respectively with the application of 2 kg B ha^{-1}. The incremental trend of the total chlorophyll content with the graded level of boron in cropping sequence in augmenting chlorophyll content in the plant leaves was recorded. The higher chlorophyll content in boron treated plants is in agreement with the findings of Liang and Shen (1994) [19]. Moreover, boron was found essential for the maintenance of normal structure of chloroplast. This result are underpinned by findings of Seth and Aery (2013) [31] who reported that application of boron as boric acid (H_3BO_3) up to 4 µ g^{-1} B concentration resulted in a maximum increment in chlorophyll content. Similar findings were also reported by Randhawa and Bhail (1974) [29], Salam *et al*. (2011) [30] and Hegazi *et al*. (2018) [13]. Du Ying Qiong *et al*. (1999) [10] also reported that boron B is responsible for enhancing chlorophyll content and rate of photosynthesis (Pn), as well as inducing dry matter production in plants.

Nitrate reductase activities

The appraisal of pooled data (Table 1) revealed a marked significant effect of the application of the graded level of boron on nitrate reductase activities of leaves in all the crops in both the years. The pooled data (Table 1) revealed that the application of 2 kg B ha^{-1} resulted in the highest nitrate reductase activities in all stage of crop growth in the cropping sequence. In cauliflower, significantly the highest nitrate reductase activities of 5.52 µmole NO_2 g^{-1} fw h^{-1} was recorded in treatment T_5 at the vegetative stage. Gradually, with the advancement of crop growth, its content augmented by 7.53 µmole NO_2 g^{-1} fw h^{-1} at the curd initiation stage and then its content further declined by 3.90 µmole NO_2 g^{-1} fw h^{-1} at maturity stage.

Table 1: Effect of boron application on total chlorophyll content of leaves (mg 100 g^{-1})

Boron levels (kg ha^{-1})	Total chlorophyll content (mg 100 g^{-1})			in-vivo nitrate reductase activity (µmole NO_2 g^{-1} fw h^{-1})		
	Cauliflower	Cowpea	Okra	Cauliflower	Cowpea	Okra
	Vegetative stage					
B_0	5.20	4.98	7.40	3.10	4.62	1.65
$B_{0.5}$	6.09	5.65	8.05	4.46	5.25	1.92
$B_{1.0}$	6.59	6.22	8.57	5.35	6.15	2.19
$B_{1.5}$	6.92	6.61	9.01	5.40	6.60	2.32
$B_{2.0}$	7.17	6.95	9.42	5.52	7.32	2.59
$CD_{(p=0.05)}$	0.15	0.16	0.14	0.08	0.08	0.09
	Curd initiation stage	**Flowering stage**	**Fruiting stage**	**Curd initiation stage**	**Flowering stage**	**Fruiting stage**
B_0	5.05	4.52	5.65	4.40	5.51	3.60
$B_{0.5}$	5.90	5.18	6.35	6.47	6.75	5.02
$B_{1.0}$	6.42	5.67	6.91	7.36	7.65	5.29
$B_{1.5}$	6.77	6.04	7.31	7.41	8.10	5.42
$B_{2.0}$	7.04	6.35	7.66	7.53	8.82	5.69
$CD_{(p=0.05)}$	0.16	0.18	0.16	0.08	0.08	0.08
	Maturity stage					
B_0	3.66	3.16	4.49	2.39	3.68	1.40
$B_{0.5}$	4.23	3.81	5.05	2.49	3.85	1.62
$B_{1.0}$	4.57	4.27	5.39	3.00	4.75	1.89
$B_{1.5}$	4.78	4.63	5.72	3.48	5.20	2.02
$B_{2.0}$	4.97	4.65	6.03	3.90	5.92	2.29
$CD_{(p=0.05)}$	0.12	0.04	0.16	0.08	0.08	0.09

In cowpea and okra leaves also, a prominent residual effect of boron fertilization was observed with the application of 2 kg B ha^{-1}. At the vegetative stage, nitrate reductase activities of 7.32 µmole NO_2 g^{-1} fw h^{-1} and 2.59 µM g^{-1} h^{-1} were recorded in cowpea and okra, respectively. Further, with crop growth progress, the highest nitrate reductase activity of 8.82 µmole NO_2 g^{-1} fw h^{-1} was recorded at the flowering stage in cowpea followed by 5.69 µmole NO_2 g^{-1} fw h^{-1} in okra at the same stage. The progressive crop growth ensued a decremental trend in nitrate reductase activities of both crops with nitrate reductase activities of 5.92 µmole NO_2 g^{-1} fw h^{-1} and 2.29 µmole NO_2 g^{-1} fw h^{-1} at the maturity stage in cow pea and okra, respectively.

The difference in nitrate reductase activities of all crops may be attributed to the difference in crop type, variety and species. This incremental trend of nitrate reductase activities in plant leaves for all the crops with added level of boron may attributed to the fact that the adequate and quick supply of boron through phloem tissues to the floral meristems can influence the uptake and metabolism of nitrogen (Camacho-Cristobal and Gonzalez-Fontes, 1999) [8]. Similar findings were reported by Matas *et al.* (2009) [24] who suggested that B deficiency might decrease nitrate uptake rather than nitrate reductase activity in tobacco plants. Hemantaranjan and Trivedi (2015) [14] also concluded that a significant increase in the nitrate reductase (NR) and nitrite reductase (NiR) activity in roots and leaves were noted. Boron deficiency causes a drastic decrease in leaf nitrate content, which leads to a decline in NR activity, an imbalance between nitrogen and carbon metabolism and, in consequence, a build-up of carbohydrates.

Ascorbic acid

Perusal of pooled data (Table 2 and Fig.1) showed that the ascorbic acid content in fresh plant leaves and edible portions of cauliflower, cowpea and okra responded significantly to the application of graded levels of boron. In cauliflower, pooled data (Table 2) revealed that application of 2 kg B ha^{-1} recorded significantly the highest ascorbic acid content in all stage of crop growth. In cauliflower leaves, the highest ascorbic acid content of 53.78 mg 100 g^{-1} was recorded at the vegetative stage while, its content augmented to 55.46 mg 100 g^{-1} at the curd initiation stage and further, its content declined with the advancement of crop growth by 40.86 mg 100 g^{-1} at the maturity stage with same level of boron.

Similarly, a prominent residual effect of boron fertilization was recorded in cowpea and okra with the ascorbic acid content of 32.09 mg 100 g^{-1} and 26.49 mg 100 g^{-1} in cowpea and okra leaves, respectively at vegetative stage of crop growth. An incremental trend of ascorbic acid content in leaves were observed and was found at the fruiting and flowering stages in cowpea and okra by 34.39 mg 100 g^{-1} and 28.93 mg 100 g^{-1}, respectively. With advancement in crop growth, its content decreased by 27.04 mg 100 g^{-1} and 23.74 mg 100 g^{-1} at maturity stage in okra and cowpea, respectively.

In respect of ascorbic acid content in edible portions of curd in cauliflower, pod in cowpea and fruit in okra, the effect of direct and residual effect of the application of the graded level of boron was found significantly prominent. The significantly highest ascorbic acid content of 24.57 mg 100 g^{-1} was recorded under treatment T_5 in curd of cauliflower. The residual effect of boron fertilization augmented to the maximum ascorbic acid content of 56.28 mg 100 g^{-1} in pod of cowpea while, in fruit of okra, its content declined to the lowest by 17.38 mg 100 g^{-1}.

The reason for the profound effect of the application of the graded level of boron in augmenting the ascorbic acid in leaves and edible portion of crops might be attributed to the soil application of boron in crops in cropping system which might have improved physiological activities and catalytic action. Further, boron influences the activity of biosynthesis of amino acid and protein and remobilization of amino acids from protein which affects the partitioning of nitrogenous compounds. In the presence of boron, protein and ascorbic acid synthesis reaction is more so ultimately the level of protein and ascorbic acid is increased (Allen and David, 2006) [1]. Since boron plays an important role in the translocation of carbohydrates from leaves to other portions of the plant, greater concentrations of ascorbic acid may have been translocated to the curd (Randhawa and Bhail, 1974) [29]. The alleviating effects of B on oxidative stress parameters were related to the improvement in antioxidant enzymes activity (ascorbate peroxidase and catalase), and the non-enzymatic antioxidant compounds (ascorbic acid). Similar observations were made by Tavallali *et al.* (2017) [35], Malewar *et al.* (1999) [21] and Singh *et al.* (2002) [34].

Table 2: Effect of boron application on ascorbic acid content of leaves (mg 100 g^{-1})

Boron levels (kg ha^{-1})	Ascorbic acid content (mg 100 g^{-1})		
	Cauliflower	**Cowpea**	**Okra**
	Vegetative stage		
B_0	37.16	22.59	17.19
$B_{0.5}$	44.75	25.54	19.94
$B_{1.0}$	48.43	28.21	22.36
$B_{1.5}$	51.78	30.30	24.53
$B_{2.0}$	53.58	32.09	26.49
$CD_{(p=0.05)}$	1.95	1.04	1.45
	Curd initiation stage	**Flowering stage**	**Fruiting stage**
B_0	45.74	23.39	19.59
$B_{0.5}$	48.76	26.21	22.49
$B_{1.0}$	50.91	28.56	24.76
$B_{1.5}$	53.01	31.10	26.92
$B_{2.0}$	54.94	34.39	28.93
$CD_{(p=0.05)}$	1.88	1.58	1.41
	Maturity stage		
B_0	30.94	19.99	14.59
$B_{0.5}$	34.01	22.81	17.36
$B_{1.0}$	36.11	25.16	19.76
$B_{1.5}$	38.27	25.09	21.70
$B_{2.0}$	40.31	27.04	23.74
$CD_{(p=0.05)}$	1.99	1.38	1.68

Protein content in the edible portions

The perusal of data elucidated in Fg. 1 showed that application of the graded level of boron significantly affected the protein content in the edible portions of cauliflower, cowpea and okra. A marked prominent effect of direct and residual effect of graded level of boron application in edible portions of curd in cauliflower, pod in cowpea and fruit in okra were recorded. Pooled data revealed that application of 2 kg B ha^{-1} recorded the highest protein content of 3.36, 5.80 and 4.42 per cent in the curd of cauliflower, pod of cowpea and fruit of okra, respectively.

The significant increase of protein content in the edible portion of crops on application of graded levels of boron in cropping sequence might be due to important role of boron in metabolic process, sugar translocation, protein synthesis and plant defense mechanism (Cakmak and Romheld, 1997) [3]. These results are in agreement with the finding of Verma *et al*. (2012) [36], Mandal and Das (2014) [22] and Jaiswal *et al.* (2015) [17] also reported that increase in protein content might be due to the significant role of B in protein and nucleic acid metabolism. Iqtidar and Rehman (1984) [16] also reported that positive linear and negative quadratic effects of boron were observed on the protein and ash contents of wheat grain.

Starch content in the edible portions

The application of graded level of boron significantly affected the starch content in the edible portions of cauliflower, cowpea and okra. The perusal of data pertaining to Fig.1 showed that the starch content decreased with the application of incremental dose of boron and the lowest was recorded with 2 kg B ha^{-1} in all the stages of crop growth in the cropping sequence.

A marked prominent effect of direct and residual effect of graded level of boron application in edible portions of curd in cauliflower, pod in cowpea and fruit in okra were recorded. The lowest starch content of 1.51 mmol hexose m^{-2} was recorded with 2 kg B ha^{-1} in curd of cauliflower. The residual effect of boron fertilization further decreased the starch content to the lowest by 1.47 mmol hexose m^{-2} in pod of cowpea followed by 1.54 mmol hexose m^{-2} in the fruit of okra with the 2 kg B ha^{-1}.

This signified an inverse relationship between added level of boron with starch content in leaves. This decrease in starch content in edible portion of crops might be ascribed to the fact that application of a higher dose of boron increased the starch phosphorylase enzyme activities which in turn decreased starch content and might be responsible for the higher breakdown of starch (Marschner, 1995) [23]. Boron-deficient plants had much higher starch contents than boron-sufficient ones and this inverse relationship between boron levels and starch content in plant tissues have been already documented by work of Camacho-Cristobal and Gonzalez-Fontes (1999) [8]. Similar findings were supported by work of Chaterjee *et al*. (2005) [9] who reported that in low B, the activity of acid phosphatase, starch phosphorylase and ribonuclease increased and that of polyphenol oxidase decreased in leaves of gram.

Crop yield

The application of graded level of boron exercised a marked significant effect on yield of all crops (Table 1). In respect of cauliflower, the highest curd yield of 232.5 q ha^{-1} was recorded as an implication of direct effect of boron fertilization with boron level of 2 kg ha^{-1}. A quantum leap in yield by 17.89 per cent over the control (190.9 q ha^{-1}) was recorded with the maximum boron level 2 kg B ha^{-1}. Whereas in cowpea and okra also, the profound effect of application of the graded level of boron was observed. In respect of cowpea and okra, the highest pod yield of 71.5 q ha^{-1} and fruit yield of 206.1 q ha^{-1} were recorded as a ramification of residual effect of boron fertilization with boron level of 2 kg ha^{-1}. A quantum leap in yield by 20.49 per cent over the control (56.9 q ha^{-1}) in cowpea and 17.51 per cent over the control (170.0) in okra was recorded with the maximum boron level 2 kg B ha^{-1}.

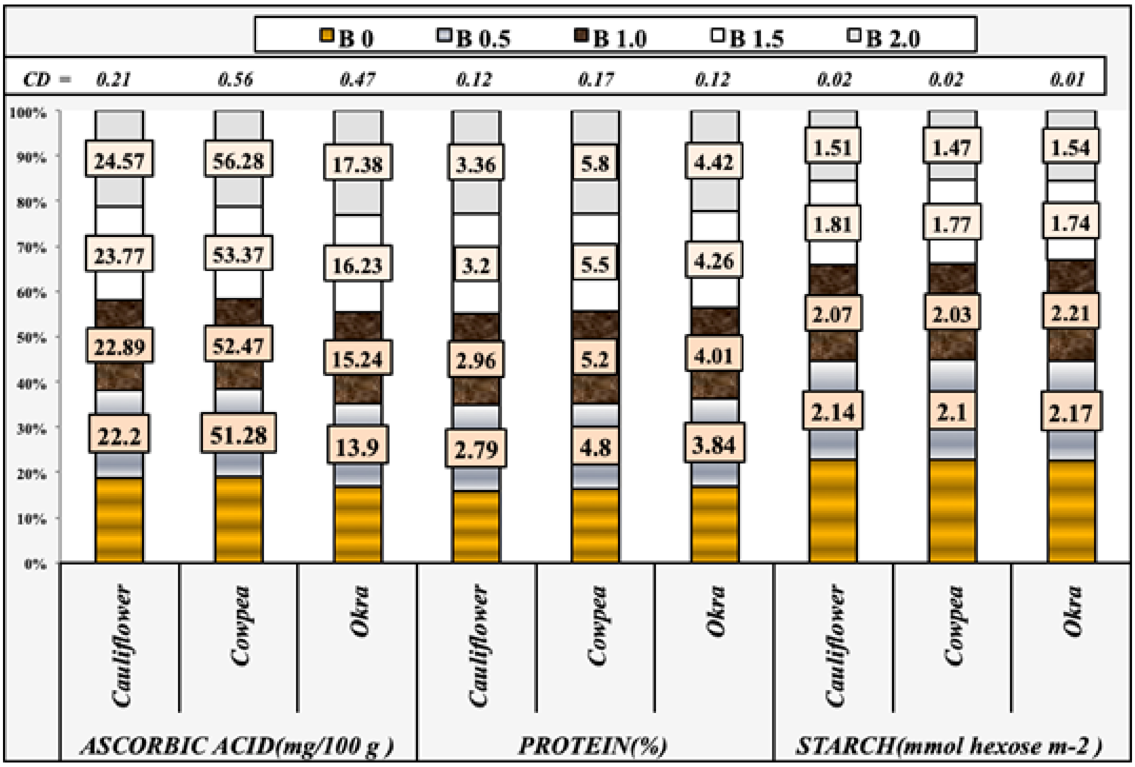

Fig 1: Distribution of crop quality parameters in edible portion of cauliflower, cowpea and okra

The enhanced yield of cauliflower as a result of B application is attributable to the increased availability of nutrients to plants (Singh and Thakur, 1991), thereby manufacturing more carbohydrates and proteins (Takkar and Randhawa 1978; Verma *et al*., 2012) [36] along with its role in enhancing their translocation from the site of synthesis to the storage organs (Sharma, 2002). Further, B plays a key role in many metabolic processes such as cell wall differentiation, cell development, N-metabolism, fertilization, fat metabolism, hormone metabolism, active salt absorption and photosynthesis (Nason and McElory, 1963) which in turn contributed to higher fresh and dry matter yield of cauliflower. Similar findings in okra were reported by Rahman *et al.* (2017), Srivastava *et al.* (2009), Saha *et al.* (2010) and Kumar and Sen (2004) who reported that application of B and Zn improved the yield and quality of okra seed. Du *et al.* (1999) [10] also found boron responsible for enhancing chlorophyll content and rate of photosynthesis (Pn), as well as inducing dry matter production in plants ultimately leading to yield improvement in peanut. The positive effects of boron on curd quality and yield of cauliflower have also been reported by Gupta (1979) and Kotur and Kumar (1989).

Table 3: Effect of graded levels of boron on crop yield (q ha^{-1}) in cauliflower-cowpea –okra cropping sequence

Boron levels (kg ha^{-1})	Cauliflower (curd)			Cowpea(pod)			Okra(fruit)		
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
B_0	185.7	196.1	190.9	54.9	58.8	56.9	168.9	171.1	170.0
$B_{0.5}$	196.5	207.1	200.3	59.4	64.2	61.8	179.9	180.2	180.1
$B_{1.0}$	205.9	219.3	212.6	63.4	68.3	65.9	186.6	189.8	188.2
$B_{1.5}$	216.2	230.6	223.4	66.1	71.0	68.6	194.9	202.8	198.9
$B_{2.0}$	224.8	240.2	232.5	68.9	74.1	71.5	201.5	210.7	206.1
$CD_{(p=0.05)}$	7.8	8.05	5.20	2.64	2.68	1.76	9.42	9.51	6.29
% Increase over control	17.40	18.36	17.89	20.3	20.7	20.49	16.2	18.8	17.51

Correlation study
Correlation results(Table 4) tangibly revealed that yield of crops exhibited a highly significant positive correlation with quality parameters *viz*., ascorbic acid and protein content in edible portion of crops in cauliflower(curd), cowpea(pod) and okra(fruit), respectively while in respect of quality parameter, starch revealed a significant negative correlation with yield of crops in the sequence. The positive correlation between the crop yield and quality parameters ie., ascorbic acid and protein content in edible portion of crops might be due to role of boron application which augmented both the yield of crops and quality parameters as explained in previous section. Similarly, starch content in crop was found to have a negative correlation with applied incremental boron dose even though the yield of crops leveraged with boron application. And this might be the possible rationale for the negative correlation between crop yield and starch content in edible portion of crops.

Table 4: Correlation between yield of crops and crop quality parameters

		Crop quality parameters								
		Ascorbic acid content (mg 100 g^{-1})			Protein content (%)			Starch content (mmol hexose m^{-2})		
		Cauli-flower (curd)	Cow-pea (pod)	Okra (Fruit)	Cauli-flower (curd)	Cow-pea (pod)	Okra (Fruit)	Cauli-flower (curd)	Cow-pea (pod)	Okra (Fruit)
Yield of crops (q ha^{-1})	Cauli-flower (curd)	0.993	0.964	0.999	0.973	0.987	0.975	-0.942	-0.942	-0.899
	Cow-pea (pod)	0.971	0.948	0.995	0.992	0.999	0.992	-0.903	-0.903	-0.850
	Okra (Fruit)	0.991	0.961	0.997	0.982	0.989	0.983	-0.943	-0.943	-0.908

Conclusion
From the foregoing experiment it can be concluded that among the different levels of boron, the experimental findings showed that application of 2 kg B ha^{-1} was found significant and the highest in augmenting the plant physiological parameters *viz*, total chlorophyll content and nitrate reductase activities in plant leaves and quality parameters *viz*., ascorbic acid and protein in edible portion in all crops as compared to other lower boron levels while the lowest were observed in control plots thereby signalling an incremental trend plant in physiological and quality parameters corresponding to the escalating boron level. Excepting starch parameter which recorded the lowest content corresponding to the highest boron application of 2 kg B ha^{-1} thereby exhibiting an inverse relationship between starch content and applied boron level in crops in cropping sequence.

References

1. Allen VB, David. Handbook of plant nutrition. CRC Press, 2006, 243.
2. Brown PH, Bellaloui N, Wimmer MA, Bassil ES, Ruiz J, Hu H *et al*. Boron in plant biology. Plant Biol. 2002; 4:205-223.
3. Cakmak I, Romheld V. Boron deficiency-induced impairments of cellular functions in plants. Plant and Soil. 1997; 193:71-83.
4. Camacho-Cristobal JJ, Gonzalez-Fontes A. Boron deficiency causes a drastic decrease in nitrate content and nitrate reductase activity, and increases the content of carbohydrates in leaves from tobacco plants. Planta. 1999; 209:528-536.
5. Camacho-Cristobal JJ, Gonzalez-Fontes A. Boron deficiency decreases plasmalemma H+-ATPase expression and nitrate uptake, and promotes ammonium assimilation into asparagine in tobacco roots. Planta. 2007; 226:443-451.
6. Camacho-Cristobal JJ, Maldonado JM, Gonzalez-Fontes A. Boron deficiency increases putrescine levels in tobacco plants. J. Plant Physiol. 2005; 162:921-928.
7. Camacho-Cristobal JJ, Gonzalez-Fontes A. Boron deficiency causes a drastic decrease in nitrate content and nitrate reductase activity, and increases the content of carbohydrates in leaves from tobacco plants. Planta. 1999; 209:528-536.
8. Camacho-Cristobal JJ, Gonzalez-Fontes A. Boron deficiency causes a drastic decrease in nitrate content and nitrate reductase activity, and increases the content of carbohydrates in leaves from tobacco plants. Planta. 1999; 209:528-536.
9. Chatterjee C, Sinha P, Dube BK. Biochemical Changes, Yield, and Quality of Gram Under Boron Stress. Communications in Soil Science and Plant Analysis. 2005; 36:(13):1763-1771.
10. Du Ying Q, Rong LX, Hua HJ, Zhiyao H. Influence of B and/or Mo application on the growth and yield of peanut. Chin J Oil Crop Sci. 1999; 21:61-66.
11. Goldbach HE, Wimmer M. Boron in plants and animals: Is there a role beyond cell-wall structure. J. Plant Nutr. Soil Sci. 2007; 170:39-48.
12. Goldbach HE, Yu Q, Wingender R, Schulz M, Wimmer M, Findeklee P. Rapid response reactions of roots to boron deprivation. J. Plant Nutr. Soil Sci. 2001; 164:173-181.
13. Hegazi ES, El-Motaium RA, Yehia TA, Hashim ME. Effect of foliar boron application on boron, chlorophyll, phenol, sugars and hormones concentration ofolive (*Olea europaea* L.) buds, leaves, and fruits. Journal of Plant Nutrition. 2018; 41(6):749-765.

14. Hemantaranjan A, Trivedi AK. Influence of boron and zinc on nitrate and nitrite reductase activity in roots and leaves, and sulfur containing amino acids, protein and oil content in seeds of soybean [*Glycine max* (L.) Merr.]. International Journal of Scientific Research in Science and Technology. 2015; 3(1):30-38.
15. Hu H, Penn SG, Lebrilla CB, Brown PH. Isolation and characterisation of soluble B-complexes in higher plants. The mechanism of phloem mobility of boron. Plant Physiol. 1997; 113:649-655.
16. Iqtidar A, Rehman SF. Effect of boron on the protein and amino acid composition of wheat grain. J. agric. Sci., Camb. 1984; 103:75-80.
17. Jaiswal AD, Singh SK, Singh YK, Singh S, Yadav SN. Effect of sulphur and boron on yield and quality of mustard (*Brassica juncea* L.) grown on Vindhyan red soil. Journal of the Indian Society of Soil Science. 2015; 63:362-364.
18. Kastori R, Plesnicˇar M, Pankovic´ D, Sakacˇ Z. Photosynthesis, chlorophyll fluorescence, and soluble carbohydrates in sunflower leaves as affected by boron deficiency. J Plant Nutr. 1995; 18(9):1751-1763.
19. Liang Y, Shen Z. Interaction of silicon and boron in oil seed rape plants. Journal of Plant Nutrition. 1994; 17:415-425.
20. Loomis WD, Durst RW. Chemistry and biology of boron. Biofactors. 1992; 3:229-239.
21. Malewar GU, Waikar SL, Siddiqui MB. Approaches and their validity in establishment of critical concentration of plant boron in cauliflower (*Brassica oleracea* var. *Botrytis*). Journal of Soils and Crops. 1999; 9(2):168-173.
22. Mandal M, Das DK. Effect of boron on yield and physiological properties in rape (*Brassica campestris*). Indian Journal of Agricultural Sciences. 2014; 84:702-706.
23. Marschner H. Mineral nutrition of higher plants. Academic Press, San Diego, 1995.
24. Matas MA, González-Fontes A, Camacho-Cristóbal JJ. Effect of boron supply on nitrate concentration and its reduction in roots and leaves of tobacco plants. Biology of Plant. 2009; 53:120-124.
25. Maurya KR, Bineeta D. Effect of boron on growth, yield, protein and ascorbic acid content of radish (*Raphanus sativus* Linn.). European Journal of Biotechnology and Bioscience. 2016; 4(9):33-34.
26. McCready RM, Guggolz J, Silviera V, Owens HS. Determination of starch and amylose in vegetables. Analytical chemistry. 1950; 22(9):1156-1158.
27. O'Neill MA, Eberhard S, Albersheim P, Darvill AG. Requirement of borate cross-linking of cell wall rhamnogalacturonan II for Arabidopsis growth. Science. 2001; 294:846-849.
28. Ramon AM, Carpena Ruiz RO, G ´ arate A. *In vitro* stabilization and distribution of nitrate reductase in tomato plants: incidence of boron deficiency. J. Plant Physiol. 1989; 135:126-128.
29. Randhawa KS, Bhail AS. Growth, yield and quality of cauliflower as influenced by nitrogen, phosphorus and boron. Indian Journal of Horticulture. 1974; 31:83-91.
30. Salam MA, Siddiquem A, Rahim MA, Rahman MA, Goffar MA. Quality of tomato as influenced by boron and zinc in presence of different doses of cowdung. Bangladesh Journal of Agricultural Research. 2011; 36(1):151-163.
31. Seth K, Aery NC. Effect of Boron on the contents of chlorophyll, carotenoid, phenol and soluble leaf protein in mung bean, *Vigna radiata* (L.) Wilczek. Proceedings of National Academy of Science, India, Biological Science. 2013; 84(3):713-719.
32. Sharma PN, Ramchandra T. Water relations andphotosynthesis in mustard plants subjected to boron deficiency. - Indian J. Plant Physiol. 1990; 33:150-154.
33. Shen ZG, Liang YC, Shen K. Effect of boron on the nitrate reductase-activity in oilseed rape plants. J. Plant Nutr. 1993; 16:1229-1239.
34. Singh RN, Singh S, Armakar S, Singh S. Effect of boron application on cauliflower in an acid Alfisols. Journal of Research Birsa Agriculture University. 2002; 14:61-63.
35. Tavallali V, Karimi S, Espargham O. Boron x *Pistacia vera* Seedlings. The Japanese Society for Horticultural Sciences (in press), 2017.
36. Verma CK, Prasad K, Yadav DD. Studies on response of sulphur, zinc and boron levels on yield, economics and nutrients uptake of mustard [*Brassica juncea* (L.) Czern & Coss.]. Crop Research. 2012; 44:75-78.