EFFECT OF MICRONUTRIENTS ON THE GROWTH AND YIELD OF WHEAT

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CERTIFICATE

This is to certify that thesis entitled ***"EFFECT OF MICRONUTRIENTS ON THE GROWTH AND YIELD OF WHEAT"*** *submitted to the* ***Faculty of Agriculture,*** *Sher-e-Bangla Agricultural University (SAU), Dhaka in partial fulfillment of the requirements for the degree of* ***MASTER OF SCIENCE (MS) IN SOIL SCIENCE****, embodies the result of a piece of bonafide research work carried out by* ***DIPTI RANI SARKAR, Registration no. 08-03026*** *under my supervision and guidance. No part of the thesis has been submitted earlier for any other degree or diploma.*

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

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ABSTRACT

A field experiment was carried out at the experimental field of Sher-e-Bangla Agricultural University (SAU), during October 2013 to February 2014, to study the effect of different levels of Zinc (Zn) and Boron (B) fertilization on the grain yield of wheat (BARI Gom-26). The experiment included four levels of Zn viz. 0, 0.02 %, 0.04 % and 0.06% Zn which were applied as foliar application and four levels of B viz. 0, 0.5, 1.0 and 1.5 kg ha^{-1} which were applied as soil application. The experiment was laid out in a randomized complete block design with three replications. The results revealed that yield and yield contributing characters were influenced significantly by levels of zinc and boron. The tallest plant (80.26 cm) and the highest grain yield (2.73 t ha^{-1}) were obtained from Zn_2 treatment (0.04 % Zn). In contrast, the shortest plant (77.73 cm) and minimum grain yield (2.30 t ha^{-1}) were observed when Zn was not applied (Zn_0 treatment). On the other hand, plant height (80.02 cm) and grain yield (2.79 t ha^{-1}) were the highest when B_2 treatment (1 kg B ha^{-1}) was imposed. The shortest plant height (76.85 cm) and the lowest grain yield (2.35 t ha^{-1}) being recorded from the control treatment B_0. All the yield and yield contributing characters were significantly affected due to the interaction effects of different levels of Zn and B. Among the interactions, the tallest plant (83.56 cm) and the highest grain (3.27 t ha^{-1}) were obtained from combined treatment Zn_2B_2.On the contrary, the lowest performances for all the studied crop characters were observed from the treatment combination Zn_0B_0 where Zn and B were not applied. The results showed that grain yield of wheat increased with increasing levels of both Zn and B up to Zn_2 treatment (0.04 %) and B_2 treatment (1.0 kg ha^{-1}) , respectively. The effect of B was more prominent than with Zn on different yield components and yield of wheat.

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LIST OF ABBREVIATIONS

AEZ	=	Agro Ecological Zone
BARI	=	Bangladesh Agricultural Research Institute
BAU	=	Bangladesh Agricultural University
BCR	=	Benefit Cost Ratio
BINA	=	Bangladesh Institute of Nuclear Agriculture
BSS	=	Bangladesh Bureau of statistics
CGR	=	Crop Growth Rate
cm	=	Centimeter
^{0}C	=	Degree Celsius
DAS	=	Days after sowing
EDTA	=	Ethylene Diamine Tetra Acetic Acid
et al.	=	and others
FAO	=	Food and Agriculture Organization
FYM	=	Farm Yard Manure
g	=	gram (s)
HI	=	Harvest Index
IAA	=	Indole Acetic Acid
kg	=	Kilogram
kg/ha	=	Kilogram/hectare
LER	=	Land Equivalent Ratio

LSD	=	Least Significant Difference
MoP	=	Muriate of Potash
m	=	Meter
NAR	=	Net Assimilation Rate
p^H	=	Hydrogen ion conc.
ppm	=	Part Per Million
RNA	=	Ribonucleic Acid
RARS	=	Regional Agriculture Research Station
RCBD	=	Randomized Complete Block Design
SAU	=	Sher-e-Bangla Agricultural University
SRDI	=	Soil Resource Development Institute
TSP	=	Triple Super Phosphate
t/ha	=	ton/hectare
UNDP	=	United Nations Development Programme
%	=	Percent

CHAPTER I

INTRODUCTION

Wheat *(Triticum aestivum L.)* is a major cereal crop and ranks second (after rice) in Bangladesh and first both in acreage and production in the world context (UNDP and FAO, 1999).About one- third of the total population of the world live on wheat grain consumption. In 2013, world production of wheat was 713 million tons, making it the third most-produced cereal after maize 1,016 million tons and rice 745 million tons (Wikipedia). Globally, wheat is the leading source of vegetable protein in human food, having a higher protein content than other major cereals, maize (corn) or rice. In Bangladesh, the amount of rice production is not enough for feeding a large number of its hungry people. Moreover, wheat constitutes 15 to 20 per cent of the staple cereal food of Bangladesh which stands on the second position considering the relative importance of all food crops (Rahman, 1980). Bangladesh produces 1302998 metric tons of wheat per annum from 1061602 acres of land with an average yield of 3.03 t ha^{-1} (BBS, 2014). Wheat grain has high food value. Wheat grains contain 14.7% protein, 2.1% fat, 78.1% starch and 2.1% mineral matter (Peterson, 1965). Bangladesh is a small country with large population and its population has an increasing trend. So, cereal crop production like wheat should be increased to meet the demand of the escalating population in this country where per capita requirement of cereal food is more than 400g. There is also a great prospect of wheat cultivation in Bangladesh as it is cultivated in winter season, when it is more or less free from climatic hazards and diseases. Thus wheat may solve to a considerable extent the food problem and save huge foreign currency of the country as well.

Fertilizers are indispensable for the crop production system of modern agriculture. It plays a very important role in utilizing the soils for an efficient crop production. Today inorganic fertilizers hold the key to success for increased crop productivity under Bangladesh agriculture. The elements essential for plants are C, H, O, N, P, K, Ca, Mg, S, Fe, Cu, B, Mn, Mo, Zn, Cl. Out of these 16 elements, 9 essential elements have been classified as "macronutrients" as these are required in relatively large amount by the plants. These elements include C, H, O, N, P, K, C Mg, S. The remaining of the elements (B, Cu, Fe, Cl, Mn, Mo and Zn) are called “trace elements” (Alloway, 1990; Brady & Weil, 2002. Essential trace elements are often called “micronutrients” because they are required in small, but in critical concentrations by living organisms. The importance of micronutrients nutrition of crops was almost overlooked. However, Micronutrients are essential plant nutrients and play a significant role in plant nutrition which finally leads healthy growth and increased yield. The availability of micronutrients in soils depends on the solubility of micronutrients, the pH and redox potential of the soil solution and nature of binding sites on the organic and inorganic particle surfaces. Soil fertility is an important factor, which determines the growth of plants. Soil fertility is determined by the presence or absence of macro and micronutrients, which are required in minute quantities for plant growth. Micronutrients also enhance plant productivity; leaf area and grain yield as well as enhance the enzymatic system of plants. Micronutrients are elements with specific and essential physiological functions in plant metabolism (Marschner, 1995). These are regarded as catalytic agents required for growth in lower amount and serve mainly as constituents of prosthetic groups in metallo-proteins and also as activators of enzymatic reactions.

In Bangladesh, nutrient stresses on soils are progressively increasing due to high cropping intensity with high yielding crop varieties, decreasing of organic matter from soil etc. So, Need for micronutrient in soil is increasing, yet the proportion of different fertilizer used in the country is not quite balanced. Micronutrient deficiency is widespread in many Asian countries due to the calcareous nature of soils, high pH, low organic matter content, salt stress, continuous drought, high bicarbonate content in irrigation water, and imbalanced application of NPK fertilizers (Narimani *et al.,* 2010). Among different micronutrient elements, Zn and B are considered to be the most important in order to obtain optimum production in case of wheat. Both Zinc and Boron are known to be required for all higher plants as essential crop nutrients and are well documented to be involved in photosynthesis, N-fixation, respiration and other biochemical pathways (Cakmak *et al.*, 1988, and Goldbach *et al.*, 1991).

Zinc is an essential component of various enzyme systems for energy production, protein synthesis and growth regulation. It also helps in the reproduction of plants. Zn is known to have an important role either as a metal component of enzymes or as a functional, structural or regulatory cofactor of a large number of enzymes (Grotz and Guerinot, 2006). Zinc is an essential micronutrient for plant growth and is absorbed by the plant roots in the form of Zn^{2+}. It is involved in diverse metabolic activities, influences the activities of hydrogenase and carbonic anhydrase, synthesis of cytochrome and the stabilization of ribosomal fractions and auxin metabolism (Tisdale *et al*., 1984). Hence, Application of Zn fertilizer is a promising short-term approach to improve Zn concentrations in seeds and can also contribute to alleviation of Zn deficiency related health problems in the developing world (Aslam *et al.*, 2014). Zinc, in addition, is reported to be having possible role in reducing the toxic effects of excessive boron (Singh *et al.*, 1990). Zinc helps in auxin metabolism, cytochrome synthesis and stabilization of ribosomal fractions (Tisdale *et al.*, 1997).

The soils of Bangladesh in some areas are deficient in some micro elements and boron is one of them. Boron is essential for growth and yield of crops. It is relatively mobile in plants and is absorbed as BO_3^-. Vitosh *et al.* (1997) expressed that B is involved in carbohydrates metabolism and it is essentially necessary for protein synthesis, pollen germination and seed and cell wall formation. Boron plays an important role in the physiological process of wheat plant such as cell elongation, cell maturation, sugar translocation, meristematic tissues development, protein synthesis and ribosome for maturation (Mengel and Kirkby, 1987). Rehem *et al.* (1998) stated that B plays a key role in water and nutrients transportation from root to shoot. They believe that boron shortage causes barren stalks and small, twisted ears and grain yield reduction through impaired development of anthers and ultimately failure of seed setting. Boron helps to develop root system, fruit setting and grain formation. Most of the amino acids increase with an increase in B supply (Iqtidar and Rehman, 1984). However, there are a few reports on the effects of boron in wheat in Bangladesh (BINA, 1993; BARI, 1978).

Among the micronutrients, Zinc and Boron deficiency are prominent in Bangladesh soils. Due to the deficiency of zinc plants exhibits poor growth, interveinal chlorosis and necrosis of lower leaves. Reddish or brownish spot often occurs on the older leaves and ultimately seed production is strikingly reduced due to its deficiency (Throne, 1957). Its deficiency is particularly widespread in cereals that are grown on calcareous soil (Graham *et al* . , 1992). Deficiency of zinc in wheat has been reported from various parts of the world, Bangladesh soils are not exception to this. Almost 50% of the world soils used for cereal production are Zn deficient (Gibbson, 2006). Zinc deficiencies are widely spread throughout Bangladesh, especially in the wheat field, deficiencies occur in neutral and calcareous soils. Boron deficiency is reported on some soils and crops (Jahiruddin *et al*., 1991). The primary function of boron is related to cell wall formation, so boron deficient plant may be stunted. It may induce male sterility in wheat. The deficiency of B causes *grain* set in *wheat* to fail higher crop yields naturally have higher requirement of nutrients due to more pressure on the land for available forms of nutrients. Its deficiency also results in impaired crop growth and development. Application of these micronutrients results in better crop growth and thus in increased crop yield (Torun *et al.*, 2001; Grewal *et al.*, 1997). Similarly, different experiments have been conducted to evaluate the response of wheat genotypes to boron application and a wide range of genotypic variation in response to B deficiency (Rerkasem and Jamjod, 1999) and toxicity (Paul *et al*., 1991) have been reported. Jahiruddin *et al*. (1995), Abedin *et al*. (1994), and Rerkasem *et al*. (1989) obtained higher yield of wheat with the application of B to the crop. Grain sterility of wheat as per world literature may be associated with the deficiency of some micronutrients, especially B (Mandal and Das, 1988, Rerkasem *et al.*, 1991 and Jahiruddin *et al.*, 1992). Boron deficiency was much reported for rabi crops, especially mustard, wheat and chickpea (Ahmed *et al*., 1991; Jahiruddin *et al*., 1995).

The prevailing situation underscores the need for investigation whether micronutrient deficiency is a causative factor for poor grain formation, grain yield and nutrient content of wheat. Thus the present study was conducted to assess the effect of micronutrients on the growth and yield of wheat.

With conceiving the above scheme in mind, the present research work has been undertaken in order to fulfill the following objectives:

Objectives:

-To find out the optimum dose of micronutrients (Zn and B) on the growth and yield of wheat.

-To study the effect of zinc and boron on the growth and yield of wheat under different doses of micronutrients.

- To show the interaction effect between zinc and boron under different doses.

CHAPTER II

REVIEW OF LITERATURE

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops in Bangladesh. 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). Among micronutrients, Zinc and Boron are the most important micronutrient elements those play a significant role in crop production. 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). Zinc is a micronutrient which is required for plant growth relatively in a smaller amount. It plays a key role in pollination and seed set processes; so that its deficiency can cause to decrease in seed formation and subsequent yield reduction (Ziaeyan and Rajaiea 2009). B also helps in protein synthesis, root system development, fruit and seed formation of plant (Brady, 1996). This chapter presents a review of literature in relation to the effect of Zn and B on wheat. It is divided into two sections; each section represents each element (Zn and B). Each section has been started with a short description about occurrences, forms and functions of an element. However, the research work so far done at home and abroad regarding the performance of wheat under different levels of zinc and boron fertilizers along with other pertinent information are reviewed below.

2.1 Zinc and Boron in wheat

2.1.1 Role of Zinc in wheat

Zinc (Zn) is a micronutrient which is required for plant growth and development relatively to a smaller amount. The total Zn content of soils lies between 10 to 300ppm. The important Zn containing minerals are sphalerite (ZnS), smithsonite ($ZnCO_3$) hemimorphite [$Zn_4(OH)_2.Si_2O_7.H_20$] and franklinite ($ZnO.Fe_2O_3$). The normal concentration range for Zn in dry matter of plant is 25 to 150ppm. Deficiencies are usually associated with leaf concentration of less than 20ppm. Plant roots absorb Zn as Zn^{2+}. Zinc is involved in a diverse range of enzymatic activities. Zinc is an important essential element present in plant enzymatic systems.

Ranjbar and Bahmaniar (2007) conducted an experiment in order to investigate the role of Zn application (soil + foliar application) on growth traits, yield, its concentration and accumulation in wheat leaves and grains, two common cultivars of wheat namely Tajan and Nye 60 have been selected. It was found that Zn had increasing effects on grain yield, total dry matter, yield, 1000-grain weight, number of tiller, grain Zn content, flag leaf Zn content, plant height, number of node, protein content and grain Fe content.

Genc *et al.* (2006) reported that Zn has vast functions in plant metabolism and consequently Zinc deficiency has a multitude of effects on plant growth. Zinc sulphate increased the Leaf Area Index, the total number of fertile tillers m^{-2}, number of spikelets $spike^{-1}$, spike length, grain $spike^{-1}$, thousand grain weight, grain yield, straw yield and biological yield and decreased harvest index. All applications of Zinc sulphate gave economic increases in margins over costs but the application of 5 kg ha^{-1} gave the highest marginal rate of return.

Seilsepour (2006) conducted an experiment to optimize consumption of Zinc and evaluate of Zinc effects on quantitative and qualitative traits of winter wheat under saline soil condition. It was done by three replications in randomized complete block design. The experiment had four treatments as Control without Zn, 40 kg ha^{-1} Zn as $ZnSO_4$, 80 kg ha^{-1} Zn as $ZnSO_4$ in soil and 120 kg ha^{-1} Zn as $ZnSO_4$ in soil. The highest grain yield (4355 kg ha^{-1}) and highest Zn concentration in seeds (39.1 mg kg^{-1}) obtained by using of 120 kg ha^{-1} Zn as $ZnSO_4$ as soil application. Use of Zinc Sulfate had not any effects on straw, ear per square meter, number of seed per ear and concentration of Fe, Mn and Cu in seeds. Totally, use of 80 kg ha^{-1} Zn as $ZnSO_4$ in soil was recommended to obtain highest grain yield with high quality in saline condition.

Zinc has been found useful in improving yield and yield components of wheat (Cakmak *et al.,* 1996; Modaihsh, 1997; Kaya *et al.,* 2002 and Singh, 2004) and adequately applied zinc has been shown to improve the water use efficiency of wheat plants (Bagci *et al.,* 2007).

The variations in number of tillers per hill, panicle length, weight of 1000 grains, yields of grain and straw, Zinc concentrations and Zinc uptake by grain and straw and Zinc concentrations both pre-sowing and post-harvest soils clearly indicated that the native Zinc concentration influenced them greatly and the variations were different in different locations. The nature of vegetations was also influenced by application. In order to obtain an optimum production and quality crops application of Zinc with other nutrients should be advised particularly for wheat cultivation (Riffat *et al.,* 2007).

In general, Zinc application appears to improve the overall field performance of wheat plants. The most of the seed-Zinc located in embryo and aleurone layer, whereas the endosperm is very low in Zn concentration .The embryo and aleurone parts are also rich in protein and phytate indicating that protein and phytate in seeds could be sinks for Zn. According to a Zn-staining study in wheat seed, Zn concentrations were found to be 150mg kg ha^{-1} in the embryo and the aleurone layer and only 15 mg kg ha^{-1} in the endosperm. The Zn-rich parts of wheat seed are removed during milling, thus resulting in a marked reduction in flour Zn concentrations (Ozturk *et al.,* 2006)

The effects of Zinc on the yield and yield components of wheat cv. Kiziltan-91 were determined in a field experiment conducted in Ankara, Turkey during 1998-2000. Zinc application increased the grain yield, number of seeds $spike^{-1}$ and seed weight $spike^{-1}$ of the crop (Atak *et al.,* 2004).

As a plant nutrient the role of Zinc in crop production, including wheat cultivation, has been well established (Kanwar and Randhawa, 1974 and Takkar *et al.,* 1971). Deficiency and response to zinc in wheat have been reported from various parts of the world. Bangladesh soils are not exception to this.

Zn supply is considered as an important factor in reproduction process. According to Brown *et al.* (1993) formation of male and female reproductive organs and pollination process are disturbed in Zn deficiency which may be attributed to the reduction of Indole acetic acid (IAA) synthesis.

Yilmaz *et al.* (1997) reported that following Zn fertilization, thousand grain weights showed an increase of 26% in wheat plants.

Hemantaranjan and Grag (1988) observed that optimum utilization of Zn and Fe significantly increased thousand grain weights in wheat.

Dwivedi and Tiwari (1992) also reported that application of Zn increased zinc uptake in grain and straw.

2.1.2 Role of boron in wheat

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).

2.2 Yield and Yield Attributing Characters

2.2.1 Effect of zinc

Zinc is a micronutrient which is required for plants growth relatively in a smaller amount. The normal concentration range for Zn in dry matter of plants is 25 to 150 mg g^{-1}. Roots absorb Zn in the form of Zn^{2+}. Zinc is involved in a diverse range of enzymatic activities.

Ghafoor *et al*. (2014) conducted this study during growing season of 2010 - 2011, to study the effect of four levels of Zinc as Zn- EDTA (0, 20, 40, 60 kg Zn ha^{-1}) on growth traits and yield of wheat variety ovanto at two different agricultural locations (Bakrajow and Kanypanka). The results showed that the increase in rates of Zn causes an increase in grain yield, grain Zn content and Zn uptake by plant, from both of locations. However, the results showed that the relative yield was decreased with increasing of Zn application rate from both of locations.

Mekkei and El-Haggan Eman (2014)conducted two field experiments to study the effect of Cu, Fe, Mn, Zn foliar application on yield and quality of four wheat cultivars (Sids 13, Sakha 94, Misr 1 and Gemeiza 7). Results showed that foliar application by all micronutrients gave significant effect on yield traits and protein content in both seasons compared with control treatment. Moreover, foliar application with combination of micronutrients (Cu+ Fe+ Mn+ Zn) produced the highest values of plant height (85.03 and 87.17 cm),tillers number m^{-2} (318.4 and 329.3), spikes number m^{-2} (279.33 and 282.9), spike length (9.32 and 9.56 cm), number of spikelets $spike^{-1}$ (16.26 and16.37), number of grains $spike^{-1}$ (39.73 and 40.98), 1000-grain weight (42.50 and 43.26 g), grain yield (6.270 and 6.400 ton ha^{-1}), straw yield (12.58and 12.77 ton ha^{-1}), biological yield (18.84 and 19.17 ton ha^{-1}) and harvest index (33.21 and 33.36 %), respectively, in both seasons followed by Zn foliar application followed by Mn foliar application followed by Fe foliar application then Cu foliar application. Among wheat cultivars Sids 13 cultivar ranked 1st in all yield traits and protein content in both seasons followed by Misr 1 followed by Gemeiza 7 cultivar. However, Sakha 94 gave the lowest values of yield traits and protein content. It concluded that sowing Sids 13 cultivar with foliar application micronutrients (Cu+ Fe+ Mn+ Zn) produce high grain yield and greatest grain protein content.

Bameri *et al. (*2012)conducted an experiment with different microelements (Zn, Fe and Mn) and found that plant height, biological yield ,grain yield and yield components were significantly affected by the application of Zn, Fe, Mn alone and combination. There was a positive effect on yield and yield components of wheat.

Ai-Qing *et al*. (2011) conducted an experiment with combination of two Fe levels (0 and 5 mgl^{-1}) and three Zn levels (0, 0.1 and 10 mgl^{-1}). Results showed that supply of Fe (5 mg l^{-1}) and Zn (0.1 mgl^{-1}) increased plant dry weight and leaf chlorophyll content compared to the Fe or Zn deficient (0 mgl^{-1}) treatments. Results from stepwise regression analysis of Fe, Zn, Cu, and Mn concentrations in wheat tissues, Root- and leaf-Fe concentrations were negatively correlated with Zn, Cu, and Mn, whereas stem-Fe concentrations were positively correlated with leaf-Mn concentrations. Root-, stem- and leaf-Zn concentrations were positively correlated with root- and stem-Cu.

Gul *et al*. (2011) designed an experimental trial to quantify the response of yield and yield component of wheat toward foliar spray of nitrogen, potassium and zinc. Yield and yield component of wheat showed significant response towards foliar spray of Nitrogen, Potassium and Zinc. Maximum biological yield (8999 kg ha^{-1}),number of grains (52) spike^{-1} and straw yield (6074 kg ha^{-1}) were produced in plots under the effect of foliar spray of 0.5%N + 0.5% K + 0.5% Zn solution (once), while control (no spray) plots produced minimum biological yield (5447 kg ha^{-1}),number of grains (29) spike^{-1} and straw yield (3997 kg ha^{-1}). Similarly maximum thousand grain weight (46 g) and grain yield (2950 kg ha^{-1}) were recorded in plots sprayed with 0.5% N + 0.5% K + 0.5% Zn solution (twice), followed by lowest values (36 g) and (1450 kg ha^{-1}) in plots having no spray (control). Among the treatment of 0.5% N + 0.5% K + 0.5% Zn solution applied either one or two times, gave best response towards yield and yield components of wheat in irrigated area of Peshawar valley.

Zeidan *et al*. (2010) carried out two field experiments for increasing wheat yield and improve grain quality by increasing Zn and Fe in grains for human food in the developing country and to investigate the effect of micronutrient foliar application on wheat yield and quality of wheat grains. Results indicated that grain yield, straw yield, 1000-grain weight and number of grains/spike, Fe, Mn and Zn concentration in flag leaves and grains as well as, protein content in grain were significantly increased by application of these elements.

Potarzycki and Grzebisz (2009) reported that zinc exerts a great influence on basic plant life processes, such as (i) nitrogen metabolism– uptake of nitrogen and protein quality; (ii) photosynthesis– chlorophyll synthesis, carbon anhydrase activity; reported that Zn-deficient plants reduce the rate of protein synthesis and protein content drastically Mn is required for biological system, enzyme activation, oxygen carrier in nitrogen fixation.

Habib (2009) stated that the appearance of micronutrient deficiency in crops reduced quality of grain and production. He conducted a field experiment on clay-loam soil to investigate the effect of foliar application of zinc and iron on wheat yield and quality at tillering and heading stage. The treatments were control (no Zn and Fe Application), 150 g Zn ha^{-1} as $ZnSO_4$, 150 g Fe ha^{-1}as Fe_2O_3, and a combination of both Zn and Fe. In this study, parameters such as wheat grain yield, seed-Zn and Fe concentration were evaluated. Results showed that foliar application of Zn and Fe increased seed yield and its quality compared with control. Among treatments, application of (Fe + Zn) obtained highest seed yield and quality.

Khan *et al.* (2008) have reported that Zinc applications actually decreased harvest index but this marginal reduction was compensated for by a greater biomass increase. It seems probable that the supplied Zinc had a mitigation effect of high temperature stress during reproductive growth. It is recommended that under such calcareous soil conditions growers can expect good returns from the application of 5 kg ha^{-1} zinc sulphate at the time of sowing. Results showed that maximum increasing of grain yield by Zn application, grain yield increase received to 1200 mg kg^{-1} in soils which contain 0.5 mg kg^{-1} available Zn .

Shaheen *et al.* (2007) conducted a pot experiment to study the yield and yield contributing characters, Zinc concentrations and its uptake by wheat. Six different locations of Bangladesh were collected. The results obtained indicated the number of tillers per hill, grain and straw yield of wheat, Zinc concentrations and Zinc uptake both in grain and straw and Zinc concentrations of pre-sowing and post—harvest soils were significantly increased with the application of Zinc. But the effect of applied Zinc was more pronounced in Khulna, BAU Farm, Maskanda and Modhupur soils than in the highly acidic Sylhet soil or calcareous soil of Ishurdi. It is evident that for obtaining increased yield of wheat, Zinc status of the soils should be improved and for this Zinc fertilization and seems imperative and care should be taken while a Zinc fertilizer to the soil. Higher rates of Zinc may be required for acid and calcareous soils.

Rajendra *et al.* (2007) also observed that the effects of the application of micronutrients on the performance of a rice-wheat cropping system were studied in Kanpur, Uttar Pradesh, India, from 1997-98 to 2000-01. Nitrogen, phosphorus and potassium at recommended rates were applied for all treatments. The gross returns and grain and straw yields increased with the application of sulfur, Zinc chloride or Zinc chloride + Zinc sulfate. The total gross returns for both crops increased by 26% over the control following the basal application of 10 kg Zinc ha^{-1} through Zinc sulfate.

Ananda and Patil (2007) reported that a field experiment was conducted during rabi season of 2002-03 on deep vertisol at Research and Development Farm, Ugar Khurd, Belgaum, Karnataka, India. The results of the study indicated that highest total dry matter (DM) production (247.6 g m^{-1} row length), plant height (95.7 cm), number of effective tillers m^{-2} (259) due to combined application of Zn at 25 kg ha^{-1} and Fe at 25 kg ha^{-1}, which also accounted for maximum number of grains per ear head (43.9), weight of grains per ear head (2.00 g) and 1000-grain weight (44.7 g). Grain and straw yields were highest (42.23 and 68.79 q ha^{-1}, respectively) with the combined application of Zn at 25 kg ha^{-1} and Fe at 25 kg ha^{-1} and it was least (37.83 and 62.51 q ha^{-1}, respectively) in control (RDF+FYM).

Jain and Dahama (2007) conducted field trials during the winter (rabi) seasons of 2001-02 and 2002-03, in Rajasthan, India, to evaluate the effects of zinc (0, 3, 6, 9 and 12 kg ha^{-1}) on the yield, nutrient uptake and quality of wheat. Zinc was applied along with the recommended doses of nitrogen and potassium. Results showed that zinc interaction had significant effect on grain, straw and biological yields, protein content, N, P, K and Zn uptake, and available zinc status after harvest. The maximum grain yield of 4907 kg ha^{-1} was recorded with the application of 6 kg zinc ha^{-1}.

Schmidt and Szakal (2007) found that the effect of Zn tetra mine complex on winter wheat protein and carbohydrate contents was evaluated during 2002 in Komarom, Croatia. Zn rates were 0.1, 0.3, 0.5, 1.0 and 2.0 kg ha^{-1}. Zn treatment at booting increased yield up to 1.0 kg ha^{-1}. Zn at 2 kg ha^{-1} was slightly toxic and reduced yield slightly. At 1 kg ha^{-1}, the yield was 0.6 t ha^{-1} higher than the control. Zn treatment increased protein content, reduced starch content (at rates higher than 0.3 kg ha^{-1}) and increased baking quality. The highest baking quality was obtained at 2 kg ha^{-1}.

Jain and Dahama (2006) have reported that application of 6 kg Zn ha^{-1} significantly increased all the growth and yield attributes (except test weight), protein content and Zn uptake by wheat over no use of Zn (control). Application of graded levels of Zn up to 9 kg Zn ha^{-1} remained at par with 12 kg Zn ha^{-1}, significantly increased Zn uptake by wheat crop over other levels. Application of 6 kg Zn ha^{-1} increased the grain and straw yields by 19.4 and 16.8% over the no use of Zn (control). Agronomic efficiency (115.3 kg ha^{-1}) and apparent Zn recovery (1.87%) were also higher at 6 kg Zn ha^{-1}.

Mahendra and Yadav (2006) conducted a field experiment, consisting of zinc levels viz., 0, 10, 20, 30 and 40 kg $ZnSO_4$ ha^{-1} conducted during rabi seasons of 2001-02 and 2002-03 on loamy sand soil of Rajasthan, India revealed that application of increasing dose of $ZnSO_4$ improved growth and yield parameters of wheat. Maximum values were recorded with the application of 40 kg $ZnSO_4$ ha^{-1}. However, it was statistically at par with 30 kg $ZnSO_4$ ha^{-1}.

Parihar *et al*. (2005) showed that the application of Zn up to 10 kg ha^{-1} increased the grain yield by 7.2 % over control. In the field experiments on Typical Ustipsamment, the effect of sulphur (0, 25 and 50 kg S ha^{-1}), zinc (0, 5 and 10 kg Zn ha^{-1}) and organic manures (10 t FYM ha^{-1} and 5 t vermi-compost ha^{-1}) were studied on wheat for yield and nutrient uptake by wheat.

Swarup and Yaduvanshi (2004) carried out an experiment on wet season rice (*Oryza sativa* L.) and winter season wheat (*Triticum aestivum* L.) cropping system at Bhaini Majra Experiment Farm, Kaithal, Inda. N, P, K and Zn doses as per treatments (120 kg N, 26 kg P, 42 kg K and 4.5 kg Zn ha^{-1}) were applied as urea, single superphosphate, muriate of potash and zinc sulphate, respectively. They found that zinc application improved the yield of rice and wheat.

Dewal and Pareek (2004) conducted a field experiment was conducted during the winter (rabi) season of 1999-2000 and 2000-01 at Jobner, Rajasthan, India, to study the effect of phosphorus, sulfur and Zinc on wheat (*Triticum aestivum*) cv. Raj. 3077. Main plots were supplied with 3 levels of Zinc (0, 5 and 10 kg Zn ha^{-1}). Data were recorded for plant height, dry matter accumulation, number of tillers, number of effective tillers, grains per spike, spike length, grain yield, straw yield and biological yield. The growth parameters, yield attributes, yield, net return and benefit: cost ratio increased significantly with application of 5 kg Zn ha^{-1}.

Singh (2004) was carried out a field experiment on wheat during the rabi season of 1998-2000 on an alkali water-irrigated loamy sand soil in Rajasthan, India, to evaluate the effect of nitrogen (0, 90.0, 112.5 and 135.0 kg N ha^{-1}) and zinc. The application of 5.0 kg Zn ha^{-1}significantly increased the growth and yield of wheat over the control, while it was at par with 6.25 and 7.5 kg Zn ha^{-1}. The highest ICBR 1:5.72 was estimated with 5.0 kg Zn ha^{-1}. The application of N significantly increased the N, P and Zn content, while Na content in grain and straw decreased. The application of Zn significantly increased the N and Zn content and decreasing trend of P and Na content was observed in grain and straw.

Chandrakuma *et al.* (2004) was conducted a field experiment in Raichur, Karnataka, India during the rabi season of 2001-02 to investigate the effects of organic, macro and micronutrient fertilizers, and methods of application on the yield of wheat. All micronutrient treatments improved the yield attributing characters. The soil application of $ZnSO_4$ at 10 kg ha^{-1} resulted in higher yield (30.19 q ha^{-1}) than the other micronutrient treatments. Combined treatments of RDF + FYM at 10 t ha^{-1}+ $ZnSO_4$ soil application at 10 kg ha^{-1} showed higher yield (38.65 q ha^{-1}) compared to the other treatment combinations.

Sundar *et al.* (2003) reported that Potted wheat plants grown on sandy clay loam (S_1) and clay loam soils (S_2) were treated with 0, 10 and 20 kg P ha^{-1}, 0, 5, 10 and 15 kg Zn ha^{-1} sandy clay loam (S_1) and clay loam (S_2). Grains per ear, test weight, grain and straw yields increased significantly only up to 10 kg Zn ha^{-1}; beyond this level, adverse effects on the yield were observed. Grains per ear, test weight, grain and straw yields were influenced by the soils and were highest with the application of 10 kg Zn ha^{-1}.

Zinc has been reported elsewhere as being effective in increasing dry matter production in wheat plants and it appears that its application acts like nitrogen addition to nutrient rich soil, stimulating greater biomass productivity at a greater proportion to the decrease in harvest index. Zinc deficiency has been reported to cause stunted plant growth and as shown here, the impact of Zinc stress on wheat growth in Zn deficient calcareous soil can be mitigated by Zn fertilization. (Imtiaz *et al.,* 2003).

Zeidan and Nofal (2002) showed that application of micronutrients only caused significant increases in straw yield, seed yield and grain protein content compared to the control. In addition, Zn foliar fertilization induced the highest increase in the majority of the studied characters. The addition of Zn is necessary for improving its foliar efficiency, growth, yield and quality of wheat.

Prasad *et al.* (2002) did a field experiment in Bihar, India for five years to study the optimal frequency of zinc application on zinc deficient soil in the rice-wheat cropping system. 'The treatments were soil and foliar application of Zn sulfate at different doses. The results indicated that the pooled yield of rice (32.5 q ha^{-1}) was higher than that of wheat grain (15.8 g ha^{-1}). The frequency of Zn application, based on 10 cropping systems, indicated that the use of 25 kg Zn sulfate ha^{-1} as soil application after a two crop interval was found to be optimal. The rates of increase in yields of rice and wheat were 52.4 and 21.0 kg Zn sulfate ha^{-1}, respectively and the per cent increase in yield of rice was 46.6 and wheat 38.1. The rice and wheat yields in the cropping system were significantly correlated with Zn removal.

Kenbaev and Sade (2002) and Hosseini (2006) have reported increase in yield components for application of Zn in wheat.

Zinc application has been reported to increase thermo-tolerance of the photosynthetic apparatus of wheat (Graham and Mc Donald, 2001).

Sharma *et al.* (2000) conducted a study in 1993-94 and 1994-95, in Rajasthan, India, to determine the effect of N at 0, 40, 80, 120 and 160 kg ha^{-1} and Zn at 0, 5 and 10 kg ha^{-1} on wheat. Wheat responded only to 5 kg Zn ha^{-1}, and Zn at this rate resulted in 13.62% and 6.14% higher grain yield compared to the control and 10 kg Zn ha^{-1}, respectively.

Micronutrients have prominent affects on dry matter, grain yield and straw yield in wheat (Asad and Rafique, 2000).

Zinc application improved spike length and effective tillers plant^{-1} and number of grains plant^{-1} (Islam *et al*., 1999).

Rajput (1997) carried out a field trial at Bahraich, Uttar Pradesh in 1991-93 rainy seasons with wheat cv. HD 2285 grown on sandy loam soil using different combinations with or without soil applied or foliar zinc and found that zinc application increased wheat yield, with no significant difference between application methods.

Modaihsh (1997) also reported that zinc application improved biological yield as well as grain yield of wheat grown on calcareous soils.

Grewal *et al.* (1997) and Torun *et al*. (2001) who have reported that increased dry matter production for application of Zn and B over control.

Brennan (1996) conducted 30 field experiments on a range of soils in different rainfall zones of south-west Australia to examine the effectiveness, relative to freshly applied Zn fertilizer of previously applied Zn fertilizer for grain yield of wheat. The soil had been fertilized with Zn at 0.2-1.2 kg Zn ha^{-1}, 9-24 years previously. The effect of applied N on grain yield and Zn concentration in the youngest emerged leaf blade was also examined. At all sites, the current application of Zn fertilizer to soil previously treated with Zn did not increase grain yield. The lowest Zn rate (0.2 kg Zn ha^{-1}) applied 15 years earlier was still fully effective for maximum grain production. The application of currently applied Zn increased the Zn concentration in the youngest emerged leaf blade for 23 experiments. Zinc concentration in the grain was increased by the current application of Zn in 25 experiments and it had no effect in 5 experiments.

Alam (1995) carried out a field experiment in Mymensingh on wheat (Variety Kanchan, Akbar and Aghrani) with 100 kg N, 80 kg P, 30 kg K, 24 kg S, 4 kg Zn, 2 kg B and 2 kg

Mo ha^{-1} respectively. He obtained that Zinc gave 2.10 t ha^{-1} grain yields among the treatments

Ismail *et al.* (1995) conducted a field experiment during rabi season of 1992-93 at Dholi, Bihar, in a Zn deficient highly calcareous sandy loam soil. Ten cultivars of *Triticum aestivum L.* were grown under 3 levels of Zn application (0, 5 and 10 kg/ha). Application of Zn markedly increased grain and straw yields but the magnitude of increase varied from one cultivar to another. Cultivars UP 262 K 8804 and HP 1102 appeared to be highly and Sonalika and HP 1633 least responsive to Zn application.

Marschner (1995) declared that Zn is essentially necessary for protein synthesis and following Zn deficiency, reduction in RNA-polymerase activity and increase in RNA destruction can severely reduce grain protein content.

Ahmed and Alam (1994) conducted a greenhouse study on four soils of Bangladesh to determine the effect of Zn and B application singly and in combination on yield and nutrient content of wheat (cv. Kanchan). The significant increase in dry matter yield was recorded from combined application of 20 kg Zn and 5 kg B ha^{-1}

Dasalkar *et al.*(1994) reported on a field experiment at Parbhani, Maharashtra with Sorghum cv. CSH-9 receiving 4 kg Zn ha^{-1} as zincated urea, zinc sulphate or zincated superphosphate or 10 FYM ha^{-1} in addition to the recommended N, P and K rates. Zincated fertilizers gave significantly higher grain yields than FYM, zincated superphosphate gave the highest grain yield of 3.71 t ha^{-1}. Wheat was grown on the same plots after sorghum to examine the residual effects. Wheat grain yield was the highest on the plot supplied with zincated superphosphate (2.35 t ha^{-1}).

Sur *et al.* (1993) showed that in alluvial soils of North Bengal and red lateritic soils of South Bengal (India) Zn application significantly increased yields of wheat. A rate of 25 to 37.5 kg ha^{-1} $ZnSO_4$ was recommended for economic returns. In a field experiment at the North Eastern Hill University, Shillong, Meghalaya, India to elucidate the distribution adsorption and utilization of Zn in wetland soils and its uptake by plant from nutrient solutions. It was concluded that the use of Zn fertilizers increased the yield of wheat in wetland soils of Meghalaya.

Barisal *et al*. (1990) carried out field experiment at 26 Zn deficient sites on typic Ustochrepts at Ludhiana, India that the critical deficiency levels of Zn for wheat were 0.60 mg Zn kg ha^{-1} soil and 19 mg kg DM in 45 day plants. Variations in grain and straw yields of wheat at the different sites were due largely to differences in Zn availability to the crop. Further, field trials at 9 locations with different levels of soil Zn (0.35 to 1.50 mg Zn kg ha^{-1} soil) and with 0, 11 or 22 kg Zn ha^{-1} applied as $ZnSO_4$ were conducted to examine the applicability of this critical level. Yields were significantly increased by Zn application.

A field trial was carried out at Jamalpur with Kanchan variety of wheat, the highest yield 4.53 t ha^{-1} was obtained in 5 kg Zn ha^{-1} application (BARI, 1989).

Mishra *et al.* (1989) found in trial in 1986-88 on a sandy loam soil with wheat it given NPK, soil application of 25 kg zinc sulphate ha^{-1} gave average grain yields of 2.62 and 2.49 t ha^{-1} respectively, compared with control treatment. The trace elements increased number of ear bearing tiller m^2, grain ear^{-1} and 1000-grain weight. The grain and straw yields of wheat increased to a considerable extent with Zn application (Singh and Singh (l989) also observed significant increase in grain yield due to the application of Zn to the soil.

Yadav and Vyas (1987) observed that grain yield of wheat increased with 30 kg $ZnSO_4$ ha^{-1} application. In a rain fed trials in 1979-81 with wheat applied N,P, K application of 0, 6 and 12 kg Zn sulphate ha^{-1} gave average grain yields of 2.04, 2.24 and 2.35 t ha^{-1}, respectively.

Baghdady *et al*. (1988) observed the DM production, Zn concentration and Zn uptake of wheat at tillering and flowering stages in a pot experiment with a sandy loam soil, amended with 0. 25, SG, 100 and 200ppm P and 0, 5, 10 and 20ppm Zn and found that dry matter yields were increased by both P and Zn. Zinc uptake was depressed by about 15% by the highest level of P.

The role of Zn include; auxin metabolism, influence on the activities of dehydrogenase and carbonic anhydrase, enzymes, synthesis of cytochrome 'C' and the stabilization of ribosomal fraction (Tisdale and Nelson, 1984).

Ali *et al.* (1982) observed that application of Zn significantly increased grain yield producing 3015, 2798 and 2780 kg ha^{-1} at Jamalpur, Madhupur and Ishurdi soils, respectively response that 20 kg Zn ha^{-1} recorded the maximum yield with the ton of 3233 kg ha^{-1}. The application of Zn increased the yields of grain and straw but the increase was not statistically significant (A1i *et al.,* 1983).

Prasad *et al.* (1981) conducted an experiment with 4 cultivars of wheat using 3 levels of Zn (0, 2.5 and 5 kg ha^{-1}). They observed that application of Zn increased yield significantly in all the varieties. They were reported that application of 4 kg Zn ha^{-1} increased grain yield of wheat (cv. Sonalika) by 1100 and 4600 kg ha^{-1} and straw yield by 4600 and 5500 kg ha^{-1} over control at Rajbari and Jessore, respectively

Motiramani *et al.* (1981) obtained wheat grain yield of 2820 kg ha^{-1} when grown without Zn and 3390 kg ha^{-1} when grown with 2.5ppm in (as $ZnSO_4$), respectively. They also observed that it had no significant effect on straw yield.

Khan *et al.* (1979) obtained highest grain yield (3380 kg ha^{-1} with the application of 5 kg Zn ha^{-1} and the application of 5 kg Zn ha^{-1} increased grain yield by 34% was over control.

Rai and Singh (1978) observed that application of 10 kg Zn ha^{-1} increased the grain yield by 1000 kg ha^{-1} over control.

Experiments were carried out under irrigated condition at Joydebpur, Jessore, Ishurdi and Bogra farms with wheat (CV. Sonalika) applying different levels of Zn at different locations. At Joydebpur, it was observed that grain yield increased due to Zn application compared to control treatment. At Jessore, it was observed that application of Zn at the rate of 1, 2 and 3ppm gave significantly higher grain yield (4131, 4201 and 4155 kg ha^{-1}, respectively) over control 3887 kg ha^{-1} (BAR1, 1978).

Gupta and Singh (1972) reported that application of 4.48 kg Zn ha^{-1} gave the highest grain yield of 1810 kg ha^{-1} compared without Zn application yielding 1660 kg ha^{-1}. Zn application significantly increased the grain and straw yields of wheat, the increase in grain yield being 13-18% over control .An experiment at Patna with Kalyansona wheat using 3 levels of Zn (0, 3.5 and 7 kg Zn ha^{-1}) showed that the highest in grain yield was by soil application of 7 kg Zn ha^{-1} .

2.2.2 Effect of Boron

Boron (B) is a micronutrient. It ranks second after zinc, as a micronutrient deficiency in Bangladesh. Mineral is the major source of boron in soils and tourmaline (borosilicate) is the dominant mineral. Tourmaline contains 3.4% B. Total boron content of soil varies from 2 to 200ppm. Boron fertilizers are applied to soils as boric acid (H_3BO_3), borax ($Na_2B_4O_7$. $10H_2O$) and solubor ($Na_2B_4O_7$. $10H_2O$ + $Na_2B_{10}O_{16}$. $10H_2O$). Boron has four available forms in soils such as H_3BO_3 (main), $B_4O_7^{2-}$, $H_2BO_3^{-}$ and HBO_3^{2-}. These forms exist in rocks and minerals, adsorbed on surfaces of clays and hydrous iron and aluminum oxides, combined with organic matter, and as free non-ionized boric acid (H_3BO_3) and B $(OH)_4^-$ in the soil solution. Less than 5% of the total soil boron is available to plants. Boron performs many functions in cell walls and cellular activities. Boron deficiency renders decrease in cell wall plasticity leading to failure of newly divided cells to enlarge. As far as plasma membrane is concerned, adequate level of boron stops the accumulation of phenolic and ceases the oxidation of components of plasma membrane. Further it is involved in the generation of H^+ ATPase, which is a driving force for ion uptake. Hence, integrity and functionality of plasma membrane is ensured with adequate supply of B. There have been numerous studies in the world with respect to the effect of B on wheat. A review of literature of important works done on the effect of B on wheat is given below.

Rashid *et al.* (2011) conducted an experiment on 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) carried out 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 1^{st} irrigation and at booting stage.

Sultana (2010) conducted 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) investigated 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.

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 (Alloway, 2008).

Ahmed *et al.* (2008) conducted 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) conducted 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) carried 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) studied 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) conducted 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) conducted 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) reported that the plant height was significantly increased with the application of B and lime whether singly or in combination.

Bhatta *et al.* (2005) reported 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) had 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) reported 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) carried out 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) initiated 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) conducted 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) found from reciprocal transfers of wheat plants between adequate and zero B root media at different development stages, that the period during which florets 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) conducted 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) determined 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) conducted 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 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 reported 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) observed 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) conducted 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) reported 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 percent higher grain yield than soil and foliar methods of application, respectively.

Rehem *et al.* (1998) stated 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) expressed that B is involved in carbohydrates metabolism and it is essentially necessary for protein synthesis, pollen germination, seed and cell wall formation.

Alam (1995) conducted 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) reported 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) carried out 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 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) opined 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) reported 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) found 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) observed 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) demonstrated 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 studied by Galrao and Sousa (1988) and observed 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 (Stevenson, 1985).

White and Collins (1982) observed 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. Grain protein contents were increased by B application (Saleh *el al.,* 1982).

Boron is essential for translocation of sugars, development of meristematic tissues, syntheses of protein, RNA and auxin and formation of ribosome (Gupta, 1979 and Mengel and Kirkby, 1982).
Lal and Lal (1980) reported 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 0.25ppm 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) observed increased grain yield of wheat because of B treatment. An experiment with three cultivars of wheat (Janak, UP 262, and Sonalika) was conducted. They observed that boron application increased yield of all three cultivars

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.

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 (Smith and Johnson, 1969 and Erikson, 1779). 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.

2.2.3 Interaction effect of Zinc and Boron:

Singh *et al.* (2015) conducted an experiment to evaluate the effect of zinc levels and methods of application of boron on the growth, yield and protein content of wheat (*Triticum aestivum* L.). The treatments comprised three levels of zinc (0, 3.5 and7 kgha^{-1}) through zinc sulphate and four methods of application of boron (0, soil application @ 0.5 kg ha^{-1}, foliar spray @ 0.5kg ha^{-1} at 45 and 60 days after sowing and soil application @ 0.25 kg ha^{-1} + foliar spray @ 0.25 kg ha^{-1} at 45, 60 DAS. On the basis of the findings of the experiment, zinc @ 7 kg ha^{-1}, soil application of boron @ 0.25 kg ha^{-1} + foliar application of boron @ 0.25 kg ha^{-1} and their combination (i.e., 7 kg ha^{-1} zinc + soil application of boron @ 0.25 kg ha^{-1} + foliar application of boron @ 0.25 kg ha^{-1}) was found superior over all other treatments in relation to plant height, dry weight, effective tillers yield and yield attributes and protein content in grains, of wheat.

Nadim *et al.* (2013**)** conducted an experiment investigate the effect of micronutrients and their application methods on wheat. Main plot possessed five micronutrients viz., Zn, Cu, Fe, Mn and B while application methods (side dressing, foliar application and soil application) were assigned to sub-plots. The results revealed that different micronutrients significantly interacted with the application methods for physiological and agronomic traits including leaf area index (LAI), crop growth rate (CGR), net assimilation rate (NAR) and grain yield. Soil application best interacted with boron for producing higher number of tillers, grains spike^{-1}, grain yield and almost all the physiological traits. This combination also resulted in the best net returns with higher benefit cost ratio.

Singh *et al.* (2008) conducted an experiment to study the individual and interactive effects of zinc (0, 5 and 10 mg Kg^{-1} soil) and boron (0, 0.75 and 1.5 mg Kg^{-1} soil) on enzymatic activity and nutrient uptake in wheat (var. HD2285). The results show increased growth of wheat by increasing the availability of the two micronutrients by soil amendment. The increase in leaf Zn and B concentration also indicate the improvement in the Zn and B status of plants on fertilization. The interaction of zinc and boron was found positive up to the level of B at 0.75 and Zn at 5 Kg^{-1} soil on increasing the leaf B, leaf Zn concentration and activity of carbonic anhydrase and decreasing the activity of starch phosphorylase and peroxidase.

Razzaque and Hossain (1991) opined that some management practices such as sub-optimal usage of fertilizers, late planting and low plant population could be the most important factors for poor wheat yield in Bangladesh. They were of the opinion that along with N, P, K, S & Zn, some other elements e.g. B, Mn and Mo might be the limiting factors for low wheat yield of this country.

Dwivedi *et al.* (1990) conducted a year trial on an acid soil (Inceptisol) of UP Himalaya in soybean-wheat crop sequence to see the relative efficacy of different methods of application of micronutrients (Cu, Zn, B, Mo and their mixture) viz. soil application (mode I), soil applied micronutrients along with lime (mode II) and foliar spray (mode III). They observed that micronutrients either alone or in mixture significantly increased the yield of both crops over no micronutrients. Mode of application had different effect on increasing yield of crops. Soil application with lime was superior to other two modes of application but the response varied among the micronutrients and crop, mixture of micronutrients was inferior to that of individual ones. Available Cu, Zn, B and Mo status in soil was higher in soil application either alone or along with lime than the initial status even after harvest of soybean and wheat.

Salet *et al.* (1990) observed that in field trial in 1989 at Santa Maria. The effects of seed treatments with 0, 40, 80 and 120 g Zn and 0, 10 or 20 g B ha^{-1} on wheat cv. BARI Gom-23 were investigated. Soil Zn and B levels were 0.7ppm and 0.69ppm respectively. Zinc and B did not affect plant height and number of grains ha^{-1}, Ears m^{-2} decreased and grain weight increased with increase in B rate. In the absence of B, Zn had an effect on grain yield with the optimum rate being 53 g Zn ha^{-1}.

From the above review of literatures we can conclude that zinc and boron have a remarkable effect on yield and yield contributing characters and quality of wheat. Some studies revealed that zinc and boron above certain levels increased the yield and yield parameters and quality of wheat. So, there is still scope for zinc and boron studies to select optimum dose for improving the yield and quality of wheat. Therefore, the present investigation is well justified to identify the optimum doses of zinc and boron fertilizers for wheat cv. BARI Gom-26 under a typical agro-climatic situation of Sher-e-Bangla Nagar, Dhaka, Bangladesh (AEZ-28).

CHAPTER III

MATERIALS AND METHODS

This chapter deals with the materials and methods used in the experiment. It includes a short description of location of the experimental plot, characteristics of soil, climate and materials used 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 October 2013 to February 2014. The field was located at the southeast part of the main academic building. The soil of the experimental plots belonged to the Agro Ecological Zone Madhupur Tract (AEZ-28).

3.2 Soil

The experiment was carried out in a typical wheat growing soil of Sher-e-Bangla Agricultural University (SAU) Farm, Dhaka, during robi season of 2013. The farm belongs to the General soil type, **"**Deep Red Brown Terrace Soil**"** under Tejgaon Series. The land was above flood level and sufficient sunshine was available during the experimental period. The morphological, physical and chemical characteristics of initial soil are presented in Tables 1 and 2.

3.3 Climate

The experimental area is under the subtropical climate. Usually the rainfall was heavy during Kharif season and scanty in Rabi season. The atmospheric temperatures increased as the growing period proceeded towards Kharif season. The weather conditions of crop growth period such as monthly mean rainfall (mm), mean temperature (^{o}C), sunshine hours and humidity (%) are presented in Appendix 2.

3.4 Planting material

Wheat (*Triticum aestivum* L.) variety BARI Gom-26 was used as plant material. BARI developed this variety and released in 2010. It is a most popular variety now due to its high yielding potentials and suitable for early and late planting (up to second week of December). This variety attains a height of 92-96 cm and it resistant to leaf rust disease. The number of tillers plant^{-1} is 3-4 and the leaves are wide and deep green in color. It requires 60-63 days to heading. Grains are amber in color and bright. Its yield is 3.5-4.5 t ha^{-1} and 1000 grain weight is 48-52 g. The seeds of this variety were collected from Bangladesh Agricultural Research Institute (BARI), Gazipur. Seeds contain 60 - 65% carbohydrate.

Table1. Morphological characteristics of the experimental field

Morphological features	Characteristics
Location	Sher-e-Bangla Agricultural University Farm, Dhaka
AEZ	Madhupur Tract
General Soil Type	Deep Red Brown Terrace Soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained

Table2. Physical and chemical properties of the initial soil sample

Characteristics	Value
Particle size analysis	
% Sand	8
% Silt	50
% Clay	42
Textural class	Silty clay
Consistency	Granular and friable when dry
pH	5.6
Bulk Density (g/cc)	1.45
Particle Density (g/cc)	2.52
Organic carbon (%)	0.68
Organic matter (%)	1.18
Total N (%)	0.06
Available P (ppm)	19.85
Exchangeable K (meq/100g soil)	0.12
Available S (ppm)	22
Available Boron	0.48 µg/g soil
Available Zinc	3.32 µg/g soil

3.5 Land preparation

The land was first opened with the tractor drawn disc plough. Ploughed soil was then brought into desirable fine tilth by 4 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 on 18 October and 22 October 2013, respectively. Experimental land was divided into unit 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.

3.6 Fertilizer application

The unit plots were fertilized with 150 kg, N, 125 kg TSP, 67 kg MoP and Gypsum 80 kg ha^{-1} respectively. Urea, triple super phosphate (TSP) and muriate of potash (MoP) were used as source of nitrogen, phosphorus and potassium, respectively. Zinc and Boron were applied as per experimental specification through Zinc sulphate (60% Zn) as foliar spray and boric acid (17% B) soil application. 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. The remaining two-thirds of urea were top-dressed in two equal splits on 20 and 55 days after sowing (DAS) the seed.

3.7 Treatments of the experiment

The experiment was two factorials with four levels of Zn and four levels of B.

3.7.1 Factor A: Zn levels

The following Zn levels were imposed in the experiment

Zn_0 = Control (No Zn Application)

Zn_1 = 0.02 % foliar application of Zn

Zn_2 = 0.04 % foliar application of Zn

Zn_3 = 0.06 % foliar application of Zn

3.7.2 Factor B: Boron levels

The following Boron levels were imposed in the experiment;

B_0 : Control(No B Application)

B_1 : 0.5 kg B ha^{-1}

B_2 : 1.0 kg B ha^{-1}

B_3 : 1.5 kg B ha^{-1}

3.7.3 Combining two factors, 16 treatment combinations were obtained

$Zn_0\ B_0$	$Zn_0\ B_1$	$Zn_0\ B_2$	$Zn_0\ B_3$
$Zn_1\ B_0$	$Zn_1\ B_1$	$Zn_1\ B_2$	$Zn_1\ B_3$
$Zn_2\ B_0$	$Zn_2\ B_1$	$Zn_2\ B_2$	$Zn_2\ B_3$
$Zn_3\ B_0$	$Zn_3\ B_1$	$Zn_3\ B_2$	$Zn_3\ B_3$

3.8 Experimental design and lay out

The experiment was laid out in a Randomized Complete Block Design (factorial). Each treatment was replicated three times. The size of a unit plot was 2 m × 2 m. The distance between two adjacent replications (block) was 1m and row-to-row distance was 0.5 m. The inter block and inter row spaces were used as footpath and irrigation/ drainage channels.

3.10 Fertilizer application

Fertilizer was applied based on BARC fertilizer recommendation guide-2012. Urea, TSP, MoP and Gypsum was used as a source of N, P, K, and S respectively. All P, K, S, B and half of N was applied at the final land preparation and the remaining half of N was applied before booting stage.

3.11 Sowing of seeds in the field

The seeds of wheat were sown in rows made by hand plough on October 25, 2013. The seeds were sown in solid rows in the furrows having a depth of 2-3 cm from the soil surface. Row to row distance was 20 cm.

3.12 Intercultural operations

3.12.1 Irrigation and weeding

Four types of irrigations were done according to the treatments during the entire growing period. The crop field was weeded twice; first weeding was done at 25 DAS (Days after sowing) and second weeding at 40 DAS. Demarcation boundaries and drainage channels were also kept weed free.

3.12.2 Protection against insect and pest

At early stage of growth, few worms (*Agrotis ipsilon*) and virus vectors (Jassid) attacked the young plants. To control these pests, Dimacron 50 EC was sprayed at the rate of 1litre per ha.

3.13 Preparation and application of Zn spray

Four level of Zn concentration was applied in experimental field. The mixture of 200 g Zn in 10 liter water is called 0.02 % Zn. Similarly 400 g Zn in 10 liter water and 600 g Zn in 10 liter water is called 0.04 % Zn and 0.06 % Zn respectively. Foliar application of zinc was done. Zinc Sulphate Monohydrate ($ZnSO_4.H_2O$) was used as a source of Zn.

3.14 Crop sampling and data collection

The crop sampling was done at the time of harvest. Harvesting date was 22/2/2014. 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 heights, spike length, number of grain Spike^{-1}, 1000 grain weight and yield were recorded separately.

3.15 Harvest and post harvest operations

Harvesting was done when 90% of the crops became brown in color. The matured crop were cut and collected manually from a pre demarcated area of 1 m^2 at the centre of each plot. After harvesting, the samples were sun dried.

3.16 Data collection

The data on the following parameters of five plants were recorded at each harvest.

1) Plant height (cm)
2) Spike length (cm)
3) Number of grains spike^{-1}
4) 1000 grain weight (g)
5) Seed yield (t ha^{-1})

3.17: Procedure of data collection

3.17.1: Plant height

The heights of five plants were measured with a meter scale from the ground level to the top of the plants and the mean height was expressed in cm.

3.17.2: Spike length

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

3.17.3 Number of grain spike^{-1}

Total grain numbers were counted from total spike that was obtained from pre-selected five plants. After that it was averaged and expressed as number of grain spike^{-1}.

3.17.4 Weight of 1000 seeds

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

3.17.5 Grain yield (t ha^{-1})

Weight of grains of the demarcated area (1 m$^{2)}$ at the centre of each plot was taken and then converted to the yield in t ha^{-1}.

3.18 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.

3.19 Collection and preparation of initial soil sample

The initial soil samples were collected before land preparation from a 0-15 cm soil depth. The samples were drawn by means of an auger from different location covering the whole experimental plot and mixed thoroughly to make a composite sample. After collection of soil samples, the plant roots, leaves etc. were picked up and removed. Then the samples were air-dried and sieved through a 10-mesh sieve and stored in a clean plastic container for physical and chemical analysis.

3.20 Chemical analysis of soil samples

Soil samples were analyzed for both physical and chemical properties in the laboratory of Soil Resource Development Institute (SRDI) Farmgate, Dhaka. The properties studied included soil texture, pH, organic matter content, total N, available P, exchangeable K and available S. The chemical properties of post harvest soil have been presented in Appendix-1. The soil was analyzed by standard methods:

3.20.1 Particle size analysis

Particle size analysis of soil was done by Hydrometer Method and the textural class was determined by plotting the values for % sand, % silt and % clay to the "Marshall's Textural Triangular Coordinate" according to the USDA system.

3.20.2 Soil pH

Soil pH was measured with the help of a Glass electrode pH meter using soil and water at the ratio of 1:2.5 as described by Jackson (1962).

3.20.3 Organic Carbon

Organic carbon in soil was determined by Walkley and Black (1934) Wet Oxidation Method. The underlying principle is to oxidize the organic carbon with an excess of 1N $K_2Cr_2O_7$ in presence of conc. H_2SO_4 and to titrate the residual $K_2Cr_2O_7$ solution with 1N $FeSO_4$ solution. To obtain the organic matter content, the amount of organic carbon was multiplied by the Van Bemmelen factor, 1.73. The result was expressed in percentage.

3.20.4 Total Nitrogen

Total nitrogen of soil was determined by Micro Kjeldahl method where soil was digested with 30% H_2O_2, conc. H_2SO_4 and catalyst mixture (K_2SO_4: $CuSO_4.5H_2O$: Se powder in the ratio of 100:10:1). Nitrogen in the digest was estimated by distillation with 40% NaOH followed by titration of the distillate trapped in H_3BO_3 with 0.01N H_2SO_4 (Bremner and Mulvaney, 1982).

3.20.5 Available Phosphorus

Available phosphorus was extracted from soil by shaking with 0.5 M $NaHCO_3$ solution of pH 8.5 (Olsen *et al.*, 1954). The phosphorus in the extract was then determined by developing blue color using ascorbic acid reduction of phosphomolybdate complex. The absorbance of the molybdophosphate blue color was measured at 660 *n*m wave length by Spectrophotometer and available P was calculated with the help of standard curve.

3.20.6 Exchangeable Potassium

Exchangeable potassium was determined by 1N NH_4OAc (pH 7.0) extract of the soil by using Flame photometer (Black, 1965).

3.20.7 Available Sulphur

Available sulphur in soil was determined by extracting the soil samples with 0.15% $CaCl_2$ solution (Page *et al.*, 1982) The S content in the extract was determined turbidmetrically and the intensity of turbid was measured by Spectrophotometer at 420 *n*m wave length.

CHAPTER IV

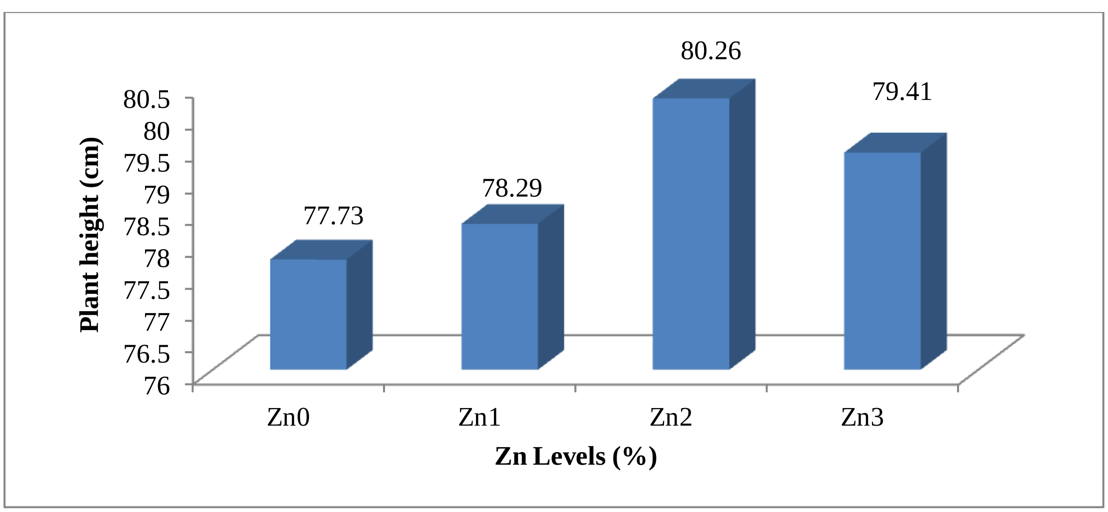
RESULTS AND DISCUSSION

The results obtained from present study for different crop characters, yields and other analyses have been presented and discussed in this chapter.

4.1 Effect of zinc on the growth and yield of wheat

4.1.1 Plant height

Under the present study, plant height was significantly influenced by the application of zinc (Fig. 1). Results revealed that the tallest plant (80.26 cm) was achieved from the treatment Zn_2 (0.04% Zn) where the shortest plant (77.73 cm) was obtained from the treatment Zn_0 (control) (Table 3). The results obtained from the treatment Zn_1 (0.02% Zn) and Zn_3 (0.06% Zn) was statistically similar with Zn_2 (0.04% Zn) treatment. Here, it was also observed that zinc had a contribution for higher plant growth and Zn_2 (0.04% Zn) showed the best result where no application of zinc treatment showed shortest plant height. Mekkei and El-Haggan Eman (2014) obtained similar results and they observed that combination of micronutrients (Zn) produced the highest values of plant height.

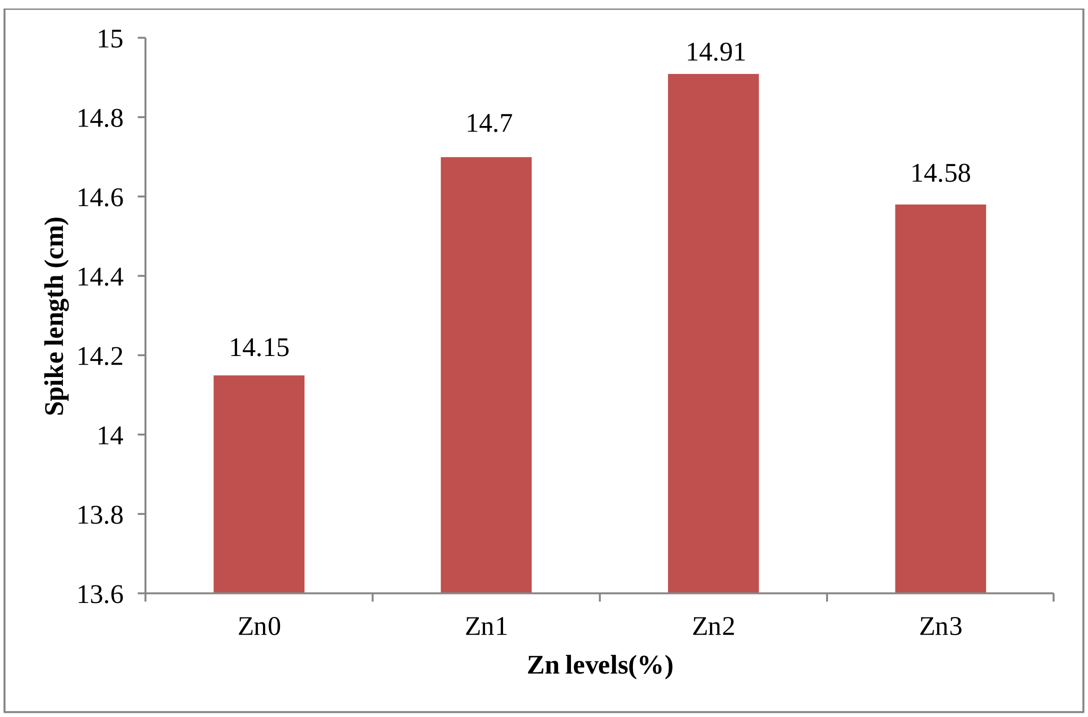


Zn_0 = 0 (control) Zn_1 = 0.02 % Zn Zn_2 = 0.04 % Zn Zn_3 = 0.06 % Zn

Fig.1: Effect of Zn levels on plant height (cm) of wheat

4.1.2 Spike length

Significant variation was observed for spike length influenced by the application of zinc (Fig. 2). Results revealed that the longest spike length (14.91cm) was achieved from Zn_2 (0.04% Zn) and the shortest spike length (14.15 cm) was obtained from Zn_0 (control) treatment which was significantly different from all other treatments (Table 3). Spike length increased with the increasing rates of Zn up to .04% Zn .Here, it can be stated that zinc had a contribution for longer spike length and Zn_2 @ 0.04% Zn showed the best result where no application of zinc (Zn_0) showed shorter spike length. Mekkei and El-Haggan Eman (2014) observed that combination of micronutrients (Cu+ Fe+ Mn+ Zn) produced the highest values of spike length, number of grains spike^{-1}. Other workers have also reported that Zinc application improved spike length and shortest from control (Dewal and Pareek, 2004 and Islam *et al*., 1999).

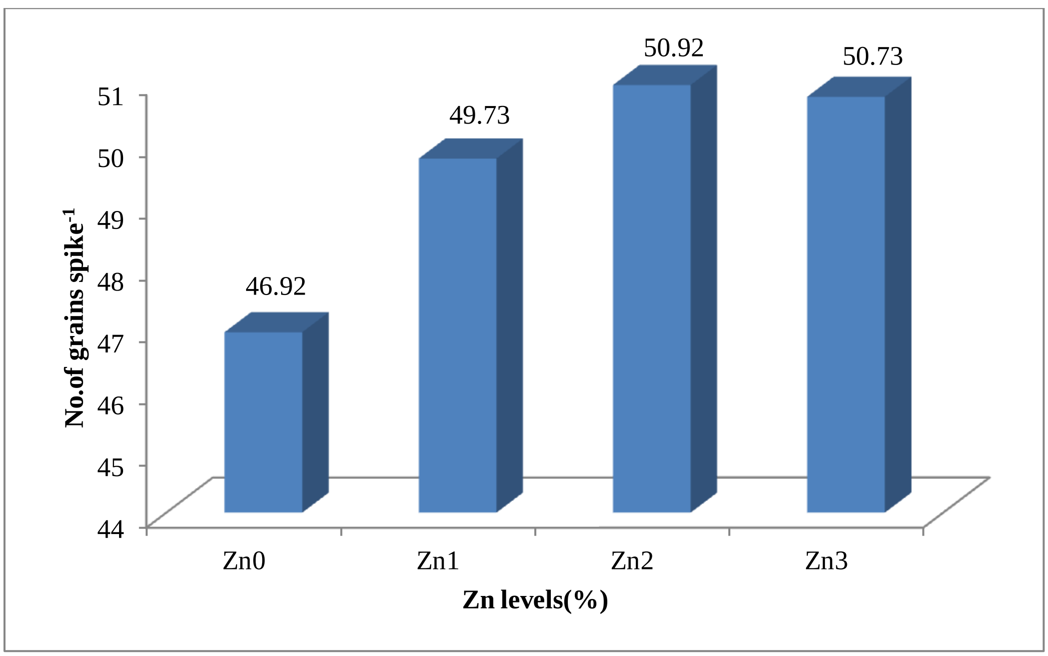


Zn_0 = 0 (control) Zn_1 = 0.02 % Zn Zn_2 = 0.04 % Zn Zn_3 = 0.06 % Zn

Fig.2: Effect of Zn levels on spike length (cm) of wheat

4.1.3 Number of grains $spike^{-1}$

The influence of Zn on the number of grains $spike^{-1}$ was statistically significant (Fig. 3). Under the present study, number of grains $spike^{-1}$ was significantly influenced by the application of zinc at different doses (Table 3). It was found that the maximum number of grains $spike^{-1}$ (50.92) was achieved from the treatment Zn_2 which was statistically similar with Zn_1 and Zn_3. Again, the minimum number of grains $spike^{-1}$ (46.92) was obtained from the treatment Zn_0 (control) which was significantly different from all other treatments. Number of grains $spike^{-1}$ increased with the increase of Zn up to Zn_2 treatment (0.04 % Zn). Mekkei and El-Haggan Eman (2014) evaluated that application with combination of micronutrients (Cu+ Fe+ Mn+ Zn) produced the highest values of number of grains $spike^{-1}$. Gul *et al*. (2011) also reported that maximum number of grains (52) $spike^{-1}$ was produced in plots under the effect of foliar spray of 0.5% N + 0.5% K + 0.5% Zn solution (once), while control (no spray) plots produced minimum number of grains (29) $spike^{-1}$.

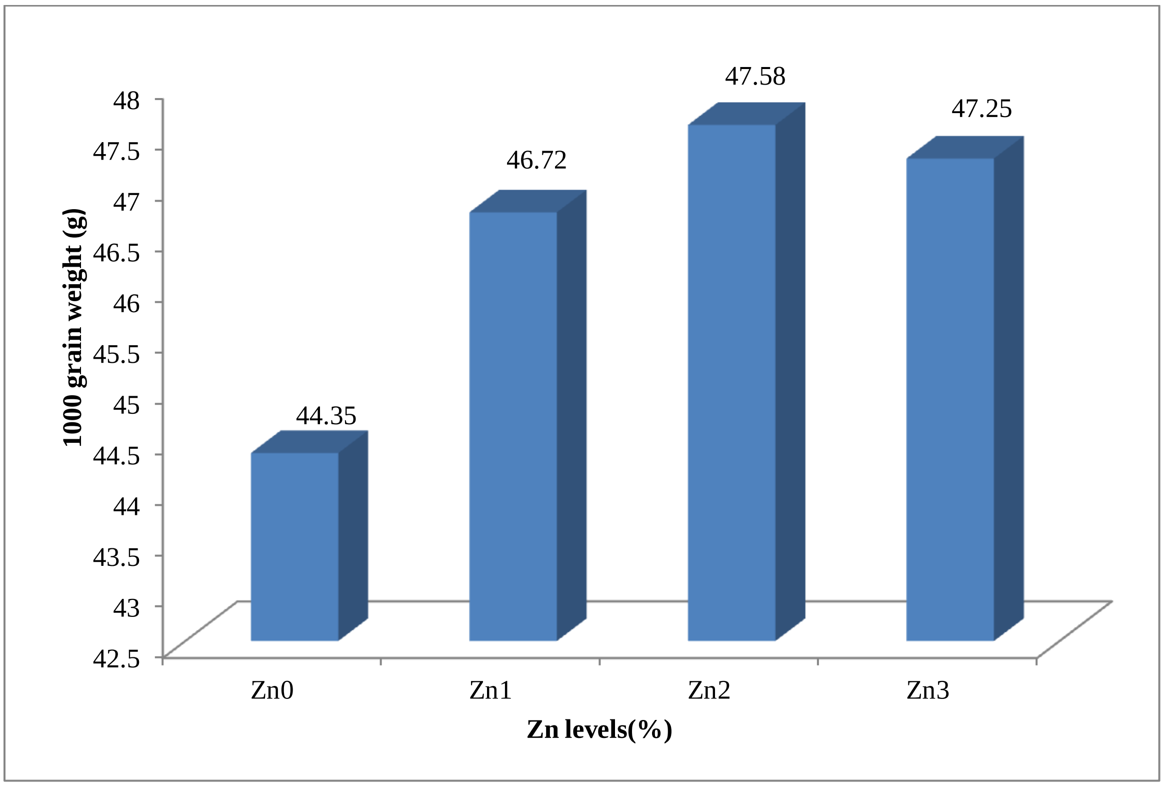


Zn_0 = 0 (control) Zn_1 = 0.02% Zn Zn_2 = 0.04% Zn Zn_3 = 0.06% Zn

Fig.3: Effect of Zn levels on number of grains $spike^{-1}$ of wheat

4.1.4 Weight of 1000 grain

Weight of 1000 grain is an important yield contributing character. Higher 1000 grain weight indicates more healthy seeds and resulted higher grain yield ha^{-1}. Here, application of different levels of zinc to the wheat crop showed significant difference on 1000 grain weight (Table 3). The highest 1000 grain weight (47.58g) was observed with Zn_2 treatment where as the lowest (44.35g) was with control treatment (Zn_0) (Fig. 4). Zeidan *et al*. (2010) showed that 1000 grains weight was significantly increased with application of foliar application of Zn. Mekkei and El-Haggan Eman (2014) also got similar results. Positive effects of Zn application on 1000 grain weight were also reported by Ananda and Patil (2007). Kenbaev and Sade (2002) and Hosseini (2006) reported that yield components increased with the increase in Zinc application.

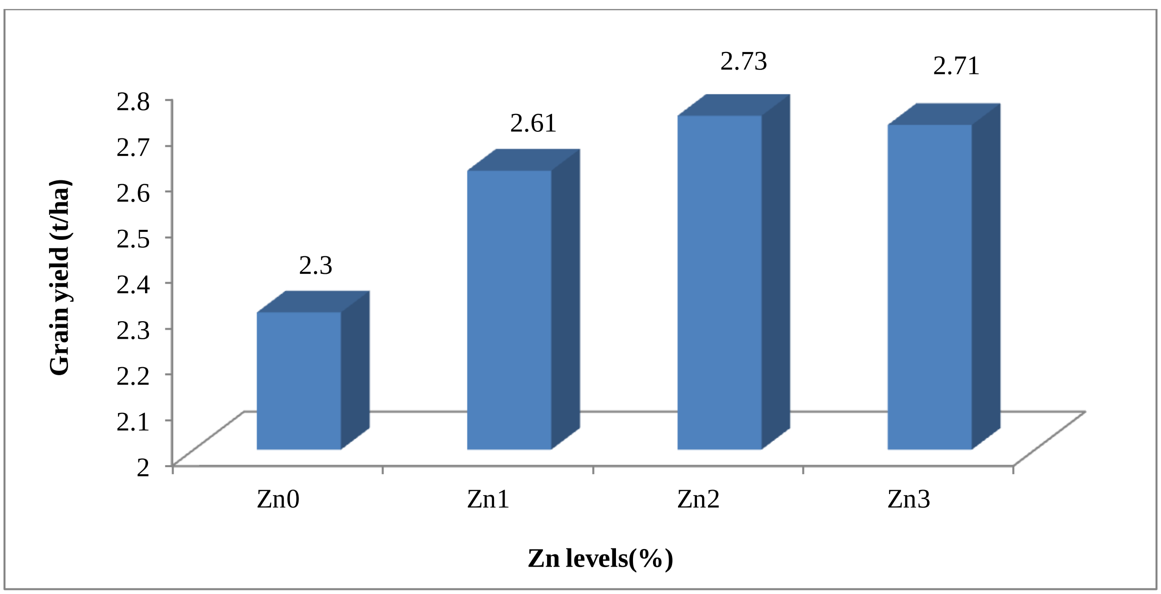


Zn_0 = 0 (control) Zn_1 = 0.02 % Zn Zn_2 = 0.04% Zn Zn_3 = 0.06 % Zn

Fig.4: Effect of Zn levels on 1000 grain weight (g) of wheat

4.1.5 Yield (t ha^{-1})

Grain yield is the main achievement of a crop production. Application of zinc played a significant role on the yield and yield components of wheat (Table 3). Yield components were influenced significantly due to application of zinc. The grain yield of wheat increased significantly due to added zinc up to the treatment Zn_2 (0.04% Zn). The highest grain yield (2.73 t ha^{-1}) was achieved from Zn_2 treatment (0.04% Zn) which was not statistically different from Zn_1 (0.02% Zn) and Zn_3 (0.06% Zn) treatment. Here, it can be stated that application of zinc @ 0.04% Zn was more effective than other doses (Fig.5). The lowest grain yield (2.30 t ha^{-1}) was obtained from the treatment Zn_0 (control; no Zn application) which was significantly different from all other treatments. Zinc is essential element for crop production and optimal size of grain, also it required in the carbonic enzyme which present in all photosynthetic tissues, and required for chlorophyll biosynthesis (Ali *et al.*, 2008; Graham *et al.*, 2000).These results agreed with Torun *et al.*, (2001) and Grewal *et al.*, (1997) who reported that increased wheat production with application of zinc over control. There were no significant difference regarding wheat yield among the treatment Zn_1 (0.02% Zn) and Zn_3 (0.06% Zn). Many authors also showed that grain yield increased significantly with increasing Zn levels (El-Majid *et al.*, 2000 and Seilsepour, 2007).



Zn_0 = 0 (control) Zn_1 = 0.02% Zn Zn_2 = 0.04% Zn Zn_3 = 0.06% Zn

Fig.5: Effect of Zn levels on yield (t ha^{-1}) of wheat

Table3. Effect of Zn levels on the growth and yield of wheat

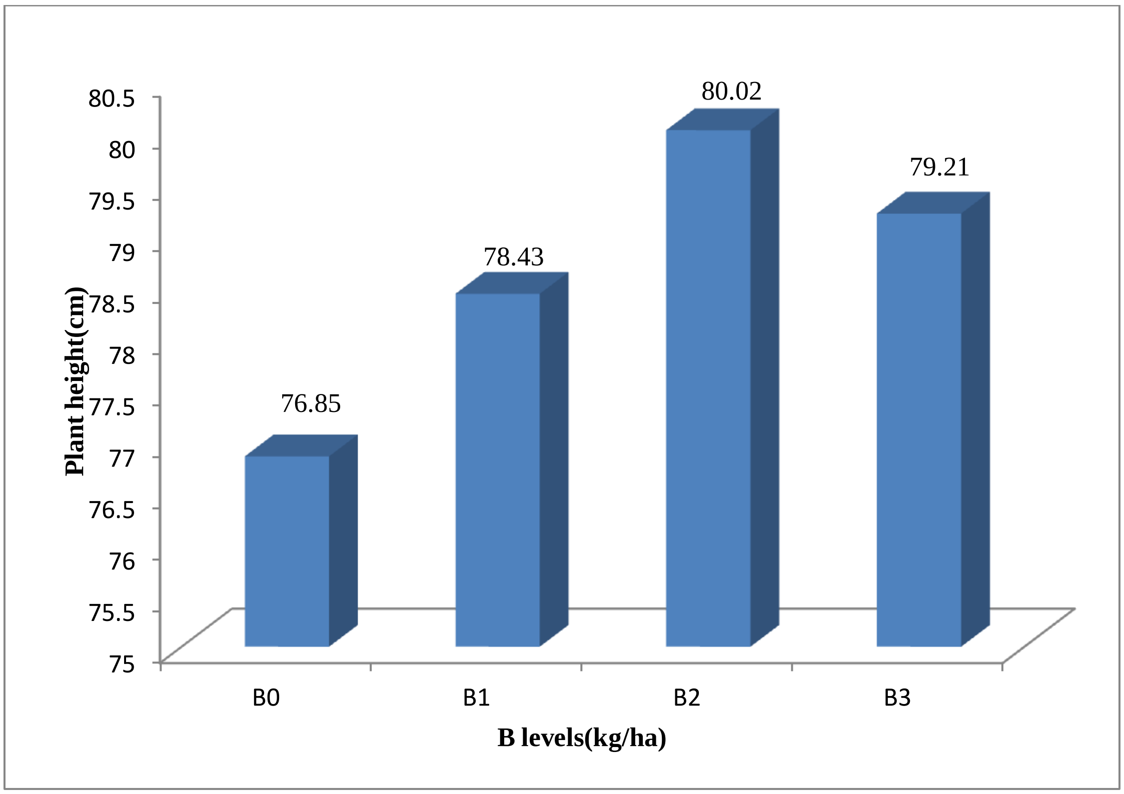
Treatments	Plant height (cm)	Spike length (cm)	No of grains $Spike^{-1}$	1000 grain weight (g)	Yield ($t\ ha^{-1}$)
Zn_0 = control	77.73^{b}	14.15^{b}	46.92^{b}	44.35^{b}	2.30^{b}
Zn_1 = 0.02% Zn	78.29^{ab}	14.70^{ab}	49.73^{a}	46.72^{a}	2.61^{a}
Zn_2 = 0.04% Zn	80.26^{a}	14.91^{a}	50.92^{a}	47.58^{a}	2.73^{a}
Zn_3 = 0.06% Zn	79.41^{ab}	14.58^{a}	50.73^{a}	47.25^{a}	2.71^{a}

Values in a column followed by a common letter are not significantly different at $p<0.05$

4.2 Effect of Boron on the growth and yield of wheat

4.2.1 Plant height

Application of different doses of boron influenced plant height significantly (Table 4). The results presented in The tallest plant height (80.02 cm) was observed when the crop field was treated with B_2 treatment (1.0 kg B ha^{-1}) which was statistically identical with B_1 treatment (0.5 kg B ha^{-1}) and B_3 (1.5 kg B ha^{-1}) treatment .The shortest plant height (76.85 cm) was produced where no B fertilization was done(Fig.6). BINA (1993) reported that plant height varied significantly by application of 1 kg B ha^{-1}.

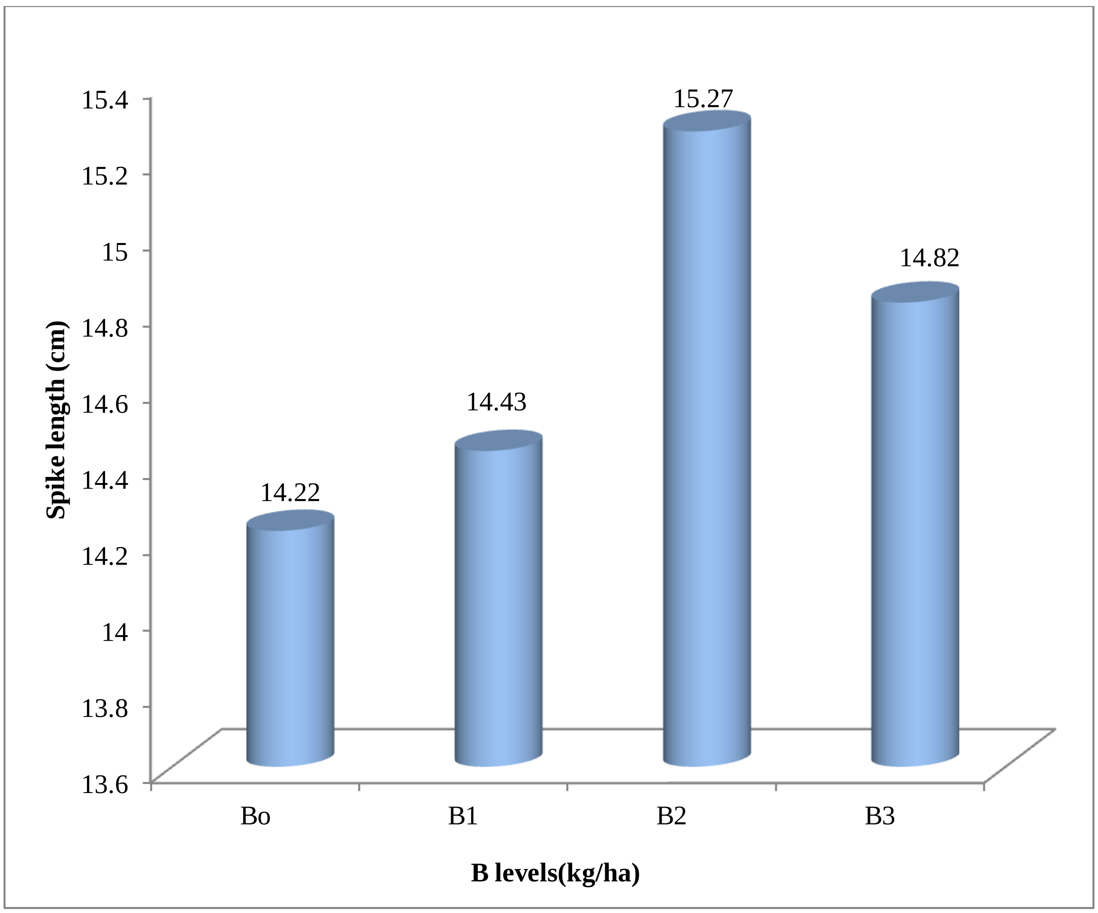


B_0 = 0 (control) B_1= 0.5 kg B ha^{-1} B_2 = 1.0 kg B ha^{-1} B_3 = 1.5 kg B ha^{-1}

Fig. 6: Effect of B levels on plant height (cm) of wheat

4.2.2 Spike length

There was a significant effect of different levels of B on spike length of wheat (Table 4). B_2 treatment (1.0 kg B ha^{-1}) produced the longest spike length (15.27cm). The shortest spike length (14.22 cm) was observed in control B_0 treatment (Fig.7). The results showed that B had positive effects to spike length. The results are in conformity with that of Mandal (1993).

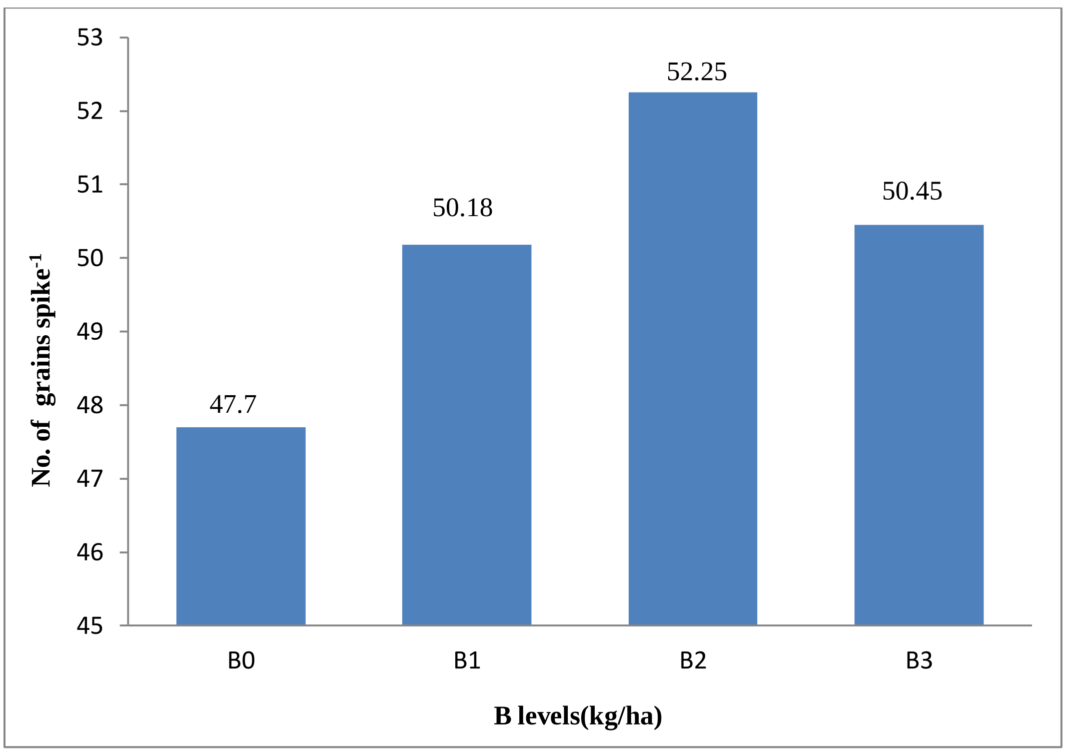


B_0= 0 kg B ha^{-1} B_1= 0.5 kg B ha^{-1} B_2 =1.0 kg B ha^{-1} B_3 =1.5 kg B ha^{-1}

Fig. 7: Effect of B levels on spike length of wheat

4.2.3 Number of grains spike^{-1}

There were also significant effects of different B levels on number of grains spike^{-1} (Table 4) .The results showed that the maximum number of grains spike^{-1} (52.25) was produced by application of B_2 treatment (1.0 kg B ha^{-1}) and the minimum number of grains spike^{-1} (47.7) was found at B_0 treatment (Fig.8).. The maximum number of grains spike^{-1} was probably attributed to reduction of sterility of wheat as B reduces male sterility of wheat. 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.

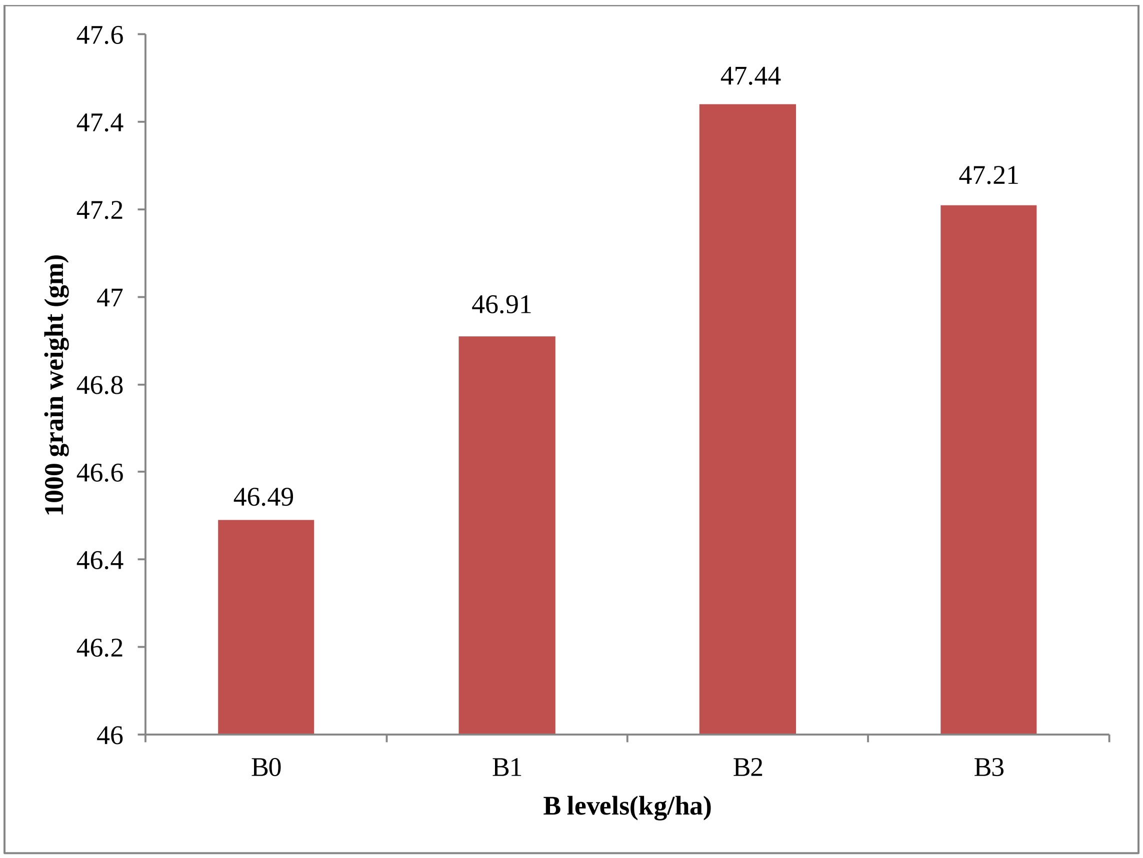


B_0= 0 (control) B_1= 0.5 kg B ha^{-1} B_2 = 1.0 kg B ha^{-1} B_3 = 1.5 kg B ha^{-1}

Fig. 8: Effect of B levels on number of grains spike^{-1} of wheat

4.2.4 Weight of 1000 grain

1000 grain weight was influenced significantly due to different levels of B application. (Table 4).The highest 1000 grain weight (47.44 g) was noted at B_2 treatment and lowest (46.49g) was obtained from B_0 treatment (Fig.9). 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.

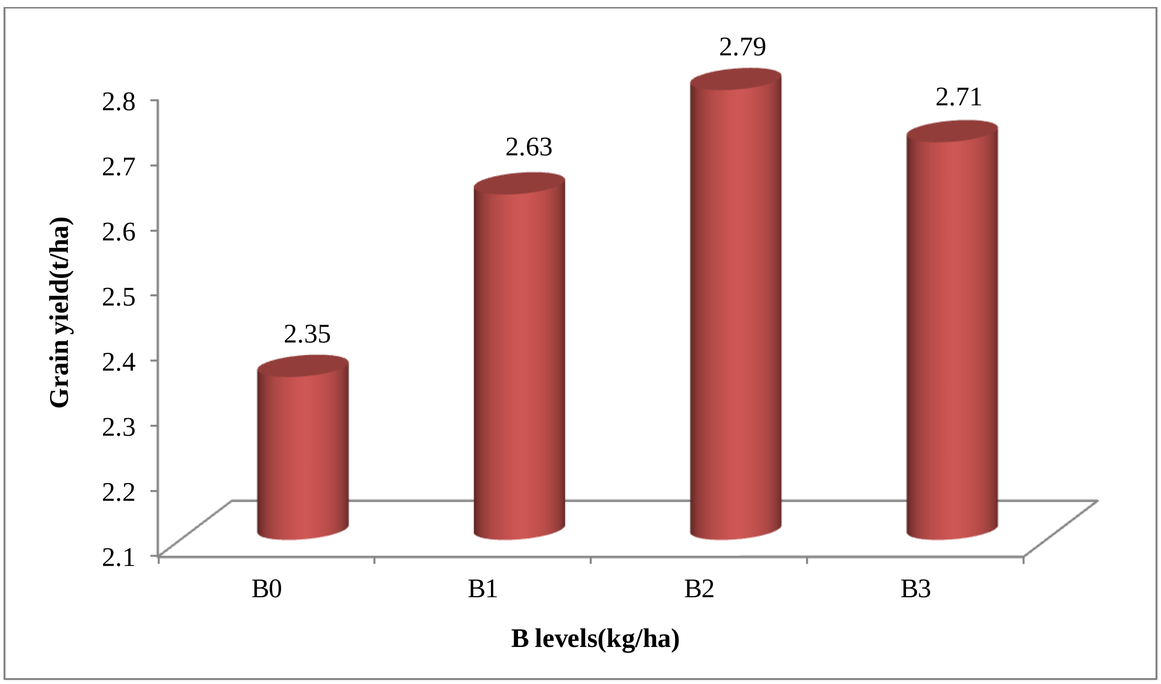


B_0 = 0 (control) B_1 = 0.5 kg B ha^{-1} B_2 = 1.0 kg B ha^{-1} B_3 = 1.5 kg B ha^{-1}

Fig. 9: Effect of B levels on 1000 grain weight (g) of wheat

4.2.5 Yield (t ha^{-1})

Grain yield was influenced significantly due to the different levels of B application (Table 4). Grain yield was increased up to the application of B_2 treatment (1.0 kg B ha^{-1}) and over this level of B the yield was decreased (Fig. 10). The highest grain yield (2.79 t ha^{-1}) was observed at B_2 treatment (1.0 kg B ha^{-1}). The lowest grain yield (2.35 t ha^{-1}) was obtained from the control B_0 treatment. The fall in grain yield of wheat in response to B might be due to the toxic effect of B above B_3 treatment (1.5 kg B ha^{-1}). The increased yield was mainly attributed to production of more number of grains $spike^{-1}$ having higher 1000 grain weight. This result was in accordance with that of Singh and Singh (1984), Mandal (1987), Galrao and Sousa (1988), Rahman (1989), BINA (1993) and Jahiruddin *et al.* (1995).



B_0 = 0 (control), B_1= 0 .5 kg B ha^{-1} B_2 = 1.0 kg B ha^{-1} B_3 = 1.5 kg B ha^{-1}

Fig. 10: Effect of B levels on grain yield (t ha^{-1}) of wheat

Table4. Effect of B levels on the growth and yield of wheat

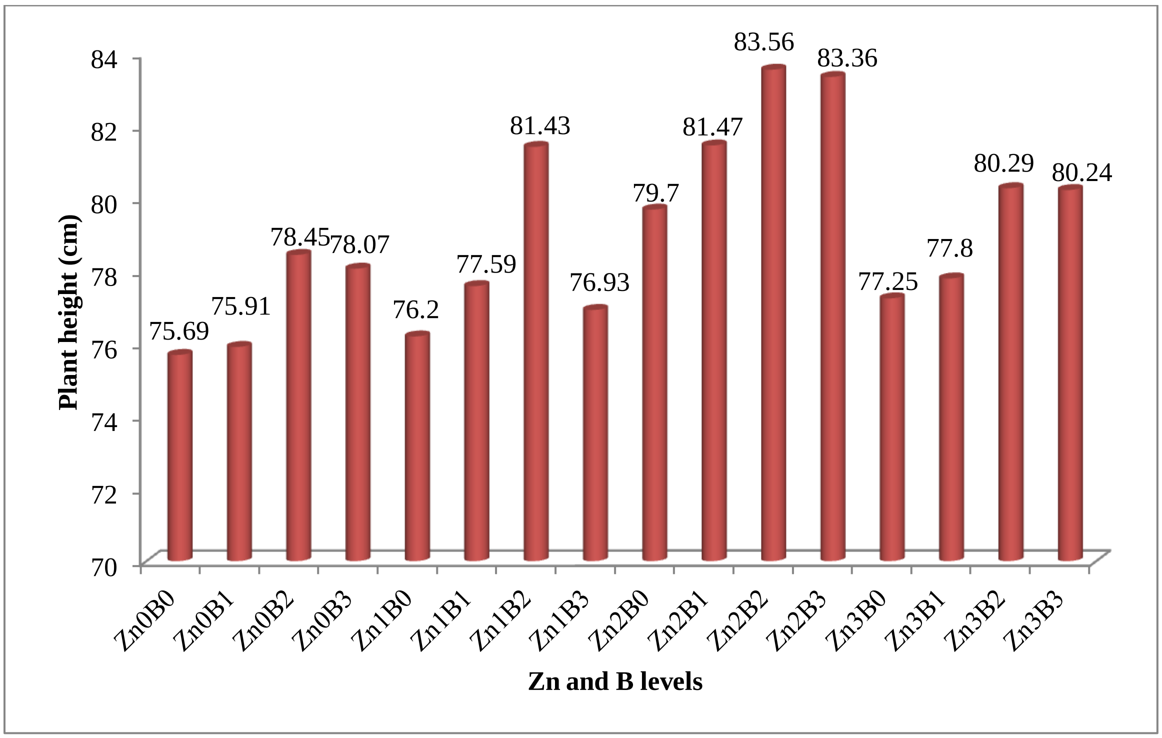
Treatments	Plant height (cm)	Spike length (cm)	No of grains $Spike^{-1}$	1000 grain weight (g)	Yield ($t\ ha^{-1}$)
B_0 = control	76.85^{b}	14.22^{b}	47.70^{b}	46.49^{a}	2.35^{b}
B_1 = 0.5kg	78.43^{ab}	14.43^{b}	$50.18.^{ab}$	46.91^{a}	2.63^{a}
B_2 =1.0 kg	80.02^{a}	15.27^{a}	52.25^{a}	47.44^{a}	2.79^{a}
B_3 =1.5kg	79.21^{a}	14.82^{ab}	50.45^{ab}	47.21^{a}	2.71^{a}

Values in a column followed by a common letter are not significantly different at $p<0.05$

4.3 Interaction effect of Zn and B levels on the growth and yield of wheat

4.3.1 Plant height

The plant height was significantly affected by the interaction effects of different levels of Zn and B (Table 5). The tallest plant (83.56 cm) was found at Zn_2B_2 treatments combination and the shortest plant (75.69 cm) was found under Zn_0B_0 treatments combination (Fig. 11). Present results indicated that plant height increased with the increasing levels of Zn and B.



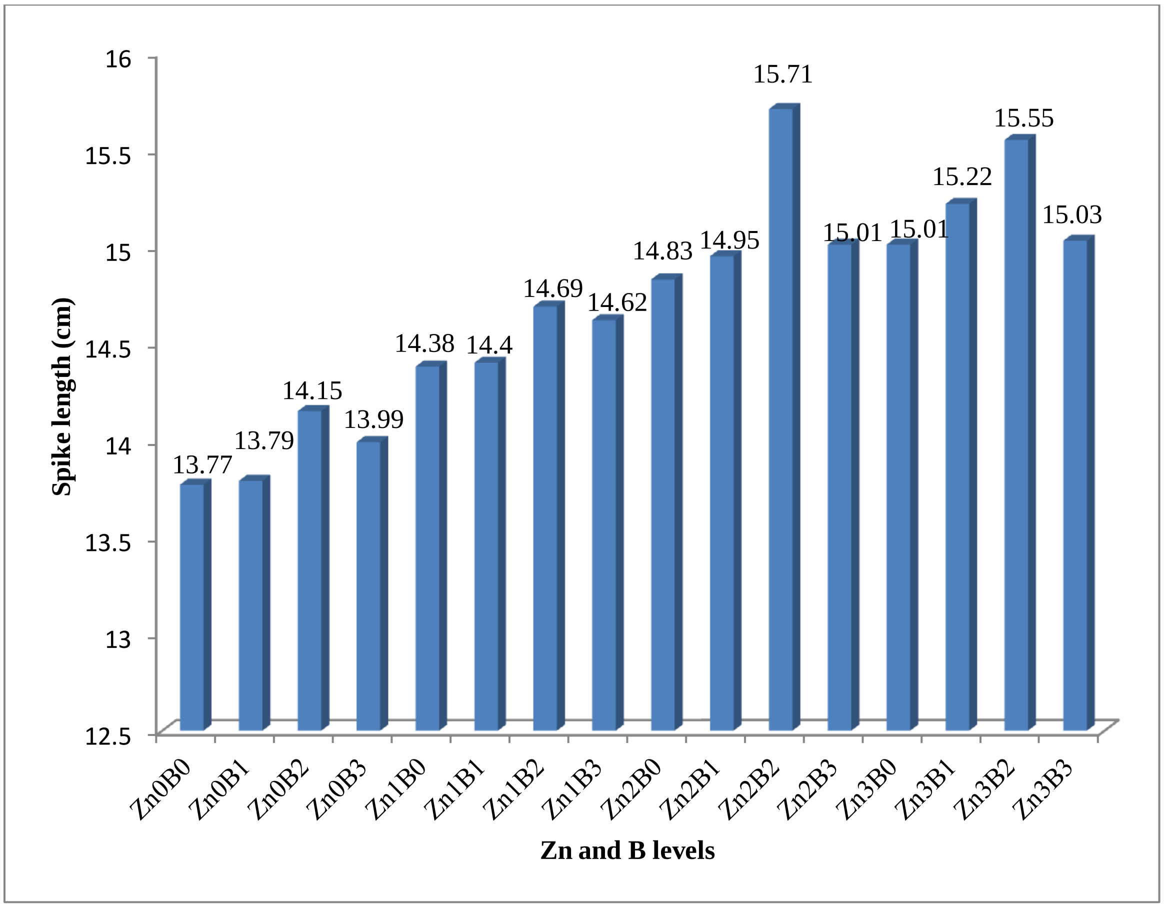
Zn_0 = 0 (control) Zn_1 = 0.02% Zn Zn_2 = 0.04 % Zn Zn_3 = 0.06% Zn

B_0 = 0 (control) B_1 = 0.5 kg B ha^{-1} B_2 = 1.0 kg B ha^{-1} B_3 = 1.5 kg B ha^{-1}

Fig. 11: Interaction effect of Zn and B levels on plant height (cm) of wheat

4.3.2 Spike length

The combined effects of Zn and B on spike length were significant (Table 5). However, the longest spike (15.71) cm) was observed with Zn_2B_2 treatments combination and the shortest value (13.77 cm) was in control Zn_0B_0 treatments combination. (Fig.12).From the above findings, it is concluded that the spike length was enhanced by Zn and B interaction. This result is agreed with that of Ziaeyan and Rajaie (2009).



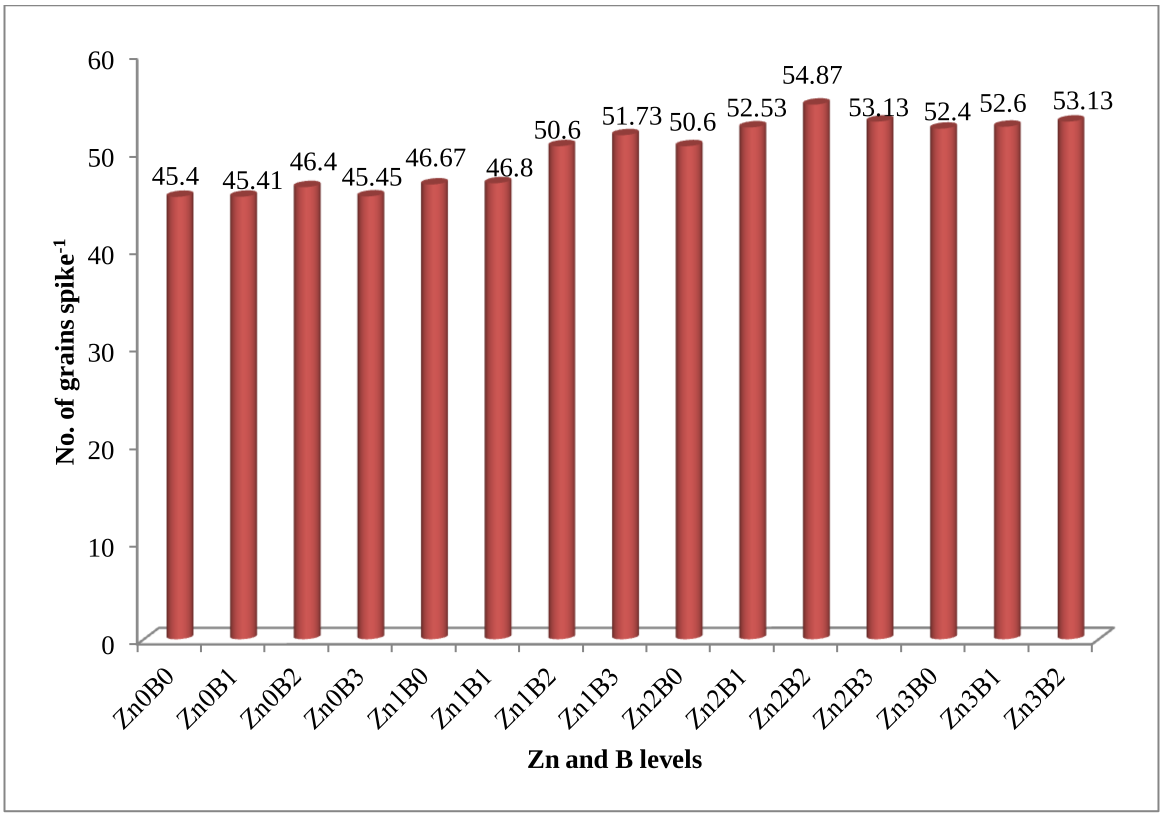
Zn_0 = 0 (control) Zn_1 = 0.02% Zn Zn_2 = 0.04 % Zn Zn_3 = 0.06% Zn

B_0 = 0 (control) B_1 = 0.5 kg B ha^{-1} B_2 = 1.0 kg B ha^{-1} B_3 = 1.5 kg B ha^{-1}

Fig. 12: Interaction effect of Zn and B levels on spike length (cm) of wheat

4.3.3 Number of grains spike^{-1}

Interaction effects of Zn and B showed significant variation on the number of grains spike^{-1} (Table 5). The number of grains spike^{-1} varied from 45.40 to 54.87 depending on the various treatments used. Zn_2B_2 treatments combination produced the maximum number of grains spike^{-1} (54.87) and the minimum (44.50) was obtained from control Zn_0B_0 treatments combination (Fig. 13). The combined positive effect of Zn and B interaction on number of grains spike^{-1} of wheat was reported by Ali *et al*. (2009).



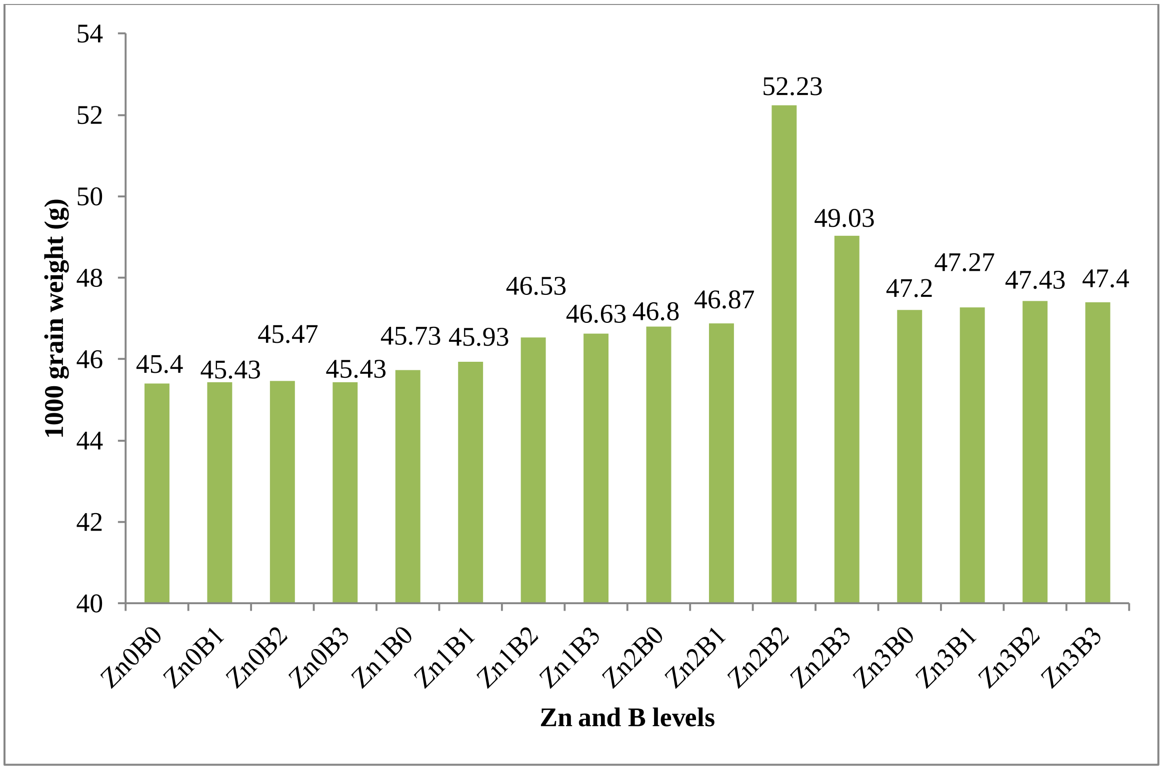
Zn_0 = 0 (control) Zn_1 = 0.02% Zn Zn_2 = 0.04 % Zn Zn_3 = 0.06% Zn

B_0 = 0 (control) B_1 = 0.5 kg B ha^{-1} B_2 = 1.0 kg B ha^{-1} B_3 = 1.5 kg B ha^{-1}

Fig. 13: Interaction effect of Zn and B levels on number. of grains spike^{-1} of wheat

4.3.4 1000 grain weight

The analysis of variance showed that the interaction effects of Zn and B were significant for 1000 grain weight (Table 5). The highest 1000 grain weight (52.23 g) was obtained from Zn_2B_2 treatments combination, while the lowest 1000 grain weight (45.40 g) was found from control Zn_0B_0 treatments combination (Fig. 14). The above results indicate that the 1000 grain weight was enhanced by Zn and B interaction. This combined positive effect of Zn and B interaction on 1000 grain weight of wheat was also reported by Ali *et al.* (2009).



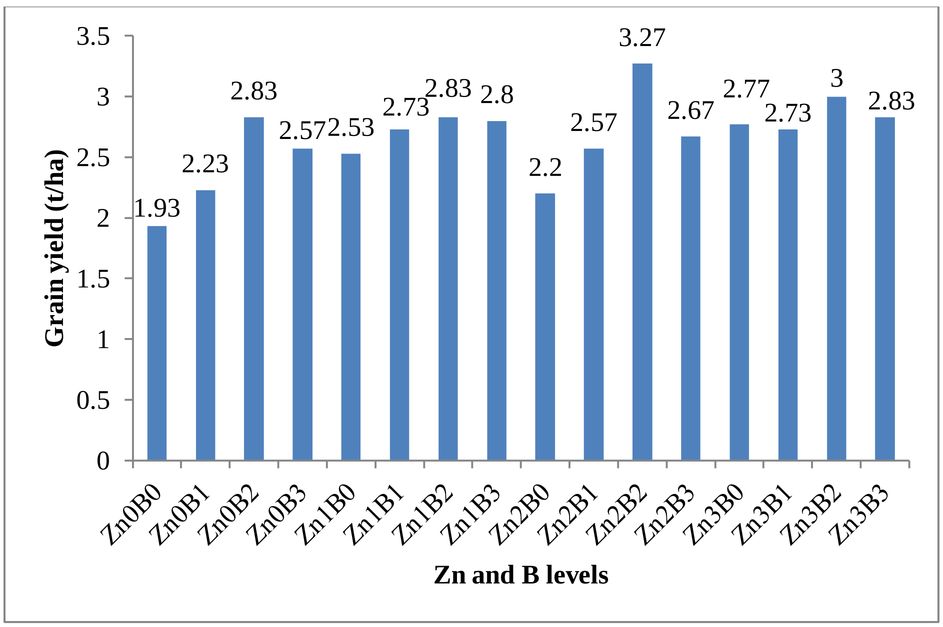
Zn_0 = 0 (control) Zn_1 = 0.02% Zn Zn_2 = 0.04 % Zn Zn_3 = 0.06% Zn

B_0 = 0 (control) B_1 = 0.5 kg B ha^{-1} B_2 = 1.0 kg B ha^{-1} B_3 = 1.5 kg B ha^{-1}

Fig. 14: Interaction effect of Zn and B levels on 1000 grain weight (g) of wheat

4.3.5 Grain yield (t ha^{-1})

The combined interaction effect of different levels of Zn and B fertilizer was significant regarding grain yield (Table 5). The highest grain yield (3.27 t ha^{-1}) was recorded at a Zn_2B_2 treatments combination and the lowest grain yield (1.93 t ha^{-1}) was recorded from Zn_0B_0 treatments combination (Fig.15). Zn in conjunction with B produced higher grain yield which is cleared from the trial. Similar results were also published by Arif *et al. (*2006). Asad *et al*., (2002) reported that foliar application of zinc at reproductive growth stage increase grain and straw yield significantly in wheat. Soylu *et al*., (2005) and Guenis *et al*., (2003) reported that significant increase in thousand grains weight with foliar application of zinc. Kenbaev and Sade (2002) and Hosseini (2006) have reported increase in yield components for foliar application of zinc. Foliar application of zinc at reproductive growth stages increase grain and straw yield significantly in wheat (Habib, 2009; Wrobel, 2006).



Zn_0 = 0 (control) Zn_1 = 0.02% Zn Zn_2 = 0.04 % Zn Zn_3 = 0.06% Zn

B_0 = 0 (control) B_1 = 0.5 kg B ha^{-1} B_2 = 1.0 kg B ha^{-1} B_3 = 1.5 kg B ha^{-1}

Fig. 15: Interaction effect of Zn and B levels on grain yield (t/ha) of wheat

Table5. Interaction effect of Zn and B levels on the yield and yield contributing characters of wheat.

Treatments combination		Plant height (cm)	Spike length (cm)	No. of grains $spike^{-1}$	1000 grain weight (g)	Yield ($t\ ha^{-1}$)
Zinc	**Boron**					
Zn_0 (Control)	B_0 = Control	75.69^{d}	13.77^{c}	45.40^{c}	45.40^{b}	1.93^{d}
Zn_0 (Control)	B_1 =0.5kg	76.93^{bcd}	13.79^{c}	45.41^{c}	44.43^{b}	2.23^{bcd}
Zn_0 (Control)	B_2 =1.0 kg	78.45^{bcd}	14.15^{bc}	46.40^{bc}	45.47^{b}	2.83^{abc}
Zn_0 (Control)	B_3 =1.5kg	78.07^{bcd}	13.99^{c}	45.45^{c}	45.43^{b}	2.57^{abcd}
Zn_1 (0.02% Zn)	B_0 = Control	75.91^{bcd}	14.38^{abc}	46.47^{bc}	45.73^{b}	2.53^{abcd}
Zn_1 (0.02% Zn)	B_1 =0.5kg	79.70^{abcd}	14.40^{abc}	46.80^{bc}	45.93^{b}	2.74^{abc}
Zn_1 (0.02% Zn)	B_2 =1.0 kg	81.43^{ab}	14.69^{abc}	50.60^{abc}	46.53^{ab}	2.83^{abc}
Zn_1 (0.02% Zn)	B_3 =1.5kg	76.20^{cd}	14.62^{abc}	51.73^{abc}	46.63^{ab}	2.80^{abc}
Zn_2 (0.04% Zn)	B_0 = Control	77.59^{cd}	14.83^{abc}	50.60^{abc}	46.80^{ab}	2.20^{cd}
Zn_2 (0.04% Zn)	B_1 =0.5kg	81.47^{ab}	14.95^{abc}	52.53^{ab}	46.87^{ab}	2.57^{abcd}
Zn_2 (0.04% Zn)	B_2 =1.0 kg	83.56^{a}	15.71^{a}	54.87^{a}	52.23^{a}	3.27^{a}
Zn_2 (0.04% Zn)	B_3 =1.5kg	80.29^{abc}	15.55^{ab}	53.13^{ab}	49.03^{ab}	2.67^{abcd}
Zn_3 (0.06% Zn)	B_0 = Control	76.03^{cd}	15.01^{abc}	52.40^{abc}	$47.20b^{a}$	2.77^{bcd}
Zn_3 (0.06% Zn)	B_1 =0.5kg	77.80^{bcd}	15.01^{abc}	52.60^{ab}	47.27^{ab}	2.73^{abc}
Zn_3 (0.06% Zn)	B_2 =1.0 kg	83.36^{a}	15.22^{abc}	53.13^{ab}	47.43^{ab}	3^{ab}
Zn_3 (0.06% Zn)	B_3 =1.5kg	80.24^{abcd}	15.03^{abc}	53.07^{abc}	47.40^{ab}	2.83^{abc}

CHAPTER V

SUMMARY AND CONCLUSION

An experiment was conducted at the research field of Sher-e-Bangla Agricultural University, Dhaka to evaluate the effect of four levels of zinc viz., 0, 0.02%, 0.04%, and 0.06% Zn and boron viz., 0, 0.5, 1.0 and 1.5 kg B ha^{-1} on grain yield and yield attributes of wheat (BARI Gom-26) during the period from October 2013 to February 2014. The experiment was laid out in a randomized complete block design with three replications. There were 48 unit plots and the size of the plot was 2m × 2m i.e. $4m^2$. There were 16 treatments combination. Wheat seed of cv. BARI Gom-26 was sown as test crop. Data on different growth and yield parameters were recorded and analyzed statistically. The results showed that plant height, spike length, number of grains $spike^{-1}$, 1000-grain weight and grain yield were significantly affected by different levels of Zn application in relation to yield. The tallest plant (80.26 cm), longest spike length (14.91 cm), maximum number of grains $spike^{-1}$ (50.92), highest 1000-grain weight (47.58 g), highest grain yield (2.73 t ha^{-1}), were obtained from Zn_2 treatment(0.04 % Zn). Correspondingly, the lowest values of these parameters from control treatment Zn_0.

Application of different levels of boron had significant effect on different parameters of wheat. The highest plant height (80.02 cm), longest spike length (15.27 cm), number of grains $spike^{-1}$ (52.25), greatest 1000-grain weight (47.44 g), highest grain yield (2.79 t ha^{-1}), was obtained from B_2 treatment (1 kg B ha^{-1}). Correspondingly, the lowest values of these parameters from control treatment B_0. The control treatment indicated the lowest value for all the yield and yield attributing characters.

Significant effects on the most of the yield and yield attributing characters were observed in the interaction effects of combined different levels of Zn and B. The tallest plant (83.56 cm), the longest spike length (15.71 cm), number of grains $spike^{-1}$ (54.87), the highest 1000-grain weight (52.23 g), highest grain yield (3.27 t ha^{-1}), were achieved from the treatments combination Zn_2B_2 (0.04% Zn ha^{-1}× 1 kg B ha^{-1}).

Finally, all the yield and yield attributing characters were found lowest in control treatments combination Zn_0B_0.

The overall results of the present study demonstrated that wheat may be grown successfully for obtaining maximum yield with the application of Zn_2 treatment (0.04 % Zn) as foliar application and B_2 treatment (1 kg B ha^{-1}) as soil application. However, before making conclusion concerning the appropriate dose of Zn and B, the study needs further investigation in other Agro Ecological Zones (AEZs) of Bangladesh for country-wide recommendation which will be useful.

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APPENDICES

Appendix1. Chemical properties of post harvest soil

Treat. combination		K (meq/ 100g)	Total N%	P	S	pH	OM
Foliar spray of Zn levels	B levels			(µg/g)			%
Zn_0=control	B_0 = Control	0.31	0.067	9.36	27.57	5.2	1.22
	B_1 = 0.5kg/ha	0.29	0.046	8.45	26.50	5.5	1.33
	B_2 = 1.0kg/ha	0.32	0.067	10.25	28.25	5.6	1.43
	B_3 = 1.5kg/ha	0.30	0.065	9.97	26.60	5.5	1.25
Zn_1 =0.02% Zn	B_0 = Control	0.31	0.069	15.75	31.25	5.4	1.44
	B_1 = 0.5kg/ha	0.33	0.067	14.95	30.45	5.3	1.18
	B_2 = 1.0kg/ha	0.28	0.060	16.09	32.06	5.1	1.27
	B_3 = 1.5kg/ha	0.27	0.073	15.61	33.50	5.5	1.19
Zn_2= 0.04% Zn	B_0 = Control	0.34	0.073	35.56	38.33	5.7	1.34
	B_1 = 0.5kg/ha	0.35	0.081	34.25	37.13	5.5	1.38
	B_2 = 1.0kg/ha	0.39	0.078	36.01	38.01	5.3	1.43
	B_3 = 1.5kg/ha	0.37	0.076	35.75	37.13	5.4	1.29
Zn_3 =0.06% Zn	B_0 = Control	0.38	0.063	29.75	33.83	5.4	1.28
	B_1 = 0.5kg/ha	0.35	0.051	30.15	32.13	5.6	1.37
	B_2 = 1.0kg/ha	0.36	0.050	31.38	33.97	5.3	1.40
	B_3 = 1.5kg/ha	0.33	0.060	30.75	35.15	5.5	1.30
Critical Level		0.12	0.12	7.0	10		

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

Appendix2. Monthly records of air temperature, relative humidity, rainfall and sunshine hours during the period from October 2013 to February 2014

Month	Year	Monthly average air temperature (^{0}C)			Average relative humidity (%)	Total rainfall (mm)	Total sunshine (hours)
		Maximum	Minimum	Mean			
Oct	2013	29.36	18.54	23.95	74.80	Trace	218.50
Nov	2013	28.52	16.30	22.41	68.92	Trace	216.50
Dec.	2013	27.19	14.91	21.05	70.05	Trace	212.50
Jan.	2014	25.23	18.20	21.80	74.90	4.0	195.00
Feb.	2014	31.35	19.40	25.33	68.78	3.0	225.50

Source: Bangladesh Meteorological Department (Climate division), Dhaka-1212.

Picture showing different stages of wheat in experimental plot