Effect of soil micronutrients (Zinc and Boron) on yield and uptake of wheat in an acid soil of West Bengal, India

Abstract: ~~Wheat~~ The production ofwheat (*Triticumaestivum*),an important staple food in the world,~~production~~ is often restricted due to micronutrients status in soil. Micronutrient deficiency in soil including boron (B) and zinc (Zn) is quite widespread in Asian countries including India due to prevalent soil and environmental conditions. A field experiment was conducted following randomized complete block design over a two-year period in an acid soil of *Terai* region of West Bengal to study the effect of zinc and boron on the yield and uptake of nutrients by wheat. The highest grain yield (4.38 t/ha) was obtained after the combined application of Znand Bover that of other treatment combinations (variable rates of B and Zn application with nutrients) or control (no nutrients, B and Zn). Application of one micronutrient might have accelerated the uptake of other micro- and macro-nutrients resulting in higher yield. A positive correlation was observed between the grain yield and the uptake of different nutrients with the weakest with Zn. A build-up of the nutrients in soils was also observed at the harvest. High response clearly demonstrated the necessity of micronutrients for improving production in the studied regions with acid soils.

Key words: micronutrients,synergistic effect, *Terai* region, deficiency, growth stages

Introduction

Wheat (*Triticumaestivum* L.)is the most important staple food for humans and is grown on more land than any other commercial crops in the world. It was grown on 216.6 million ha land in 2012[1] producing 674.9 million tonnes of wheat globally, the third most produced cereal (perhaps any food crop) after maize (875.1 million tonnes) and rice (718.3 million tonnes) [1]. Wheat has higher protein content than either maize (corn) or rice or any other cereals and is the leading source of vegetable protein in human food globallyreference?. In 2012, India produced 94.9 million tonnes of wheat from a cultivated area of 29.9 million ha, the largest area devoted to wheat production by any country in the world [2].

Comment [MA1]: Maybe wheat has more protein than other cereals, but I think there should be a reference. It seems as if the author says that wheat is a leading source of vegetable protein, but surely legumes will fit this role better?

With the demand of ever-increasing population, the present day agriculture became more and more intensive and mined available nutrients from soil over years. However, one of the major triggering factors behind the dramatic improvement in the production and yield of wheat was the supply of artificial nutrient source for plant growth and development especially the use of synthetic nitrogen fertilizer. Potash and phosphorus fertilizer in addition to the nitrogen fertilizer supplied the major nutrients for the growth, development and production of wheat. In addition to these major (macro) nutrients, there are some nutrients, which are essential for wheat growth but needed only in very small (micro) quantities. Among these, Boron (B), Zinc (Zn), Iron, (Fe), Copper (Cu), Manganese (Mn), and Chlorine (Cl) are known to have effect on the grain- as well as straw-yield of wheat. These micronutrients play a pivotal role in the yield improvement of wheat crop [3]. They are needed in trace amount while the adequate supply improves nutrient availability and positively affects the cell physiology that is reflected in yield as well [4, 5]. A number ofmicronutrients are part of the photosynthesis and respiration processes, chlorophyll formation, nucleic acid and protein synthesis, nitrogen-fixation and other biochemical pathways [6-8]. However, the deficiency of micronutrients are wide spread in many Asian countries including India due to calcareous nature of soils, high pH, low organic matter, salt stress, prolonged draught, high bicarbonate content in irrigation water and imbalanced application of NPK fertilizers [9, 10]. The deficiency of micronutrients can induce the stress in plants including low crop yield and quality, imperfect plant morphological structure (such as fewer xylem vessels of small size), widespread infestation of various diseases and pests and low fertilizer use efficiency.

Zinc is one of the important micronutrients, which is important in the production of various crops including wheat [11, 12]. It improves the number of grains per spike [13]. In addition to the improvement of yield and yield components of wheat [14, 15], adequate supply of Zn can improve the water use efficiency of wheat plants [16]. Zinc is also known to provide thermo-tolerance to the photosynthetic apparatus of wheat [17]. The presence of Zn is important in plant metabolism and thus the growth and production [18]. The Zn deficiency is the third most common deficient nutrient after nitrogen and phosphorus [19, 20]. Zinc deficiency in plants not only reduces the grain yield, but also the nutritional quality [21].

Boron is another 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 one in field [22]. Boron is essential for cell division and elongation of meristematic tissues, floral organs and the flower male fertility, pollen tube germination and its elongation and the seed andfruit formation. Lack of B can cause the 'wheat sterility' resulting in increased number of open spikelets and decreased number of grains per spike [23]. The B deficiency in soil can affect seedling emergence and cause an abnormal cellular development in young wheat plant [24]. Deficiency of B also inhibits root elongation by limiting cell division in the growing zone of root tips [25]. Deficiency of B is known to inhibit the leaf expansion and reduction in photosynthesis though the exact role of boron in photosynthesis is still least understood of all the mineral nutrients. In the field, sexual reproduction is often affected by low B reducing the grain yield significantly but without any visual symptoms expressed during vegetative growth.

The *Terai* region is located at the south of the outer foothill of the Himalaya and Siwalik hills and the north of the Indo-Gangetic plain. It spreads over a number of states in India including Himachal Pradesh, Haryana, Uttaranchal, Uttar Pradesh, West Bengal, Sikkim and Assam. It also covers a major part in Nepal, Bhutan and Bangladesh. The *Terai* region is the habitat of millions of people. It is a very productive region and agriculture is the base of the economy of the habitants. Rice and wheat are important crops of this region. The rice-wheat system is the most important cropping pattern in this region and considered to be the major determinant factor of the agriculture-based economy. However, the intensive cultivation practices overexploited the natural soil resource base, which was further enhanced by the imbalanced use of inputs [22, 26].

The deficiency of B and Zn in soils of different agro-climatic zones isnot rare and *Terai* region is not an exception ~~of that~~ in this regard. Deficiency of different micronutrients has been reported from this region. Among the most prevalent ones, the deficiency of Zn is estimated to be the highest [27, 28]. Incidence of B deficiency from the areas of West Bengal and Bihar has also been reported [26]. Comprehensive study on the effect as well as the interaction of these nutrients on the production of wheat at this part of the world would help understanding constraitns of cultivation and decreasing the yield gap to secure food for the future.

Based on the above perspectives the present study was undertaken in the *Terai* region of West Bengal on the following objectives:

- ❖ To assess the effect of Zn and B on the yield of wheat.
- ❖ To study the interaction effect of Zn and B on the yield of wheat.
- ❖ To evaluate the residual status of Zn and B in soil at different stages of wheat crop.

Materials and Methods

Experimental site:

A field experiment wascarried out at the agricultural farm of Uttar BangaKrishiViswavidyalaya,Pundibari, Cooch Behar, West Bengal, India. The farm is located within the *Terai* Agro-climatic zone and its geographic location is 26°19'86" N latitude and 89°23'53" E longitude. The elevation of the farm is 43 meters above the mean sea level. The field experiment wascarried outin the same field during the winter season of 2010-11 and 2011- 12.

Experimental plots:

The local topography of the study area is almost flat with good drainage facilities. The soil of the experimental site is sandy loam in texture. Before laying out the experimental plots, a set of surface soil samples were collected over the whole experimental area, composite together and tested in the laboratory following the methods described in the followingsub-section. The measured physical, chemical and physico-chemical properties were used as the baseline measurement for the experimental plots (Table 1).

Table 1: Initial characteristics of experimental soil for two years

Characteristics	Measurements	
	2011	2012
pH	5	5
EC (dS/m)	0.05	0.05
Organic Carbon (%)	1.04	1.02
Nitrogen (kg/ha)	206.98	188.16
Phosphorus (kg/ha)	0.76	0.89
Potassium (kg/ha)	89.60	88.48
Boron (kg/ha)	0.68	0.62
Zinc (kg/ha)	0.73	0.84

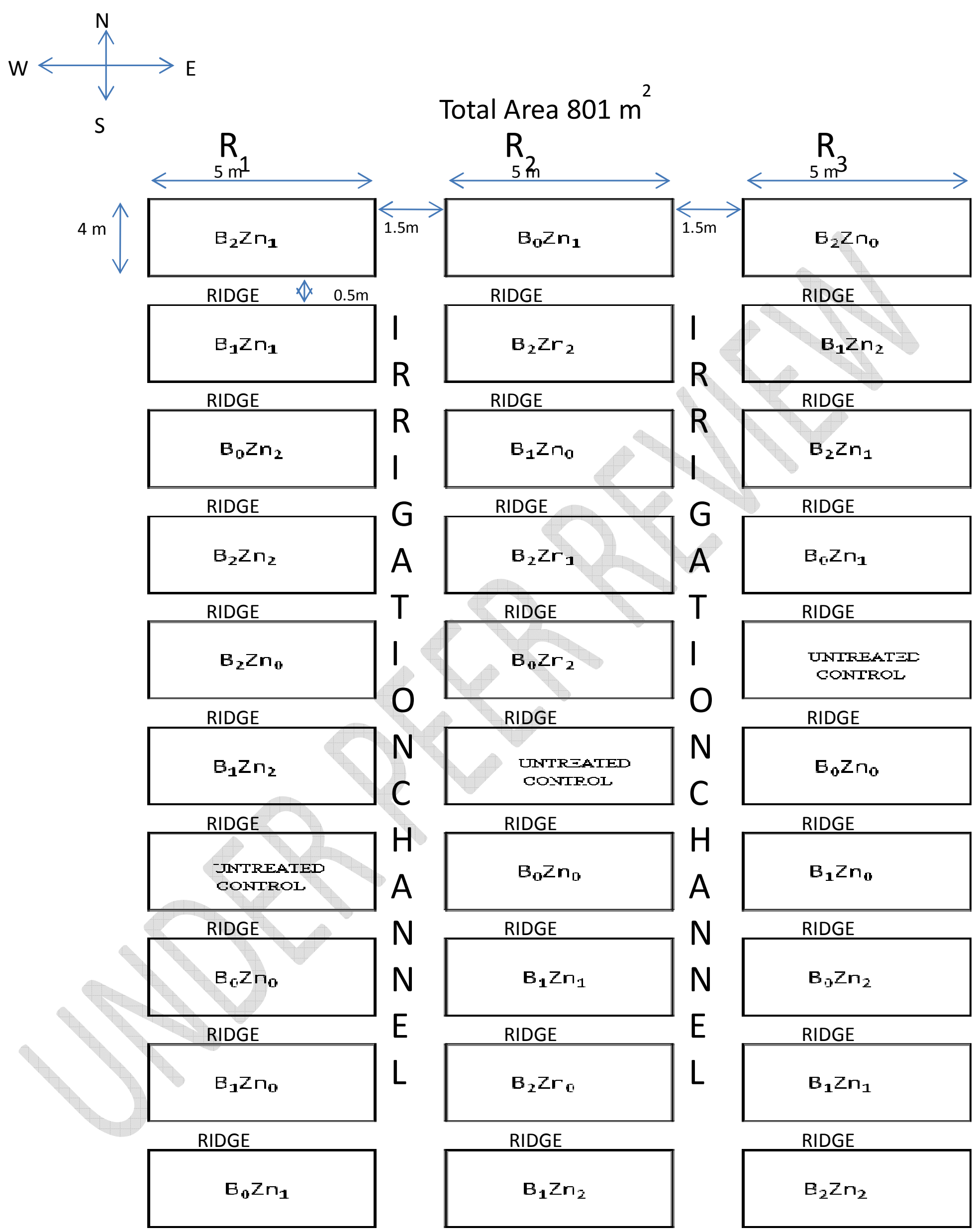

Fig. 1: Layout of experimental plots for the field experiment. Same layout was used for both years.

A set of 30 experimental plots (5 m × 4 m) were laid out following randomized complete block design (RCBD) for this experiment (Fig. 1). Ten treatment combinations (Table 2) were developed following three doses of B (0 kg/ha, 5 kg/ha and 10 kg/ha), three doses of Zn (0 kg/ha, 12.5 kg Zn sulphate/ ha and 25 kg Zn sulphate/ ha) and a treatment without application of any nutrients (T_{10}). Though the treatment T1 (B_0Zn_0) received recommended doses of N, P, and K, treatment T10 (control) did not receive any nutrient or micronutrients (B and Zn). The treatments were replicated three times in this field experiment (Fig. 1).

Table 2: Details on the experimental plots and treatment combinations

Experimental details			
Crop	:	Wheat (*Triticumaestivum* L.)	
Variety	:	NW 1014	
Experimental design	:	Randomized Complete Block Design	
Total Area	:	$801m^2$	
Plot size	:	5 m × 4 m	
Number of replication	:	3	
Spacing	:	23 cm (Row to Row)	
Treatments	:	T_1-B_0Zn_0, T_2-B_0Zn_1, T_3-B_0Zn_2, T_4-B_1Zn_0, T_5-B_1Zn_1, T_6-B_1Zn_2, T_7-B_2Zn_0, T_8-B_2Zn_1, T_9-B_2Zn_2, T_{10}- Control.	
		B_0 = without Boron	Zn_0 = without Zinc Sulphate
		B_1 = 5 kg/ha of Boron	Zn_1 = 12.5 kg/ha of Zinc Sulphate
		B_2 = 10 kg/ha of Boron	Zn_2 = 25 kg/ha of Zinc Sulphate

Field operations:

The land preparation for this experiment was started with a deep ploughing (21 and 22, December 2010 and 12 and 13 December 2012) using a tractor. A laddering (similar to levelling of soil surface) was performed after a day of soil drying following two secondary tillage using a power tiller in order to prepare a good soil tilth. The weeds and stubbles were removed by hand picking and the final laddering was performed to prepare the seed bed. Bunds and channels were prepared manually to prepare the experimental plots following the specifications mentioned in Table 1. Nitrogen (N, 100 kg/ha), Phosphorus (P, 60 kg/ha) and Potassium (K, 30 kg/ha), in the form of Urea, single super phosphate, muriate of potash; B as Borax(10 kg/ha, sodium borate), and Zn as Zn Sulphate (25 kg/ha) were applied to the soil as per the treatments.Full dose of P andK and half of the recommended dose of N and full dose of B, Zn were surface applied as

Comment [MA2]: Is it necessary to write the elements' names in capital letters? If you decide to, then Borate and Potash should surely also be in capital letters?

basal dose and incorporated in the soil. The remaining half of the recommended dose of N was applied as top dressing at 21 days after sowing (DAS), after completion of the first weeding.

The wheat variety of NW-104 was used for this experiment @100 kg ha^{-1}. Sowing was completed in rows (spacing 23 cm) in North-South using a duck-foot tyne at a depth of 2.5 to 3 cm. Two weeding operations were performed manually on 21 DAS and 45 DAS. Two irrigations were applied on 21 DAS (after weeding and fertilizer application) and 65 DAS. The excess water was drained out using drainage channels.

Comment [MA3]: kg ha^{-1} or kg/ha? You use both. Stick to one. See page 6 for example.

The soil and plant samples were collected for laboratory analysis on 21 (CRI- crown root initiation stage), 55 (tillering stage), 70 (booting stage) and 110 DAS (maturity). Leaving the border rows, half of the area in each plot was marked for recording biometrical observation including destructive plant sampling and other half for recording yield components and yield of wheat.The height (from ground level) of five randomly selected plants were recorded and averaged from each plot. The measured plants were tagged after first measurement for subsequent measurements. Dry weight of both roots and shoots were also recorded. The number of tillers per m^2 was recorded from 10 randomly selected plants. The crop was harvested from net plot area discarding the border row. The number of panicles per plant was recorded from 10 randomly selected plants and converted to number of panicles per m^2. Length of panicles was measured prior to harvest and average length was calculated. Number of grains per panicle as well as ~~,~~ 1000 grain dry weight ~~was~~ were also recorded for each treatment. The final yield of wheat and straw was recorded after sun drying and thrashing. The yields were recorded and calculated as tonne per ha following,

Grain yield (t ha^{-1})= (Plot yield (kg) × 10000 / Plot size (m^2) × 1000)

Experimental methods:

Collected soil and plant samples were tested in laboratory following the methods described below.

a) **Soil pH:**pH of soil samples (soil:water 1:2.5) was determined in suspensions using a Systronics glass electrode-pH meter [29].
b) **Soil Electrical Conductivity (EC):**Electrical Conductivity was measured in soil-water suspensions (soil:water 1:2.5)[29] using a digital conductivity meter of Systronics (Model No. 304).

c) **Soil Organic Carbon (OC):** Organic carbon content of samples was estimated by ~~Walkely~~ Walkleyand Black's titration method [30].

d) **Mechanical Analysis of soils:**Clay-content of soils was determined by the hydrometer method [31]. The texture of the soils was also ascertained from the particle-size distribution of sand, silt and clay.

e) **Available nitrogen (N):** Available nitrogen in soil and plant was determined by alkaline $KMnO_4$ method developed by Subbiah and Asija[32].

f) **Available phosphorus (P):**Available P in soil and plant content was determined by extracting the soil with a mixture of 0.03 M NH_4F and 0.025 M HCl[33] followed by colorimetric measurement using spectrophotometer (Systronics Model No. 167) [34].

g) **Available potassium (K):** Available K concentration in soil and plantwas measured using a flame photometer (Systronics Model No128) [34]. The extraction was carried out with neutral normal ammonium acetate.

h) **Available Zinc (Zn):** DTPA-(Diethylenetriaminepentaacetic acid) extractable Zn^{+2} of s soil and plant samples weredetermined by extraction with the extractant containing 0.005M DTPA, 0.01M $CaCl_2$ and 0.1M Triethanol amine buffered at pH 7.3 [35] followed by the measurement using Atomic Absorption Spectrophotometer.

i) **Available Boron (B):** Available Boron in soil and plant was extracted by boiling a known amount of soil with double distilled water (in 1:2.5 ratio) prepared by quartz glass distillation apparatus, for five minutes under a reflux condenser, followed by cooling and filtration [36]. The concentration was measured using Atomic Absorption Spectrophotometer.

Statistical analyse~~i~~s

Comment [MA4]: Surely there was more than one analysis? Then analyses.

Statistical analysis for the collected data was performed in SigmaPlot (Systat Software Inc.). The significant difference between the treatments was tested using ANOVA and LSD. The interaction between the effect of B and Zn was tested using two-way ANOVA. The correlation between the yield components and nutrient uptakes were also calculated. The figures were prepared using the SigmaPlot.

Results and Discussion

The yield components and grain yield of wheat are shown in Table 3. A significant difference was observed among the treatment combinations on yield components and grain yield of wheat.

The maximum mean grain yield (4.38 t/ha) was observed in the treatment T_6 (B_1Zn_2), while minimum was observed in the control (1.68 t/ha) (Table 3). Relatively higher yield was obtained from the treatments T_1 (B_0Zn_0) to T_9 (B_2Zn_2) over that of the control (T_{10}). The lowest harvest index was observed in T_4 (B_1Zn_0) and the highest in controls (T_{10}) (Table 3). The application of B and Z in combination significantly ($p < 0.05$) increased the grain yield of wheat.The grain yield increase with B and Zn addition was reported byChaudryet al.[37]. Boron concentration has been reported to increase grain yield of durum wheat by 16% [38]. This may be due to the requirement of B in wheat during the vegetative stage leading to high response to the grain yield [39, 40]. Therefore, even a small amount of Zn and B directly affected the grain yield. Mandal [41]reported a direct relationship between the number of grains and tillers and the wheat yield under B deficient soils of*Terai*region of West Bengal.

The effect of B on the grain and straw yield found was found to be significant at alpha = 0.05 (95% significant level). However, the scenario was little different for Zn. For example, for no B application, Zn had not any effect on crop yield,.w~~W~~hile with regular dose of B (5 kg B/ha), the yield increased linearly. This indicated that with a regular application of B, the efficiency of Zn increased with the application rate considered in this study. However, with excess (more than regular) application of B, the effect of Zn decreases indicating antagonistic effect between the micronutrient at high dose, specifically the high dose of B.The two-way ANOVA following a general linear model with alpha = 0.05 ~~found~~ showed a significant interaction between the effect of B and Zn on the grain and straw yield of wheat. This means that the difference in the mean values among the different levels of B and Zn is great enough to exclude the possibility that the difference is just not due to random sampling variability after allowing for the effects of differences in Zn and B, respectively. Therefore, care should be taken in deciding the amount of micronutrient application, which may have different effect. From this study, it could be suggested to choose a regular dose of B for better efficiency of Zn. Sometime a high dose of Zn could be even beneficial with a controlled application of B.

In spite of the highest dry biomass production until the booting stage in T_6 (B_1Zn_2), the T_8 (B_2Zn_1) produced the highest dry straw at maturity(Fig. 2). Combination of B and Zn might have boosted the vegetative growth during the early stage, while the high amount of Zn along with a regular dose of B improved the yield and yield components of wheat at maturity [14, 15]. A combination of regular dose of Zn and B (T_5) could not produce high amount of straw compared

Comment [MA5]: Format: t/ha or t ha^{-1}

Comment [MA6]: Not sure: was found to be significant or was found to be not significant?

Comment [MA7]: format

to other treatments with single or double dose of either Zn or B or in combination (Fig. 2). For example high straw yield with very little differencewas observed among treatments T_4 (B_1Zn_0), T_6 (B_1Zn_2), T_7 (B_2Zn_0) and T_8 (B_2Zn_1). The lowest biomass production was recorded in control (T_{10}) at all stages of crop growth.

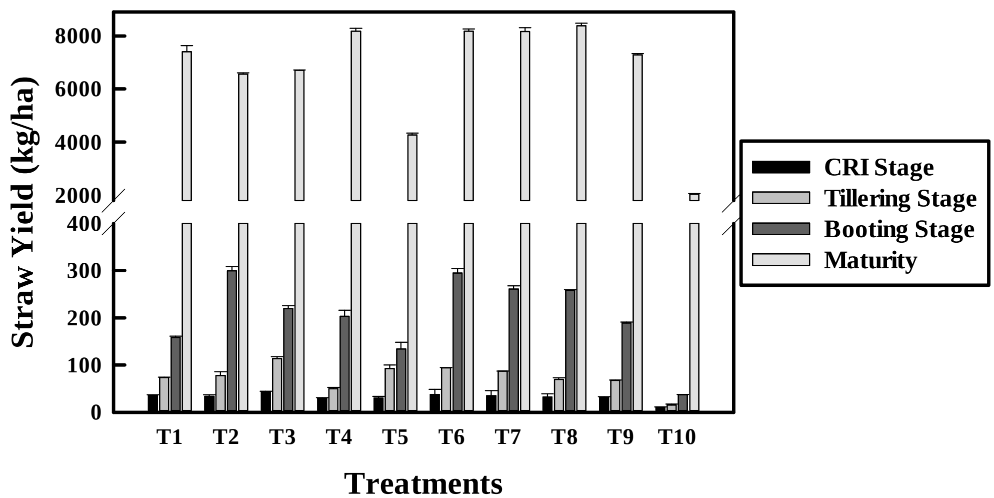

Fig. 2: Effect of treatments on average straw yield (kg/ha) over two years at different stages of wheat growth. The standard deviation of measurement is shown as error bars. The CRI stage indicates crown root initiation.

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A significant difference in the nutrient uptake was recorded in different treatments and at different growth stages. The highest uptake (kg/ha) of N over the entire growth period was recorded in treatment T_6 (B_1Zn_2) and minimum in T_{10} (control) (Fig. 3).The maximum amount of N uptake at different growth stages was not consistent. For example, T_2 (B_0Zn_1) was recorded with the highest amount of N uptake during booting stage (Fig. 3). While the highest amount of P uptake was recorded in T_7 (B_2Zn_0), the highest amount of K uptake was recorded in T_8 (B_2Zn_1)(Fig. 3). Similar to N uptake, a variable amount of P and K uptake was also recorded at different growth stages in different treatments. The highest amount of B and Zn uptake was

Comment [MA9]: format

recorded in treatment T_9 (B_2Zn_2) (Fig. 3). High amount of B and Zn application might show some synergistic

Comment [MA10]: Layout problem?

Table 3: Effect of treatments on the yield components and grain yield (t/ha) of wheat. The data from 2011 and 2012 are shown along with the average over two years. S.D. stands for standard deviation.

Treatments	Tiller/Sq. m.			Grains/Spike			1000 Grain weight			t/ha			Harvest Index (%)		
	2011	2012	Mean (S.D.)	2011	2012	Mean (S.D.)	2011	2012	Mean (S.D.)	2011	2012	Mean (S.D.)	2011	2012	Mean (S.D.)
T1	171	168	169.5 (2.12)	37	36	36.5 (0.70)	45.72	45.75	45.74 (0.02)	2.89	2.77	2.83 (0.08)	27.7	27.6	27.6 (0.07)
T2	156	156	156.0 (0)	41	42	41.5 (0.70)	42.74	42.80	42.77 (0.04)	2.73	2.80	2.77 (0.05)	29.5	29.8	29.7 (0.21)
T3	165	162	163.5 (2.12)	39	39	39.0 (0)	45.92	45.72	45.82 (0.14)	2.95	2.89	2.92 (0.04)	30.6	30.1	30.4 (0.35)
T4	143	145	143.8 (1.41)	43	43	43.0 (0)	44.54	44.00	44.27 (0.38)	2.73	2.74	2.74 (0.01)	25.2	24.9	25.1 (0.21)
T5	158	150	153.8 (5.66)	42	42	42.0 (0)	51.50	51.51	51.51 (0.01)	3.41	3.25	3.33 (0.11)	44.1	43.5	43.8 (0.42)
T6	188	185	186.3 (2.12)	48	51	49.5 (2.12)	47.64	47.34	47.49 (0.21)	4.29	4.47	4.38 (0.13)	34.6	35.2	34.9 (0.42)
T7	176	174	174.8 (1.41)	50	53	51.5 (2.12)	43.80	43.83	43.82 (0.02)	3.84	4.04	3.94 (0.14)	32.3	32.8	32.6 (0.35)
T8	134	137	135.3 (2.12)	45	46	45.5 (0.70)	44.74	44.20	44.47 (0.38)	2.69	2.79	2.74 (0.07)	24.4	24.8	24.6 (0.28)
T9	143	142	142.3 (0.71)	52	50	51.0 (1.41)	41.38	39.38	40.38 (1.41)	3.07	2.80	2.93 (0.19)	29.7	27.6	28.7 (1.48)
T10	122	124	122.8 (1.41)	36	39	37.5 (2.12)	37.00	36.00	36.50 (0.71)	1.62	1.74	1.68 (0.08)	44.1	46.4	45.2 (1.63)

Table 4: Effect of treatments on the uptake of nutrients (kg/ha) by seed.The data from 2011 and 2012 are shown along with the average over two years. S.D. stands for standard deviation.

Treatments	Nitrogen			Phosphorus			Potassium			Boron			Zinc		
	2011	2012	Mean (S.D.)	2011	2012	Mean (S.D.)	2011	2012	Mean (S.D.)	2011	2012	Mean (S.D.)	2011	2012	Mean (S.D.)
T1	70.47	59.66	65.06 (7.64)	1.40	1.74	1.57 (0.24)	23.14	24.90	24.02 (1.24)	0.280	0.255	0.267 (0.02)	0.297	0.228	0.262 (0.05)
T2	58.17	58.89	58.53 (0.51)	1.58	1.50	1.54 (0.06)	19.14	22.43	20.78 (2.33)	0.249	0.253	0.251 (0.01)	0.314	0.168	0.241 (0.10)
T3	64.54	59.85	62.19 (3.32)	1.40	1.24	1.32 (0.11)	19.21	21.66	20.44 (1.73)	0.292	0.271	0.282 (0.02)	0.406	0.361	0.384 (0.03)
T4	69.54	66.06	67.80 (2.46)	2.29	1.90	2.09 (0.28)	25.93	27.43	26.68 (1.06)	0.211	0.239	0.225 (0.02)	0.300	0.645	0.472 (0.24)
T5	83.94	72.69	78.32 (7.95)	2.25	1.88	2.07 (0.26)	18.74	21.09	19.92 (1.66)	0.237	0.289	0.263 (0.04)	0.554	0.292	0.423 (0.18)
T6	121.25	116.31	118.78 (3.49)	2.61	2.46	2.54 (0.08)	38.59	44.67	41.63 (4.30)	0.231	0.385	0.308 (0.11)	0.482	0.402	0.442 (0.06)
T7	104.39	101.86	103.12 (1.79)	2.53	2.41	2.47(0.11)	28.83	36.38	32.60 (5.34)	0.215	0.246	0.230 (0.02)	0.413	0.333	0.373 (0.06)
T8	63.97	70.97	67.47 (4.50)	1.20	1.11	1.16 (0.06)	18.81	30.64	24.73 (8/36)	0.190	0.232	0.211 (0.03)	0.255	0.195	0.225 (0.04)
T9	77.27	72.02	74.65 (3.71)	1.77	1.47	1.62 (0.21)	18.40	26.56	22.48 (5.77)	0.171	0.197	0.184 (0.02)	0.284	0.175	0.229 (0.07)
T10	13.14	9.75	11.45 (2.40)	0.76	0.79	0.77 (0.02)	7.28	9.58	8.43 (1.62)	0.061	0.060	0.060 (0.00)	0.020	0.065	0.043 (0.03)

effect to provide higher amount of uptake. The treatment T_{10} (control) always recorded with the least amount of nutrient uptake.

A significant difference was observed in the uptake of different nutrients by seed (Table 4). The highest uptake of almost all nutrients (N, P, K, and B) ~~were~~ was recorded in treatment T6 (B_1Zn_2) except for Zn, the highest uptake of which was recorded in treatment T_4 (B_1Zn_0) (Table 4). The highest production as well as the interaction between the micro-nutrients (B and Zn) in treatment T_6 facilitated higher amount of nutrients uptake in seed[42]. The lowest uptake of all nutrients was recorded in treatment T_{10} (control). A similar trend was observed for the uptake of nutrients by straw (Table 5).

Table 5: Effect of treatments on the uptake of nutrients (kg/ha) by straw along with average(in brackets) grain yield and straw yield over two years.

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Treatments	Grain yield (S.D.)	Straw yield (S.D.)	Nitrogen (S.D.)	Phosphorus (S.D.)	Potassium (S.D.)	Boron (S.D.)	Zinc (S.D.)
T1	2829.83 (89.10)	7410.68 (220.6)	60.26 (7.66)	0.34(0.01)	109.61 (2.83)	0.118 (0.02)	1.130 (0.01)
T2	2768.95 (49.49)	6558.93 (45.6)	19.26 (6.36)	0.38(0.00)	107.67 (2.34)	0.252 (0.03)	2.134 (1.60)
T3	2921.77 (46.67)	6702.67 (13.2)	51.61 (1.43)	0.21(0.03)	111.44 (12.46)	0.172 (0.02)	0.821 (0.21)
T4	2736.29 (9.89)	8177.83 (107.7)	27.29 (28.78)	0.36(0.05)	131.95 (14.75)	0.296 (0.26)	1.723 (0.71)
T5	3325.93 (114.55)	4268.08 (68.7)	25.67 (2.12)	0.21(0.00)	73.80 (1.44)	0.230 (0.01)	0.581 (0.06)
T6	4377.06 (126.57)	8171.53 (84.7)	84.69 (7.35)	0.23(0.01)	141.31 (3.87)	0.477 (0.03)	1.756 (2.11)
T7	3942.73 (140.71)	8160.33 (146.6)	20.36 (22.25)	0.40(0.07)	149.46 (13.66)	0.413 (0.00)	1.947 (2.34)
T8	2736.62 (68.59)	8376.87 (96.9)	34.00 (1.26)	0.33(0.00)	155.96 (8.56)	0.227 (0.03)	5.001 (6.15)
T9	2931.12 (190.92)	7288.23 (44.6)	25.52 (4.48)	0.17(0.00)	120.57 (5.46)	0.567 (0.01)	3.448 (4.61)
T10	1679.67 (86.97)	2033.42 (28.2)	2.28 (0.03)	0.06(0.04)	30.75 (0.89)	0.049 (0.00)	0.246 (0.31)

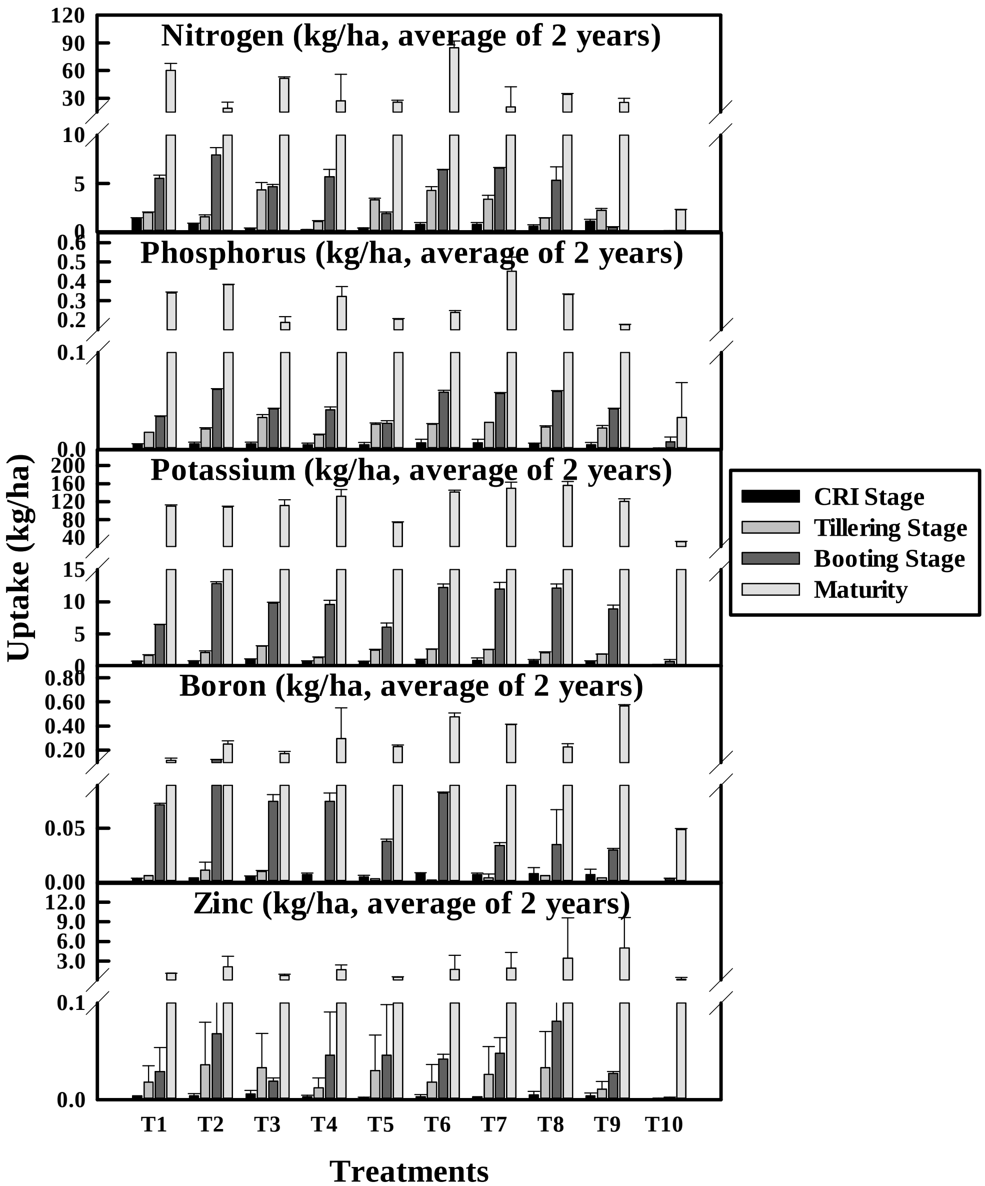

Fig. 3: Effect of treatments on the uptake of nutrients (N, P, K, B, and Zn) at different growth stages (CRI, Tillering, Booting and Maturity) of wheat.The standard deviation of measurement is shown as error bars. The CRI stage indicates crown root initiation.

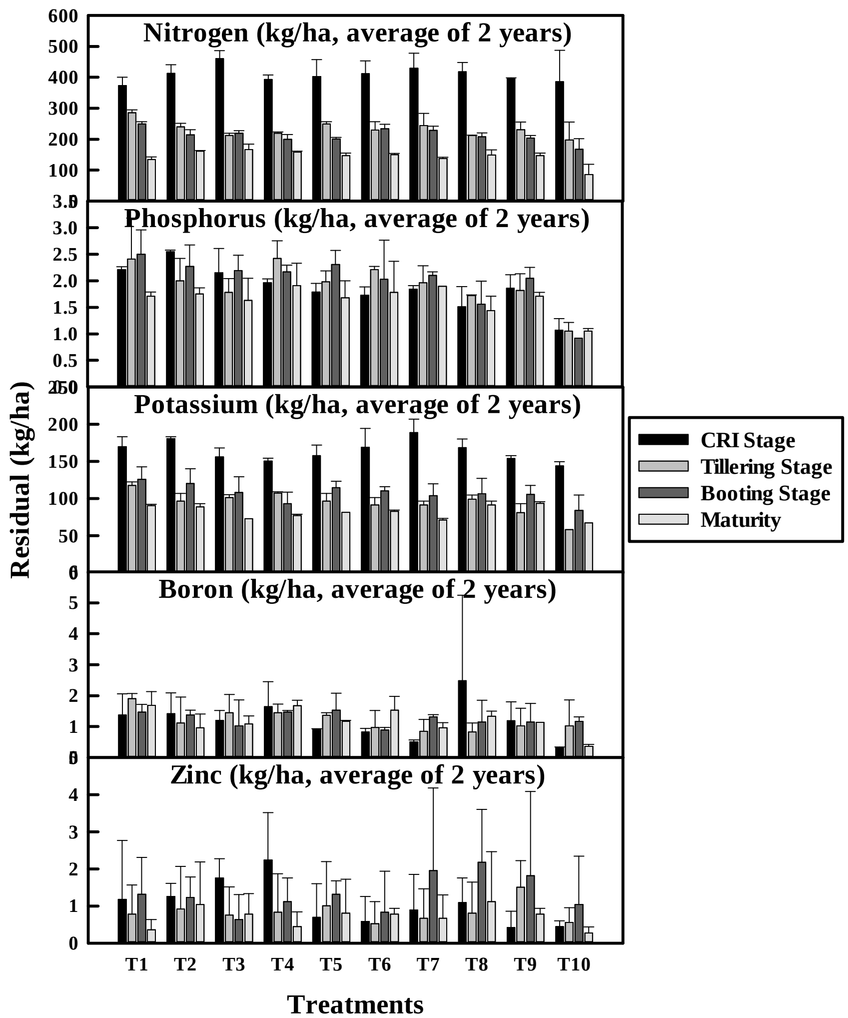

Fig. 4: Effect of treatments on the residual nutrient (N, P, K, B, and Zn) status at different growth stages (CRI, Tillering, Booting and Maturity) of wheat.The standard deviation of measurement is shown as error bars. The CRI stage indicates crown root initiation.

The B and Zn concentration in seeds (Table 4) and straw (Table 5) were calculated after dividing the total uptake of nutrients by the total grain and straw production. It clearly showed that with the increasing production, the concentration of nutrients, both B and Zn in seed and straw decreased.

There was significant difference in the residual N status of soil at different treatment plots and at different growth stages. Initial application of N resulted a high amount of residual N at the CRI stage and gradually decreased towards maturity, which had the least amount of residual N (Fig. 4). Minimum demand of the applied N at the beginning of the growth stages resulted in a high amount of residual N at the CRI stage, while the high demand towards maturity left the least amount of residual N. High demand during the peak growth stages such as tillering and booting resulted in a very similar amount of residual N, which was lower than that at CRI stage. The highest amount of residual N was recorded in treatment T_3 (B_0Zn_2) and the least lowest amount was recorded in treatment T_{10} (control) (Fig. 4). The residual K status in soil at different growth stages of wheat showed a very similar trend as that of N (Fig. 4). The CRI stage was recorded with the highest amount of residual K, which in general decreased towards maturity. There was a significant difference between the treatments at different growth stages. Treatment T_7 (B_2Zn_0) was recorded with the highest of amount of residual K at the CRI stage, while Treatment T_1 (B_0Zn_0) was recorded with the highest amount of K at other growth stages (Fig. 4). The absence of micronutrients in treatment T_1 might have inhibited the uptake resulting in a high amount of residual K.

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The residual P in soil showed a little different trend than N and K (Fig. 4).There was no specific trend of residual P at different growth stages. In general, a higher amount of residual P was recorded at the CRI stage compared to tillering and booting stage. This might be due to the presence of unavailable form of P at the beginning of the growth stage. While the difference between the growth stages of wheat was not significant, the difference between the treatments was significant. The highest amount of P was recorded in treatment T_2 (B_0Zn_1) for the CRI stage while treatment T_4 (B_1Zn_0) at the maturity. The least lowest amount of residual P was recorded in treatment T_{10} (control) (Fig. 4).

There was a significant difference in the residual B status in soil at different nutrient treatment combinations.However, the difference was not significant at different growth stages. There was no specific trend on the residual amount of B among the growth stages (Fig. 4). For example, while the treatment T_8 (B_2Zn_1) was recorded with the highest amount of residual B at the CRI stage, treatment T_1 (B_0Zn_0) was recorded with the highest amount of B at the tillering stage (Fig. 4).A similar trend in the residual Zn content was observed at different growth stages and at different treatments. For example, the highest amount of residual Zn was observed in treatment T_4 (B_1Zn_0) at the CRI stage, while the highest amount of residual Zn was observed in treatment T_8 (B_2Zn_1) at the booting stage (Fig. 4). A growth stage dependent Zn demand and the residual Zn were also reported by Ozturk et al. [43]. The variation in the residual Zn might also be due to the combined effect of pH, EC, organic carbon and P, which ultimately controls the Zn availability [44]. ~~A least~~ The lowest amount of residual B and Zn was observed in treatment T_{10} (control). In general a lower amount of Zn was recorded at maturity, which indicates a demand of Zn in the production of crop.

Table 6: Correlation (*r*) between soil available nutrient status at harvest and the nutrient content in straw averaged over two years

	Plant N	Plant P	Plant K	Plant B	Plant Zn
Soil N	0.41**	0.59**	0.66**	0.39**	0.33*
Soil P	0.36**	0.63**	0.67**	0.60**	0.11
Soil K	0.28*	0.39**	0.38**	0.31*	0.64**
Soil B	0.68**	0.57**	0.63**	0.26*	0.25*
Soil Zn	0.10	0.50**	0.48**	0.35	0.64**

*- $p < 0.05$, ** $p < 0.01$

Table 7: Correlation (*r*) between soil available nutrient status at harvest and the nutrient content in seed averaged over two years

	Soil N	Soil P	Soil K	Soil B	Soil Zn
Seed N	0.54**	0.76**	0.23*	0.56**	0.37**
Seed P	0.40**	0.83**	-0.03	0.47**	0.07
Seed K	0.48**	0.71**	0.19	0.63**	0.25*
Seed B	0.80**	0.74**	0.32*	0.69**	0.41**
Seed Zn	0.70**	0.80**	-0.06	0.64**	0.15

*- $p < 0.05$, ** $p < 0.01$

A positive correlation was observed between the uptake of different nutrients and the grain and straw yield irrespective of different treatments (Fig. 5).The correlation coefficient (*r*) was as high as 0.97 between K uptake (kg/ha) and the straw yield (t/ha). There was a very weak correlation between the Zn uptake and the grain yield (Fig. 5). The uptake of nutrients was governed by the soil, environmental and management practices. For example, the availability of B was determined by the availability of Zn in soil [28]. Santra et al. [45] also reported an increased amount of DTPA extractable Zn with the application of B. The relationship between B and Zn was found to be synergistic making high amount of Zn available in soil. A high correlation was also observed between the residual nutrient status in soil and the nutrient status is straw(Table 6) or between residual status in soil and the nutrient status is seed (Table 7).

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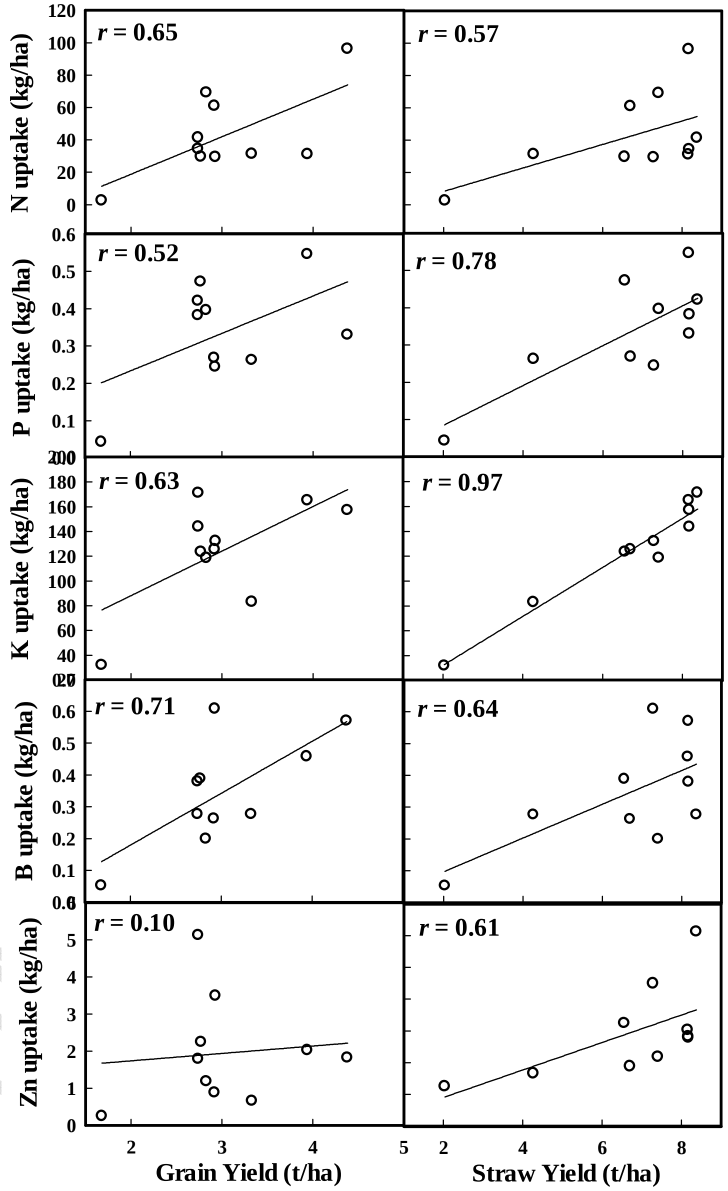

Fig. 5: Correlation coefficient (*r*) between the nutrient (N, P, K, B, and Zn) uptake (kg/ha) by plants and the grain and straw yield (t/ha) of wheat.

Conclusions

This study examined the effect of Boron and Zinc on the yield and uptake of different nutrients by wheat in the acid soil region of West Bengal, India. The yield components and grain yield of wheat showed a significant difference among the treatment combinations. The maximum average grain yield (4.38 t/ha) over two years was observed in the treatment $T_6$with higher amount of Zn application along with recommended dose of Boron application. The minimum grain yield was observed in treatmentT_{10}(the control) (1.68 t/ha). A relatively higher yield was obtained from the treatments with any nutrient combination over that of the control (T_{10}). Along with the difference in grain yield, a significant difference in straw yield was also observed among the treatments. The application of Boron and Zinc might show some synergistic effects leading to high grain and straw yield in the acid soil region. The presence of micro-nutrients and their combination also affected the uptake of nutrients in different growth stages of wheat. The interaction effect was also visible in the uptake nutrients by seeds. A positive correlation was observed between the uptake of nutrients and the yield of grain and straw in this study region with acid soils. The residual nutrient status showed a build-up of nutrients in soils.

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