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Research Paper

Production and economics of irrigated transplanted basmati rice (*Oryza sativa*) as influenced by substitution of nutrients through organics in Jammu region of India

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ABSTRACT

A field experiment was conducted during the rainy (*kharif*) season 2015 and 2016 at Chatha, Jammu and Kashmir, to evaluate the effect of substitution of nutrients through organics on production and economics of irrigated transplanted basmati rice (*Oryza sativa* L.). The study revealed that, plant height, dry-matter accumulation, tillers/hill, effective panicles/m^2, grains/panicle, grain and straw yields of basmati rice were significantly highest in 100% NPK (recommended dose of fertilizers-RDF) than 50% NPK + 50% N through vermicompost and FYM (1 : 1), 50% NPK + 50% N through vermicompost, 50% NPK + 50% N through FYM, 25% NPK + 75% N through vermicompost and FYM (1 : 1), 25% NPK + 75% N through vermicompost, 25% NPK + 75% N through FYM, 100% N through vermicompost and FYM (1 : 1), 100% N through vermicompost and 100% N through FYM , but were statistically at par with 75% NPK + 25% N through vermicompost and FYM (1 : 1); 25% yearly replacement of RDF with vermicompost and FYM (1:1) on N basis; 75% NPK + 25% N through vermicompost; 25% yearly replacement of RDF with vermicompost on N basis, 75% NPK + 25% N through FYM and 25% yearly replacement of RDF with FYM on N-basis during both the years. Likewise, the maximum net returns (₹60,790 and ₹71,322 were realized with 100% NPK followed by treatment 75% NPK + 25% N through vermicompost and FYM (1 : 1) with the net returns to the tune of (₹54,426 and ₹68,129/ha) during 2015 and 2016 respectively.

Key words *: Basmati rice, Economics, Farmyard manure, Organic nutrient sources, Vermicompost, Yield*

Rice is the most widely grown cereal crop and is staple food for more than half of the world's population. Its importance can be recognized by the fact that the year 2004 was declared as International year for rice by the United Nations. This reputation has not been conferred to any other cereal crop. It is the only cereal with completely sequenced genome consisting of 430 mega base pair (Ashfaq *et al.,* 2013). Globally, India occupies a pride place in rice cultivation having production of 112.91 million tonnes from an area of 43.79 m ha with productivity of 25.78 q/ha (Anonymous, 2018). Basmati rice occupies a special place in human diet because of its excellent cooking qualities and aroma and as a result it has a high demand in the international market. The cultivation of basmati rice is more remunerative because it fetches more than double price than coarse rice and is the globally reputed aromatic group of rice (Singh and Sikka, 2007). Basmati rice is a super-specialty export quality high-volume. high-value crop with comparatively low nutrient requirement. Productivity and quality of basmati rice depends on the environmental conditions and the agronomic management practices. The low nitrogen requirement of basmati rice and coincidence of its growing season with the rains are good for the conservation of the natural resources and environmental health (Aulakh *et al.,* 2016).

Shrinking land resources coupled with increased demand for food to feed the burgeoning population has over-exploited the cultivated lands and posed a serious challenge to the traditional resilience characteristics of these crop lands. Increased health consciousness among the masses has augmented the demand for safe and quality foods for which a comprehensive organic food production technology needs to be developed with emphasis on quality enhancement and yield stability in comparison to the yield and quantity aspects realized under conventional practices of crop production. This may become possible

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through the progressive substitution of inorganic sources of nutrients with organics to meet crop nutrient requirement for attaining higher and stable yield. Hence a study was carried out to assess the effect of differential substitution of nutrients through organics on basmati rice in the irrigated plains of Jammu subtropics.

MATERIALS AND METHODS

The field experiment was conducted during the rainy (*kharif*) season 2015 and 2016 at Research farm, Main campus Chatha of the Sher-e-Kashmir University of Agricultural Sciences and Technology- Jammu (32°40' N, 73° 64' E 293 meters above mean sea-level) Jammu, Jammu and Kashmir, to study the effect of substitution of nutrients through organics on productivity and economics of irrigated transplanted basmati rice. The experiment was laid out in randomized block design, consisting of 16 treatments in 3 replications. The initial soil status of the experimental field was sandy clay loam, with bulk density of 1.44 g/cc, organic carbon 0.45%, *p*H 7.81, electrical conductivity EC 0.21 dS/m, while available nitrogen, phosphorus and potassium were 249.88 kg/ha, 13.79 kg/ha and 148.45 kg/ha, respectively. There was a substantial variation in rainfall of both the seasons, as rainy season of 2016 (804.2 mm) recorded higher rainfall than rainy season 2015 (724.1 mm). Further, in comparison to seasonal normal rainfall (720 mm), basmati crop grown during the rainy season 2015 received 0.56 and rainy season 2016 received 11.69% more rains during their respective crop growing periods.

The treatment details were: T_1, 100% NPK (30 : 20 : 10 kg/ha); T_2, 75% NPK + 25% N through vermicompost; T_3, 50% NPK + 50% N through vermicompost; T_4, 25% NPK + 75% N through vermicompost; T_5, 100% N through vermicompost; T_6 25% yearly replacement of recommended dose of fertilizer (RDF) through vermicompost; T_7, 75% NPK + 25% N through FYM; T_8, 50% NPK + 50% N through FYM; T_9, 25% NPK + 75% N through FYM; T_{10}, 100% N through FYM; T_{11}, 25% yearly replacement of RDF through FYM; T_{12}, 75% NPK + 25% N through vermicompost and FYM (1 : 1); T_{13}, 50% NPK + 50% N through vermicompost and FYM (1 : 1); T_{14}, 25% NPK + 75% N through vermicompost and FYM (1 : 1); T_{15}, 100% N through vermicompost and FYM (1 : 1); T_{16}, 25% yearly replacement of RDF through vermicompost and FYM (1 : 1). Treatment T_2 and T_6; T_7 and T_{11}; T_{12} and T_{16} were similar during the first year of experiment whereas during second year T_3 and T_6; T_8 and T_{11}; T_{13} and T_{16} were alike. The per cent NPK content in vermicompost was N (1.60), P (0.80) and K (0.73) during the rainy season 2015, whereas during the rainy season 2016 vermicompost contained N (1.53%), P (0.79%) and K(0.67%). Composition of FYM was N (0.60 %), P (0.23%) and K (0.30%) during the rainy season 2015, whereas during the rainy season 2016 composition of FYM was N (0.60 %), P (0.24%) and K (0.29%). The method of application included whole quantity of phosphorus, potassium and organic manures (vermicompost and FYM) along with half of the total remaining nitrogen as basal, whereas rest of the nitrogen was top-dressed in 2 equal splits in basmati rice-at tillering and panicle-initiation stage as per the treatments. Organic manures and inorganic fertilizers were applied manually. Rice variety Seedlings of 30 days age and 33 days age of 'Basmati 370' were transplanted on 13 July and 11 July and harvested on 11 November and 8 November during the rainy season of 2015 and 2016 respectively. All the management practices were adopted as per the recommendations under irrigated condition except for the nutrient-N and its organic sources which were applied as per the treatments of the present investigation. In basmati rice, 5 plants were selected and tagged for the measurement of plant height, number of tillers/hill and yield attributes after leaving 2 rows from each side of the plot measuring 5.4 m × 3 m whereas sampling for dry-matter accumulation was done from the fourth row. Net returns and benefit: cost ratio were computed based on cost of cultivation, and grain and straw yields with their prevailing market price. The data collected for different parameters were statistically analyzed using Gomez and Gomez (1984) randomized block design. The results are presented at 5% level of significance (P=0.05) for making comparison between treatments.

RESULTS AND DISCUSSION

Growth parameters

Plant height, dry-matter accumulation and number of tillers/hill of basmati rice at maturity were significantly influenced by differential substitution of nutrients through organics (Table 1). Among the different treatments, significantly highest growth parameters, viz. plant height, dry-matter accumulation and number of tillers/hill, were recorded with treatment T_1 which were found significantly superior than treatments T_{13}, T_3, T_8, T_{14}, T_4, T_9, T_{15}, T_5 and T_{10} and statistically at par with treatments T_{12}, T_{16}, T_2, T_6, T_7 and T_{11} during the rainy season of 2015 and 2016, while the lowest growth parameters were recorded with treatment in which 100% N was substituted through FYM, 100% N through vermicompost, 100% N through vermicompost and FYM (1 : 1), 25% NPK + 75% N through FYM, 25% NPK + 75% N through vermicompost and 25% NPK + 75% N through vermicompost and FYM. This might be due to improved the uptake of total nitrogen 28.43–38.17% at all stages which ultimately led to better growth parameters and contributed accumulating higher dry matter as compared to organic treatments. These observations are in agreement with those recorded by Reddy (1985) and Rajeshwari (1990).

Yield and yield attributes

The yield attributes, viz. number of effective panicles/hill, number of grains/panicle and grain yield, of basmati rice were significantly influenced by differential substitution of nutrients through organics during the both the seasons (Table 2). Significantly highest number of effective panicles/hill, number of grains/panicle, grain and straw yields of basmati rice were recorded under treatment with T_1 which were found significantly superior to treatments T_{13}, T_3, T_8, T_{14}, T_4, T_9, T_{15}, T_5 and T_{10} and statistically at par with treatments T_{12}, T_{16}, T_2, T_6, T_7 and T_{11} during both the season. Significantly highest grain yield of basmati rice (2.84 t/ha and 3.23 t/ha) was recorded during both the years with treatment T_1; however statistically at par with treatments T_{12}, T_{16}, T_2, T_6, T_7 and T_{11} and significantly superior to treatments T_{13}, T_3, T_8, T_{14}, T_4, T_9, T_{15}, T_5 and T_{10}

Table 1. Effect of differential substitution of nutrients through organics on growth parameters of basmati rice

Treatment	Plant height (cm)		Dry matter accumulation (g/hill)		Number of tillers/hill	
	2015	2016	2015	2016	2015	2016
T^{1}	116.3	118.1	14.6	15.5	8.4	8.8
T^{2}	112.5	113.7	14.4	15.3	8.1	8.6
T^{3}	96.6	98.0	12.3	13.1	6.8	7.1
T^{4}	80.9	82.9	10.2	10.9	5.5	6.2
T^{5}	78.8	81.1	9.8	10.4	5.2	6.1
T^{6}	111.4	112.9	14.3	15.3	8.1	8.5
T^{7}	111.1	112.7	14.3	15.2	8.0	8.4
T^{8}	95.3	95.5	12.2	13.0	6.3	7.1
T^{9}	80.5	82.1	10.1	10.8	5.4	6.1
T^{10}	77.5	79.5	9.6	9.9	5.1	6.0
T^{11}	111.0	112.3	14.3	15.2	8.0	8.1
T^{12}	115.4	116.7	14.4	15.5	8.3	8.7
T^{13}	97.2	98.5	12.4	13.2	7.0	7.2
T^{14}	81.4	81.6	10.2	11.0	5.5	6.2
T^{15}	80.3	82.5	10.1	10.7	5.3	6.1
T^{16}	113.3	114.8	14.4	15.4	8.2	8.7
SEm±	4.7	4.6	0.6	0.6	0.2	0.2
CD(P=0.05)	13.6	13.4	1.8	1.9	0.6	0.8

Details of treatments are given under Materials and Methods

Table 2. Effect of differential substitution of nutrients through organics on yield-attributing characters and yield of basmati rice

Treatments	Effective panicles/m^2		Grains/panicle		1,000-grain weight (g)		Grain yield (t/ha)		Straw yield (t/ha)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
T_1	211.6	236.0	72.0	74.2	21.6	21.8	2.8	3.2	7.0	7.4
T_2	207.9	235.1	71.5	73.8	21.2	21.4	2.6	3.1	6.8	7.4
T_3	185.0	209.3	61.9	65.8	20.6	21.0	2.1	2.5	5.7	6.2
T_4	163.7	184.0	54.0	55.7	20.5	20.9	1.7	2.1	4.6	5.0
T_5	162.7	182.1	53.5	55.3	19.9	20.7	1.4	1.9	4.1	4.5
T_6	207.6	234.3	71.1	73.7	21.1	21.3	2.5	3.0	6.8	7.3
T_7	207.2	234.2	70.4	73.6	21.0	21.2	2.5	2.9	6.8	7.3
T_8	184.9	209.4	61.8	65.7	20.6	21.0	2.1	2.5	5.7	6.1
T_9	163.3	183.8	53.7	55.5	20.4	20.9	1.7	2.1	4.3	4.6
T_{10}	162.6	181.0	53.4	55.2	19.6	20.5	1.4	1.9	4.1	4.5
T_{11}	207.1	234.1	70.2	73.5	20.7	21.1	2.5	2.9	6.8	7.3
T_{12}	209.9	236.2	71.5	74.1	21.6	21.7	2.6	3.1	6.9	7.4
T_{13}	186.0	210.1	63.0	66.0	20.7	21.1	2.2	2.5	5.9	6.3
T_{14}	163.9	184.6	54.2	58.2	20.6	20.9	1.7	2.1	4.8	5.2
T_{15}	163.0	183.2	53.6	55.4	19.9	20.8	1.4	1.9	4.2	4.6
T_{16}	208.1	235.3	71.4	73.9	21.4	21.5	2.6	3.1	6.9	7.4
SEm±	7.2	8.1	2.4	2.5	0.7	0.8	0.1	0.1	0.3	0.3

respectively, during the rainy season of 2015 and 2016.

The variation in yield-attributing characters in basmati rice might be due to more application of phosphorus (20 kg/ha) in 100% NPK (recommended dose of fertilizer) when compared with the other treatments; being part of DNA phosphorus played an imperative role in building genetic part of the plant. These results confirm the findings of Iqwal *et al.,* 2002; Arif *et al.,* 2006). Significantly highest grain and straw yields in basmati with treatments 100% NPK (recommended dose of fertilizer) and 75% NPK +25% substitution of organics either through vermicompost or FYM or vermicompost and FYM in combination might be attributed to the greater availability and uptake of macro and micronutrients and their active participation in carbon assimilation, photosynthesis, starch formation, translocation of proteins and sugars, entry of water into the plant roots and their development etc. Combination of organic and inorganic fertilizers also enhances the process of tissue differentiation, i.e from somatic to reproductive phase leading to higher grain and straw yields. These results are also in confirm findings of Hossaen *et al.* (2011). The highest increase of 34.41% and 10.00% of grain and straw yield, respectively, in basmati rice was recorded in the second year compared with the first year with treatment in which 100% N was substituted through FYM followed by 33.58% and 9.41% increase with treatment of 100% N through vermicompost whereas the lowest increase of 13.79% and 6.49% in grain and straw yield was registered with 100% NPK. The possible reasons for highest per cent increase in grain and straw yields with organics in the second year over the first year could be owing to improvement in build up in nutrients nitrogen and potassium in soil when compared to RDF. Our findings confirm those of Singh *et al.* (2006).

Economics

Adoption of any technology by the farmers depends on the net returns they get by adopting the technology. Application of 100% NPK (recommended dose of fertilizers) recorded the minimum cost of cultivation in basmati rice during the rainy season of 2015 and 2016 (Table 3). It was owing to low cost of fertilizers under this treatments during both the years. The maximum cost of cultivation in basmati rice was involved under treatment in which 100% N was substituted through vermicompost, due to higher cost of vermicompost. The maximum gross and net returns were realized under treatment 100% NPK (recommended dose of fertilizers) closely followed by 75% NPK + 25% N through vermicompost and FYM (1 : 1) during the rainy season of 2015 and 2016. The gross returns and net returns were higher during 2016 than 2015. It was might be owing to higher grain yield 3.24 t/ha of basmati rice, highest sale price (₹3,000/qt) and minimum cost of cultivation (₹20,782/ha) of basmati rice during 2016 as compared to 2015. This conforms the findings of Malviya *et al.* (2012). The highest benefit: cost ratio (2.93 and 3.43) were recorded with 100% NPK (recommended dose of fertilizers) whereas the lowest with treatment in which 100% N was substituted through vermicompost.

Hence, application of 100% NPK (recommended dose of fertilizers) and 75% NPK + 25% N through vermicompost and FYM (1 : 1) were adjudged as better

Table 3. Effect of differential substitution of nutrients through organics on relative economics of basmati rice

Treatment	Cost of cultivation(ha)		Gross returns(/ha)		Net returns(/ha)		Benefit: cost ratio	
	KY_1	KY_2	KY_1	KY_2	KY_1	KY_2	KY_1	KY_2
T_1	20,782	20,782	81,572	92,104	60,790	71,322	2.93	3.43
T_2	24,137	24,309	75,589	89,500	51,452	65,191	2.13	2.68
T_3	27,493	27,836	63,419	73,131	35,925	45,295	1.31	1.63
T_4	30,849	31,363	49,810	60,438	18,960	29,074	0.61	0.93
T_5	33,911	34,597	49,996	64,938	16,084	30,340	0.47	0.88
T_6	24,137	27,836	74,971	86,110	50,834	58,274	2.11	2.09
T_7	21,637	21,637	74,639	85,494	53,001	63,857	2.45	2.95
T_8	22,493	22,493	62,522	72,951	40,029	50,458	1.78	2.24
T_9	23,346	23,346	49,239	59,923	25,892	36,577	1.11	1.57
T_{10}	23,911	23,911	48,600	64,425	24,688	40,513	1.03	1.69
T_{11}	21,637	22,493	74,450	85,641	52,812	63,147	2.44	2.81
T_{12}	22,887	22,973	77,314	91,102	54,426	68,129	2.38	2.97
T_{13}	24,993	25,164	63,925	74,063	38,931	48,898	1.56	1.94
T_{14}	27,099	27,356	51,168	62,152	24,068	34,796	0.89	1.27
T_{15}	28,911	29,254	50,713	66,218	21,801	36,963	0.75	1.26
T_{16}	22,887	25,164	76,365	89,616	53,,477	64,451	2.34	2.56

Details of treatments are given under Materials and Method
KY_1, Rainy season 2015; KY_2, rainy season 2016

treatments for better productivity and economics of irrigated transplanted basmati rice as influenced by substitution of nutrients through organics in Jammu region of India.

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Research Paper

Effect of irrigation management and boron fertilization on growth and yield of bread wheat (*Triticum aestivum*) in sub-Himalayan region of West Bengal

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ABSTRACT

A field experiment was conducted during the winter (*rabi*) seasons of 2015–16 and 2016–17 at Uttar Banga Krishi Vishwadidyalaya Cooch Behar, West Bengal, to work out the effect of irrigation management and boron fertilization on growth and yield of bread wheat (*Triticum aestivum* L.). The experiment was laid out in split-plot design, having 4 main-plot treatment, viz. I_1, 1 irrigation at crown-root-initiation (CRI) stage; I_2, 2 irrigations at CRI and booting stage; I_3, 3 irrigations at CRI, jointing and flowering stage; I_4, 4 irrigations at CRI, tillering, booting and dough stage, and 5 subplot treatment, viz. B_0, control; B_1, boron @ 1 kg/ha; B_2, boron @ 2 kg/ha; B_3, boron @ 3 kg/ha; B_4, foliar spray of 0.03% solution of boron at pre-flowering stage, replicated thrice. Result indicated that, 3 irrigations (I_3) and B_4 application followed by B_2 resulted in the highest growth and yield-attributing characters. The grain yield and straw yield were increased up to 3 irrigations (I_3), but declined with 4 irrigations (I_4). Treatment B_4 gave the highest grain and straw yields which was at par with the B_2 treatment. The highest grain and straw yields (4.63 t/ha and 5.57 t/ha) were recorded with I_3B_4 treatment combination. The treatment combination I_3B_4 recorded the highest boron concentration in plant (4.42 mg/kg). Water use efficiency was decreased with the increase in number of irrigations, whereas B_4 followed by B_3 recorded the highest water-use efficiency (22.1 and 21.8 kg/ha-mm). The net returns and return per rupee invested were maximum in the I_3B_4 (₹28,800/ha) and ₹2.23) followed by I_3B_2) ₹26,400/ha) and ₹2.14) treatment combination.

***Key word* :** Boron fertilization, Economics, WUE, Growth, Irrigation management, Yield

Irrigation is one of the primary and costly inputs which has direct effect on growth and yield of wheat, and yield can be increased by irrigation at the right time and appropriate quantity. A change in the optimal temperature during its vegetative and reproductive growth adversely affects the rate and duration of growth and yield of wheat. It is not possible to modify the adverse environment during growth of wheat under field condition. However, favourable soil moisture regime can be created by timely scheduling of irrigation. Abd El *et al*. (2012) reported that the water-deficit condition at the tillering and flowering stage reduced significantly the growth traits. Saren *et al*. (2004) reported that, 4 irrigations applied at crown-root-initiation (CRI), tillering, flowering and grain-development stages resulted in the maximum plant height, dry-matter accumulation, leaf-area index (LAI) and crop-grown stage (CGR) of wheat on sandy-loam soil. Yadav *et al*. (2010) reported higher yield and yield attributes were found with 4 irrigations at critical growth stages of wheat.

Therefore, it should be efficiently used to attain maximum water-use efficiency. Its economized use will not only save this natural resource but also make the production of wheat crop more remunerative, where high lifting of groundwater has already caused surface problem like arsenic contamination. Hence, it is also important to evaluate the most critical stages for wheat under economized use of irrigation water without compromising the maximization in production in Sub-Himalayan region of West Bengal.

Boron deficiency is a wide-spread nutritional disorder, scattered throughout the world. The Sub-Himalayan region of West Bengal is characterized by sandy loam in soil texture and high rainfall that causes high rate of leaching of boron as $B(OH)_3$ as well as base-forming cations making this zone acidic in reaction. This chronic deficiency of boron in soil results in poor grain setting in wheat leading to declined productivity. Boron deficiency affects pollen development during the pollen mother cell stage which coincides with the booting stage. The productivity of this problematic soil and wheat yield may be improved by applica-

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tion of boron and other nutrients along with recommended dose. Keeping the above facts in view, the present investigation was undertaken to work out the effect of irrigation management and boron fertilization on growth and yield of wheat.

MATERIALS AND METHODS

A field experiment was carried out during the winter (*rabi*) seasons of 2015–16 and 2016–17 at the instructional farm of Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, (26%19'86" N, 89%23'53" E, 43 m above mean sea-level) West Bengal, to work out the effect irrigation management and boron fertilization on growth and yield of wheat. The experimental soil was sandy loam with *p*H 5.46, medium in organic carbon (.078%), medium in available nitrogen (138.1 kg/ha), medium in available phosphorus (14.8 kg/ha), low in available potassium (79.9 kg/ha) and available boron (0.82 kg/ha). The experiment was laid out in split-plot design with 20 treatment combinations, having 4 main-plot treatment, viz. I_1, 1 irrigation at CRI stage; I_2, 2 irrigations at CRI and booting stage; I_3, 3 irrigations at CRI, jointing and flowering stage; I_4, 4 irrigations at CRI, tillering, booting and dough stage and 5 subplot treatment B_0, control; B_1, boron @ 1 kg/ha; B_2, boron @ 2 kg/ha; B_3, boron @ 3 kg/ha; and B_4, foliar spray of 0.03% solution of boron at pre-flowering stage, replicated thrice. The soil was prepared by tractor-drawn cultivator followed by rotavator. The whole experimental field was divided into 60 subplots following the layout plan. Fertilizers were applied @ 120 : 60 : 40 N : P_2O_5 : K_2O kg/ha through urea, single superphosphate and muriate of potash. The 60 kg N and full dose of P_2O_5 and K_2O was broadcasted during the final land preparation. Rest 60 kg/ha nitrogen was applied in 2 splits equal halfs–top-dressed at crown-root initiation stage (23 DAS) and active tillering stage (45 DAS). Boron fertilizer was mixed with soil and then broadcasted on the plots at final land preparation for even distribution. In case of foliar application, boron was applied @ 0.03% solution at pre-flowering stage (65 DAS). The source of boron fertilizer was actibor (di-sodium tetra borate penta-hydrate). The wheat variety 'PBW 343' was taken in the present study. Seeds were treated with mancozeb @ 2 g/kg seeds before sowing to control fungal diseases. The seed was sown on 18 and 16 September during both the seasons. Irrigations were scheduled as per the treatments taken under study. The water-use efficiency (WUE) was calculated:

$$\text{WUE} = \frac{\text{Grain yield}}{\text{Total water use}}\ \text{kg/ha-mm}$$

Hand-weeding and 2,4-D were applied to eradicate the weeds. The crop was matured in the last week of March and harvested on 27th and 28th March during both the seasons. The data collected from the field and laboratory experiment were statistically analysed and the treatment variations were tested at 5% level of significance by 'F' test.

RESULTS AND DISCUSSION

Growth parameters

The growth parameters, viz. plant height, dry-matter accumulation and tiller number, are presented in Table 1. Significantly highest plant height (90.2 cm) was recorded with 3 irrigations (I_3) which was at par with 4 irrigations (I_4). Among the boron-containing treatment, B_1 recorded the highest plant height (90.3 cm). Three irrigations (I_3) resulted in the highest dry-matter accumulation (707.2 g/m^2) followed by I_4 treatment. The B_4 accumulated more dry-matter (690.4 g/m^2) which was at par with B_1 and B_2. The highest dry-matter accumulation was recorded with foliar-applied boron (B_4) and this might be owing to more absorption of boron that caused better pollen viability and fertilization. The maximum number of tillers/m^2 was observed with 3 irrigations (I_3) (308.5). Among the boron-containing treatment, foliar-applied boron (B_4) resulted in significantly highest number of tillers/m^2 (301.5) over other boron-containing treatments including the control. The growth parameters were increased up to 3 irrigations and boron fertilization and this might be owing to better moisture as well as boron availability to plants, whereas further increase in irrigation, i.e. 4 irrigations, it was declined due to physiological constraints. It was reported that, irrigation at tillering, stem-elongation stage, booting and grain-filling stage resulted in the higher yield of wheat (Mubeen *et al.,* 2013).

Yield attributes

The data of yield attributes, viz. spikes/m^2, spike length, filled grains/spike, sterility % and test weight, are presented in Table 1. The maximum spikes/m^2 (286) were recorded with 3 irrigations (I_3) followed by 4 irrigations (I_4) and 2 irrigation (I_2). Among the basal application of boron, the spikes/m^2 were increased up to 2 kg/ha boron (B_2), then decreased with the further increase in boron, i.e. 3 kg/ha (B_3). The highest spikes/m^2 (268.5) were recorded with foliar-+applied boron (B_4), being at par with 2 kg/ha boron (B_2). The spike length was found to be non-significant. The filled grains/spike were increased up 3 irrigations (I_3) and it was decreased with 4 irrigation (I_4). Significantly highest filled grains/spike (47.7) were recorded with 3 irrigations (I_3). Among the basal application of boron, the higher filled grains/spike were recorded with 2.0 kg/ha boron (B_2). The highest filled grains/spike were recorded with foliar-applied boron (B_4) which was significantly different from other boron treatments including the control. The maximum test weight (40.7 g) was recorded with 3 irrigation treatment (I_3). Among the basal application, the 2 kg/ha boron (B_2) recorded significantly higher test weight (40.5 g). The 3 irrigation treatment (I_3) in lowest sterility % (2.68). The sterility %, recorded with different boron treatments were statistically at par. Singh *et al.*(2012) reported that, increasing the number of irrigations significantly increased the effective tillers/m^2, ear length (cm), spikelets/ear, grains/ear, 1,000-grain weight biological yield and economic yield (q/ha), straw yield (q/ha) and harvest index.

Grain yield

The grain yield recorded with different levels of irrigation are given Table 2. The grain yield was increased up to 3 irrigations and declined with 4 irrigations. Significantly higher grain yield (4.08 t/ha) was recorded with three irrigations (I_3). The grain yield was also increased with boron-containing treatments compared to the control. Among the basal application of boron the higher grain yield was recorded with B_2 (3.76 t/ha). The highest grain yield (3.81 t/ha) was recorded with foliar-applied boron (B_4) which was at par with the B_2. The interaction effect between levels of irrigation and levels of boron application was found to be significant. The highest grain yield (4.63t/ha) was recorded with I_3B_4 treatment combination. Sarwar *et al.* (2010) reported 27.2–30.5% increase in grain yield with increase in irrigation frequency from 2 to 4 owing to availability of more water. Our results support the findings Debnath *et al.* (2011) and Singh *et al.* (2012).

Straw yield

The straw yield was increased with the increase in irrigation. Higher straw yield (5.26 t/ha) was recorded with 4 irrigations (I_3). The straw yield was increased with all boron-containing treatments compared to the control. The highest straw yield (5.25 t/ha) was with foliar application of boron (B_4) which was at par with basal applied B_2 (5.23 t/ha). The interaction effect between levels of irrigation and levels of boron application was found to be non-significant. Our results confirm the findings Debnath *et al.* (2011) and Singh *et al.* (2012).

Harvest index

The maximum harvest index (44 %) was noted with 3 irrigations (I_3) followed by 1 irrigation (I_1) (Table 1). Foliar applied boron (B_4) resulted in the highest harvest index This might be owing to more pollen viability caused better fertilization. Our findings the result of Singh *et al.* (2012).

Soil-available boron at flowering stage of wheat

The soil-available boron decreased with the increase in level of irrigation and increased with the increase in level

Table 1. Effect of irrigation management and boron fertilization on growth, yield attributes and water-use efficiency (WUE) of wheat (mean data of 2 years)

Treatment	Plant height (cm)	Dry-matter accumulation (g/m^2)	Tiller/ m^2	Spikes/ m^2	Spike length (cm)	Filled grain/ spike	Sterility (%)	Test weight (g)	Harvest index (%)	WUE (kg/ha-mm)
Level of irrigation										
I_1, 1 irrigation at CRI stage	80.4	620.5	263.9	204.0	9.56	40.6	3.17	38.9	41.5	28.3
I_2, 2 irrigations at CRI and booting stage	84.9	641.4	276.5	214.5	9.43	42.7	2.84	39.5	39.0	20.7
I_3, 3 irrigations at CRI, jointing and flowering stage	90.2	707.2	308.5	286.0	9.74	47.7	2.68	40.7	44.0	19.3
I_4, Four irrigations at CRI, tillering, booting and dough stage	89.3	692.6	302.3	276.5	9.58	45.9	2.97	40.3	40.5	13.8
SEm±	0.41	1.60	1.40	5.54	0.08	0.4	0.08	0.60	0.55	0.14
CD (P=0.05)	1.42	5.62	4.92	19.52	N.S	1.40	0.25	NS	1.90	0.48
Level of boron										
B_0, Control	71.9	635.7	273.1	219.5	9.29	41.5	4.84	38.3	41.5	18.7
B_1, Boron @ 1.0 kg/ha	90.3	662.6	285.9	241.5	9.66	44.0	2.49	40.1	40.5	20.0
B_2, Boron @ 2.0 kg/ha	90.1	682.5	295.2	256.0	9.69	45.3	2.34	40.5	41.5	21.8
B_3, Boron @ 3.0 kg/ha	89.4	655.8	283.4	240.5	9.55	43.5	2.35	39.7	41.0	20.1
B_4, Foliar spray @ 0.03% solution of boron at pre-flowering stage	89.2	690.4	301.5	268.5	9.70	46.7	2.55	40.6	42.0	22.1
SEm±	0.50	2.12	0.95	6.55	0.14	0.20	0.16	0.57	0.01	0.18
CD (P=0.05)	1.43	6.14	2.75	18.96	N.S	0.60	0.47	NS	NS	0.51

CRI, Crown-root initiation

Table 2. Effect of irrigation management and boron fertilization on grain yield of bread wheat (mean data of 2 years).

Treatment	Level of irrigation (I)									
	Grain yield (t/ha)					Straw yield (t/ha)				
Level of boron (B)	I_1, 1 irrigation: at CRI stage	I_2, 2 irrigations: at CRI and booting stage	I_3, 3 irrigations: at CRI, jointing and flowering stage	I_4, 4 irrigations: at CRI, tillering, booting and dough stage	Mean	I_1, 1 irrigation: at CRI stage	I_2, 2 irrigations: at CRI and booting stage	I_3, 3 irrigations: at CRI, jointing and flowering stage	I_4, 4 irrigations: at CRI, tillering, booting and dough stage	Mean
B_0, Control	2.95	2.99	3.52	3.49	3.24	4.26	4.63	4.66	4.62	4.54
B_1, Boron @ 1.0 kg/ha	3.08	3.35	3.72	3.65	3.45	4.48	5.31	5.43	5.38	5.15
B_2, Boron @ 2.0 kg/ha	3.35	3.49	4.51	3.68	3.76	4.59	5.37	5.45	5.52	5.23
B_3, Boron @ 3.0 kg/ha	3.01	3.32	4.05	3.53	3.48	4.31	5.12	5.19	5.15	4.94
B_4, Foliar spray @ 0.03% solution of boron at pre-flowering stage	3.37	3.55	4.63	3.70	3.81	4.56	5.38	5.57	5.54	5.25
Mean	3.15	3.34	4.08	3.61		4.44	5.17	5.26	5.24	
Interaction	*I*	*B*	*I* × *B*	*B* × *I*		*I*	*B*	*I* × *B*	*B* × *I*	
SEm±	0.049	0.063	0.118	0.106		0.101	0.101	0.218	0.216	
CD (P=0.05)	0.177	0.179	0.369	0.378		0.347	0.306	NS	NS	

CRI, Crown-root initiation

Table 3. Effect of irrigation management and boron fertilization on available boron in soil and boron concentration in plant at flowering stage of wheat (mean data of 2 years)

Treatment	Level of irrigation (I)									
	Available boron in soil (kg/ha)					Boron concentration in plant (mg/kg)				
Level of boron (B)	I_1, 1 irrigation: at CRI stage	I_2, 2 irrigations: at CRI and booting stage	I_3, 3 irrigations: at CRI, jointing and flowering stage	I_4, 4 irrigations: at CRI, tillering, booting and dough stage	Mean	I_1, 1 irrigation: at CRI stage	I_2, 2 irrigations: at CRI and booting stage	I_3, 3 irrigations: at CRI, jointing and flowering stage	I_4, 4 irrigations: at CRI, tillering, booting and dough stage	Mean
B_0, Control	0.95	0.97	0.95	0.99	0.96	2.90	2.95	2.96	2.94	2.93
B_1, Boron @ 1.0 kg/ha	1.51	1.45	1.33	1.33	1.40	3.01	3.20	3.37	3.40	3.21
B_2, Boron @ 2.0 kg/ha	1.76	1.72	1.51	1.47	1.62	3.08	3.54	3.93	3.40	3.38
B_3, Boron @ 3.0 kg/ha	2.11	2.04	1.62	1.59	1.84	2.96	3.29	3.56	3.31	3.21
B_4, Foliar spray @ 0.03% solution of boron at pre-flowering stage	1.03	0.95	0.97	1.01	0.99	3.10	3.84	4.42	3.52	3.56
Mean	1.47	1.42	1.28	1.28		3.01	3.37	3.65	3.32	
Interaction	*I*	*B*	*I* × *B*	*B* × *I*		*I*	*B*	*I* × *B*	*B* × *I*	
SEm±	0.030	0.029	0.063	0.067		0.011	0.010	0.021	0.024	
CD (P=0.05)	0.105	0.084	0.182	0.177		0.038	0.029	0.064	0.062	

CRI, crown-root initiation

of boron (Table 3). The lowest soil-available boron was found with 3 irrigations (I_3) (1.28 kg/ha), but highest with B_3 (1.84 kg/ha), which (B_3) was significantly different from all other boron-containing treatment including the control. The interaction effect between levels of irrigation and levels of boron was significant. Uddin *et al.* (2008) noticed that, boron application at booting stage improves the grain setting by improving the grain-filling process and reducing the male sterility often observed in boron-deficient condition.

Boron concentration in plant at flowering stage of wheat

The boron concentration in plant was increased up to 3 irrigations (I_3) but further increase in irrigation (I_4), its concentration in plant decreased (Table 3). The 3 irrigation treatment (I_3) recorded with significantly highest boron concentration in plant (3.64 mg/kg) followed by 4 irrigations (I_4) and 2 irrigations (I_2). Among the basal application of boron, 2 kg/ha boron (B_2) revealed significantly higher boron concentration in plant (3.38 mg/kg) followed by 1.0 kg/ha boron (B_1) and 3.0 kg/ha boron (B_3). The foliar-applied boron (B_4) recorded significantly highest boron concentration in plant (3.56 mg/kg) than all the treatments. The interaction effect was found to be significant on boron concentration in plant. It was apparent from the result that, the highest boron concentration in plant (4.42 mg/kg) was recorded with I_3B_4 treatment combination. It was reported that, foliar-applied boron enhanced the boron concentration of the reproductive organs making efficient utilization of boron at flowering stage (Mortvedt, 2000; Sarkar *et al.,* 2007).

Table 4. Effect of irrigation management and boron fertilization on economics of wheat (mean data of 2 years)

Treatment	Gross returns (000 ×₹/ha)	Net returns (000 ×₹/ha)	Returns/₹ invested
I_1B_0	51.8	12.1	1.47
I_1B_1	54.5	14.7	1.55
I_1B_2	58.4	18.4	1.66
I_1B_3	54.1	14.0	1.54
I_1B_4	58.9	18.7	1.68
I_2B_0	53.8	9.6	1.53
I_2B_1	59.2	14.9	1.69
I_2B_2	61.3	16.9	1.74
I_2B_3	58.7	14.1	1.67
I_2B_4	62.0	17.2	1.76
I_3B_0	60.5	11.8	1.72
I_3B_1	64.0	15.2	1.82
I_3B_2	75.4	26.4	2.14
I_3B_3	69.0	19.9	1.97
I_3B_4	78.1	28.8	2.22
I_4B_0	60.8	7.7	1.73
I_4B_1	63.7	10.4	1.81
I_4B_2	64.1	10.6	1.82
I_4B_3	61.9	8.3	1.76
I_4B_4	64.7	10.9	1.84
SEm±	1.92	1.15	0.02
CD (P=0.05)	5.77	3.43	0.07

Details of irrigation and boron treatments are given under Materials and Methods

Water-use efficiency

The water-use efficiency (WUE) decreased with the increase in number of irrigations (Table 1). The lowest WUE recorded with I_4 treatment (13.8 kg/ha-mm) was significantly lower than the other irrigation treatments. The highest WUE was recorded with I_1 (28.3 kg/ha-mm) treatment. Among the boron-containing treatment, B_4 followed by B_3 exhibited the highest water-use efficiency (22.1 and 21.8 kg/ha-mm). Maurya and Singh (2008) also reported a decrease in WUE with an increase in irrigation levels due to proportionately less increase in grain yield with increase in evapotranspiration.

Economics

The maximum gross and net returns resultedin in I_3B_4 combination ₹78,000 and ₹28,800 followed by I_3B_2 (₹75,400 and ₹26,400/ha) treatment combination (Table 4). The return per rupee invested was maximum in I_3B_4 (₹2.22) followed by I_3B_2 (₹2.14) treatment combination.

It could be concluded that the 3 irrigations along with boron @ 2 kg/ha or foliar spray @ 0.03% resulted in the highest grain and straw yields and proved superior in boron-deficient soil of Sub-Himalayan region of West Bengal.

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