Influence of Boron Application Methods on Morpho-physiological Attributes and Yield of Wheat (*Triticum aestivum* L.)

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Influence of Boron Application Methods on Morpho-physiological Attributes and Yield of Wheat (*Triticum aestivum* L.)

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Dedicated to My Beloved Parents

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CERTIFICATE

*This is to certify that the thesis entitled, "**Influence of Boron Application Methods on Morpho-physiological Attributes and Yield of Wheat (Triticum aestivum L.)**"submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN AGRICULTURAL BOTANY,** embodies the result of a piece of bonafide research work carried out by **UMMA MUSARRAT MISU**, Registration number 19-10055 under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that any help or source of information, received during the course of this investigation has duly been acknowledged.

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Influence of Boron Application Methods on Morpho-physiological Attributes and Yield of Wheat

(*Triticum aestivum* L.)

ABSTRACT

The experiment was carried out in a typical soil of Sher-e-Bangla Agricultural University, Dhaka, during the period from November 2019 to March 2020 to study the Influence of Boron Application Methods on Morpho-physiological Attributes and Yield of Wheat (*Triticum aestivum* L.). The experiment was laid out Randomized Complete Block Design (RCBD) with three replications. The treatments were T_0: Control, T_1: Soil application of 2 kg/ha B, T_2: Seed priming, T_3: Foliar spray at primordial stage, T_4: Foliar spray at booting stage, T_5: Foliar spray at primordial and booting stages, T_6: Foliar spray at grain filling stage. The rate of Boron for soil application was 2 kg/ha B from boric acid (17% B), the rate for each foliar spray was 0.4% boric acid solution and seed priming was done by soaking wheat seeds into 0.1% boric acid solution. Data were recorded on different growth, yield and yield contributing parameters. Most of the parameters showed significant difference among the treatments. Results indicated that the highest plant height (94.467 cm), maximum total no. of tiller hill^{-1} (3.7000), longest length of flag leaf (23.393 cm), highest breadth of flag leaf (2.6267cm), longest spike length (12.887 cm), maximum no. of total grain spike^{-1} (68.867), maximum no. of filled grain spike^{-1} (67.733), maximum spikelet fertility (%) (98.353), maximum thousand grain weight (52.667 g), maximum total Grain weight ha^{-1} (2.8945 t ha^{-1}), maximum straw yield (3.2611 t ha^{-1}) were found in T_5 treatment (Foliar spray at primordial and booting stages, 0.4% boric acid). Maximum leaf no. plant^{-1} (12.783) were found in T_1 treatment (Soil application of 2 kg/ha B). And, highest the SPAD value (51.063), no. of effective tillers plant^{-1} were (2.6667) found in T_6 treatment (Foliar spray at grain filling stage, 0.4% boric acid). Once more, the highest no. of in-effective tiller hill^{-1} (0.1733), un-filled grain spike^{-1} (2.1900) was recorded from T_0 treatment (Control).

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ACRONYMS

% =	Percent
@ =	At the rate
^0C =	Degree Centigrade
AEZ =	Agro-Ecological Zone
BARI =	Bangladesh Agricultural Research Institute
BBS =	Bangladesh Bureau of Statistics
BRRI =	Bangladesh Rice Research Institute
CIMMYT =	International Maize and Wheat Improvement Centre
cm =	Centimeter
DAPI =	4,6-diamidino-2-phenylindole
DAS =	Days after sowing
DNA =	Deoxyribonucleic acid
e.g. =	exempli gratia (for example)
et al. =	and others (*at elli*)
etc. =	et cetera (others and so forth)
FAO =	Food and Agriculture Organization
g =	gram (s)
i.e. =	id est (that is)
Kg =	Kilogram
Kg/ha =	Kilogram/hectare
LSD =	Least Significant Difference
m =	Meter
m.a.s.l =	Meters above sea level
MoA =	Ministry of Agriculture
MoP =	Muriate of potash
pH =	Hydrogen ion conc.
RCBD =	Randomized Complete Block Design
RNA =	Ribonucleic acid
SAU =	Sher-e-Bangla Agricultural University
SRDI =	Soil Resource Development Institute
t ha^{-1} =	ton per hectare
TSP =	Triple Superphosphate

Chapter I

INRODUCTION

CHAPTER I

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the most widely grown crop in the world, both in terms of area and productivity, and wheat is consumed by almost two-thirds of the world's population. Wheat is the most important grain crop in Bangladesh, followed by rice. (Fakir *et al.*, 2016). It is an annual plant in the Poales (Glumiflorae) order and Poaceae family. Wheat is one of the first domesticated crop plants, originated in the Middle East about 10,000 years ago and spread throughout the Old World (Lev-Yadun *et al.*, 2000). There are three levels of ploidy in the genus *Triticum*: diploid (2n=2x= 14), tetraploid (2n=4x =28), and hexaploid (2n=6x=42) (Provan *et al.*, 2004). Hexaploid bread or common wheat (*T. aestivum*), which is widely produced and utilized for human consumption, is one of the most important modern wheat cultivars among the various species of wheat. Tetraploid Durum wheat (*T. durum*), hexaploid Spelt wheat (*T. spelta*) and tetraploid (*T. polonicum)* are the others (Miller and Pike, 2002). Wheat is cultivated on one of the most land of any food crop (220.4 million hectares, 2014). Wheat trade is larger than that of all other crops combined. Wheat output was 772 million tonnes in 2017, with a prediction of 766 million tonnes in 2019, making it the second most-produced cereal after maize (FAO, (2014). The total area under wheat crop of FY (2019-20) has been estimated 3,32,274 hectors, that compared to 3,30,348 hectors of FY (2018-19). That is 0.58% higher than the previous year. Total production of wheat in FY (2019-20) has been estimated 10, 29,354 metric tons compared to 10,16,811 metric tons of the last FY (2018-19), which is 1.23% higher. Average yield rate of wheat has been in this year (2019-20) estimated 3.098metric tons per hector which is 0.65 % higher than that of last year (2018-19) (BBS, 2020).

Wheat has a higher protein level than the other major cereals, maize or rice, making it the most important source of vegetable protein in human food. The amount of rice produced in Bangladesh is insufficient to satisfy the country's hungry people. Furthermore, wheat provides for 15 to 20% of Bangladesh's staple cereal food, ranking it in second place among all the food crops in terms of relative importance (Rahman, 1980). The grains of wheat have high nutritive value containing 14.70%

protein, 2.14% fat, 78.10% starch and 2.10% mineral matter (Kumar *et al*., 2011). Seed quality, soil salinity, water logging, increased pricing, poor irrigation water management and distribution, and improper and inadequate usage of fertilizers supplied with no additional micronutrients are all issues that hamper higher production (Iftikhar *et al.*, 2010).

Many studies have showed that micronutrients have an important role in crop plant growth and development, resulting in higher quality and quantity agricultural produce. Micronutrients are known to play a role in photosynthesis, nitrogen fixation, respiration, and other biochemical processes. Micronutrients, according to Reddy (2004), aid in chlorophyll generation, nucleic acid synthesis, protein synthesis, and play an active role in various photosynthetic enzymatic activities.

Fertilizers are important to modern agricultural crop production system. It is important in maximizing the use of soils for efficient agricultural production. Inorganic fertilizers are now the key to increased crop productivity in Bangladesh agriculture. C, H, O, N, P, K, Ca, Mg, S, Fe, Cu, B, Mn, Mo, Zn, Cl are all necessary components for plants. Nine essential elements have been classed as "macronutrients" because they are required in relatively significant quantities by plants. C, H, O, N, P, K, C, Mg, and S are some of these elements. The remaining elements are known as "trace elements" and include B, Cu, Fe, Cl, Mn, Mo, and Zn (Alloway, 1990; Brady & Weil, 2002). Essential trace elements are commonly referred to as "micronutrients" since they are required by living organisms in minute but crucial concentrations. The role of micronutrients in crop nutrition was almost completely overlooked. Micronutrients, on the other hand, are necessary plant nutrients that play an important role in plant nutrition, resulting in healthy growth and enhanced production. The solubility of micronutrients, the pH and redox potential of the soil solution, and the type of binding sites on organic and inorganic particle surfaces all influence their availability in soils. Micronutrients help improve plant productivity, including leaf area and grain output, as well as the plant's enzymatic system. Micronutrients are components in plant metabolism that perform particular and important physiological functions (Marschner, 1995). Despite the fact that micronutrients are only required in minimal levels, their availability improves nutrient availability and has a positive impact on cell physiology, which is reflected in yield (Taiwo *et al.*, 2001; Adediran *et* *al.*, 2004). Micronutrient insufficiency has emerged as a major yield limiting problem, which can be primary (due to low total content) or secondary (related to soil conditions that affect plant access) (Sharma & Chaudhary, 2007). Because of rising economic and environmental concerns, the usage of micronutrients is especially critical (Siddiqui *et al.*, 2009). More to the point, the technique through which micronutrients are applied has an impact on crop growth and production. Micronutrients (Zn, Fe, B) considerably enhanced wheat yield over control, according to Chaudry *et al.*, (2007), while Chowdhury *et al.*, (2008) found that boron application (soil + foliar) was the best strategy for increasing wheat grain output.

As a result, providing micronutrients to plants, whether through soil application, foliar spray, or side dressing, improves crop quality and production (Malakouti, 2008). According to Arif *et al.*, (2006), foliar treatment of micronutrients at the tillering, jointing, and booting stages improves wheat production. Nutrient stresses on soils in Bangladesh are gradually growing as a result of high cropping intensity with high yielding crop types, loss of organic matter from the soil, and other factors. As a result, while the demand for micronutrients in soil is growing, the amount of different fertilizers utilized in the country is not evenly distributed. Due to the calcareous character of soils, high pH, low organic matter content, salt stress, continuous drought, high bicarbonate concentration in irrigation water, and uneven application of NPK fertilizers, micronutrient insufficiency is endemic in many Asian countries (Narimani *et al.*, 2010).

Boron is a micronutrient that is required in modest amounts for plant growth. Its deficit is significantly more common in crops grown in soil with a lot of free carbonates, little organic matter, and a high pH (Lindsay, 1991 and Rashid, 1996). Some sections of Bangladesh's soils are lacking in some micro elements, including boron. Boron is required for crop growth and productivity. It is absorbed as BO_3^- and is relatively mobile in plants. B is involved in carbohydrate metabolism and is needed for protein synthesis, pollen germination, seed and cell wall development, according to Vitosh *et al.* (1997). Boron is required for cell elongation, cell maturation, sugar translocation, the formation of meristematic tissues, protein synthesis, and the maturation of ribosomes in wheat plants (Mengel and Kirkby, 1987). According to Rehem *et al.* (1998), B is involved in the movement of water and nutrients from the root to the shoot. Boron deficiency, they believe, causes barren stalks and undersized, twisted ears, as well as a loss in grain yield due to defective anther development and, ultimately, seed failure. Boron promotes in the establishment of the root system, fruit set, and grain. With an increase in B supply, the majority of amino acids increase (Iqtidar and Rehman, 1984). However, there are a few findings from Bangladesh on the effects of boron in wheat (BINA, 1993; BARI, 1978).

Wheat, a globally grown crop, responds positively to B treatment in terms of growth and yield (Chakraborti and Barman, 2003; Soylu and Topal, 2004). Wheat's response to B in non-irrigated fields was observed in a Pakistani study (Chaudhry *et al.*, 2007). They also stated that the application of B increased wheat yield. Soils with little organic matter, coarse texture, high pH, prolonged dryness, intensive cultivation, low micronutrient content, and nutrient mining can all be converted to B deficient soils (Mengel and Kirkby, 2001; Niaz *et al.* 2007). Because wheat is grown all over the world, the deficit may be discovered in new and different places throughout time. It's important to look into how to fix them. According to Ahmad *et al.* (2012), addressing B deficiency in soils through external treatment can result in higher yields of high-quality crops. Sources, rates, formulations, and timing, as well as B application methods in soil/to plants, all affect crop production on B deficient soils. B application methods in the soil and/or foliar improve crop production, quality, content, and uptake of B (Ahmad *et al.*, 2012). In 1923, it was discovered that boron (B) is required for plant growth (Warington, 1923). B insufficiency is the most common micronutrient deficiency reported in the field (Gupta, 1979). Wheat (*Triticum aestivum* L.), like other cereals, has traditionally been thought to have a low requirement for B (Marten and Westermann, 1991). Some soils and crops have been shown to be deficient in boron (Jahiruddin *et al.*, 1991). Because boron's major role is cell wall production, a boron-deficient plant may be stunted. It has the possibility to trigger male sterility in wheat. Higher crop yields inherently have higher nutrient requirements due to more strain on the land for available forms of nutrients, and a deficiency of B causes grain set in wheat to fail. Crop growth and development are also hampered when it is inadequate. The use of these micronutrients results in improved crop growth and, as a result, higher crop yields (Torun *et al.*, 2001; Grewal *et al.*, 1997). Similarly, various investigations evaluating the response of wheat genotypes to boron treatment have been done, and a wide range of genotypic variation in response to B deficiency

(Rerkasem and Jamjod, 1999) and toxicity (Paul *et al.*, 1991) has been recorded. With the application of B to the crop, Jahiruddin *et al.* (1995), Abedin *et al.* (1994), and Rerkasem *et al.* (1989) were able to attain improved wheat yields. According to the research, wheat grain sterility is associated with a lack of certain micronutrients, particularly B (Mandal and Das, 1988, Rerkasem *et al.*, 1991 and Jahiruddin *et al.*, 1992). Boron insufficiency in rabi crops, particularly mustard, wheat, and chickpea, has been widely noted (Ahmed *et al.*, 1991; Jahiruddin *et al.*, 1995).

The application of macro and micronutrient fertilizer in the cultivation zone may not be sufficient to meet the crop's requirements for root growth and nutrient consumption. Alternatively, these micronutrients can be applied as foliar sprays (Arif *et al.*, 2006). To overcome micronutrient deficiency in subsoil, foliar spray of these micronutrients has been reported to be equally or even more effective than soil treatment (Ali *et al*,. 2009; Hussanin *et al*,. 2012). Foliar application of micronutrients increased grain yield components and protein percentage in seed in wheat, maize, rice, barley, and sorghum (Boorboori *et al.*, 2012).

With the view of the above aspects, the present research was undertaken with the following objectives:

1. To find out the effect of boron (B) on growth and yield of wheat.
2. To find out the appropriate methods of application of boron for better yield of wheat.

CHAPTER II

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

Wheat (*Triticum aestivum* L.) is considered as one of the main cereal crops in the world including Bangladesh. Wheat has contributed more calories and protein to the world's diet than any other food crop (Hanson *et al.*, 1982). A good number of research works have been done on this crop in different countries of the world. The yield of any crop like wheat is very closely related to the supply of plant nutrients. The role of macro and micronutrients are crucial in wheat production in order to achieve higher yields (Arif *et al.*, 2006). Micronutrients deficiency has become a major constraint for wheat productivity in many countries of the world. The deficiency of micronutrients may be due to their low total contents or decreasing availability of them by soil aggregate fixation (Jafarimoghadam, 2008; Ranjbar and Bahmaniar, 2007). Boron (B) is a necessary element for plants growth and development (Muntean, 2009). Its deficiency has been realized as the second most important micronutrient constraint in crops after that of zinc (Zn) on global scale (Ahmed *et al.*, 2009). It is required by plants in many metabolic processes, including plasma membrane stability, cell wall strength, nucleic acid metabolism, cell division, plant hormone synthesis, fruit and seed development, sugar synthesis, and transport (Brown *et al.*, 2002; Bassil & Brown, 2004; Oliveira *et al.*, 2006). Research into the constraints of wheat production in Bangladesh by wheat agronomists during 1988 to 1990 revealed that a host of natural as well as managerial factors are affecting wheat yield. The reduction in wheat yield is estimated at (a) 23–42% due to foliar diseases; (b) 8–16% due to soil pathogens; (c) 25–46% due to farmers' fertilizer doses 6 (which is lower than the recommended doses); (d) 2.1% and 33.7% due to lack of irrigation under high and the low fertility situations; and (e) late seeding at the rate of 1.3% per day of delay after November 30th (Ahmed and Meisner, 1996). This chapter presents a review of literature in relation to the effect of B on wheat. Each section has been started with a short description about occurrences, forms and functions of an element. However, the available literature, related to the topic has been presented below.

2.1 The function of Boron in plants

B is a member of metalloid family elements from Group IIIA of the periodic table and has properties intermediate between metals and non-metals. B atom has one less (three) valence electron. This property causes an electron deficiency that has a dominant effect on the behavior of B in chemical processes. Elements of this type usually have metallic bonding, however, the small size and high ionization energies of B lead to covalent rather than metallic bonding (Kot, 2009). B has unique property among elements with structural complexity of its allotropic modifications. Many organic compounds including B-O are known (Thompson, 1980; Bowser and Fehlner, 1989). There are also a binary B sulphides and B-sulphur anions. They might form chains, rings and networks (Greenwood and Earnshaw, 1997). Simple alcohols react with boric acid to give esters $B(OR)_3$. For instance, polyhydric alcohols form cyclic esters with boric acid (Steinberg, 1964).

Borates are mainly natural occurring form, however, less often form is boric acid and much more rarely one is BF^-_4 ion. The formation of $B(OH)_3$ interaction in aqueous solution is easily understood. $B(OH)_3$ is the main compound exists at physiological pH. It behaves as a weak Lewis acid (Ka $=6x10^{-10}$, pK_a 9.1) according to the equilibrium in Equation (1). Thus, boric acid mainly exists as the undissociated acid $B(OH)_3$ and low amount of borate anion $B(OH)^-_4$ in aqueous solution at physiological pH (Bolanos *et al.*, 2004).

$B(OH)_3+H_2O \leftrightarrow B(OH)^-_4+ H^+$ (1)

The essentiality of B for vascular plants was first shown in *Vicia faba* (Warington, 1923). Since that time, B has been established as an essential micronutrient for plant growth (Brown *et al.*, 2002).

Loomis and Durst (1992) suggest that apiose can be the key sugar moiety for borate-crosslinking complex from driselase-treated radish root cell walls. Furthermore, a correlation between pectin sugars and B content in cell walls of tobacco and squash was reported (Hu and Brown, 1994). Eventually, Kobayashi *et al.* (1996) purified the pectin fraction from cell walls of radish root and isolated the first B-containing pectic polysaccharide complex (rhamnogalacturonan II (RG-II)-B) from plants. They also demonstrated that removal of B from the RG-II-B complex lowered the molecular weight of the complex by half. RG-II is a complex polysaccharide of the pectic fraction of cell walls. Its apiose residue is responsible for binding of B to the polysaccharide chains. Fleischer *et al.* (1998) found that B deficiency rapidly increased cell wall pore size in suspension-cultured *Chenopodium album* L. cells.

Moreover, the larger pore size in B deficient cells correlated with dB-RG-II and after B-was supplied again, pore size was lowered (Fleischer, 1999). These results suggest that the formation of dB-RG-II also influences plant growth, metabolism and physiologically important processes such as cell wall modification.

Under B deficiencies, there are rapid changes in membrane function such as membrane transport processes and the composition of the cell membrane. Potassium uptake by plants does not occur in the absence of B (Schon *et al.*, 1991). Leakage of K^+ from sunflower (*Helianthus annuus*) leaves was 35 times higher in B-deficient than in control plants (Cakmak *et al.*, 1995). B is also stated to play an important role in phosphate transport across membranes (Loughman, 1977). Heyes *et al.* (1991) suggest that the membrane capacity is under the influence and probable control of the low levels of B in the cell due to B maintaining a preferred conformation of the active protein in the membrane.

Membrane potential measurements show that the proton gradient was affected by B (Blaser-Grill *et al.*, 1989). In fact, glycoprotein complexation with B at the membrane surface creates additional negative charges which can influence the electrostatics across the membrane. Beside the glycoproteins, both glycolipids in the bilayer, as well as transmembrane and surface glycoproteins (Alberts *et al.*, 1994), have oligosaccharide side chains capable of forming borate complexes. This interaction can change the membrane permeability, surface charge and rigidity.

In contrast to primary cell wall structure and membrane function, possible role of B in plant metabolism is still less well studied. In plants, B deficiency inhibits glucose-6-phosphate dehydrogenases, leading to increased production of phenols (Gomez-Rodriguez *et al.*, 1987; Heyes *et al.*, 1991). Borate is inhibitor for alcohol dehydrogenase (Weser, 1968; Smith and Johnson, 1976). These competitive inhibitions likely contain complexation with the ribityl hydroxyls of the coenzyme NAD (nicotinamide adenine dinucleotide), slowing its conversion to NADH. Blevins and Lukaszewski (1994) have demonstrated that boric acid inhibits allantoate amidohydrolase, a manganese-containing enzyme. Similarly, the activity of indolyacetic acid oxidase depended on B nutrition in squash root apices (Blevins and Lukaszewski, 1998).

B can be involved in a number of metabolic pathways due to the formation of complexes with a variety of hydroxylated molecules. Berger (1949) suggested that B plays an important role in the translocation of sugars. Shortly after, Gauch and Dugger (1953) showed that B speeds up the uptake and transport of sugars in normal versus B deficient plants. Eventually, Hu *et al.* (1997) characterized soluble sorbitol-B-sorbitol complexes from the floral nectar of peach and mannitol-B-mannitol complexes from phloem sap of celery as first identified B transport molecules. They suggest that the sugar or polyol transport molecules affect B movement in phloem.

The most plentiful form of B in soil solution is the soluble undissociated boric acid H_3BO_3. Plants take up B from soil in this chemical form. There are three different molecular mechanisms for B uptake by roots depending on B availability. These are passive diffusion across lipid bilayer, facilitated transport by major intrinsic protein (MIP) channel and an energy-dependent high affinity transport system by means of BOR transporters (Tanaka and Fujiwara, 2008).

Under normal and toxic B conditions, passive process that comprises mostly B diffusion across the lipid bilayer carries on the boric acid absorption in roots (Brown *et al.*, 2002; Tanaka and Fujiwara, 2008). In fact, the lipid permeability coefficient of boric acid was calculated theoretically (Raven, 1980) and experimentally from isolated membrane vesicles (Dordas *et al.*, 2000; Stangoulis *et al.*, 2001). As a result, it can pass membranes by a passive process in order to satisfy B requirement in plants (Brown *et al.*, 2002).

Recent studies state that B uptake might be performed by channels mediated membrane transport in addition to passive diffusion. Dordas *et al.* (2000) demonstrated that maize PIP1 (a member of the MIP family) expression in Xenopus laevis oocytes leading to an increase of B absorption. Lately, AtNIP5;1 has been identified as a novel boric acid channel in Arabidopsis that belongs to the nodulin 26-like intrinsic proteins (NIP) subfamily of the MIPs family (Takano *et al.*, 2006). The expression of AtNIP5;1 is up-regulated in roots under B-deficiency. Two independent T-DNA insertion lines of NIP5;1 showed lower biomass production and elevated sensitivity of root and shoot development to B limitation. These data suggests that it is crucial for B import into root cells under B deficiency (Takano *et al.*, 2006).

OsNIP3;1 has also been identified as a boric acid channel required for efficient growth under B limitation in rice (Hanaoka and Fujiwara, 2007).

When B has been absorbed by root cells, B must be loaded into xylem. An energy-dependent high-affinity transport system mediated by BOR transporters is mainly responsible for export B towards xylem under B-deficient conditions. BOR1 was identified as the first efflux-type boron transporters for xylem loading in Arabidopsis under B limiting conditions since the mutant plants showed a lowered transport of B to the shoot under B limitation (Takano *et al.*, 2002). Afterwards, another BOR-1 like gene has been identified in rice (OsBOR1). It has role in both xylem loading of B and its absorption into the root cells under B deficiency (Nakagawa *et al.*, 2007).

B is transported through vascular system to shoot tissue mediated by transpiration stream when B is into xylem (Raven, 1980; Shelp *et al.*, 1995). Also, B can be transported by phloem to reproductive and vegetative tissues (Shelp *et al.*, 1995; Matoh and Ochiai, 2005), though this capacity changes among species (Brown and Shelp, 1997). The formation of B-diol complexes is one of the suggested mechanisms for phloem transport of B (Brown and Hu, 1996; Hu *et al.*, 1997).

In fact, B can bind to cis-hydroxyl groups of sugar alcohols such as mannitol and sorbitol. This allows B to be transported through phloem. For example, B-polyol complexes were characterized from the phloem sap in Apium graveolens (Hu *et al.*, 1997). Additionally, it was shown that transgenic tobacco with elevated sorbitol levels had higher capacity to transport B by phloem and enhanced tolerance to B limitation (Bellaloui *et al.*, 1999; Brown *et al.*, 1999). However, B transport by means of phloem also occurs in plants that are not able to produce these types of complexes, especially to young tissues. Importantly, this translocation is not as efficient as phloem transport via sugar alcohols (Stangoulis *et al.*, 2001a; Takano *et al.*, 2001; Matoh and Ochiai, 2005). Still, the molecular mechanism that supports this type of transport remains unclear. Recently, Tanaka *et al.* (2008) identified a boric acid channel (NIP6;1) in Arabidopsis thaliana. They suggest that it is responsible for B transfer from xylem towards phloem in young shoot tissues under B limitation.

2.2 Role of Boron in wheat

Wheat is the universal cereal of the Old World agriculture and the world's foremost consumed crop plant followed by rice and maize (FAOSTAT, 2011). It is the most widely adapted crop, growing in diverse environments spanning from sea level to regions as high as 4570 m.a.s.l. in Tibet (Percival, 1921). It grows from the Arctic Circle to the equator, but most suitably at the latitude range of 30° and 60°N and 27° and 40°S (Nuttonson, 1955). A crop of wheat is harvested somewhere in the world during every month of the year (Briggle and Curtis, 1987).

Boron application has proved beneficial in increasing the yield of cereals like rice and wheat, oilseeds (rapeseed and mustard) owing to the beneficial effect of boron on reproductive growth of crops like importance of boron in promoting growth of pollen tube and there by establishing positive correlation between boron and number of flowers not aborted and fruit growth (ONiell et al., 2004).

Boron application in wheat has been observed to increase the yield because of the significant role of boron in reproductive growth (Anther, pollen and ovule development). Boron application is warranted in crops like wheat for improved yield, owing to limited phloem mobility (Cakmak, 1994). Grain un-filling in wheat can be overcome by boron application as normal ear fails to flower and development of inflorescence and setting of spikelets is restricted due to boron deficiency (Rerkasem and Jamjod, 2004). Fakir *et al*., (2016) registered significantly higher number of spikelets spike^{-1}, number of grains spike^{-1}, 1000 seed weight and grain yield after boron application.

Boron being vital for cell division, cell wall solidification, hormonal growth seed formation and sugar translocation plays an important role in terms of quantity of flowers and weight of seeds (Bolanos *et al*., 2004). An adequate supply of boron is pre requisite for maintaining the assimilate supply to the developing grains (Dixit *et al.*, 2002). Rani. P.S. and Latha (2017) found that addition of boron alone resulted an increase of 1.37t ha-1 over control owing to 45% increase in filled grains, highest among treatments.

Many of the developing countries that depend on wheat as a staple crop are not self-sufficient in wheat production, and accordingly, wheat is their single most important imported commodity. Wheat also accounts for the largest share of emergency food aid (Dixon *et al.*, 2009). Boron (B) is a micronutrient. It ranks second after zinc, as a micronutrient deficiency in Bangladesh. Boron plays a key role in pollen germination and pollen tube growth, stimulation of plasma membrane, anther development, floret fertility and seed development. 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. Boron is an important mineral nutrient stimulates a number of physiological processes in vascular plants. It is important for carbohydrate metabolism, translocation and development of cell wall and RNA metabolism (Marschner, 1995).

The wheat plants with male sterility and grain set failure due to B deficiency may at the same time actually have more tillers and greater weight of the straw. This seems to agree with a lower requirement of B for vegetative than reproductive growth. In addition to the greater functional requirement of B in anthers and carpel, sensitivity to B deficiency of reproductive development in wheat and other Triticeae cereals, may also be related to B supply to these organs during critical time (Subedi *et al.*, 1997 and Pant *et al.*, 1998).

Shorrocks (1997) noted that countries where B deficiency, based on responses to B application, in wheat has been reported included Bangladesh, Brazil, Bulgaria, China, Finland, India, Madagascar, Nepal, Pakistan, South Africa, Sweden, Tanzania, Thailand, USA, USSR, Yugoslavia, Zambia. Reports of B deficiency in wheat have also been reported from India (Singh *et al.*, 1976;; Mandal and Das, 1988 and Dwivedi *et al.*, 1990).

In many cases, B deficiency is at least partially responsible for the induction of floret sterility and low grain set and its impact may be exacerbated by environmental factors (Rawson, 1996 and Rerkasem, 1996).

2.3 Boron deficiency and its effect

Boron deficiency in field grown wheat was first observed almost concurrently on different sides of the world following the spread of semidwarf, ‘green revolution’ wheat in the 1960s. Grain set failure associated with male sterility was observed in wheat in Brazil in 1962 (Silva and Andrade, 1980). Diagnosis of B deficiency was confirmed by positive responses to B application. The same happened in Nepal in 1964, among introduced high yielding Mexican and Indian wheat germplasm (Misra *et al.*, 1992). Boron deficiency was found to be the cause of almost complete crop failure in some 40,000 ha of wheat in Heilongjian Province in the north of China in 1972 and 1973 (Li *et al.*, 1978).

Boron is relatively immobile in plant, and thus its availability is essential at all stages of growth, especially during maturity development. The deficiency of B has been reported to result in considerable yield reduction in various crops, like cereals (rice, corn, wheat), legume, oilseed and fruit trees (Sinha *et al.*, 1991; Borkakati & Takkar, 2000; Niaz *et al.*, 2007; Rashid *e.t al.*, 2005; Johnson *et al.*, 2005; Zia *et al.*, 2006). Rashid 2006, on the other hand, found that B fertilizer increased the yield of B-deficient crops.

Moreover, fertilizers are energy intensive to produce and are very expensive. The present price hike of fertilizers is one of the main constraints to increase the economic yield of crops. Thus efforts are needed to minimize its losses and to enhance its economic use. Foliar fertilization, that is nutrient supplementation through leaves, is an efficient technique of fertilization which enhances the availability of nutrients. It has been observed that utilization of fertilizers especially urea applied through soil is not as effective as when it is supplied to the plant through foliage along with soil application (Mosluh *et al.*, 1978).

Boron deficiency is more common in dry land crops, as in wheat (Jahiruddin, 2011). This is because of impaired transport of B from soil solution to absorbing root surface during dry season. Boron is involved in flowering, fruiting, and seed formation of crops (Ho, 1999). Boron deficiency can substantially reduce yield of wheat (Rerkasem B, 2004). Boron deficiency depresses wheat yield primarily through grain set failure, caused by male sterility which is associated with poorly developed pollen and anthers (Rerkasem, 2004). In fertilizer schedule an inclusion of B often decides the success and failure of the crops (Dwivedi *et al.*, 1990). Efficiency of B application depends on the time and method of B application. Boron can be applied to the soil, foliar sprayed or added as seed treatments. Foliar application is done at later stages of crop growth when crop stands are already established; this method of B application has been found more effective in yield improvement and grain enrichment (Johnson, *et al.*, 2005).

Boron (B) was shown to be essential to plant growth in 1923 (Warington, 1923). Among the micronutrients, deficiency of B is the most frequently encountered in the field (Gupta, 1979). However, along with other cereals, wheat (*Triticum aestivum* L.) has generally been considered to have a low requirement for B (Marten and Westermann, 1991). Lack of reports of deficiency in wheat and other small grains from areas such as the USA where B deficiency is widespread in other crop species (Lamb, 1967) further reinforced the perception of wheat being relatively free of B deficiency problems. Boron deficiency in field grown wheat was first observed almost concurrently on different sides of the world following the spread of semidwarf, 'green revolution' wheat in the 1960s. Grain set failure associated with male sterility was observed in wheat in Brazil in 1962 (Silva and Andrade, 1980). Diagnosis of B deficiency was confirmed by positive responses to B application. The same happened in Nepal in 1964, among introduced high yielding Mexican and Indian wheat germplasm (Misra *et al.*, 1992). Boron deficiency was found to be the cause of almost complete crop failure in some 40,000 ha of wheat in Heilongjian Province in the north of China in 1972 and 1973 (Li *et al.*, 1978).

Countries where B deficiency, based on responses to B application, in wheat has been reported included Bangladesh, Brazil, Bulgaria, China, Finland, India, Madagascar, Nepal, Pakistan, South Africa, Sweden, Tanzania, Thailand, USA, USSR, Yugoslavia, Zambia (Shorrocks, 1997). Reports of B deficiency in wheat continue to come out of India (Singh *et al.*, 1976; Ganguly, 1979; Sarkar and Chakraborty, 1980; Mandal and Das, 1988; Dwivedi *et al.*, 1990). Most of these were from the northeastern states of Bihar, West Bengal, Orissa, Meghalaya and Assam. It was already common local knowledge in the 1980s that the problem does not stop at the international borders, but extends into neighboring areas of Bangladesh and Nepal (Reuter, 1987). ''Wheat sterility'', the term associated with depressed percentage of florets with grain, has been reported from many parts of Nepal, with B deficiency, low temperature stress during reproductive development (Subedi, 1992), water logging at flowering, low soil nitrogen and hot dry wind (Misra *et al.*, 1992) suggested as possible causes. An imprecise way in which the term ''sterility'' is used may sometimes lead to inaccurate diagnosis of the causal factor. Except at higher altitudes, responses to B application have identified B deficiency as the cause of grain set failure in wheat in Nepal (Sthapit, 1988; Subedi, 1992). Boron deficiency was also found to be the cause of massive sterility observed in the northern wheat zone of Bangladesh. Application of B increased wheat yield in farmers' field by 8.5– 14% (equivalent to approximately 60% of the yield gains due to plant breeding in the past 20 years; D.A. Saunders, pers. comm.). Recent studies have confirmed widespread problem of B deficiency in wheat in this part of Asia (Kataki *et al.,* 2002).

The adjoining areas of India, Nepal and Bangladesh is probably the world's most extensive area of B deficient wheat so far reported, covering at least several hundred thousand hectares. The problem of B deficiency affects wheat farmers of the area, who are some the world's poorest, in two ways. Firstly, they continue to suffer grain set failure and yield loss each year. Secondly, they are prevented from realizing benefits from new improved wheat varieties with greater yield potential and better resistance to important diseases, since these varieties turned out to be poorly adapted to low B soils. Boron deficient wheat has also been found in northern Thailand (Rerkasem *et al.,* 1989) and southwestern China to the Myanmar border (Yang, 1992; Rerkasem, 1996). Anyone attempting to improve wheat production in Myanmar should keep a close watch on B deficiency especially with introduced germplasm of semi-dwarf wheat from CIMMYT (Rerkasem *et al.*, 2004).

The most rapid response to B deficiency in higher plants is the cessation of root elongation (Dugger, 1983; Shelp, 1993; Marschner, 1995; Dell and Huang, 1997), but this has rarely been seen in wheat. Boron deficiency in early vegetative growth is much less readily inducible in wheat than in dicotyledons. For example, Snowball and Robson (1983) found that after a transfer to a solution culture to which no B had been added wheat root continued growing normally for a considerable time, while root growth in subterranean clover (*Trifolium subterraneum* L.) stopped immediately. In most of these earlier studies, B deficiency was induced in vegetative growth in wheat only after B in the nutrient solution had been depleted by plant uptake. Characteristic symptoms in young wheat plants made B deficient in this way include longitudinal splitting of the newer leaves close to the midrib and the development of a saw tooth effect on the margins of young leaves reflecting abnormal cellular development (Snowball and Robson, 1983).

Other evidence of lower requirement for B and lower sensitivity to B deficiency in wheat has all been based on early vegetative growth. A comparative study of early vegetative growth at 30 days from germination has shown wheat to grow almost normally in a nutrient solution without added B in which various legumes were adversely affected by B deficiency (Chapman *et al.*, 1997). Similarly, the lower external and internal requirement for B in wheat than sunflower (*Helianthus annuus*) and marri (*Corymbia calophylla*) were judged on the basis of early vegetative growth of 10–20 days (Asad *et al.*, 2001). The young wheat plants grew well and were free of B deficiency symptoms in a nutrient solution with 0.13 mM B in which vegetative growth of the two dicotyledons, marri and sunflower, was severely depressed by B deficiency. Dry weight of both marri and sunflower was depressed by B deficiency with <1.2 μM Bin the nutrient solution. The difference between wheat and the two dicotyledons was even greater in the B concentration in the young open leaf associated with maximum growth, referred to as internal requirement by the authors. Ten day old wheat achieved maximum dry weight with ≥1.2 mg B kg^{-1} DW, whereas marri and sunflower did not until they had exceeded 18–20 mg B kg^{-1} DW. The lower B requirement in graminaceous species than dicotyledonous species is said to be related to their different cell wall composition (Marschner, 1995). Their shoots have been shown to contain 4–7 mg B kg^{-1} cell wall (CW) compared with 20–40 mg B kg^{-1} CW in dicotyledonous plants (Matoh, 1997).

These early vegetative responses to B in wheat, however, may or may not correlate with whole plant responses. None of the effects of low B on early vegetative growth cited above has ever been observed in the field. An exception is the longitudinal split along the midrib observed in solution culture (Snowball and Robson, 1983), commonly seen the field in Thailand, Bangladesh and Nepal.

The first symptom of B deficiency in field grown wheat is seen during anthesis, when florets remain open longer than normal. When viewed from a distance of 3–4 m against the sun, the ears have a translucent appearance, like paper lamps. Examination of the florets just before or during anthesis shows poorly developed pollen and sometimes anthers, leading to the association between male sterility and B deficiency (Li *et al.*, 1978; Silva and Andrade, 1983; Rerkasem *et al.*, 1989). A simple staining with iodine (in a KI/I2 solution) may be used for pollen examination (Cheng *et al.*, 1992). Dead pollen shows up misshapen, shriveled and unstained by iodine. However, pollen with starch deposits that stain blue black with iodine is not always viable. A more precise assessment of pollen viability may be made with a fluorochromatic (FCR) test or staining with 40, 6-diamidino-2-phenylindole2HCl (DAPI). Pollen that exhibited an adverse effect of B deficiency as a 30–70% depression in viability by the FCR test was indistinguishable from B sufficient pollen by the iodine stain (NaChiangmai *et al.*, 2002). The adverse effect of B deficiency on pollen viability was also shown in the absence of one or more of the nuclei by the DAPI test. In addition to male fertility, B deficiency has also been shown to depress pollen germination and so the fertilization process (Cheng and Rerkasem, 1993). Grain set was partially restored when B deficient female wheat flowers were fertilized with B sufficient pollen (Rerkasem *et al.*, 1993) and further enhanced by an application of B solution to the stigma (Rerkasem and Jamjod, 1997a). An increase in grain set in B deficient plants by hand pollinating with fertile pollen confirmed that male sterility is the primary effect of B deficiency on grain set in wheat (Rerkasem *et al.*, 1993).

Anthers and carpel account for a much larger proportion of B content of the ear of wheat relative to their dry weight (Rerkasem and Lordkaew, 1996). Wheat anthers and carpel contain several times the B concentration of the whole ear. Grain set failure was associated with less than 10 mg B/k (Rerkasem *et al.*, 1997). In contrast, the critical B deficiency concentration for vegetative growth in wheat has been estimated at 1 mg B/kg (Huang *et al.*, 1996; Asad *et al.*, 2001).

At present it is still unclear what function B is required for in the development of anthers, pollen and carpel that is different from that for somatic tissues including the secondary sexual part of the ear such as rachis, glumes and lemmas. Anthers with lower B contents appeared to have a normal tapetum and lignified endothecium (Rerkasem *et al.*, 1997). These were different from Cu deficient anthers, with their amoeboid tapetal cells (Jewell *et al.*, 1988) and absent lignification of the endothecium (Dell, 1981). Pollen abortion in field grown plants has been found to take place sometime after uninucleate vacuolar stage, microsporogenesis in B deficient wheat having proceeded normally prior to this (Rerkasem *et al.*, 1997). This suggests the B requirement for the later stage of pollen development after meiotic and at least the earlier stage of mitotic cell division had occurred. Others have suggested the critical phase during the late tetrad to young microspore stages (Huang *et al.*, 2001). These authors also showed that B withdrawal during mitosis II had an adverse effect on pollen viability. The transient nature of the critical phase coupled with the more precise control of B supply in solution culture may account for any differences between field and glasshouse observations.

To understand whole plant response to a nutrient deficiency, and thus to apply the understanding to field grown, commercial crops, it is necessary to consider responses of different growth processes in relation to one another as well as the response of individual processes. The relationship may be in the chronological order in which the processes occur in the life cycle of the plant and in their relative sensitivity to the deficiency. Irreversible adverse effects that occur earlier may over-ride effects on more sensitive processes or organs that occur later. Boron deficiency causes flower buds to shed in some species, e.g. in apple (*Malus domestica*) (Dong *et al.*, 1997); black gram (*Vigna mungo* L). Hepper); (Noppakoonwong *et al.*, 1997) and sunflower (Blamey *et al.*, 1987). In such cases it may be of little consequence that the development of the male and female gametes are more sensitive to B deficiency if the flower buds had been lost even before meiosis. On the other hand, a greater sensitivity of the development of the stamen or carpel or the fertilization process may make one of them the limiting step if the B deficiency is not severe enough to cause prior irreversible damage.

A key to understanding B deficiency in wheat appears to be the relative sensitivity of its reproductive process. Published accounts of responses to low B in field grown wheat invariably reported on the effect of B deficiency on male fertility, grain set and grain yield. Evidence of adverse effects of low B on vegetative parameters such as straw yield, tiller number, and secondary reproductive organs such as number of spikelets per ear is rare. In contrast to the effect on male fertility and grain set, B deficiency tended to increase the weight of individual grains. The adverse effects of B deficiency on male fertility have also been reported in barley (*Hordeum vulgare* L.), durum wheat (*Triticum durum* Dest.) and triticale (x*Triticosecale Wittmack*) (Jamjod and Rerkasem, 1999; Rerkasem *et al.*, 2004). In barley and triticale, there are also additional effects on degeneration of terminal spikelets, which give the ear the ‘rat-tail’ symptom and fewer spikelets per ear (Wongmo *et al.*, 2004). In the case of barley, B deficiency may also delay ear emergence by its effect on development following the induction of the floral primordia (Phasook, 2001).

In wheat (Subedi *et al.*, 1997; Pant *et al.*, 1998), along with barley (Ambak and Tadano, 1991; Jamjod and Rerkasem, 1999), plants with male sterility and grain set failure due to B deficiency may at the same time actually have more tillers and greater weight of the straw. This seems to agree with a lower requirement for B for vegetative than reproductive growth. In addition to the greater functional requirement for B in the anthers and carpel as discussed above, sensitivity to B deficiency of reproductive development in wheat, and the other Triticeae cereals, may also be related to B supply to these organs during critical times. Boron is transported from plant roots via the xylem, driven by water potential gradient created by transpiration. The site of the reproductive process most sensitive to B deficiency in wheat along with barley, durum and triticale is in the non-transpiring ear, while it develops inside the leaf sheath. The effect of B deficiency on male fertility in wheat may therefore be expected to operate through interrupted supply of B for anthers and pollen development. On the other hand, it is as yet unclear how wheat avoids the effect of B deficiency on terminal spikelets development that causes the rat-tail symptom and depression in the number of spikelets per ear in barley and triticale.

The occurrence of wheat sterility in farmer's field in Nepal (Sthapit, 1988; Misra *et al.*, 1992; Tiwari, 1996) and Bangladesh (Saifuzzaman and Meisner, 1996) has often been reported to be highly variable. Confirmation of B deficiency as the cause, however, has sometimes been hindered by imprecise definition of ''sterility''. Percentage of florets without grain measures the combined success of two different processes, florets development (photosynthetic capacity) and fertilization (grain set). Boron deficiency, on the other hand, specifically affects grain set only. Unless there is a B sufficiency control, grain set failure is more precisely measured with the grain set index (GSI). The GSI is defined as the percentage grain bearing in two basal florets of 10 central spikelets (Rerkasem and Loneragan, 1994). Among florets of a wheat spikelet, the two basal florets are the first to develop, while development of terminal florets is dependent on the supply of photosynthate. The absence of a grain in either or both of the basal florets of a spikelet is therefore indicative of grain set failure. Focusing on central spikelets removes the possibility of a confounding effect of incompletely developed basal and terminal spikelets. Without the need for a B sufficiency control, the GSI is very useful to evaluate responses to low B in nurseries with large entry numbers (Rerkasem and Jamjod, 1997a; Anantawiroon *et al.*, 1997).

The extent of B deficiency in the screening environment may be indicated by inclusion of a set of check genotypes covering a range of responses to low B. The GSI is also useful to quantify the problem of grain set failure in wheat, triticale and barley under a wide range of on-farm environmental conditions. The presence of common varieties with known susceptibility to B deficiency allows verification of B deficiency as the likely limiting factor. Depression in grain set may be compensated for by an increase in the weight of individual grains (Rerkasem and Loneragan, 1994; Subedi *et al.*, 1997; Pant *et al.*, 1998). Wheat grain yield is therefore sometimes not as sensitive to B deficiency as grain set.

2.4 Application of Boron

Muhmood *et al*., (2014) conducted a field experiment to determine the effect of boron on seed germination, seedling vigor and wheat yield. The experimental treatment consisted of five treatments viz. recommended dose (RD) of NPK (control), RD of NPK + 0.5 kg ha-1 B, RD of NPK + 1.0 kg ha^{-1} B, RD of NPK + 1.5 kg ha^{-1} B and RD of NPK + 2.0 kg ha^{-1} B were used; randomized complete block design with three replications. The results showed that boron had no effect on yield components, except, grain per spike and 1000 grain weight which were improved significantly with its application. Wheat leaf B content increased with B application. Maximum grain and straw yield (4.85 and 9.16 Mg ha^{-1}, respectively) was recorded with 2.0 kg B ha^{-1} along with recommended dose of NPK. Boron had no effect on seed germination; however, seedling vigor i.e. shoot and root length improved with B application.

Boron can be used both by soil application as well as foliar feeding. Foliar applied B is believed to retain significant phloem mobility to flowering meristems from either senescing leaves and/or bark. Thus, foliar sprays of B provide not only a means to apply B at a particular growth stage, but it also permits a rapidly-acting remedial action soon after the deficiency diagnosis (Rashid *et al.*, 2004).

Dunn and Jones (2001) reported an increase in rice yield of Kaybonnett variety when fertilized with B (soil or foliar) application. All B applications increased rice yields over the untreated check. In 1999, the foliar applications produced higher yields than soil applied boron. The average for all four B treatments in an application type was also greater in the foliar application during the first year of project. In 2000, the soil application produced greater rice yield. The two year average, however, showed the soil applications produced greater yields for the same boron application rate. The 0.5lb B/a for both soil and foliar applications (170 bu/a) showed the greatest increase compared to the untreated check (145 bu/a).

A greenhouse experiment was conducted in North-west India to study the effect of soil applied boron on yield of berseem (*Trifolium alexandrium* L.) and soil boron fractions in boron deficient calcareous soils. Three soils with varying calcium carbonate content viz. 0.75% (Soil I), 2.6% (Soil II), and 5.7% (Soil III) were collected from different sites of Ludhiana, Bathinda, and Shri Muktsar Sahib districts, Punjab, India. The treatments consisted of six levels of soil applied boron viz. 0.5, 0.75, 1.0, 1.25, 1.5, and 2.0 mg B kg^{-1} along with control. The green fodder yield and dry matter yield increased significantly at 0.75 mg B kg^{-1} soil treatment level in the first cutting, while these were significant at 1.0 mg B kg^{-1} soil treatment level in all soils at second, third, and fourth cuttings. Among all three calcareous soils, Soil I with lower calcium carbonate was the best soil in respect of mean yield in comparison to Soil II and Soil III. Combined effect of boron level and soils had significant effect on yield of berseem. There was a significant increase in mean dry root biomass at 1.0 mg B kg^{-1} soil level over control and then remained non-significant with further high levels of soil applied boron. The mean dry root biomass decreased significantly for the soils having 0.75%, 2.6%, and 5.7% calcium carbonate levels. Readily soluble fraction is considered to be easily available fraction of B for plant uptake and consisted of 0.47–0.62% in Soil I, 0.31–0.43% in Soil II, and 0.24–0.34% in Soil III of the total boron. Among all B fractions, mean readily soluble, specifically adsorbed, and oxide-bound fractions got increased significantly with increase in B levels. Readily soluble and organically bound B fractions were more in Soil I as compared to Soil II and Soil III. Specifically adsorbed boron, oxide bound fraction, residual and total boron were more in Soil III in comparison to Soil I and Soil II. Among all fractions, residual fraction accounted for the major portion of the total B. It comprised of 92.71–93.90% in Soil I, 94.51–95.40% in Soil II, and 94.91–95.25% in Soil III of the total boron. (Sidhu, & Kumar, 2018).

The study was conducted in field experimental area of the Directorate of Land Reclamation, Canal Bank Moghalpura, Lahore to evaluate the effect of foliar application of boron (B) on yield and yield components of wheat in a calcareous soil.

Randomized Complete Block Design (RCBD) was used for four B foliar application rates (0, 10.0, 20.0 and 30.0 mg/L) in three replications. The results showed that effect of B was significant on grain yield, number of grains spike-1 and 1000 grain weight. The highest grain yield of wheat (6.5 ton h^{-1}) was observed when 10 mg/L B was applied. Application of 20 mg/L B resulted in a significant decline in wheat grain yield (4.7 ton h^{-1}). The detrimental effects of the highest B application on yield components were also observed. The decline in the quantity and quality yields of with increasing B might be due to the toxicity effect of higher concentration of foliar application. (Raza *et al.*, 2014).

Foliar fertilization or foliar feeding is one of the most important methods of fertilizer application, In agriculture practices fertilizer because foliar nutrients facilitate easy and quick consumption of nutrients by penetrating the stomata or leaf cuticle and enters the cells. Foliar application of Boron single or shared with other micronutrients had positive effect on growth, yield and yield parameters of wheat crop. In optimizing fertilization strategies, addition of foliar application develops fertilizer use efficiency and reduces soil pollution. Foliar application of Boron single or shared with other micronutrients at different growth stages have been shown to be effective in efficient consumption of Boron by wheat and thus increase grain sitting and increase the grain yield, number of grains per spike, number of spikelet per spike and thousand grain weight. (Rawashdeh & Sala, 2014).

Generally, wheat productivity severely affected due to imbalanced fertilizer application, and on other hand NPB are 100%, 90% and 55% deficient in Pakistani soils as well as K deficiency appears rapidly. Therefore appropriate nutrient management is essentially required to obtain economic wheat yield. A field experiment was carried out at Student's Experimental Farm, Department of Agronomy, Sindh Agriculture University Tandojam, during 2014-15. The trial was arranged on randomized complete block design, replicated thrice and treatments included: Control (untreated), NPK= 90:60:60 kg ha^{-1}, NPK = 90-30-30 kg ha^{-1} + B: 1% (tillering), NPK = 120:60:60 kg ha^{-1} + B: 1% (tillering), NPK = 90:30:30 kg ha^{-1} + B: 2% (tillering), NPK = 120:60:60 kg ha^{-1} + B: 2% (tillering).The statistical analysis of data proved that various combinations of NPK and boron application displayed significant ($P<0.05$) effects on nearly all the growth and yield components of wheat. Thus, maximum plant height 86.7, more tillers 418.0 m^2, increased spike length 11.6 cm, grains spike^{-1} 51.0 and 49.0, grain weight plant^{-1} 7.9 g, seed index (1000 grain weight) 41.7 g, biological yield 9131.7 kg ha^{-1}, grain yield 3880.0 kg ha^{-1} and harvest index 42.5 were noted at NPK-120-60-60 kg ha^{-1} + B 2% at tillering phase, Whereas, all growth and yield parameters were measured poor under control (un-treated) plots. Hence, it was decided from the results that use of NPK = 120:60:60 kg ha^{-1} and 2% foliar application of boron at tillering stage proved better as compared to other treatments. (Leghari *et al.*, 2016).

2.5 Effect of Boron on growth and yield

Among the micronutrient elements boron is the only non-metal which is required for a number of growth processes such as (i) new cell development in meristematic tissue, (ii) proper pollination and fruit or seed weight, (iii) translocation of sugars, starches, nitrogen and phosphorus and (iv) synthesis of amino acids and proteins, articulated by Tisdale *e.t al*. (1997).

Rashid *et al.* (2011) reported B deficiency in rainfed wheat in Pakistan. They reported a B deficiency incidence and spatial distribution in rainfed wheat (*Triticum aestivum* L.) in 1.82 Mha Pothohar plateau in Pakistan, its relationship with soil types, crop responses to B, and internal B requirement and B fertilizer use efficiency of wheat. Plant and soil analyses indicated deficiency in 64% of the 61 sample fields; geostatistics aided contour maps delineated B deficient areas. In rainfed field experiments, B use increased wheat yields up to 11%. Fertilizer requirement was 1.2 kg B ha^{-1}.

Ahmad *et al*. (2011) conducted an experiment on the effect of B application time on the yield of wheat, rice and cotton crop in Pakistan. The results revealed that B application at sowing time to wheat increased significantly the number of tillers plant^{-1} (15%), number of grains spike^{-1} (11%), 1000 grain weight (7%) and grain yield (10%) over control. Among the treatments, B application at sowing time showed the best results followed by B application at the 1st irrigation and at booting stage.

Sultana (2010) carried out an experiment at BAU farm, Mymensingh to see the effect of foliar application of B on wheat. Boron application exerted significant influence on the yield and grain set of wheat. In a field experiment at BAU farm, Mymensingh observed that grain yield was significantly influenced by different rates of B.

Schnurbusch *et al.* (2010) determined B toxicity tolerance in wheat and barley. In barley, they have identified genes controlling B toxicity tolerance at two of the four known B toxicity tolerance loci, both of which encode B transporters Emon *et al.* (2010) conducted a study on molecular marker-based characterization and genetic diversity of wheat genotypes in relation to B use efficiency. The study found that INIA 66 and BAW1086 were the most B efficient genotypes and thus could be used for developing B efficient varieties.

Alloway (2008) found Boron deficiency is the second most widespread micronutrient problem. Whenever the supply of boron is inadequate, yields will be reduced and the quality of crop products is impaired, but susceptibility varies considerably with crop species and cultivars.

Ahmed *et al.* (2008) studied two pot experiments to investigate the effect of spraying silicon (0, 250 and 1000ppm SiO_2) and/or B. They showed that both silicon levels either alone or combined with B significantly increased shoot height and leaf area as well as grain yield/plant and weight of 1000 grains.

Halder *et al*. (2007) carried out a field trial during rabi season in Calcareous Brown Floodplain Soils of Regional Agriculture Research Station (RARS), Jessore in Bangladesh with the objective of evaluating the response of wheat varieties to different levels of B and to determine the optimum dose of B for maximizing yield of wheat cultivars Protiva, Gourab and Sourav. They observed that Protiva along with 2 kg B ha^{-1} produced significantly the highest yield in both the years with the highest mean grain yield (5.3 t ha^{-1}) by 66% increase over B control.

Rahmatullah *et al*. (2006) studied out a field experiment during 2004-05 in Pakistan to investigate the effect of B application (@ 0, 1 and 2 kg ha^{-1}) on wheat system. Boron application significantly affected wheat grain yield that ranged from 2.70 to 3.49 t ha^{-1}, recording the highest increase of 19.9% over the control from 1 kg ha^{-1}. The number of tillers m^{-2}, spikes m^{-2}, spike length, plant height and 1000-grain weight of wheat also differed significantly from control for B treatment.

Ghatak *et al*. (2006) reported the effect of B on yield, and grain concentration and uptake of N, P and K of wheat in red and laterite soils of West Bengal. Application of 15 to 20 kg borax ha^{-1} recorded higher values of yield attributes and yield. The increase in grain yield over control was 4.5 to 7.7 percent. The optimum dose of borax was 14 kg ha^{-1} during the first year and 10.4 kg ha^{-1} in the second year. Thus, a dose of 10 to 15 kg borax/ha may be beneficial for higher production of wheat in this region.

Jolanta Korzenniows (2006) demonstrated a field trial, involving foliar application of B to evaluate the effect of foliar spray of B on different cultivars of wheat. Foliar fertilization treatments caused a significant grain yield increase of four out of ten winter wheat cultivars. The average yield increment ranged between 9 and 15%.

Wrobel *et al*. (2006) analyzed a pot experiment in Poland, to investigate the effect of B fertilizer application on spring wheat grown in light soil, deficient in B and subjected to periodic drought stress. Application of B fertilizer increased the grain and straw yields of spring wheat. This study demonstrated that B was able to mitigate drought effects, and its application to soil during tillering stage improved the parameters of the main yield components, thus increasing yield level and enriching the chemical composition of wheat grain.

Mete *et al*. (2005) stated that the plant height was significantly increased with the application of B and lime whether singly or in combination.

Bhatta *et al*. (2005) found that application of B fertilizer to the soil at sowing had a significant positive effect on the number of grains per spike, reduction of sterility and grain yield of wheat.

Gunes *et al*. (2003) conducted a one year (2000-01) field study during the cropping season on the effect of B on yield and some yield components of bread (*Triticum aestivum* cv. Bezostaia) and durum wheat. (*T. durum* cv. Kiziltan) cultivars in B-deficient soil (0.68 mg kg, NH_4OAC-extractable). Boron was applied to soil as H_3BO_3 at 0, 0.5, 1.0, 1.5, 2.0 and 2.5 mg ha^{-1} in the greenhouse, and 0, 1.0, 2.0, 3.0, 4.0 and 5.0 kg ha^{-1} in the field. In the field, the grain yield increased from 3668 to 5475 kg ha-1 at 4.0 kg B ha^{-1} in Bezoslaja and from 4668 to 4360 kg ha^{-1} at 2.0 kg B ha^{-1} in Kizillan. At higher B levels, the grain yield of the cultivars decreased. The results show that B fertilizer application should be considered in fertilizer recommendations after additional research under different soil, genotype and environmental conditions.

Kataki *et al*. (2001) observed that the soil application of B at sowing reduced sterility by more than 50% and doubled wheat yield by increasing grain set.

El-Magid *et al*. (2000) conducted an experiment on clay soil in Egypt during 1990-99 and 1999-2000 to investigate the effect of micronutrient spraying during jointing stage, 45 days after emergence. The treatments were: control; B as boric acid at 0.06%; Cu as EDTANA-Cu at 0.10%; Zn EDTANA-Zn at 0.10%; Mn as EDTANA-Mn at 0.10% and Fe as EDTANA-Fe at 0.10%. Spraying with Fe, Zn, Mn or B increased shoot height, while Cu had little effect on this parameter. The nutrients increased the number of tillers per plant and shoot weight. Elements Fe, Cu, Zn and Mn increased grain and straw yields, while B increased only the straw yield. Zinc, Mn or Fe increased N concentrations from 17.15 mg/100 g in the control to 17.61, 17.32 and 17.28 mg/100 g, respectively, while Cu and B reduced B content. Zinc, Mn, B, Fe and Cu increased plant P and K contents.

Islam *et al*. (1999) conducted a field experiment in 1992/93 on alluvial soils in Bangladesh, with wheat cv. Kanchan giving 20 kg S ha^{-1} , 4 kg Zn ha^{-1} and 2 kg B ha^{-1} , singly and in all possible combinations. Grain yield and yield component values generally increased by application of S, Zn and B. Sulphur had the greatest effect on grain yield, followed by B and Zn. Application of three elements together (S+ Zn+ B) produced the highest grain yield. Application of each element increased the plant content of that element.

Hossain *et al*. (1997) carried out an experiment to evaluate the performance of wheat cv. Kanchan, Aghrani and Akbar with and without application of B. Yield was highest in cv. Kanchan and was increased by B applied @ 2 kg/ha.

Rawson (1996) observed from reciprocal transfers of wheat plants between adequate and zero B root media at different development stages, that the period during which florets 27 are sterilized by B insufficiency can be very short. It was shown that spikes could also be sterilized by enclosing the whole plant in a clear plastic bag during the critical period, even though the plants were growing with adequate B provided in sub-irrigated gravel culture. It was observed that one of the effects of enclosure is to prevent transpiration and possibly the associated uptake and movement of B to the reproductive growth centers. It appeared that a prior period in adequate B had different effect on sterility amongst genotypes. One genotype (Fang 60) showed evidence of a B reserve that could be utilized even after a period equivalent to 3 phyllochrons whereas others appeared to have no B pool. Spikes which were fully sterilized by inadequate B could have their fertility raised marginally by a spray of boric acid even several days after they had emerged.

Jahiruddin *et al*. (1995) determined three identical field experiments to examine the effect of B on grain set, yield and some other parameters of wheat cultivars grown in Old Brahmaputra Floodplain soils. The varieties were Aghrani, Kanchan and Sonalika. They found that B had a marked positive influence on grain set and yield. The results also varied between varieties and between locations. In general, Kanchan variety and B @ 3 kg ha^{-1} did the best. It was apparent that grain yield of wheat was highly dependent on the number of grains per spike.

Subedi *et al*. (1995) demonstrated the effect of sowing time and B application on sterility in four different genotypes of wheat. They showed that added B had a significant effect on the number of grains $spike^{-1}$, spikelets $spike^{-1}$, sterility, 1000 seed weight and boron content in the flag leaf at anthesis but not on the grain yield. However, there were significant interactions between boron and genotypes for the number of grains per spike and sterility, because varieties susceptible to B deficiency (SW-41 and BL-1022) showed response to added boron for sterility but BL-1249 and Fang-6 were not affected by B application.

Hossain *et al*. (1994) carried out a fertilizer trial on Old Brahmaputra Floodplain soil at Jamalpur during winter season of 1992-93 to see the response of wheat to S, Zn, B and Mo. It appeared that the grain yield was significantly influenced by the fertilizer 28 treatments. The treatment containing S, Zn, B and Mo together produced the highest yield (3632 kg ha^{-1}) and the control receiving none of them recorded the lowest (2361 kg/ha). As regards to the contribution of individual elements, performance of B was prominent.

Abedin *et al*. (1994) from a field trial at BAU farm, Mymensingh stated that soil application of B @ 4 kg ha^{-1} and the foliar spray at tillering plus booting stages of crop increased 19% grain yield over control. There was no variation in grain yield between the varieties used. The results indicated that the grain yield of wheat was depressed mainly by poor number of grains $spike^{-1}$ which resulted from male sterility induced by B deficiency. The N and B contents in grain were found to be increased by soil application of B but not by foliar spray of B.

Mandal (1993) opined that pollen of B resistant genotype germinated on the stigmata of B susceptible genotype, the pollen tube came across the stigmatic pathway but did not proceed further and thus its growth was restricted to the stigma. Thus, B is the medium for successful way of overcoming the stylar incompatibility of B susceptible genotypes. A study was performed on selection criterion to assess wheat B tolerance of wheat at seedling stage. On average, excess B reduced root length and number and had no effect on the number of days from inhibition to germination and germination percentage; however, significant differences have been found among the genotypes. The imposed B treatments demonstrated 5.2% stronger effect on lateral root length in comparison to primary root length. Therefore, total root length reduction may be more valuable selection criterion for B tolerance in wheat.

Jahiruddin *et al*. (1992) analyzed a series of field experiments with B in wheat at several locations in Bangladesh. The results show that B deficiency might be a causative factor for floret sterility in wheat. The yield of wheat after B treatment increased by more than 30% and this was related to the increase in the number of grains per spike. Response of wheat to B varied from one location to another. Soil application appeared to be a better method of B treatment compared to foliar spray. Such study indicates that non-viable pollen grains can result from deficiency of B.

Mitra and Jana (1991) observed from a 3 year field experiments in India that application of B increased the yield attributes of wheat. Significant response was obtained from application up to 20 kg borax ha^{-1} which gave an additional grain yield of 18.90 kg ha^{-1} over control. Among the methods of B application half soil + half foliar produced significantly more effective tillers which in turn gave 6.6 and 8.8 % higher grain yield than soil and foliar methods of application, respectively.

Rehem *et al*. (1998) observed that B plays a key role in water and nutrients transportation from root to shoot. They believe that B shortage causes barren stalks and small, twisted ears.

Vitosh *et al*. (1997) reported that B is involved in carbohydrates metabolism and it is essentially necessary for protein synthesis, pollen germination, seed and cell wall formation.

Alam (1995) carried out an experiment that showed, a field trial in Mymensingh on wheat variety (Kanchan, Aakbar and Agrani) with 100 kg N, 80 kg P, 30 kg K, 4 kg Zn, 2 kg Mo ha^{-1} respectively. He observed that application B deficiency, they are nevertheless useful as indicators of the lower limit of B sufficiency. For example, wheat plants with >4 mg B kg-1 in the ear (Rerkasem and Lordkaew, 1992) or >7 mg B kg-1 in the flag leaf at boot stage are unlikely to be affected by B deficiency In wheat, B deficiency causes poor anther and pollen development and low grain set. In vitro germination tests also showed that B was required for pollen germination and tube growth in wheat.

Abedin *et al*. (1994) opined that application of B to B deficient brown soil results in significant positive effects on number of total tillers $plant^{-1}$ .Grain yield of wheat is depressed by poor number of grains ear-1 which may result from B deficiency.

Mandal (1993) conducted an experiment with 21 wheat varieties in the Tarai region of India in order to find out the effect of B application on grain yield and other yield component. Most of the varieties showed positive response to B with respect to grain 30 yield, number of grains per spike and spike length. Grain yield was increased basically through the increase in number of grains per spike. However, varieties like BAU 2076, HI 968. BR 350 and BW 121 showed very small response to B for most of the trials.

Razzaque and Hossain (1991) reported that along with N, P, K, S and Zn, some other elements e.g. B, Mn and Mo might be the limiting for low wheat yield of this country. The yield of wheat increased with low B content in irrigation water but decreased at higher level. The effect was pronounced on sandy soil than on clay soil. Four trials were conducted in two AEZs of Bangladesh to examine the effect of B on grain set of wheat and observed that number of grains spike-1 and grain yield responded significantly to B treatment. Crop response to B varied between the locations.

Mitra and Jana (1991) found that the number of total tillers $plant^{-1}$ significantly increased by B application up to 20 kg borax ha^{-1}. The problem can be corrected by B application to the soil. Thus B deficiency can cause yield reduction by reducing grain set through impaired development of anther and pollen grain.

Rerkasem (1989) observed genotype variation in the response of wheat to B. He observed five genotypes responded to added B (1.1 kg B ha^{-1}). Some information on the assessment of grain set failure and diagnosis of B deficiency in wheat. They found that basal floret fertility (average number of grains in the two basal florets, $F_1 + F_2$ of 10 central spikelets) was a good index for assessment of grain set failure (Rerkasem, 1991).

Thalooth *et al*. (1989) demonstrated that regardless the source of N fertilization of wheat plants with B, increasing plant height. Plant height increased significantly by application of 1 kg B ha^{-1} (BINA, 1993).

Rahman (1989) revealed that the application of 3 kg B ha^{-1} significantly increased plant height, number of spikes per sqm, number of filled grains per spike, 1000 grain weight, grain yield and straw yield. Omission of boron from the complete treatment reduced the wheat yield by 20.4%.

Effect of B on male sterility of wheat was reported by Galrao and Sousa (1988) and noticed that the low yield of wheat was associated with male sterility (51.8%), which was aggravated by high temperature and low relative humidity of air during heading stage. The application of B reduced the male sterility by 94% and increased the grain yield by 1230 kg ha^{-1}.

Boron helps to develop root system, fruit setting and grain formation. The B content in wheat is 8.5 to 18.5ppm. The deficiency and toxicity level of B is 15ppm and above 200ppm, respectively. The younger leaves of wheat grown in B deficient soil become white, rolled and frequent trapped at the apex within the rolled subtending leaf; this experiment was carried out by Stevenson, (1985).

An experiment was conducted by White and Collins (1982) showed that insufficient B supply during seed development resulted in poor grain or seed yield of wheat in spite of sufficient Boron supply at early stage of development for normal growth. Field trials at Benisenf in 1978-79 Boron application depressed growth but 1.2 kg B per feddan increased grain number and weight spike-1 although higher rates depressed their yield components.

Gupta, (1979); Mengel and Kirkby, (1982) reported that Boron is essential for translocation of sugars, development of meristematic tissues, syntheses of protein, RNA and auxin and formation of ribosome.

Lal and Lal (1980) found that grain yield of wheat was increased with increased in the Boron concentration from 0.7 to 1.7ppm in irrigation water. The critical level of B in soils was 0.25 ppm for spring wheat and < 0.1ppm B caused complete grain sterility. Boron application @ 2.9 kg ha^{-1} to wheat cultivar Giza.157 increased the number of spikelet $spike^{-1}$ and the number of filled grain and grain $spike^{-1}$.

Singh and Singh (1976) said increased grain yield of wheat because of B treatment. An experiment with three cultivars of wheat (Janak, UP 262, and Sonalika) was conducted. They noticed that boron application increased yield of all three cultivars 32 Janak showed better performances over other cultivars. They also observed that soil application of B was more effective then foliar application. The dry matter at 6 weeks stage, grain and straw yields decreased significantly as Ca: B ratio decreased below 16.0: 22.3 and 9:1, respectively. The uptake of N, Na and B by grain and straw incised significantly with application of B.

Smith and Johnson (1969); Erikson (1779) narrated that, Boron is necessary for growth and yield of wheat. It has both direct and indirect effects on fertilization. Indirect effects are related to increase in amount and change in sugar composition of nectar, where by the flowers of species that rely on pollinating insects become more attractive to insects. The development of wheat anthers and pollen is affected by B deficiency. In B deficient wheat, the pollen does not accumulate starch and the nuclei when present are abnormal. The middle rate of B concentration gave the highest plant height.

Similarly, number of grain per spike is an important yield participating parameter and has a direct consequence on the grain yield of wheat stated by Tahir *et al*. (2009) and Gunnes *et al.* (2003). They reported that 1000-grain weight was significantly increased when Boron was sprayed on wheat at proper stage.

Wongmo *et al*. (2004) articulated that Boron insufficiencies caused reduction in grain setting in form of decreased number of grain per spike and grains per spikelet at the same time as in barley, low Boron significantly inferior the number of spikelet per spike by 23 to 75 percentages in addition enthused terminal spikelet worsening.

Khan *et al*. (2006) stated that Boron application at rate one kg B ha^{-1} significantly increased 1000 grain weight as compared to control.

Tahir *et al*. (2009) found that, foliar application of Boron in wheat at four different growth stages i.e at tillering, jointing, booting and anthesis increased number of grain per spike over control. The maximum number of grain per spike was obtained in treatment where Boron was sprayed at booting growth stage. Number of grain per spike increased 11.73 % as compared to control. While Mitra and Jana (1991) who reported that Boron application significantly increased the number of grains per spike.

Ali *et al*. (2009) expressed that foliar application of Zinc and Boron at 20 g L^{-1} and 30 g L^{-1}, respectively significantly increased number of spikes per square meter, grains per spike, 1000 grain weight, biological yield and grain yield as compared to control, during both growing seasons. Highest number of grains per spike was produced by combined application of both Zinc and Boron.

Tahir *et al*. (2009) described thousand grain weight has a straight effect on final grain yield of wheat crop. More the weight of grains, better will be the grain yield also he found that 1000 grain weight increased when Boron was applied at jointing stage which was at par with the treatments where Boron was applied at tillering, booting and anthesis stage.

Nadim *et al*. (2011) revealed that application of Boron at 2 kg ha^{-1} with basal dose of NPK significantly improved the number of grains per spike.

Rehman *et al*. (2012) elaborated that foliar application of Boron at 1250 mL ha^{-1} in booting stage increased number of grain per spike. The number of grain per spike increased 16.65% over control and also found that application of Boron at booting stage increased thousand grain weight (22.50%) over the control.

Nadim *et al*. (2012) reported that soil and foliar spray application of Boron at 2 kg ha^{-1} increased thousand grain weight in wheat plant and increased number of grain per spike (54.25) as compared to side dressing and soil application.

Moghadam *et al*. (2012) found that foliar application of Boron no significant effect on 1000 grain weight. Ali *et al.* (2009) found that Combined foliar application of both Zinc and Boron significant increase thousand grains weight. Thousand grains weight increased 4.88% over control treatment.

Hussain *et al.* (2005) stated that foliar application of Boron at three growth stages of wheat i.e. at tillering, booting and milking significant improvement in number of grains per spike and 1000 grain weight.

Foliar application of micronutrients mixture ‘Shelter’ containing (Fe = 1%, Mn = 2%, Zn = 2%, Cu = 1%, B = 1%) at various growth stages improved 1000 grain weight in wheat, articulated by Kahn *et al*. (2010).

Tahir *et al.* (2009) narrated the more harvest index will be for the reason of the physiological potential for converting dry matter into grain yield. Effects of Boron application on harvest index were claimed the most effect of Boron application on harvest index was reported at anthesis stage in wheat.

Pandey and Gupta (2013) found that foliar application of Boron at all stages increased the yield parameters like number of pods, pod size and number of seeds formed per plant, also improved the seed yield and seed quality in terms of storage seed proteins and carbohydrates in black gram. Krudnak *et al.* (2013) found that B application at planting date could increase pollen viability and percent seed set of sunflower.

Fakir *et al.* (2018) described that, inclusion of Boron (B) in fertilizer management practice most often determines the yield performance of crops. Methods of supply of B to plants demands more research to come to a conclusion. The effect of different methods of boron application on the nutrient concentration and uptake of wheat (*Triticuma estivum* L.cv. Shatabdi) was studied through a field experiment at Bangladesh Agricultural University (BAU) farm, Mymensingh during rabi season of 2012-13. The experiment was laid out in a randomized complete block design (RCBD) with six treatments and three replications. The treatments were- (i) B–control (no addition of B), (ii) soil application @ 1.5 kg ha^{-1} , (iii) seed priming @ 0.4% boric acid solution, (iv) foliar spray @ 0.4% boric acid solution at primodia stage (37DAS), (v) foliar spray @ 0.4% boric acid solution at booting stage (55 DAS),and (vi) foliar spray at primodia stage (37DAS) and booting stages (55 DAS). Boric acid was used as a source of boron. Seed priming was done by soaking wheat seeds into 0.1% boric acid solution for 10 hours and then seeds were dried before sowing. Foliar spray of B at primodia and booting stage of crop (T_6) recorded the highest B concentration of grain (19.60 µg g^{-1}) and the control (T_1) treatment performed the lowest B concentration (6.75 µg g^{-1}). Similarly, the foliar spray of B at primodia and booting stages of crop (T_6) recorded the highest B uptake by both grain and straw that was statistically identical to foliar spray of B at booting stage of crop (T_5) in both cases. In view of cost-return analysis, foliar spray of B at primodia and booting stage treatment required the highest input cost but obtained the highest gross return, while control B required the lowest input cost along with lowest gross return.

Grain yield of wheat crop is the result of combined effect of various yield contributing components reported by Tahir *et al.* (2009). Different experiments have been carried out by (Rerkasem and Jamjod, 1997; Paull *et al.*, 1991) to evaluate the response of wheat to Boron application and a wide range of genotypic variation in response to Boron absence and toxicity.

Li and Ling (1997); Shaaban *et al.* (2001) stated that improved growth and high-quality yields were attained when crops were supplied with Boron. Helder *et al.* (2007) found that appliation 2 kg Boron ha1 produced significantly highest yield in both the years of study.

Chaudhry *et al.* (2007) found that micronutrients (Zn, Fe, and B) significantly increased the wheat yield over control when applied single or in combination with each other.

The ten winter wheat cultivars tested differed significantly in their nutritional demands for Boron. At the same concentration of Boron in soil, four out of ten wheat cultivars responded to foliar Boron application with 8.6- 15.2% grain yield increase while the other six cultivars did not respond to the treatments, narrated by Korzeniowska (2008).

Foliar application of Boron at reproductive stage enhanced grain yield and different yield components of wheat, revealed by Wroble (2009); Ahmad and Irshad (2011).

Application of Boron in wheat at tillering, jointing, booting and anthesis stage significantly increased grain yield when Boron was applied, It is explained by Tahir *et al.* (2009).

Moeinian *et al.* (2011) described that foliar 1% Boron increased grain yield of wheat under drought stress. Also found that the proline content of grain and gluten percentage of the grain was significantly affected with Boron foliar spraying and irrigation treatments.

Soil application of Boron fertilizer has positive impact on the yield and different yield components of wheat, rice and cotton crop. Thirty one field experiments were conducted to evaluate the response of wheat, rice and cotton to Boron application the results showed that the soil application of Boron fertilizer has positive impact on the yield and different yield components of wheat, rice and cotton crop. Soil application not only considerably raises yield of these crops but it is as well inexpensive and effortless to utilize for the farmers. This experiment conducted by Ahmad and Irshad, 2011.

Soylu *et al.* (2004) who narrated that grain yields in all genotypes of wheat crop were increased significantly by the application of fertilizer Boron as compared to control.

Moghadam *et al.* (2012) explained that foliar application of Boron and Zinc had positive effect on yield and yield components of wheat.

Chaudhry *et al.* (2007) found that micronutrients (Zn, Fe, and B) significantly increased the wheat yield over control when applied single or in combination with each other.

A field experiment was carried out to evaluate the response of wheat to market available micronutrient application (Fe = 1%, Mn = 2%, Zn = 2%, Cu = 1%, B = 1%). The results showed that application of micronutrient significantly enhanced the number of grains per spike, 1000 grain weight, grain yield, straw yield, biological yield and harvest index at different growth stages of wheat. In conclusion, commercially obtainable foliar application may be useful to get better the wheat crop, explained by Khan *et al.* (2010).

Nadim (2011) explained, study the physiology and yield attributes of wheat using different levels of Zn, Cu, Fe, Mn and B alone and in different combinations, he found that the use of micronutrients significantly affected wheat yield. Among micronutrients, the application of Boron at 2 kg ha^{-1} and Copper at 8 kg ha^{-1} had significantly positive effect on most of yield contributing parameters of wheat.

Wrobel (2009) and Uddin *et al.* (2008) mentioned that the foliar fertilization with Boron has a positive effect on the main wheat yield components, significantly improving grain yield.

Raza *et al.* (2014) described that foliar application of Boron was significant affected on grain yield, number of grains spike-1and 1000 grain weight. The highest grain yield of wheat (6.5 ton h^{-1}) was observed when 20 mg L^{-1} Boron was applied.

Zahoor *et al.* (2011) found field experiment to determine the effect of different application rates of B on yield and quality of cotton. The results showed that B application at any stage improved plant growth and photosynthetic rate, leaf nitrogen, achene oil, seed yield and protein contents of sunflower plant.

Kandi *et al.* (2012) stated that B foliar application on safflower plant had the highest positive effect on plant biological yield, harvest index and seed Boron content.

Chapter III

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

Details of different materials used and methodologies followed in the experiment are presented in this chapter. It includes a short description of location of the experimental site and layout, characteristics of soil and climate, land preparation materials used etc. for the experiment. The details of the experiment are given below.

3.1 Experimental site

The research work was carried out at the experimental field of Sher-e-Bangla Agricultural University, Dhaka during the period from November 2019 to March 2020. It is located under the Agro-ecological zone of Madhupur Tract, AEZ-28 (23^0 41' N latitude and 90^0 22') at an elevation of 8 m above the sea level (Appendix 6). Morphological characteristics of the experimental field is given in Appendix 1.

3.2 Soil and climate

The experimental plot was situated in the subtropical zone. The soil was clay loam in texture and olive gray with common fine to medium distinct dark yellowish brown mottles with pH 5.47 to 5.63 and 0.82% organic carbon content. The physio-chemical properties of the soil are presented in Appendix-2 and Appendix-3 respectively. The experiment was conducted in the month of November to March. The monthly average minimum and maximum temperature and relative humidity during the crop period was 16.75°C to 22.45°C and 57% to 76%, respectively. The monthly average rainfall was 37 mm. Details of the metrological data of air temperature, relative humidity, rainfall and sunshine hour during the period of the experiment were noted from the Bangladesh Meteorological Department, Sher-e-Bangla Nagar, Dhaka-1207 this is presented in Appendix 4.

3.3 Planting material

Wheat (*Triticum aestivum* L.) variety BARI Gom -33 was used as plant material. It is developed by Wheat Research Centre (WRC), Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh. It is high yielding wheat variety. This variety, which was hybridized between KACHU and SALALA varieties, was brought into this country in 2013 through harvest plus trial. The BAW 1260 genetic line is initially selected by observing in different climates. In 2016 and 2017 by laboratory and field trial it is proved that this variety is resistance to wheat blast. Later in 2017 it is released by National Seed Board. Its stem and leaf are dark green color; tillers are semi erect during heading. Flag leaf is wide and droopy. It is Zn-enriched variety. The seeds of this variety were collected from Bangladesh Agricultural Research Institute (BARI), Gazipur.

3.4 Land preparation

The land was first opened with the tractor drawn disc plough. Ploughed soil was then brought into desirable fine tilth by 3 operations of ploughing and harrowing with country plough and ladder. The stubble and weeds were removed. The first ploughing and the final land preparation were done 13 November 15 November, respectively. Experimental land was divided into 21 plots following the design of experiment. The plots were spaded one day before seed sowing and the basal dose of fertilizers was incorporated thoroughly before seed sowing.

3.5 Fertilizer application

Fertilizers were applied to each plot as per treatments. All these fertilizers were applied in soil before sowing of crop except urea, which was used in split doses. Besides boron, every treatment received 165 kg urea ha^{-1}, 145 kg TSP ha^{-1}, 105 kg MoP ha^{-1}, Gypsum 115 kg ha^{-1} and Zinc sulphate 12 kg ha^{-1}. Fertilizers such as urea, TSP, MoP, gypsum, Zinc sulphate and boric acid were used as sources for N, P, K, S, Zn and B, respectively. The whole amount of TSP, MoP, gypsum, boric acid and one third of the urea were applied at the time of final land preparation prior to sowing. Boron was applied as per experimental specification through boric acid (17% B).

One-third dose of urea and full dose of all other fertilizers were applied as basal to the individual plots during final land preparation. The second dose of urea was applied after 30 days of sowing (crown root stage) and the third split after 55 days after sowing (booting stage). For foliar spray treatments, boric acid solution was sprayed at 55, 75 and 90 days after sowing to represent primordial, booting and grain filling stages of crop, respectively.

3.6 Treatments of the experiment

There were seven boron treatments, as follows:

T_0: Control (no application of B)

T_1: Soil application of 2 kg/ha B

T_2: seed priming, o.1% boric acid

T_3: Foliar spray at primordial stage, 0.4% boric acid

T_4: Foliar spray at booting stage, 0.4% boric acid, 0.4% boric acid

T_5: Foliar spray at primordial and booting stages, 0.4% boric acid

T_6: Foliar spray at grain filling stage, 0.4% boric acid

3.7 Experimental design and lay out

The experiment was laid out in a Randomized Complete Block Design. Each treatment was replicated three times. The size of a unit plot was 3 m × 2 m. The distance between two adjacent replications (block) was 0.5m and row to row distance was 0.5 m. The inter block and inter row spaces were used as footpath.

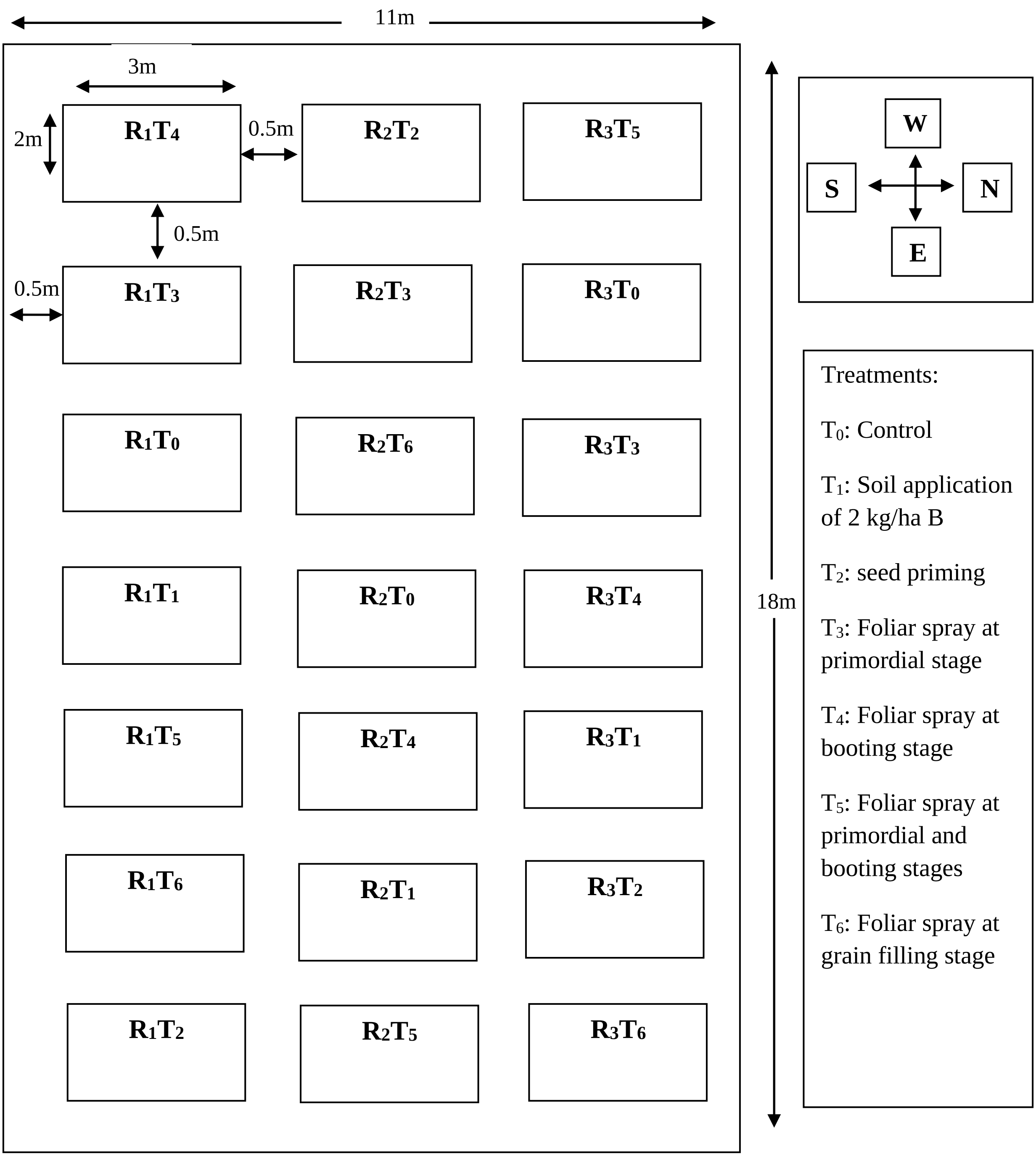

Fig.1. Layout of experiment field

3.8 Sowing of seeds in the field

The seeds of wheat were sown by following broadcasting method. In this method the seeds were broadcasted and then worked in by harrowing in order to cover them. The seeds of wheat were sown on November 17, 2019.

3.9 Intercultural operations

3.9.1 Irrigation and weeding

The cultural practices such as weeding and insecticide spraying were done as and when required. Three irrigations were provided during the entire growing period. The crop field was weeded third time; the first weeding was done at 20 DAS (Days after sowing), the second weeding at 35 DAS and the third weeding at 50 DAS. Demarcation boundaries and drainage channels were also kept weed free.

3.9.2 Protection against insect and pest

The field was attacked by wheat aphid (*Schizaphis graminum*) which was successfully controlled by using ACTARA (contains 250 g/kg thiamethoxam formulated as a water dispersible granule) insecticide. Furadan was applied as fungicide. Also zinc phosphide bait was used as rodenticide for controlling rat.

3.10 Preparation and application of Boron

The rate of B for soil application was 2 kg B ha^{-1} from boric acid (17% B) and the rate for each foliar spray was 0.4% boric acid solution. Seed priming was done by soaking wheat seeds into 0.1% boric acid solution for 10 hours and then seeds were dried before sowing.

3.11 Crop sampling and data collection

The crop sampling was done at the time of harvest. Harvesting date was 19/03/2020. At each harvest, five plants were selected randomly from each plot. The selected plants of each plot were cut carefully at the soil surface level. The plant height, total number of tillers planr^{-1}, number of effective tillers plant^{-1}, number of in-effective tillers plant^{-1}, leaf number plant^{-1}, Length and breadth of flag leaf, spike length, SPAD, number of total grains spike^{-1}, number of filled grains spike^{-1}, number of unfilled grains spikelet $^{-1}$, Spikelet fertility(%), 1000 grains (seed) weight, total grain weight and straw yield were recorded separately.

3.12 Harvesting operations

Harvesting was done when crop completed its maturity and spikes were turned golden brown color. The matured crop were cut and collected manually. After harvesting, the samples were sun dried.

3.13 Procedure of data collection

3.13.1 Plant height

Plant height was calculated and recorded when it reached at maturity. Randomly selected plants were measured using tape, through bottom to tip of the spike in centimeters and the mean height was expressed in cm.

3.13.2 Number of tillers plant^{-1}

Total number of tillers hill^{-1}, number of effective tillers hill^{-1}, number of non-effective tillers hill^{-1} were counted before harvesting. Finally the mean value was calculated as their number hill^{-1}.

3.13.3 Leaves plant^{-1}

Leaves hill^{-1} in each plot was counted at different stages and average value was counted.

3.13.4 Length and breadth of flag leaf

Length and breadth of flag leaf was counted of random five plants and average value was counted at cm.

3.13.5 Spike length

Spike length were measured from five plants and then averaged. This was taken at the time of harvest and it is expressed in cm.

3.13.6 SPAD value

The SPAD value measurements with the SPAD meter at vegetative stage. Randomly five plants were selected for all the plots and average value was calculated. The readings were taken from midway between leaf base and tip of a leaf blade.

3.13.7 Number of grain spike^{-1}

Total grain numbers were counted from whole spike that was obtained from the plants and number of filled grains spike^{-1}, number of unfilled grains spike^{-1} also counted. After that mean value was calculated and expressed as number of grain spike^{-1}.

3.13.8 Spikelet fertility (%)

It was determined by the following formula from the sampled plants as follows

$$\text{Spikelet fertility (\%)} = \frac{\text{no.of fertile grains} \times 100}{\text{total no.of floret}}$$

3.13.9 Weight of 1000 seeds

One thousand cleaned dried seeds were counted randomly from each harvested sample and weighed by using a digital electric balance and the mean weight was expressed in gram.

3.13.10 Total Grain weight

Weight of grains of the each plot was weighed by using a digital electric balance and the mean weight was expressed in gram.

3.13.11 Straw yield

Straw yield was taken from the central 6 m-^{2} of each plot and was used to calculate straw yield m^{-2} and finally converted to t ha^{-1}.

3.14 Analyses of data

The data collected on different parameters were statistically analyzed to obtain the level of significance using the MSTAT-computer package program. 5% level of significance was used to compare the mean differences among the treatments.

Chapter IV

RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

The results of the present study are presented in several terms. The experiment was conducted to study the Methods of Application of Boron influencing the growth and Yield of Wheat (*Triticum aestivum* L.) The results are presented and discussed under the following parameters.

4.1 Effect of Boron on the growth and yield of wheat

4.1.1 Plant height

Application of different doses of boron influenced plant height significantly (Appendix 5). The findings showed that the longest plant (94.467 cm) was found in T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid) which was statistically identical to T_4 treatment (Foliar spray at booting stage, 0.4% boric acid), T_3 treatment (Foliar spray at primordial stage), T_6 treatment (Foliar spray at grain filling stage), T_1 treatment (Soil application of 2 kg/ha B), T_2 (seed priming, o.1% boric acid) respectively. Whereas the shortest plant height (87.600 cm) was recorded from T_0 (Control) treatment (Fig.2). BINA (1993) reported that plant height varied significantly by application of 1 kg B ha^{-1}.

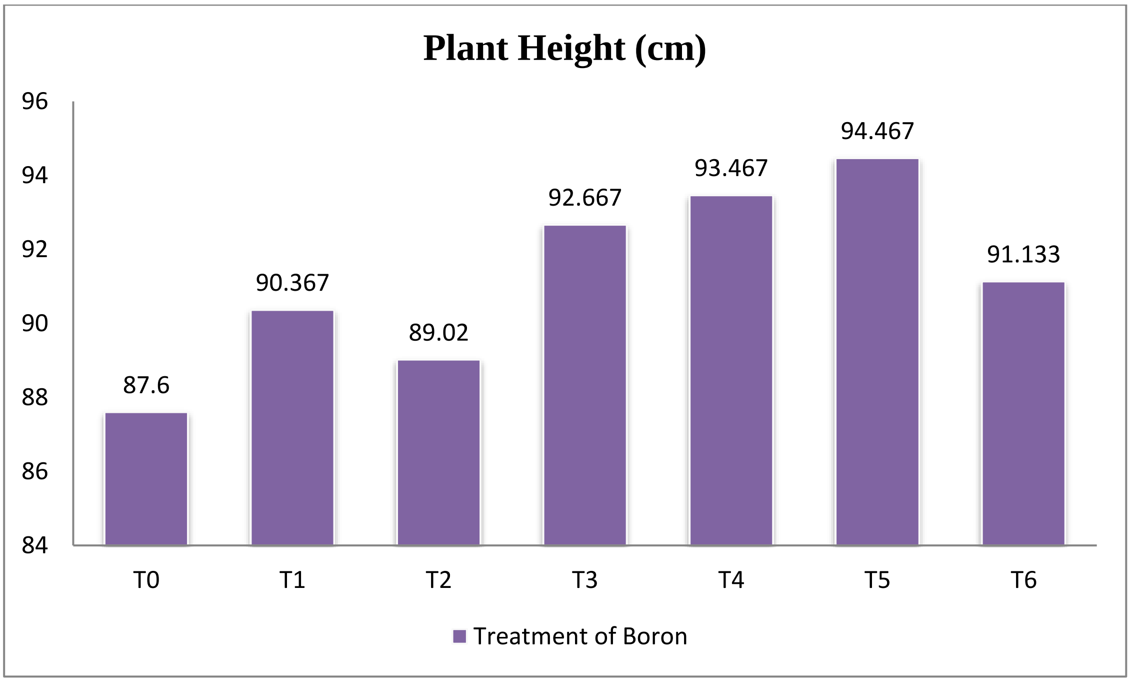

Fig.2: Effect of B on plant height (cm) of wheat

[T0 (Control), T_1 (Soil application of 2 kg/ha B), T_2 (seed priming, o.1% boric acid), T_3 (Foliar spray at primordial stage, 0.4% boric acid), T_4 (Foliar spray at booting stage, 0.4% boric acid), T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid), T_6 treatment (Foliar spray at grain filling stage, 0.4% boric acid)]

4.1.2 Total no. of tillers plant^{-1}

There was a significant effect of different levels of B on total no. of tillers plant^{-1} of wheat (Appendix 5). The highest number of total tillers plant^{-1} (3.7000) was found in T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid) followed by T_4 (Foliar spray at booting stage, 0.4% boric acid), T_3 (Foliar spray at primordial stage) respectively. T_1 (Soil application of 2 kg/ha B) and T_6 (Foliar spray at grain filling stage) give the statistically same result. Whereas the lowest number of total tiller hill^{-1} (2.1867) was recorded from T_0 (Control) treatment (Fig. 3). Ahmad *et. al*., (2011) revealed that B application at sowing time to wheat increased significantly the number of tillers plant^{-1} (15%). Similarly, Nazim et al. (2005) reported improvement in productive tillers with foliar application of B. Ahmad and Irshad (2011) advocated increase in productive tillers m^{-2} with application of B. Foliar application of B at booting stage significantly affected fertile tillers (Saleem, 2020).

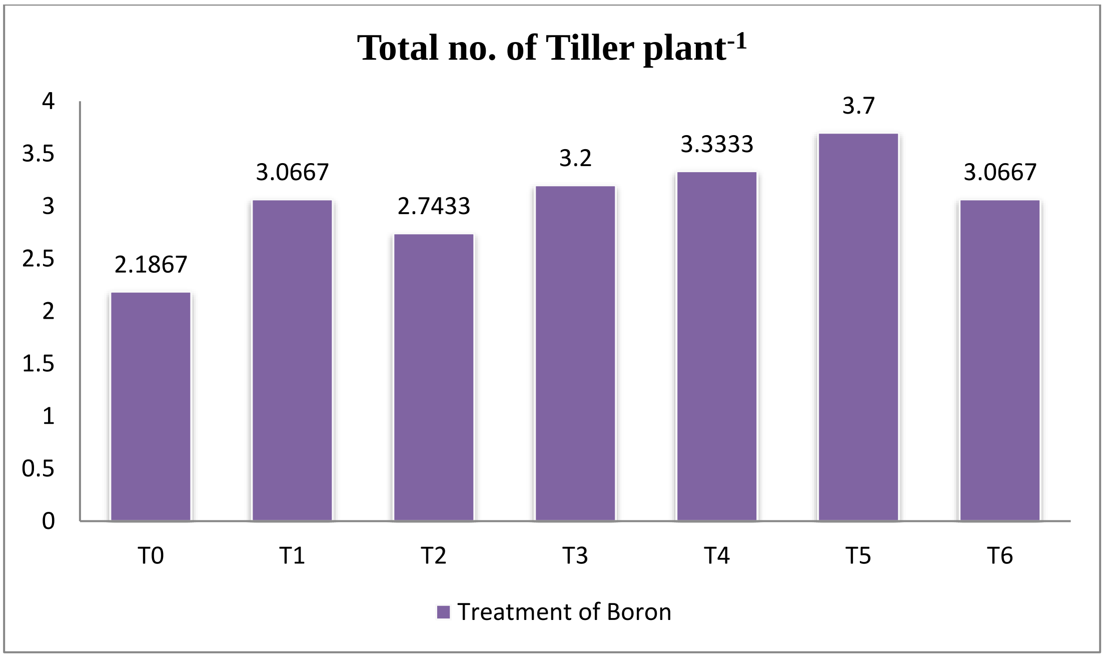

Fig.3: Effect of B on Total no. of tiller plant^{-1}of wheat

[T_0 (Control), T_1 (Soil application of 2 kg/ha B), T_2 (seed priming, o.1% boric acid), T_3 (Foliar spray at primordial stage, 0.4% boric acid), T_4 (Foliar spray at booting stage, 0.4% boric acid), T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid), T_6 treatment (Foliar spray at grain filling stage, 0.4% boric acid)]

4.1.3 Leaf no. plant^{-1}

Leaf no. plant^{-1} was influenced significantly by application of B (Appendix 5). Result showed that the highest number of leaf 12.783 was recorded under T_1 (Soil application of 2 kg/ha B) followed by T_4 treatment (Foliar spray at booting stage, 0.4% boric acid), T5 (Foliar spray at primordial and booting stages, 0.4% boric acid), T_3 (Foliar spray at primordial stage, 0.4% boric acid) T_6 (Foliar spray at grain filling stage, 0.4% boric acid), T_2 (seed priming, o.1% boric acid) respectively. T_0 (Control) give the lowest value (9.500) (Fig. 4). Soil application of Boron was significantly affected on leaf no. hill^{-1}.

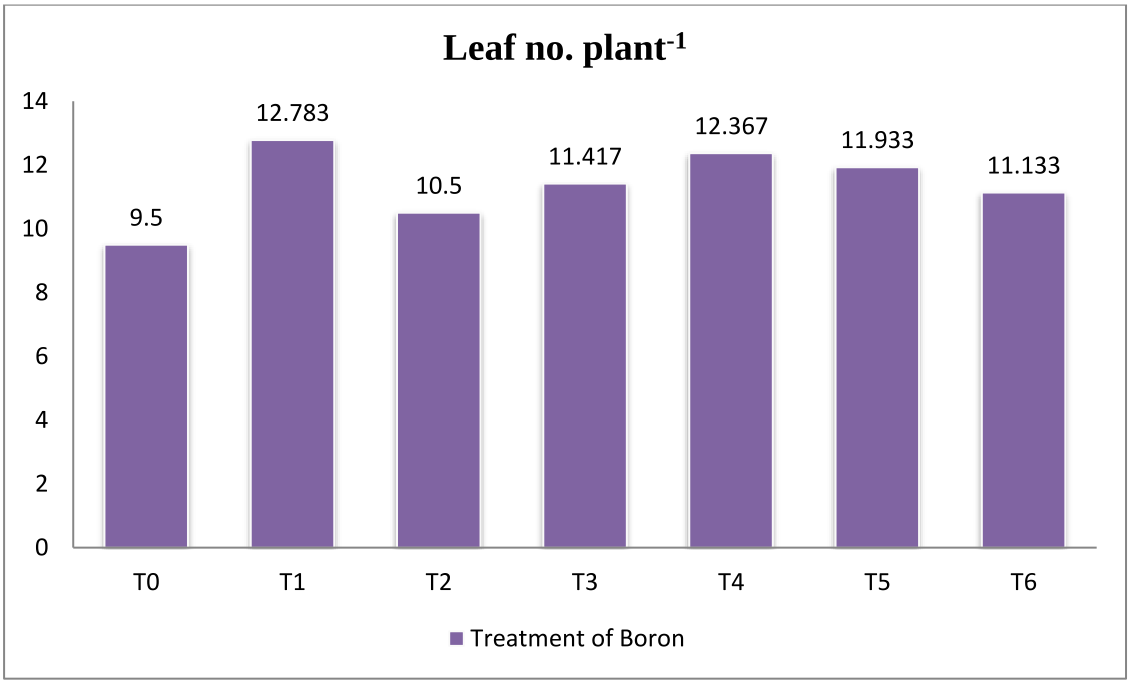

Fig.4: Effect of B on Leaf no. plant^{-1}of wheat

[T_0 (Control), T_1 (Soil application of 2 kg/ha B), T_2 (seed priming, o.1% boric acid), T_3 (Foliar spray at primordial stage, 0.4% boric acid), T_4 (Foliar spray at booting stage, 0.4% boric acid), T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid), T_6 treatment (Foliar spray at grain filling stage, 0.4% boric acid)]

4.1.4 Length of flag leaf (cm)

Application of boron influenced significantly in terms of length of flag leaf of wheat (Appendix 5). T_5 treatment (Foliar spray at primordial and booting stages, 0.4% boric acid) produced the longest length (23.393 cm) followed by T_4 (Foliar spray at booting stage, 0.4% boric acid), T_3 (Foliar spray at primordial stage, 0.4% boric acid), T_6 (Foliar spray at grain filling stage, 0.4% boric acid), T_1 (Soil application of 2 kg/ha B), T_2 (seed priming, o.1% boric acid) respectively. The shortest Flag leaf length (20.430 cm) was observed in control T_0 treatment (Table 1). Subedi et al. (1995) found that added B had a significant effect on the number of grains spike^{-1}, spikelets spike^{-1}, sterility, 1000-seed weight and boron content in the flag leaf at anthesis.

4.1.5 Breadth of flag leaf (cm)

The experimental findings showed that the breadth of flag leaf of wheat significantly due to the application of different level of boron treatments (Appendix 5). The results showed that the maximum value for breadth of flag leaf (2.6267cm) was produced by application of T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid) and T_4 (Foliar spray at booting stage, 0.4% boric acid) treatment which was statistically identical with T_3 (Foliar spray at primordial stage, 0.4% boric acid), T_1 (Soil application of 2 kg/ha B), T_6 (Foliar spray at grain filling stage, 0.4% boric acid), T_2 (seed priming, o.1% boric acid), T_1 (Soil application of 2 kg/ha B) respectively. Minimum value (2.2333) was found at T_0 (Control) treatment (Table 1). Subedi et al. (1995) found that added B had a significant effect on the number of grains spike^{-1}, spikelets spike^{-1}, sterility, 1000-seed weight and boron content in the flag leaf at anthesis.

4.1.6 Spike length (cm)

There was a significant effect of different levels of B on spike length of wheat (Appendix 5). T_5 treatment (Foliar spray at primordial and booting stages, 0.4% boric acid) produced the longest spike length (12.887 cm) followed by T_4 treatment (Foliar spray at booting stage, 0.4% boric acid), T_3 treatment (Foliar spray at primordial stage, 0.4% boric acid), T_1 treatment (Soil application of 2 kg/ha B), T_2 (seed priming, o.1% boric acid), T_6 treatment (Foliar spray at grain filling stage, 0.4% boric acid) respectively. The shortest spike length (12.293 cm) was observed in control T_0

treatment (Table 1). The results are in conformity with that of Mandal (1993). Rahmatullah et al. (2006) also found Boron application significantly affected wheat spike length.

Table 1. Effects of different methods of boron application on Length of flag leaf (cm), Breadth of flag leaf (cm) and Spike length (cm) of wheat

Treatment	Length of flag leaf(cm)	Breadth of flag leaf(cm)	Spike length (cm)
T_0	20.430 d	2.2333 d	12.293 d
T_1	21.717 c	2.5133 bc	12.700 ab
T_2	20.847 d	2.3033 d	12.603 bc
T_3	22.633 ab	2.6267 ab	12.773 ab
T_4	23.100 ab	2.6900 a	12.830 a
T_5	23.393 a	2.6900 a	12.887 a
T_6	22.333 bc	2.4667 c	12.423 cd
LSD (%)	0.851	0.153	0.218
CV (%)	2.170	3.440	0.970

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

4.1.7 SPAD Value

SPAD was influenced significantly by application of Boron application (Appendix 5). Maximum value (51.063) found in T_6 treatment (Foliar spray at grain filling stage, 0.4% boric acid), followed by T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid), T_4 treatment (Foliar spray at booting stage, 0.4% boric acid), T_3 treatment (Foliar spray at primordial stage, 0.4% boric acid), T_1 treatment (Soil application of 2 kg/ha B), T_2 (seed priming, o.1% boric acid) respectively. Minimum value (48.80) was found at T_0 (Control) treatment (Fig.5). Micronutrients, according to Reddy (2004), aid in chlorophyll generation, nucleic acid synthesis, protein synthesis, and play an active role in various photosynthetic enzymatic activities. So, it has positive effect on boron application.

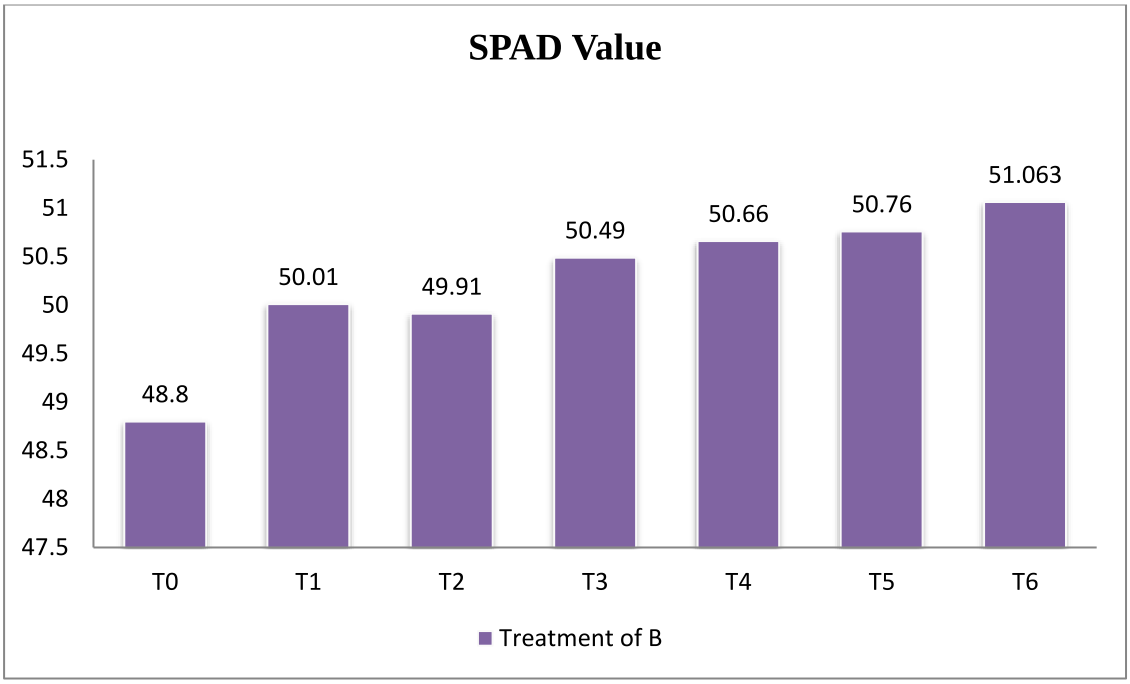

Fig.5: Effect of B on SPAD of wheat

[T_0 (Control), T_1 (Soil application of 2 kg/ha B), T_2 (seed priming, o.1% boric acid), T_3 (Foliar spray at primordial stage, 0.4% boric acid), T_4 (Foliar spray at booting stage, 0.4% boric acid), T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid), T_6 treatment (Foliar spray at grain filling stage, 0.4% boric acid)]

4.1.8 No. of effective tiller plant^{-1}

Application of boron significantly influenced the number of total tiller plant^{-1} of Wheat (Appendix 5). The findings showed that the highest number of total tiller hill^{-1} (2.6667) was found in T_6 treatment (Foliar spray at grain filling stage, 0.4% boric acid) followed by T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid), T_4 treatment (Foliar spray at booting stage, 0.4% boric acid), T_3 treatment (Foliar spray at primordial stage, 0.4% boric acid), T_2 (seed priming, o.1% boric acid), T_1 treatment (Soil application of 2 kg/ha B) respectively. Where the lowest number of total tiller plant^{-1} (1.9333) was recorded from T_0 (Control) treatment (Table 2). Ahmad and Irshad (2011) advocated increase in productive tillers m^{-2} with application of B.

4.1.9 No. of in-effective tiller plant^{-1}

Significant variation was found by application of boron in terms of number of in-effective tiller plant^{-1} for wheat (Appendix 5). The findings showed that the highest number of in-effective tiller plant^{-1} (0.1733) was found in T_0 (Control) followed by T2 (seed priming, o.1% boric acid), T6 treatment (Foliar spray at grain filling stage, 0.4% boric acid), T_1 treatment (Soil application of 2 kg/ha B), T_3 treatment (Foliar spray at primordial stage, 0.4% boric acid), T_4 treatment (Foliar spray at booting stage, 0.4% boric acid), T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid) respectively. Whereas the lowest in-effective tiller plant^{-1} (0.0633) was recorded from T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid) (Table 2). Foliar application of B at booting stage significantly affected fertile tillers (Saleem, 2020).

Table 2. Effects of different methods of boron application on No. of effective tiller plant^{-1} and No. of in-effective tiller plant^{-1} of wheat

Treatment	No. of effective tiller plant^{-1}	No. of in-effective tiller plant^{-1}
T_0	1.9333 d	0.1733 a
T_1	2.0000 cd	0.1167 bc
T_2	2.1333 bcd	0.1567 ab
T_3	2.2667 abcd	0.0867 cd
T_4	2.4000 abc	0.0733 d
T_5	2.5333 ab	0.0633 d
T_6	2.6667 a	0.1333 ab
LSD (%)	0.415	0.04
CV (%)	10.270	20.030

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

4.1.10 No. of total grain spike^{-1}

Significant variation was found by the application of boron in terms of number of total grain of spike^{-1} of wheat (Appendix 5). The findings showed that the highest number of total grain spike^{-1} (68.867) was found in T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid) followed by T_4 treatment (Foliar spray at booting stage, 0.4% boric acid), T_3 treatment (Foliar spray at primordial stage, 0.4% boric acid, T_1 treatment (Soil application of 2 kg/ha B), T_6 treatment (Foliar spray at grain filling stage, 0.4% boric acid), T_2 (seed priming, o.1% boric acid) respectively. where the lowest number of total grain spike^{-1} (52.800) was recorded from T_0 (Control) treatment (Table 3). Similar results were also reported by Mandal (1987), Mandal and Das (1988) and Rahman (1989). Gunes (2003) who reported marked increase in number of grains spike^{-1} of wheat for application of Boron.

4.1.11 No. of filled grain spike^{-1}

Application of boron significantly influenced the filled grain spike^{-1} of wheat (Appendix 5). The findings showed that the highest filled grain spike^{-1} (67.733) was found in T5 (Foliar spray at primordial and booting stages, 0.4% boric acid) followed by T4 treatment (Foliar spray at booting stage, 0.4% boric acid), T_1 treatment (Soil application of 2 kg/ha B), T_3 treatment (Foliar spray at primordial stage, 0.4% boric acid), T_6 treatment (Foliar spray at grain filling stage, 0.4% boric acid), T_2 (seed priming, o.1% boric acid) respectively. Where the lowest filled grain spike^{-1} (50.610) was recorded from T0 (Control) treatment (Table 3). Rani. P.S. and Latha (2017) found that addition of boron alone resulted an increase of 1.37 t ha^{-1} over control owing to 45% increase in filled grains, highest among treatments.

4.1.12 No. of un-filled grain spike^{-1}

There was significant variation by application of boron in terms of un-filled grain number spike^{-1} of wheat (Appendix 5). The findings showed that the highest number of un-filled grain spike^{-1} (2.1900) was found in T_0 (Control) followed by T2 (seed priming, o.1% boric acid), T_6 treatment (Foliar spray at grain filling stage, 0.4% boric acid), T_1 treatment (Soil application of 2 kg/ha B), T_3 treatment (Foliar spray at primordial stage, 0.4% boric acid), T_4 treatment (Foliar spray at booting stage, 0.4% boric acid) respectively. Where the lowest number of un-filled grain spike^{-1} (1.1333) was recorded from T_5 treatment (Foliar spray at primordial and booting stages, 0.4% boric acid) (Table 3). Fakir *et al.* (2016) registered significantly higher number of spikelets spike^{-1}, number of grains spike^{-1}, 1000 seed weight and grain yield after boron application.

Table 3. Effects of different methods of boron application on No. of total grain spike^{-1}, No. of filled grain spike^{-1} and No. of un-filled grain spike^{-1}of wheat

Treatment	No. of total grain spike^{-1}	No. of filled grain spike^{-1}	No. of un-filled grain spike^{-1}
T_0	52.800 e	50.610 e	2.1900 a
T_1	64.403 bc	62.637 bc	1.7667 b
T_2	58.290 d	56.373 d	1.9167 ab
T_3	64.440 bc	62.907 bc	1.5333 bc
T_4	65.760 b	64.393 b	1.3667 cd
T_5	68.867 a	67.733 a	1.1333 d
T_6	63.167 c	61.400 c	1.7667 b
LSD (%)	2.461	2.372	0.386
CV (%)	2.210	2.190	13.020

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

4.1.13 Spikelet fertility (%)

The results for Spikelet fertility (%) showed significant effect of fertilizer levels (Appendix 5). The maximum result (98.353) found in T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid) followed by T_4 treatment (Foliar spray at booting stage, 0.4% boric acid), T_3 treatment (Foliar spray at primordial stage, 0.4% boric acid), T_1 treatment (Soil application of 2 kg/ha B), T_6 treatment (Foliar spray at grain filling stage, 0.4% boric acid), T_2 (seed priming, o.1% boric acid). Minimum value (95.850) was found at T_0 (Control) treatment (Table 4). Mitra and Jana (1991) who reported that Boron application significantly increased the number of fertile grains per spike.

4.1.14 1000 grain weight (gm)

1000 grain weight was influenced significantly due to different levels of B application. (Appendix 5).The highest 1000 grain weight (52.667 g) was noted at T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid) followed by T_6 treatment (Foliar spray at grain filling stage, 0.4% boric acid), T_4 treatment (Foliar spray at booting stage, 0.4% boric acid), T_3 treatment (Foliar spray at primordial stage, 0.4% boric acid), T_1 treatment (Soil application of 2 kg/ha B), T_2 (seed priming, o.1% boric acid) respectively. Lowest (42.433 g) was obtained from T_0 treatment (Table 3). These results explained that the weight of 1000 grain depends on the B fertilization. Such results are in conformity with the findings of Mete *et al.* (2005) and Soylu *et al.* (2005) who reported that the weight of 1000 grain increased significantly with the increased B fertilization.

Table 4. Effects of different methods of boron application on Spikelet fertility (%) and 1000 grain weight (gm) of wheat

Treatment	Spikelet fertility (%)	1000 grain weight (gm)
T_0	95.850 e	42.433 c
T_1	97.253 cd	47.000 bc
T_2	96.710 d	43.000 c
T_3	97.623 bc	48.000 ab
T_4	97.927 ab	49.000 ab
T_5	98.353 a	52.667 a
T_6	97.207 cd	50.000 ab
LSD (%)	0.593	4.719
CV (%)	0.340	5.590

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability

4.1.15 Total Grain weight (t ha^{-1})

Application of boron influenced significantly in terms of grain weight ha^{-1} of wheat (Appendix 5). The findings showed that the highest grain weight (2.8945 t ha $^{-1}$) was found in T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid), followed by T_4 treatment (Foliar spray at booting stage, 0.4% boric acid), T_3 treatment (Foliar spray at primordial stage, 0.4% boric acid), T_6 treatment (Foliar spray at grain filling stage, 0.4% boric acid), T_1 treatment (Soil application of 2 kg/ha B, T_2 (seed priming, o.1% boric acid) respectively. while the lowest grain weight (2.1111 t ha $^{-1}$) was recorded from T_0 (Control) (Fig. 6). This result was in accordance with that of Mandal (1987), Galrao and Sousa (1988), Rahman (1989), BINA (1993) and Jahiruddin *et al.* (1995). They found boron has significant effect in total grain weight.

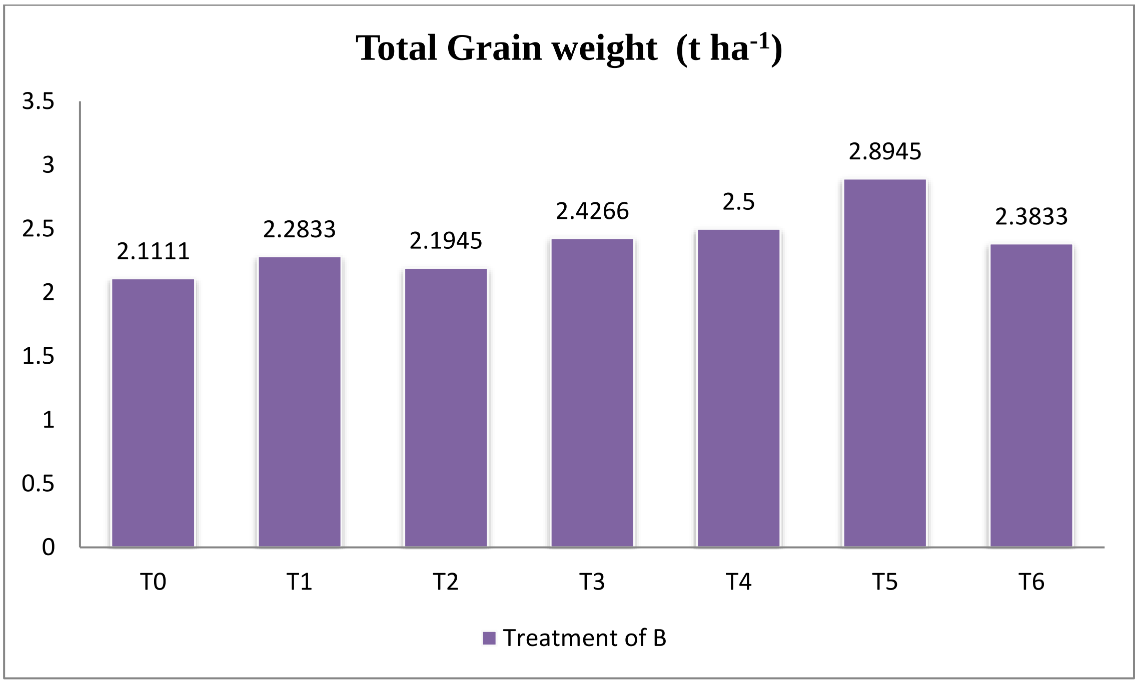

Fig. 6: Effect of B on Total Grain weight ha^{-1}of wheat

[T_0 (Control), T_1 (Soil application of 2 kg/ha B), T_2 (seed priming, o.1% boric acid), T_3 (Foliar spray at primordial stage, 0.4% boric acid), T_4 (Foliar spray at booting stage, 0.4% boric acid), T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid), T_6 treatment (Foliar spray at grain filling stage, 0.4% boric acid)]

4.1.16 Straw Yield (t ha^{-1})

Straw Yield ha^{-1} of wheat was influenced significantly by application of boron (Appendix 5). The findings showed that the highest straw weight (3.2611 t ha^{-1}) was found in T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid) followed by T_6 treatment (Foliar spray at grain filling stage, 0.4% boric acid), T_4 treatment (Foliar spray at booting stage, 0.4% boric acid), T_3 treatment (Foliar spray at primordial stage, 0.4% boric acid), T_1 treatment (Soil application of 2 kg/ha B), T_2 (seed priming, o.1% boric acid) respectively. Where the lowest straw weight (2.6221 t ha^{-1}) was recorded from T_0 (Control) (Fig.7). Saleem *et al*., showed that significantly the higher straw yield (5.136 t ha^{-1}) was recorded with 1.5% B spray at booting stage, while, the minimum straw yield (4.99 t ha^{-1}) recorded was from control. An increase of 2.92 % was observed with B spray in comparison to control. Nazim *et al.* (2005) also reported an upsurge in the straw yield with B spray. These findings are also in line with Muhmood *et al*. (2014) who observed increased straw yield with application of B.

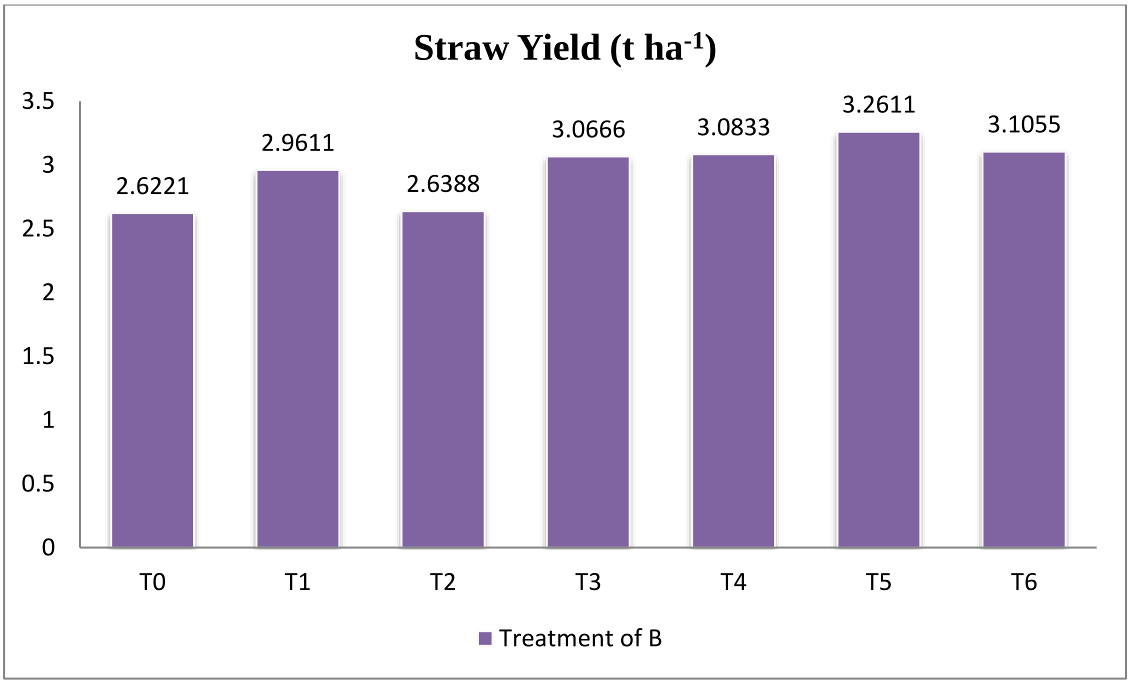

Fig.7: Effect of B on Straw Yield ha^{-1} of wheat

[T_0 (Control), T_1 (Soil application of 2 kg/ha B), T_2 (seed priming, o.1% boric acid), T_3 (Foliar spray at primordial stage, 0.4% boric acid), T_4 (Foliar spray at booting stage, 0.4% boric acid), T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid), T_6 treatment (Foliar spray at grain filling stage, 0.4% boric acid)]

4.2 Correlation matrix among different plant characters in wheat plant

4.2.1 Plant height

Plant height had positive and significant relation with Total no. of tiller plant^{-1} (r = 0.958), Length of flag leaf (r = 0.988), Breadth of flag leaf (r = 0.972), SPAD (r =.812), No. of total grain spike^{-1}(r =.933), No. of filled grain spike^{-1} (r = .940), Spikelet fertility (r = .979) Thousand Grain weight (r = .906) Grain weight (r = .915), Straw Yield (r = .924). It showed Negative and significant correlation with No. of in-effective tiller plant^{-1} (r = -.976), No. of total grain spike^{-1} (r = -.985). It also showed Positive and non significant correlation with Leaf no. plant^{-1} (r = 0.699), Spike length (r = 0.701), No. of effective tiller plant^{-1} (r = 0.708) (Table 5).

4.2.2 Total no. of tillers plant^{-1}

Total no. of tillers plant^{-1} had positive and significant relation with Leaf no. plant^{-1} (r = .793), Length of flag leaf (r = .945), Breadth of flag leaf (r = .933), SPAD (r = .856), No. of total grain spike^{-1} (r = .987), No. of filled grain spike^{-1} (r = .989), Spikelet fertility (r = .989), Thousand Grain weight (r = .914), Grain weight (r = .904), Straw Yield (r = .918). It showed Negative and significant correlation with No. of in-effective tiller plant^{-1} (r = -.931) and No. of filled grain spike^{-1} (r = -.966). It also showed Positive and non significant correlation with Spike length (r = 0.684), No. of effective tiller plant^{-1} (r = 0.694) (Table 5).

4.2.3 Leaf no. plant^{-1}

Leaf no. plant^{-1} had positive and significant relation with Breadth of flag leaf (r = .811), No. of total grain spike^{-1} (r = .866), No. of filled grain spike^{-1} (r = .860), Spikelet fertility (r = .793). It showed Negative and significant correlation with No. of in-effective tiller plant^{-1} (r = -.768). The findings showed that Leaf no. plant^{-1} had Positive and non significant correlation with Leaf no. plant^{-1}(r = 0.71), Spike length (r = 0.635), SPAD (r = 0.623), No. of effective tiller plant^{-1} (r = 0.298), Thousand Grain weight (r = 0.663), Grain weight (r = 0.54), Straw Yield (r = 0.714). It also showed Negative and non significant correlation with No. of un-filled grain spike^{-1} (r = 0.705) (Table 5).

4.2.4 Length of flag leaf

Length of flag leaf had positive and significant relation with Breadth of flag leaf (r = .967), SPAD (r = .853), No. of effective tiller plant^{-1} (r = .763), No. of total grain spike^{-1} (r = .934), No. of filled grain spike^{-1}(r = .939), Spikelet fertility (r = .962), Thousand Grain weight (r = .942) , Grain weight (r = .891), Straw Yield (r = .961). It showed Negative and significant correlation with No. of in-effective tiller plant^{-1} (r = -.952), No. of un-filled grain spike^{-1} (r = -.954). The findings showed that Length of flag leaf had Positive and non significant correlation with Spike length (r = 0.604) (Table 5).

4.2.5 Breadth of flag leaf

Breadth of flag leaf had positive and significant relation with SPAD (r = .761), No. of total grain spike^{-1} (r = .941), No. of filled grain spike^{-1} (r = .946), Spikelet fertility (r = .962), Thousand Grain weight (r = .862), Grain weight (r = .830), Straw Yield (r = .911). It showed Negative and significant correlation with No. of in-effective tiller plant^{-1} (r = -.989), No. of un-filled grain spike^{-1} (r = -.948). The findings showed that Length of flag leaf had Positive and non significant correlation with Spike length (r = 0.741), No. of effective tiller plant^{-1} (r = 0.582) (Table 5).

4.2.6 Spike length

Spike length had Negative and significant correlation with No. of in-effective tiller plant^{-1} (r = -.810), No. of un-filled grain spike^{-1} (r = -.772). It showed Positive and non significant correlation with SPAD (r = 0.269), No. of effective tiller plant^{-1} (r = 0.037), No. of total grain spike^{-1} (r = 0.656), No. of filled grain spike^{-1}(r = 0.666), Spikelet fertility (r = 0.73), Thousand Grain weight (r = 0.413), Grain weight (r = 0.635), Straw Yield (r = 0.635) (Table 5).

4.2.7 SPAD Value

SPAD had positive and significant relation with No. of effective tiller plant^{-1} (r = .896), No. of total grain spike^{-1} (r = .853), No. of filled grain spike^{-1} (r = .851), Spikelet fertility (r =.834), Thousand Grain weight (r = .862), Straw Yield (r = .858). It showed Negative and significant correlation with No. of un-filled grain spike^{-1} (r = -.758). The findings showed that Positive and non significant relation with Grain weight (r = 0.691). It also showed Negative and non significant correlation with No. of in-effective tiller plant^{-1} (r = -0.703) (Table 5).

4.2.8 No. of effective tiller plant^{-1}

No. of effective tiller plant^{-1} had positive and significant relation with Thousand Grain weight (r = .827), Straw Yield (r = .776). It showed Positive and non significant correlation with No. of total grain spike^{-1} (r = 0.65), No. of non-filled grain spike^{-1} (r = 0.652), Spikelet fertility (r = 0.669), Grain weight (r = 0.697). It also showed Negative and non significant correlation with No. of in-effective tiller plant^{-1} (r = -0.541), No. of un-filled grain spike^{-1} (r = -0.65) (Table 5).

4.2.9 No. of in-effective tiller plant^{-1}

No. of in-effective tiller plant^{-1} had positive and significant relation with No. of in-filled grain spike^{-1} (r = .970). It showed Negative and significant correlation with No. of total grain spike^{-1} (r = -.922), No. of filled grain spike^{-1}(r = -.929), Spikelet fertility (r = -.963), Thousand Grain weight (r = -.837), Grain weight (r = -.868), Straw Yield (r = -.878) (Table 5).

4.2.10 No. of total grain spike^{-1}

No. of total grain spike^{-1} had positive and significant relation with No. of filled grain spike^{-1} (r = 1.000) Spikelet fertility (r = .979), Thousand Grain weight (r = .911), Grain weight (r = .848), Straw Yield (r = .931). It showed Negative and significant correlation with No. of un-filled grain spike^{-1} (r = -.929) (Table 5).

4.2.11 No. of filled grain spike^{-1}

No. of filled grain spike^{-1} had positive and significant relation with Spikelet fertility (r = .983) Thousand Grain weight (r = .913) Grain weight (r = .857) Straw Yield (r =.931). It showed Negative and significant correlation with No. of un-filled grain spike^{-1} (r = -.937) (Table 5).

4.2.12 No. of un-filled grain spike^{-1}

No. of un-filled grain spike^{-1} had Negative and significant correlation with Spikelet fertility (r = -.982), Thousand Grain weight (r = -.876), Grain weight (r = -.944), Straw Yield (r = -.880) (Table 5).

4.2.13 Spikelet fertility

Spikelet fertility had positive and significant relation with Thousand Grain weight (r = .897), Grain weight (r = .899), Straw Yield (r = .911) (Table 5).

4.2.14 Thousand Grain weight

Thousand Grain weight had positive and significant relation with Grain weight (r = .903), Straw Yield (r = .987) (Table 5).

4.2.15 Grain weight

Grain weight had positive and significant relation with Straw Yield (r = .868) (Table 5).

4.2.16 Straw Yield

Straw Yield had positive and significant relation with Plant height (r = .924), Total no. of tiller plant^{-1} (r = .918), Leaf no. plant^{-1}(r = .961), Breadth of flag leaf (r = .911), SPAD (r = .858), No. of effective tiller plant^{-1} (r = .776), No. of total grain spike^{-1} (r = .931), No. of filled grain spike^{-1} (r = .931), Spikelet fertility (r = .911), Thousand Grain weight (r = .987), Grain weight (r = .868). It showed Negative and significant correlation with No. of in-effective tiller plant^{-1} (r = -.878), No. of un-filled grain spike^{-1} (r = -.880). The findings showed that Positive and non significant relation with Leaf no. plant^{-1} (r = 0.714), Spike length (r = 0.635) (Table5).

Table 5. Correlation matrix among the wheat plant characters under study

Variable	PH	TNTPH	LNPH	LFL	BFL	SL	SPAD	NETPH	NNeTPH	NTGPS	NFGPS	NNfGPS	SF	TGW	GW	SY
PH	1															
TNTPH	.958**	1														
LNPH	0.699	.793*	1													
LFL	.988**	.945**	0.71	1												
BFL	.972**	.933**	.811*	.967**	1											
SL	0.701	0.684	0.635	0.604	0.741	1										
SPAD	.812*	.856*	0.623	.853*	.761*	0.269	1									
NETPH	0.708	0.694	0.298	.763*	0.582	0.037	.896**	1								
NNeTPH	-.976**	-.931**	-.768*	-.952**	-.989**	-.810*	-0.703	-0.541	1							
NTGPS	.933**	.987**	.866*	.934**	.941**	0.656	.853*	0.65	-.922**	1						
NFGPS	.940**	.989**	.860*	.939**	.946**	0.666	.851*	0.652	-.929**	1.000**	1					
NNfGPS	-.985**	-.966**	-0.705	-.954**	-.948**	-.772*	-.758*	-0.65	.970**	-.929**	-.937**	1				
SF	.979**	.994**	.793*	.962**	.962**	0.73	.834*	0.669	-.963**	.979**	.983**	-.982**	1			
TGW	.906**	.914**	0.663	.942**	.862*	0.413	.862*	.827*	-.837*	.911**	.913**	-.876**	.897**	1		
GW	.915**	.904**	0.54	.891**	.830*	0.635	0.691	0.697	-.868*	.848*	.857*	-.944**	.899**	.903**	1	
SY	.924**	.918**	0.714	.961**	.911**	0.635	.858*	.776*	-.878**	.931**	.931**	-.880**	.911**	.987**	.868*	1

**, 1% level of significance; *, 5% level of significance

Note: PH=Plant height, TNTPH=Total no. of tiller plant^{-1},LNPH=Leaf no. plant^{-1}, LFL=Length of flag leaf, BFL=Breadth of flag leaf, SL=Spike length, NETPH=No. of effective tiller plant^{-1}, NNeTPH=No. of in-effective tiller plant^{-1}, No. of total grain spike^{-1} =NTGPS, NFGPS=No. of filled grain spike^{-1},NNfGPS=No. of un-filled grain spike^{-1}, SF=Spikelet fertility, TGW=Thousand Grain weight , GW=Grain weight , SY=Straw Yield

Chapter V

SUMMARY AND CONCLUSION

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The experiment was conducted at the research field of Sher-e-Bangla Agricultural University, Dhaka to evaluate Methods of Application of Boron Influence to Morpho-physiological Attributes and Yield of Wheat (*Triticum aestivum* L.) during the period from November 2019 to March 2020. The experiment was laid out into Randomized Complete Block Design (RCBD) with three replications. There were 21 unit plots and the size of the plot was 3m × 2m i.e. 6m^2. There were 7 treatments. All intercultural operations were practiced as and when required. Wheat seed of cv. BARI Gom-33 was sown as test crop. Data on different growth and yield parameters were recorded and analyzed statistically. Most of the parameters showed significant difference among the treatment. However, the highest value was always observed for any boron treatment and the lowest value was noted for the control treatment.

In terms of different methods of boron application at different stage of wheat significant variation was found for the most of the parameters. Results indicated that the highest plant height (94.467 cm) was found in T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid) where the shortest plant height (87.600 cm) was recorded from T_0 (Control) treatment. The highest number of total tiller hill^{-1} (3.7000) was found in T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid), the lowest number of total tiller hill^{-1} (2.1867) was recorded from T_0 (Control) treatment. The highest number of leaf 12.783 was recorded under T_1 (Soil application of 2 kg/ha B), T_0 (Control) give the lowest value (9.500). T_5 treatment (Foliar spray at primordial and booting stages, 0.4% boric acid) produced the longest length (23.393 cm), the shortest Flag leaf length (20.430 cm) was observed in control T_0 treatment. The results showed that the maximum breadth of flag leaf of wheat (2.6267cm) was produced by application of T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid), minimum value (2.2333) was found at T_0 (Control) treatment. T_5 treatment (Foliar spray at primordial and booting stages, 0.4% boric acid) produced the longest spike length (12.887 cm), the shortest spike length (12.293 cm) was observed in control T_0 treatment. Maximum SPAD value (51.063) found in T_6 treatment (Foliar spray at grain filling stage, 0.4% boric acid), Minimum value (2.2333) was found at T_0 (Control) treatment. The findings showed that the highest number of total tiller hill^{-1} (2.6667) was found in T_6 treatment (Foliar spray at grain filling stage, 0.4% boric acid), the lowest number of total tiller hill^{-1} (1.9333) was recorded from T_0 (Control). The highest number of non-effective tiller hill^{-1} (0.1733) was found in T_0 (Control), the lowest non effective tiller hill^{-1} (0.0633) was recorded from T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid). The findings showed that the highest number of total grain spikelet^{-1} (68.867) was found in T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid), where the lowest number of total grain spikelet^{-1} (52.800) was recorded from T_0 (Control). The highest filled grain spikelet^{-1} (67.733) was found in T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid), the lowest filled grain spikelet^{-1} (50.610) was recorded from T_0 (Control). The findings showed that the highest number of non-filled grain spikelet^{-1} (2.1900) was found in T_0 (Control), Where the lowest number of non-filled grain spikelet^{-1} (1.1333) was recorded from T_5 treatment (Foliar spray at primordial and booting stages, 0.4% boric acid). The maximum Spikelet fertility (%) (98.353) found in T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid), minimum value (95.850) was found at T_0 (Control) treatment. The highest 1000 grain weight (52.667 g) was noted at T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid), lowest (42.433 g) was obtained from T_0 treatment. The findings showed that the highest total grain weight (2.8945 t ha^{-1}) was found in T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid), while the lowest total grain weight (2.1111 t ha^{-1}) was recorded from T_0 (Control). The findings showed that the highest straw weight (3.2611 t ha^{-1}) was found in T_5 (Foliar spray at primordial and booting stages, 0.4% boric acid), where the lowest straw weight (2.6221 t ha^{-1}) was recorded from T_0 (Control).

Conclusion:

Wheat yield is markedly affected due to grain set failure and unhealthy grain induced by boron deficiency. This element deficiency can be overcome by boron fertilizer use. Boron fertilizer can be effectively used through foliar spray at booting stage of crop.

- From the above findings, it can be concluded that the highest performance regarding yield and yield contributing parameters were obtained to the effect of T_5 treatment (Foliar spray at primordial and booting stages, 0.4% boric acid).

- Although seed soaking into boric acid solution was found to be a weak method of boron application compared to soil or foliar application, still it produced better result than control treatment.
- Finally, all the yield and yield attributing characters were found lowest in control treatments.

However, it needs more trials under farmer's field conditions at different agroecological zones of Bangladesh for the conformation of the results.

Chapter VI

REFERENCES

CHAPTER VI

REFERENCES

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Chapter VII

APPENDICES

Appendix 1. Morphological characteristics of the experimental field

Morphological features	Characteristics
Location	Sher-e-Bangla Agricultural University Research Farm, Dhaka
AEZ	AEZ-28, Modhupur Tract
General Soil Type	Deep Red Brown Terrace Soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled

Appendix 2. Physical composition of the soil

Soil separates	%	Methods employed
Sand	20	Hydrometer method (Day, 1915)
Silt	45	Do
Clay	35	Do
Texture class	clay loam	Do

Appendix 3. Chemical composition of the soil

Sl. No.	Soil characteristics	Analytical data	Methods employed
1	Organic carbon (%)	0.45	Walkley and Black, 1947
2	Total N (%)	0.03	Bremner and Mulvaney, 1965
3	Total S (ppm)	225.00	Bardsley and Lanester, 1965
4	Total P (ppm)	840.00	Olsen and Sommers, 1982
5	Available N (kg/ha)	54.00	Bremner, 1965
6	Available P (ppm)	20.54	Olsen and Dean, 1965
7	Exchangeable K (me/100 g soil)	0.10	Pratt, 1965
8	Available S (ppm)	16.00	Hunter, 1984
9	pH (1:2.5 soil to water)	5.6	Jackson, 1958
10	CEC	11.23	Chapman, 1965

Source: Soil Resource and Development Institute (SRDI), Farmgate, Dhaka

Appendix 4. Monthly records of air temperature, relative humidity, rainfall and sunshine hours of the experimental site during the period from November, 2019 to March, 2020

Month	Year	Monthly average air temperature (^{o}C)			Average relative humidity (%)	Total rainfall (mm)	Total sunshine (hours)
		Maximum	Minimum	Mean			
Nov	2019	24.9	18.5	21.7	74	37	216.4
Dec	2019	19.3	15.5	17.4	74	5	212.50
Jan	2020	18.5	15	16.75	76	21	212.50
Feb	2020	21.6	18	19.8	59	1	195.00
Mar	2020	26.4	18.5	22.45	57	30	225.50

Appendix 5. Analysis of variance

Source Of variance	DF	Plant height (cm)	Total no. of tiller hill^{-1}	Leaf no. hill^{-1}	Length of flag leaf(cm)	Breadth of flag leaf(cm)	Spikelet length (cm)	SPAD	No. of effective tiller hill^{-1}
Replication	2	0.259	0.068	1.178	0.156	0.005	0.007	0.267	0.059
Treatment	6	18.178**	0.682**	3.810**	3.755**	0.100**	0.143**	1.711**	0.224**
Error	12	2.033	0.055	0.667	0.229	0.007	0.015	0.309	0.055

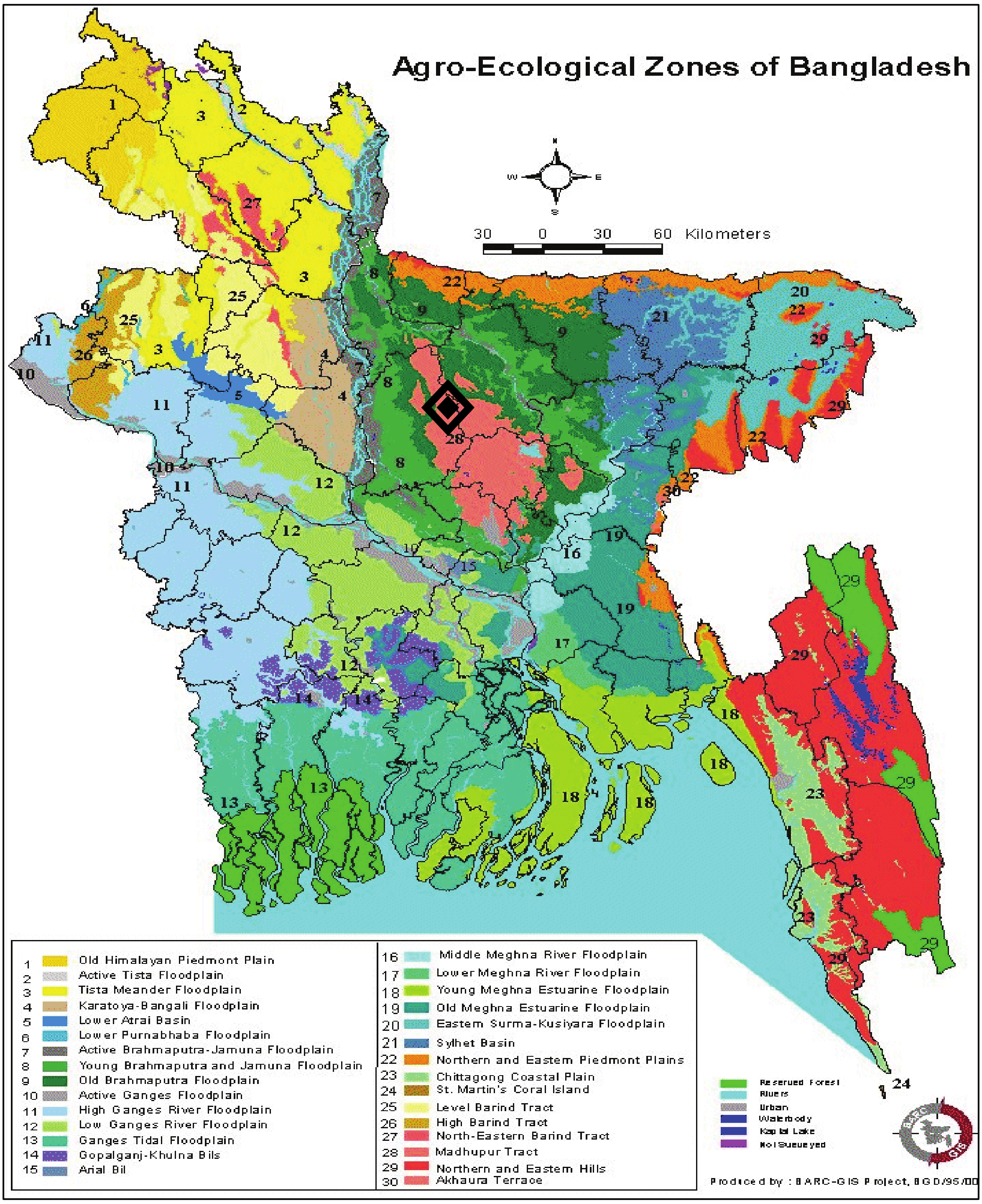
**, 1% level of significance

Appendix 5. Contd.

Source	DF	No. of non-effective tiller hill^{-1}	No. of total grain spikelet^{-1}	No. of filled grain spikelet^{-1}	NO. of non-filled grain spikelet^{-1}	Spikelet Fertility (%)	1000 grain weight (gm)	Grain weight (kg)(total)	Straw Yield(kg)
Replication	2	0.0001	1.609	1.540	0.053	0.120	5.361	0.007	0.034
Treatment	6	0.005**	85.400**	96.278**	0.374**	2.032**	40.796**	0.071**	0.064*
Error	12	0.001	1.915	1.779	0.047	0.111	7.039	0.010	0.018

**, 1% level of significance *, 5% level of significance

Appendix 6. Experimental location on the map of Agro-Ecological Zone of Bangladesh.



Experimental area under study

Plates: Image of different stages of wheat in experimental plot

Plates: Image of different stages of wheat in experimental plot Contd.