Original Research Article

Direct and Residual Effect of Boron Application on Yield and Nutrients Content under Rice–Wheat Cropping System

ABSTRACT

Aims: To investigate the direct and residual effect of boron application on yield and nutrient content under rice-wheat cropping system in middle Gangatic alluvial plan.
Study design: Completely random design (CRD).
Place and Duration of Study: Net-house of the Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, India during 2017-18.
Methodology: The pot experiment was comprised with ten treatments among them eight for boron (ranges from 0.5 to 4.0 mg B kg^{-1}) along with control and recommended dose of fertilizer (RDF). Rice (*Oryza sativa* L.) variety ARIZE 6444 was used as test crop and after harvesting of rice crop, wheat (*Triticum aestivum* L.) variety HUW 468 was grown in the same pot without fresh application B. The yield data was recorded after harvesting of rice and wheat. The nutrient content in grain and straw and post-harvest soil properties were analyzed using standard protocol.
Results: The maximum grain yield in rice (44.07 g pot^{-1}) was recorded in T_5 (RDF + 1.5 kg B ha^{-1}), whereas in wheat (19.70 g pot^{-1}) was observed in T_8 (RDF + 3 kg B ha^{-1}). The maximum straw yield in rice (24.35 g pot^{-1}) was recorded in T_5 (RDF+ 1.5kg B ka^{-1}), whereas in wheat (48.65g pot^{-1}) was in T_8 (RDF + 3 kg B ha^{-1}). Application of RDF along with 1.5 kg B ha^{-1} was recorded the maximum (48.99%) harvest index in rice, whereas its (B) residual effect in wheat crop was maximum in RDF + 2 kg B ha^{-1}. Application of B @ 1.5 kg B ha^{-1} significantly enhanced the Fe, Cu, Mn and Zn content in rice grain, whereas residual effect of 3 kg ha^{-1} B application has significantly improved the Fe, Cu and Mn content in wheat grain.
Conclusion: It was found that application of B did not increased grain yield of rice and wheat significantly over RDF. A significant residual effect of B application in rice was noticed even after the harvest of wheat crop particularly at highest doses of B application.

Keywords: *Boron; harvest index; nutrient content; rice; wheat; yield.*

1. INTRODUCTION

Rice–wheat cropping system (RWCS) is a major cropping system contributing one third of cereal production in the country. However, the system is not sustainable due to the decline in soil fertility and also in organic matter. The factor productivity of fertilizers has also decreased leading to higher requirement of plant nutrients to be applied to obtain the same yield. Rice-wheat is the major prevalent system in the Indo-Gangatic Plains with an estimated area of 13.5 million hectares in South Asia [1]. Rice-wheat is a nutrient exhaustive system and nutrient removal from the soil is much higher than fertilizer input. As a result, wide spread micronutrient deficiencies occurred in rice-wheat system. Growth and yield of rice crop is a result of its interaction with environmental factors, soil conditions, availability of water and nutrients uptake from the soil. Rice crop needs seventeen essential nutrients. In Uttar Pradesh, rice is cultivated in 70 districts out of which 7 districts (Bijnour, Kushinagar, Pilibheet, Chandauli, Bagpat, Ambedkar and Varanasi) are under high productivity group. The total area under rice cultivation is 56.96 M ha with average productivity of 2,042 kg ha^{-1}. India is the second largest producer of wheat after China. Uttar Pradesh is the largest producer of wheat in India which account for 35.03% from a large area

35.12% with productivity 2.7 tonnes ha^{-1}. Area under wheat production is distributed in three Agroclimatic zones, *viz*, western Uttar Pradesh (3.29 million ha), eastern Uttar Pradesh (5.24 millian ha) and central Uttar Pradesh (0.68 millian ha).

Boron (B) is important micronutrient that is essential for plant growth and improves the production efficiency of wheat. However, the deficiency of B is the most frequently encountered in field [2]. Lack of B can cause ‘wheat sterility’ resulting in increased number of open spikelets and decreased number of grains per spike [3]. The B deficiency in soil can affect seedling emergence and cause an abnormal cellular development in young wheat plant [4]. It also inhibits root elongation by limiting cell division in the growing zone of root tips [5]. Deficiency of B is known to inhibit the leaf expansion and reduction in photosynthesis. In the field, sexual reproduction is often affected by low B reducing the grain yield significantly without any visual symptoms expressed during vegetative growth.

Boron is an important mineral nutrient which stimulate a number of physiological processes in vascular plants, It is important for carbohydrates metabolism, translocation and development of cell wall and RNA metabolism [6,7]. Boron has been found to play a key role in pollen germination and pollen tube growth, stimulate the plasma membrane, anther development, floret fertility and seed development [8,9]. Deficiency of B causes reduction in leaf photosynthetic rate, total dry matter production, plant height and number of reproductive structures during squaring and fruiting stage [10]. Boron is associated with one or more of the following processes: calcium utilization, cell division, flowering and fruiting, carbohydrate and nitrogen metabolism, disease resistance, water relations and catalyst for certain reactions [11,12]. Boron stabilizes the structure of plasma membrane by complexing membrane compounds containing cis-diol groups such as glycoproteins and glycolipids to keep channels and enzymes at optimum conformation within the membrane.

Micronutrient deficiency in soil including that of B is quite widespread in Asian countries including India due to prevalent soil and environmental conditions. Among micronutrients, zinc (Zn) and B deficiency accounts about 49% and 33%, respectively in Indian soils, which reduce not only the yield but also the nutritional quality of the produce. Boron deficiency is the second most important micronutrient constraint in crops after that of Zn on global scale. Its deficiency has been widely found in highly calcareous soils of Bihar, Eastern Uttar Pradesh, Tamil Nadu and Saurashtra, sandy soils of Haryana and Rajasthan, hill and sub-mountaneous soils of north Himalayan and North East Himalayan states and in red and lateritic soils of Orissa, Karnataka, Andhra Pradesh and Kokan region [13]. Widespread deficiencies of B in soils of Uttar Pradesh [14] and its direct influence on the growth and yield of cereals and other crops [16] increased its importance considerably. Deficiencies of B emerge because of intensive cropping, use of high analysis fertilizers and adoption of high yielding varieties [17, 18]. Boron is found to have its residual impact on the successive crops, it is imperative that application of B containing fertilizers are needed to exploit the production potential of crops under cropping systems and also to mitigate the deficiencies of this nutrient.

Keeping in view the important role of B in increasing grain yield, the present investigation was under taken to investigate the direct and residual effect of B application on yield and nutrient uptake by rice-wheat cropping system in Varanasi, Uttar Pradesh, India.

2. MATERIAL AND METHODS

2.1. Study area

An experiment was carried out in the net-house of the Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, India, taking rice as a test crop during *kharif*-2017 and wheat crop during *rabi* 2017-18. Varanasi is situated at an altitude of 80.71 m above mean sea level and located between 25^{o} 18’ North latitude and 80^{o} 36’ East longitudes. Varanasi falls in a semi-arid to sub humid climate with moisture deficit index between 20-40. The average annual rainfall of this region is about 1100 mm. Generally, the maximum and the minimum temperature ranged between 20-42^{o}C and 9-28^{o}C, respectively. The mean relative humidity is about 68% which rise to 82% during wet season and goes down to 30% during dry season.

2.2. Experimental setup

The B deficient soil was collected from the dry land Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi. The soil was alluvial representing an Inceptisol (Typic Ustochrept). The experimental soil had pH 7.05 (1:2.5), EC 0.504 dS m^{-1}, OC 0.60% and calcium carbonate 0.47%. The available nitrogen (N), phosphorus (P), potassium (K) and sulfur (S) content was 112, 37, 157.70 and 15.43 kg ha^{-1}, respectively and the DTPA extractable zinc (Zn), copper (Cu), iron (Fe), manganese (Mn) and B contents of soil was 0.49, 4.2, 38.9, 5.6 and 0.42 mg kg^{-1}, respectively. Ten kg of this soil was filled in each pot after grinding to pass through 2 mm sieve. The experiment was laid down in a completely randomized design (CRD) with ten treatments and treatments detail was given in Table. 1. Rice (*Oryza sativa* L.) variety ARIZE 6444 was used in the study and after harvesting of rice crop, wheat (*Triticum aestivum* L.) variety HUW 468 was grown in the same pot without fresh application B. Required quantities of fertilizers for 10 kg soil were calculated and applied in liquid form using urea, KH_2PO_4 and muriate of potash as source of N, P and K, respectively. The recommended N, P_2O_5 and K_2O were 150, 60 and 60 kg ha^{-1}, respectively for rice and 120, 60 and 60 kg ha^{-1} for wheat, respectively. Half of N and full dose of P and K were applied at the time of transplanting of rice and remaining N fertilizer was applied in two equal splits at tillering and flower initiation stages. In wheat, half of N and full dose of P and K was applied at the time of sowing and remaining N fertilizer was applied in two equal splits at tillering and flower initiation stages. Pots were irrigated as per requirement of the wheat crop and for rice; continuous submerged condition was maintained up to the physiological maturity.

Table 1. Treatment details

Treatment code	Rice	Wheat
T_1	Absolute control (without fertilizer)	Absolute control (without fertilizer)
T_2	Control: RDF* (N: P_2O_5: K_2O @ 150:60:60 kg ha^{-1})	Control: RDF (N: P_2O_5: K_2O @ 120:60:60 kg ha^{-1})
T_3	RDF + 0.5 kg B ha^{-1} soil application	RDF + residual effect of boron applied in rice
T_4	RDF + 1.0 kg B ha^{-1} soil application	RDF + residual effect of boron applied in rice
T_5	RDF + 1.5 kg B ha^{-1} soil application	RDF + residual effect of boron applied in rice
T_6	RDF + 2.0 kg B ha^{-1} soil application	RDF + residual effect of boron applied in rice
T_7	RDF + 2.5 kg B ha^{-1} soil application	RDF + residual effect of boron applied in rice
T_8	RDF + 3.0 kg B ha^{-1} soil application	RDF + residual effect of boron applied in rice
T_9	RDF + 3.5 kg B ha^{-1} soil application	RDF + residual effect of boron applied in rice
T_{10}	RDF + 4.0 kg B ha^{-1} soil application	RDF + residual effect of boron applied in rice

*RDF = Recommended dose of fertilizer.

2.3. Soil and plant sample analysis

The soil samples were collected from each pot after the harvesting of rice and wheat crop. Soil samples were drying in a shade followed by clods broking and ground on wooden plank with wooden roller and finally passed through 0.5 mm sieve for physico-chemical analysis. The soil samples were then stored in polythene bags. The soil samples were analyzed for pH with the help of pH meter by preparing soil-water suspension in the ratio of 1:2.5 [19] and electrical conductivity was measured in the same solution by the help of EC meter and expressed as dS m^{-1}. Potassium permanganate (1 N $K_2Cr_2O_7$) oxidizable carbon was determined by the method outlined by [20]. And available B content of soil was determined by Hot $CaCl_2$- extractable method [21]. The plants were harvested at full maturity stage and washed in detergent solution (0.2% liquid), 0.1 N hydrochloric acid (HCl) solution and de-ionized water in sequence and dried at 70^{o}C till the constant weight. The plant samples (straw and grain) were digested in a di-acid mixture of nitric acid and perchloric acid (9:4 v/v HNO_3: $HClO_4$) and analyzed for Fe, Cu, Mn, Zn and Ni using atomic absorption spectrophotometer (Agilent 240FS) as per procedure outlined by [22]. For determination of B content in grain and straw, plant samples were kept in muffle furnace at 550-600^{o}C temperature for 8-12 hrs. And B was extracted by using 5ml of 20% HCl or H_2SO_4 and determination was done by using Azomethine-H indicator.

2.4. Statistical analysis

The data were subjected to one-way analysis of variance (ANOVA) using SPSS version 16.0 software. Duncan's multiple range test (DMRT) was performed to test the significance of difference between the treatments at $p = 0.05$.

3. RESULTS AND DISCUSSION

3.1. Grain and straw yield

Examination of data clearly showed that the grain yield in rice as well as wheat significantly increased with direct application of B and its residual effect on wheat (Table 2). The grain yield varied from 15.33 to 44.07 g pot^{-1} and 7.76 to 19.70 g pot^{-1} in rice and wheat, respectively. The maximum grain yield in rice was recorded in T_5 (RDF + 1.5 kg B ha^{-1}) whereas in wheat, it was observed in T_8 (RDF + 3 kg B ha^{-1}). The residual effect of RDF + 3 kg B ha^{-1} (T_8) was recorded the maximum (19.70 g) grain yield of wheat followed by T_7 and T_6 which increased by 37, 26 and 24% over RDF (T_2). This increase in yield of rice might be due to the fact that micronutrients exerted a beneficial effect on chlorophyll content in the leaves and dry matter in plant which increased the productivity. Gour *et al*. (2015) and Ram *et al*. (2014) reported that grain yield of rice increased with application of Zn, S and B [23, 24]. Positive effects of B on the yield and yield components of rice were also reported earlier by other researchers [3]. Khan *et al*. (2011) were found that spike length significantly increased with the application of B applied to wheat alone and both to wheat and rice at 2 and 1 kg ha^{-1} over control [25].

Table 2. Direct and residual effect of boron application on grain yield, straw yield, harvest index and test weight in rice and wheat

Treatment	Grain yield (g pot^{-1})		Straw yield (g pot^{-1})		Harvest Index (%)	
	Rice	Wheat	Rice	Wheat	Rice	Wheat
T_1	15.33 ±3.23 a	7.76 ±.53 a	24.50 ±.90 a	18.19 ±.54 a	47.61 ±.91 bcd	42.68 ±1.31 a
T_2	38.03 ±2.58 c	14.36 ±2.05 b	45.69 ±2.58 cd	31.39 ±3.93 b	48.46 ±1.13 cd	44.85 ±0.37 b
T_3	39.50 ±6.19 c	15.23 ±.52 b	47.79 ±4.36 de	36.80 ±1.67 bc	48.00 ±.96 bcd	44.45 ±0.34 bc
T_4	40.13 ±4.63 c	16.36 ±2.86 b	51.07 ±1.32 ef	37.88 ±5.25 bc	48.43 ±.72 cd	44.32 ±0.19 bc
T_5	44.07 ±.90 c	16.73 ±3.08 b	54.35 ±2.05 f	39.76 ±2.84 bc	48.99 ±.42 d	45.00 ±0.40 bc
T_6	26.46 ±9.50 b	17.90 ±2.13 b	48.72 ±3.39 de	43.29 ±4.80 bc	48.51 ±.70 cd	45.26 ±0.07 c
T_7	24.73 ±6.45 ab	18.06 ±1.21 b	42.57 ±3.30 c	43.73 ±4.16 bc	47.04 ±1.18 bc	43.89 ±0.88 bc
T_8	22.83 ±5.46 ab	19.70 ±.89 b	38.05 ±2.29 b	48.65 ±3.15 c	47.48 ±1.24 bcd	43.80 ±0.41 bc
T_9	24.80 ±4.82ab	17.65 ±.82 b	35.64 ±1.42 b	40.73 ±6.69 bc	46.22 ±1.05 b	42.61 ±1.25 bc
T_{10}	21.43 ±4.39 ab	15.66 ±3.27 b	35.56 ±1.43 b	43.54 ±1.66 bc	44.43 ±1.26 a	39.88 ±1.12 bc

Data on straw yield of rice and wheat has been presented in (Table 2). It was evident that straw yield of rice and wheat significantly increased with application of different doses of B along with RDF. The straw yield in rice and wheat ranged from 24.50 to 54.35 g pot^{-1} and 18.19 to 48.65 g pot^{-1}, respectively. The maximum straw yield in rice and wheat was recorded in T_5 (RDF +1.5 kg B ha^{-1}) and T_8 (RDF+3 kg B ha^{-1}), respectively. Application of 1.0 and 1.5 kg B ha^{-1} along with RDF (T_4 and T_5) was significantly increased the straw yield by 19 and 12% over RDF in rice. The residual effect of application of 3 kg B ha^{-1} (T_8) and 2.5 kg B ha^{-1} (T_7) with RDF increased straw yield by 55 and 39% over RDF (T_2) in wheat. It is evident from the results that direct application of B and its residual effect with RDF, might have facilitated the growth of the plant, due to its involvement in many metallic enzyme system, regulatory functions and auxin production [26], increased synthesis and transport of carbohydrates to the sink [27]. This is also in conformity with the results found by Uddin *et al*. (2002) and Ram *et al*. (2014) [28, 29].

3.2. Harvest Index

The harvest Index ranged (HI) from 46.61 to 48.99% and 42.68 to 45.26% in rice and wheat, respectively (Table 2). The maximum HI in rice (48.99%) was in T_5 followed by T_6 (48.51%). The residual effect of 2 kg B ha^{-1} with RDF and 1.5 kg B ha^{-1} + RDF increased HI by 0.91 and 0.33% over RDF in wheat. Remesh and Rani (2017) [29] also found that HI and cost of cultivation showed a non-significant variation in all the levels of soil and foliar application. Our findings agree well to Halder *et al*. (2007), Korzeniowska, (2008) and Wrobel (2009) for grain yield and HI [30, 31, 32]. The higher value of grain yield with B application without any respective increase in straw yield resulted remarkable increase in HI. The positive contribution of B for biological yield and HI has also been confirmed by Shah (2009), Tombo *et al*. (2008) and Alam *et al*. (2000) [33, 34, 35].

3.3. Nutrients content in grain and straw

3.3.1. Iron content

The data pertaining to Fe concentration in rice and wheat grain as presented in Table 3. The Fe concentration of rice grain varied from 126.83 to 163.20 mg kg^{-1}, whereas in wheat, it varied from 52.96 to 79.90 mg kg^{-1}. The maximum Fe content in rice (163.20 mg kg^{-1}) and in wheat (79.90 mg kg^{-1}) was recorded in treatment T_5 (1.5 kg B ha^{-1} + RDF) and T_8 (RDF + 3 kg B ha^{-1}), respectively. Application of 1.5 kg B ha^{-1} with RDF and 1 kg B ha^{-1} with RDF increased Fe content in rice grain by 24 and 17% over RDF (T_2). The residual effect of 3 kg B ha^{-1} + RDF and 2.5 kg B ha^{-1} + RDF increased Fe content in grain by 32 and 27% over RDF in wheat. The data pertaining to Fe concentration in rice and wheat straw as presented in Table 3. The Fe concentration of rice varies from 262.66 to 345.00 mg kg^{-1}, whereas in wheat, it varied from 105.33 to 163.66 mg kg^{-1}. The maximum Fe in rice (345 mg kg^{-1}) and in wheat (163.66 mg kg^{-1}) was recorded in treatment T_9 (3.5 kg B ha^{-1} + RDF) and T_8 (RDF + 3 kg B ha^{-1}), respectively. Application of 1.5 kg B ha^{-1} with RDF (T_5) and 1 kg B ha^{-1} with RDF (T_4) increased Fe content in rice straw by 1% and 16% over RDF (T_2). The residual effect of 3 kg B ha^{-1} + RDF increased Fe content by 31% over RDF in wheat straw. This finding was lined with the findings of Arif (2012) [36].

3.3.2. Copper content

The data pertaining to Cu concentration in rice and wheat are presented in Table 3. The Cu concentration of rice varies from 3.46 to 7.26 mg kg^{-1}. The maximum Cu content in rice (7.26 mg kg^{-1}) was recorded in treatment T_5 (1.5 kg B ha^{-1}) and in wheat (7.26 mg kg^{-1}) T_8. Application of 1.5 kg B ha^{-1} with RDF and 1 kg B ha^{-1} (T_4) with RDF increased Cu content in rice grain by (94%) and (70%) over RDF (T_2). The residual effect on wheat grain recorded was increased in Cu content by 19 and 19% in T_8 and T_7, respectively over RDF (T_2). The data pertaining to Cu concentration in rice and wheat as presented in Table 3. The Cu concentration in rice straw varied from 6.63 to 13.16 mg kg^{-1}. The maximum Cu content in rice straw (13.16 mg kg^{-1}) was recorded in treatment T_5 and in wheat (14.50 mg kg^{-1}) T_8, respectively. Application of 1.5 kg B ha^{-1} with RDF (T_5) and 1 kg B ha^{-1} + RDF (T_4) increased Cu content in straw by (93%) and (88%), respectively over RDF (T_2). The residual effect of T_8 and T_7 showed an increase of Cu content in wheat straw by 28 and 27%, respectively over RDF (T_2). From result, it was noticed that Cu content in straw was higher than grain. Similar type of finding was also reported by Arif (2012) [36].

3.3.3. Manganese content

The data on Mn concentration in rice and wheat grain has been presented in Table 3. The data showed that Mn concentration in rice grain ranged between 10.1 to 14.06 mg kg^{-1}, whereas in wheat it varies from 7.56 to 11.86 mg kg^{-1}. The maximum Mn concentration in rice (14.06 mg kg^{-1}) and in wheat (11.86 mg kg^{-1}) was recorded in treatment T_5 (1.5 kg B ha^{-1}) and T_8 (3 kg B ha^{-1}), respectively. The data on Mn concentration in rice and wheat straw has been presented in Table 3. The data showed that Mn content in rice straw ranged between 123.33 to 176.33 mg kg^{-1}, whereas in wheat, it ranged from 98.66 to 132.00 mg kg^{-1}. The maximum Mn concentration in rice (176.33 mg kg^{-1}) and in wheat (132.00 mg kg^{-1}) was recorded in treatment T_5 (1.5 kg B ha^{-1}) and T_8 (3 kg B ha^{-1}), respectively. The finding of this experiment was conformity with the results found by Halder *et al*. (1981) [37].

3.3.4. Zinc content

Table 3. Direct and residual effect of boron application in soil on concentration of micronutrient cation (mg kg^{-1}) in rice and wheat

Treatment	Fe				Cu				Mn				Zn			
	Rice		Wheat		Rice		Wheat		Rice		Wheat		Rice		Wheat	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
T_1	126.83 ±52.49 a	325.00 ±15.39 c	52.96 ±5.19 a	105.33 ±0.88 a	3.46 ±0.11 a	6.63 ±0.20 a	4.80 ±0.55 a	10.36 ±0.17 a	10.00 ±0.36 ab	123.33 ±2.51 a	7.56 ±2.94 a	98.66 ±1.20 a	16.60 ±0.35 a	17.37 ±0.19 a	16.20 ±0.80 a	24.87 ±0.38 a
T_2	131.50 ±40.71 a	341.33 ±26.95 c	60.26 ±14.21 ab	125.00 ±1.15 b	3.76 ±0.05 a	6.80 ±0.36 a	5.10 ±0.05 a	11.36 ±0.12 b	10.56 ±0.06 ab	162.33 ±1.52 bc	7.83 ±1.15 a	102.00 ±0.57 a	17.13 ±0.20 ab	28.37 ±0.09 d	16.70 ±0.06 ab	26.50 ±0.06 b
T_3	153.36 ±2.28 a	267.00 ±6.08 a	62.10 ±.47 ab	132.00 ±1.15 c	5.50 ±2.00 ab	11.10 ±0.70 cd	5.13 ±0.32 a	12.13 ±0.08 c	13.30 ±3.50 ab	169.00 ±2.64 bcd	8.33 ±1.91 a	108.66 ±3.17 b	18.33 ±1.02 abc	30.13 ±0.15 e	17.53 ±0.41 bc	29.23 ±0.28 c
T_4	153.63 ±2.02 a	287.66 ±5.03 ab	62.40 ±1.34 ab	132.66 ±1.20 c	6.30 ±2.11 ab	12.83 ±0.40 fg	5.40 ±0.20 a	12.23 ±0.26 c	13.40 ±4.85 ab	174.33 ±8.73 cd	8.43 ±2.01 a	114.33 ±0.88 c	19.07 ±0.99 bc	30.30 ±0.46 e	16.63 ±2.17 ab	30.07 ±0.26 cd
T_5	163.20 ±9.06 a	294.00 ±7.00 b	66.90 ±6.09 ab	141.33 ±0.88 d	7.26 ±3.05 b	13.16 ±0.25 g	5.50 ±0.47 a	12.70 ±0.45 c	14.06 ±0.75 b	176.33 ±11.59 d	8.73 ±1.78 a	118.00 ±0.57 cd	20.00 ±0.21 c	32.43 ±0.12 f	17.77 ±0.82 ab	30.67 ±0.38 d
T_6	152.00 ±1.73 a	274.66 ±9.07 ab	74.73 ±1.78 ab	152.66 ±0.88 e	5.83 ±1.09 ab	12.10 ±0.30 ef	5.70 ±0.05 a	13.90 ±0.15 d	13.33 ±1.61 ab	174.00 ±9.00 cd	10.06 ±0.20 a	122.00 ±0.57 d	19.67 ±1.20 c	30.00 ±0.26 e	18.20 ±1.35 ab	31.13 ±0.23 d
T_7	145.00 ±8.54 a	264.00 ±3.00 a	76.76 ±12.47 ab	160.66 ±2.02 f	5.46 ±2.45 ab	11.80 ±0.62 de	6.13 ±0.03 a	14.43 ±0.35 d	12.43 ±3.35 ab	165.33 ±1.52 bcd	11.26 ±0.81 a	122.33 ±2.18 d	18.40 ±0.55 abc	27.33 ±0.09 c	19.50 ±2.80 ab	34.17 ±0.55 e
T_8	144.96 ±44.64 a	262.66 ±7.37 a	79.90 ±7.64 b	163.66 ±.88 f	5.20 ±0.17 ab	10.73 ±0.28 c	6.16 ±0.91 a	14.50 ±0.11 d	10.56 ±0.28 ab	161.33 ±6.65 b	11.86 ±1.11 a	132.00 ±0.57 e	17.30 ±0.06 ab	27.27 ±0.12 c	20.67 ±0.41 b	36.60 ±1.06 f
T_9	140.06 ±20.69 a	345.00 ±9.00 c	75.96 ±1.46 ab	151.00 ±1.52 e	4.50 ±0.17 ab	8.90 ±0.30 b	5.96 ±0.35 a	11.16 ±0.14 b	10.20 ±0.10 ab	169.00 ±5.56 bcd	11.16 ±0.96 a	120.00 ±0.57 d	17.20 ±0.45 ab	27.23 ±0.20 c	17.50 ±0.67 ab	28.83 ±0.20 c
T_{10}	130.10 ±44.01 a	337.00 ±22.11 c	68.30 ±6.42 ab	143.33 ±0.88 d	4.10 ±0.20 a	8.83 ±0.70 b	5.60 ±0.40 a	10.26 ±0.08 a	9.50 ±1.55 a	164.00 ±2.00 bc	9.36 ±0.73 a	109.00 ±3.60 b	16.97 ±0.07 ab	26.03 ±0.09 b	16.93 ±0.15 ab	26.20 ±0.06 b

The data pertaining to Zn content in rice and wheat has been presented in Table 3. The maximum Zn concentration in rice grain (20 mg kg^{-1}) and in wheat grain (20.67 mg kg^{-1}) was recorded in treatment T_5 (RDF + 1.5 kg B ha^{-1}) and T_8 (RDF + 3 kg B ha^{-1}), respectively. The concentration of Zn increased in rice grain with application of 1.5 kg B ha^{-1} + RDF (T_5) followed by RDF + 2 kg B ha^{-1} (T_6), which has respective increase of 17 and 15% over RDF (T_2). The data pertaining to Zn content in rice and wheat straw has been presented in Table 3. The maximum Zn concentration in rice straw (32.43 mg kg^{-1}) and in wheat straw (36.60 mg kg^{-1}) was recorded in treatment T_5 (RDF+ 1.5 kg B ha^{-1}) and T_8 (RDF+3 kg B ha^{-1}), respectively. The concentration of Zn increased with application of 1.5 kg B ha^{-1} + RDF (T_5) followed by 1 kg B ha^{-1} + RDF (T_4) which increased by 14 and 7%, respectively over RDF (T_2) in rice. In case of residual effect, 3 kg B ha^{-1}(T_8) and 2.5 kg B ha^{-1} (T_7) increased Zn content in wheat straw by 38 and 29%, respectively over RDF (T_2). It was noted that Zn content in straw was more than grains in rice. Ram *et al.* (2014) also observed that, Zn content in rice straw increased significantly with application of RDF+Zn+B+S [24]. The results were also conformity of results found by Bhutto *et al*. (2013) and Dash *et al*. (2015) [38, 39].

3.3.5. Boron content

Boron content in grain of rice and wheat (Fig. 1) was lower than the straw due to less mobility of B to reproductive parts. But in case of wheat concentration was more in the grain as well as straw as compared to rice. Boron content was found to be increased with increase in B doses may be attributed to the increased yield as well as its concentration in grain and straw. Similar results were reported by Khan *et al*. (2011) [25]. The B content in rice grain (Fig. 1) varied from 4.89 to 11.81 mg kg^{-1} and in wheat grain 12.19 to 24.58 mg kg^{-1}. Highest contents of B were observed in wheat grain grown on residual application of B as compared to direct effect on rice. This might be due to the high B requirement of wheat crop. The direct effect of 1.5 kg B ha^{-1} + RDF and residual effect of 3 kg B ha^{-1} + RDF increased B content in grain of rice and wheat by 123 and 119%, respectively over RDF (T_2). The maximum content of B was recorded in T_{10} in both crops grain with respective increase of 160% in rice grain and 153% in wheat grain over RDF (T_2). The B concentration in straw of rice and wheat was non-significant, and ranged from 4.54 to 9.61 mg kg^{-1} (Fig. 1). The highest concentration was achieved with the application of B applied both to wheat and rice (cumulative) at 2 kg B ha^{-1}. The application of 2 and 1 kg B ha^{-1} to rice crop increased the B concentrations in leaves up to 7.26 and 5.7 mg B kg^{-1}. The application of 2 and 1 kg B ha^{-1} to previous crop (wheat) and nil to rice increased the B concentrations up to 6.25 and 4.54 mg B kg^{-1}.

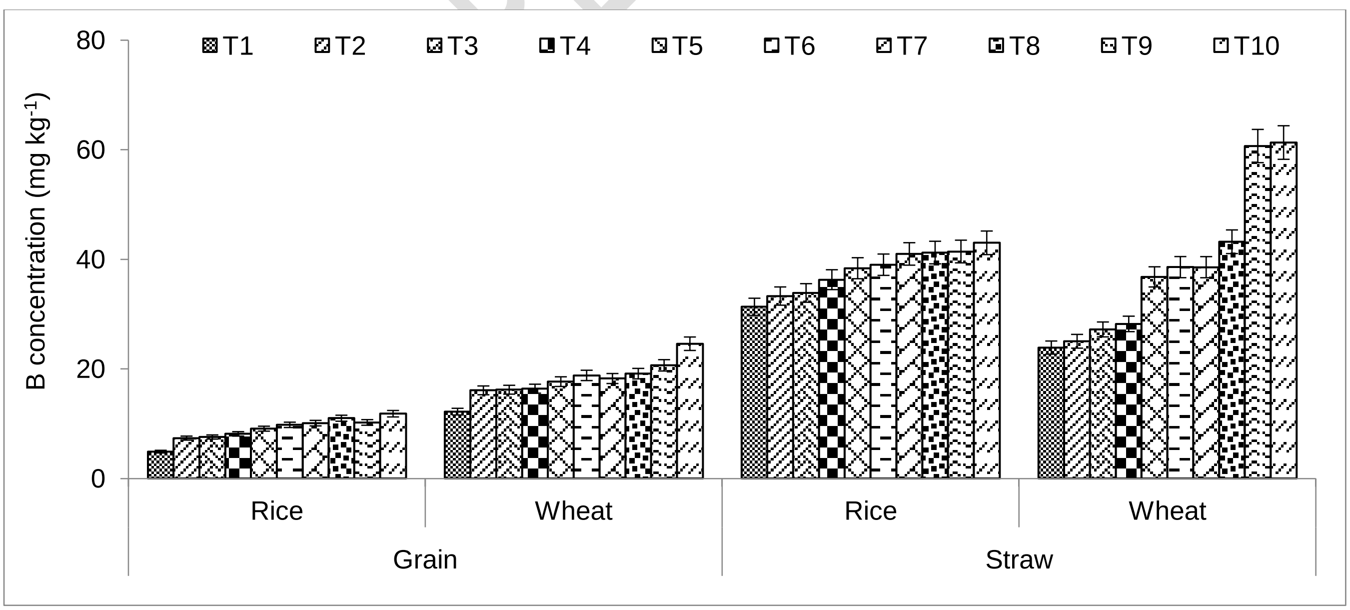

Fig. 1. Direct and residual effect of boron application on concentration of boron in grain, straw and post-harvest soil of rice and wheat

3.4. Post-harvest soil physic-chemical properties

3.4.1. Soil reaction (pH)

The data pertaining to pH of the soil as influenced by different doses of B application and chemical fertilizer are presented in Table 4. The pH of soil ranged between 7.1 to 7.27 and 7.3 to 7.52 in rice and wheat, respectively. The maximum pH in rice (7.3) was recorded in T_7 (RDF + 2.5 kg B ha^{-1}), whereas in wheat (7.25) it was in treatment 1kg B along with RDF (T_4). It was evident that the residual effect of 1kg B ha^{-1} with RDF (T_4) increased pH of soil in wheat as compare to 100% RDF (T_2), however, the effect was non-significant. Ram *et al*. (2014) also reported that pH of post-harvest soil did not vary significantly with the application of S, Zn and B [24].

3.4.2. Electrical conductivity (EC)

Data pertaining to EC of soil has been presented in Table 4. The EC of soil varied from 0.46 to 0.50 and 0.47 to 0.57 dS m^{-1} in post-harvest soil of rice and wheat, respectively. The minimum EC (0.46 dS m^{-1}) was recorded in absolute control (T_1) and maximum in all fertilized pots (T_2 to T_{10}) in rice. However, the increase in EC was non-significant in all the treatment with each other in wheat. Ram *et al*. (2014) reported that EC of post-harvest soil did not vary significantly with the application of S, Zn and B [24].

3.4.3. Organic carbon (OC)

The organic carbon content in soil of rice varied from 0.56% to 0.65% where in wheat ranged between 0.53% to 0.65% (Table 4). The maximum OC percent was recorded in 1.5 kg B ha^{-1} along with RDF (T_5) followed by 3 kg B ha^{-1}, 3.5 kg B ha^{-1} and 4 kg B ha^{-1} (T_8, T_9 and T_{10}) the corresponding increase was 16, 11 and 11%, respectively over RDF (T_2). Treatment which received residual effect of 2.5 kg B ha^{-1} along with RDF (T_7) was recorded maximum OC content followed by T_8 (3 kg B ha^{-1}) which increased by 5 and 3% over RDF in wheat. Ram *et al*. (2014) reported that OC content of post-harvest soil did not vary significantly with the application of S, Zn and B [24].

3.4.4. Boron content

The data pertaining to $CaCl_2$ extractable B content in post-harvest soil (Table 4) showed a significant variation which ranged from 0.54 to 4.13 mg kg^{-1} and 0.29 to 1.25 mg kg^{-1} in rice and wheat, respectively. The maximum B in rice and wheat soil (4.13 mg kg^{-1} and 1.25 mg kg^{-1}, respectively) was recorded in T_{10} (4 kg B ha^{-1}) followed by T_8 (RDF+3 kg B ha^{-1}) and T_9 (RDF+3.5 kg B ha^{-1}) which was significantly increased by 175, 140 and 134%, respectively in rice and by 310, 300 and 310%, respectively in wheat over RDF (T_2). Similar results were reported by Gupta and Cutcliffe (1978) and Rakshit *et al*. (2002) [40, 41].

4. CONCLUSION

It was found that application of B did not increased grain yield of rice and wheat significantly over RDF. However, application of B @ 2 kg ha^{-1} or higher doses significantly decreased the rice grain yield. In, wheat, the grain yield was at par in all the treatments. A significant residual effect of B application in rice was noticed even after the harvest of wheat crop particularly at highest doses of B application. But, application of B @ 1.5 kg B ha^{-1} significantly enhanced the Fe, Cu, Mn and Zn content in rice grain, whereas residual effect of 3 kg ha^{-1} B application has significantly improved the Fe, Cu and Mn content in wheat grain.

Table 4. Direct and residual effect of boron application in soil on pH, EC, organic carbon and B content in post-harvest soil of rice and wheat

Treatment	pH		EC (dSm^{-1})		OC (%)		B (mg kg^{-1})	
	Rice	Wheat	Rice	Wheat	Rice	Wheat	Rice	Wheat
T_1	7.12 ± 0.09 a	7.32 ± 0.06 a	0.46 ± 0.01 a	0.47 ± 0.00 a	0.60 ± 0.03 a	0.65 ± 0.26 b	0.54 ± 0.13 a	0.29 ± 0.06 a
T_2	7.26 ± 0.10 ab	7.38 ± 0.12 a	0.50 ± 0.01 b	0.48 ± 0.03 a	0.65 ± 0.08 a	0.62 ± 0.01 ab	1.50 ± 0.42 b	0.30 ± 0.10 a

T_3	7.27 ± 0.07 ab	7.49 ± 0.08 a	0.50 ± 0.01 b	0.47 ± 0.01 a	0.60 ± 0.06 a	0.61 ± 0.04 ab	1.63 ± 0.46 b	0.39 ± 0.12 ab
T_4	7.27 ± 0.08 ab	7.52 ± 0.06 a	0.49 ± 0.01 b	0.47 ± 0.02 a	0.61 ± 0.02 a	0.59 ± 0.01 a	1.87 ± 0.12 b	0.67 ± 0.04 bc
T_5	7.29 ± 0.04 ab	7.426 ± 0.04 a	0.49 ± 0.00 b	0.49 ± 0.01 a	0.56 ± 0.00 a	0.56 ± 0.01 a	2.08 ± 0.29 b	0.82 ± 0.04 cd
T_6	7.23 ± 0.03 ab	7.48 ± 0.03 a	0.50 ± 0.01 b	0.48 ± 0.00 a	0.59 ± 0.05 a	0.59 ± 0.03 a	2.16 ± 0.26 b	0.91 ± 0.03 cde
T_7	7.37 ± 0.19 ab	7.47 ± 0.03 a	0.50 ± 0.02 b	0.51 ± 0.00 a	0.59 ± 0.06 a	0.65 ±0.00 ab	2.29 ±1.08 b	1.07 ± 0.05 de
T_8	7.28 ± 0.03 ab	7.48 ± 0.01 a	0.50 ± 0.01 b	0.48 ± 0.01 a	0.62 ± 0.03 a	0.64 ± 0.01 ab	3.61 ± 0.08 d	1.20 ± 0.04 e
T_9	7.27 ± 0.06 ab	7.47 ± 0.02 a	0.50 ± 0.01 b	0.49 ± 0.00 a	0.62 ± 0.02 a	0.63 ± 0.01 ab	3.51 ± 0.17 d	1.23 ± 0.27 e
T_{10}	7.27 ± 0.07 ab	7.51 ± 0.00 a	0.49 ± 0.01 b	0.50 ± 0.00 a	0.62 ± 0.02 a	0.58 ± 0.01 a	4.13 ± 0.21 d	1.25 ± 0.01 e

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