EFFECT OF ZINC AND COPPER ON THE YIELD AND QUALITY OF WHEAT

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CERTIFICATE

This is to certify that thesis entitled ***"EFFECT OF ZINC AND COPPER ON THE YIELD AND QUILITY 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* ***RIFA SONIA, Registration no. 11-04617*** *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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Dedicated to

My

Beloved Parents

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ABSTRACT

A field experiment was carried out at the experimental field of Sher-e-Bangla Agricultural University (SAU) farm, during November 2015 to February 2016, to study the effect of different levels of Zinc (Zn) and Copper (Cu) fertilization on the yield and quality of wheat (BARI Gom-30). The experiment included three levels of Zn viz. 0 (control), 3 kg ha^{-1} Zn, 6 kg ha^{-1} Zn and three levels of Cu viz. 0 (control), 2 kg ha^{-1} Cu and 4 kg ha^{-1} Cu 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 by different levels of zinc and copper alone and their interaction. The tallest plant (68.22 cm), the highest grain yield (202 g m^{-2})/(2.02 t ha^{-1}) and the highest concentration of Zn (42.20 ppm) and Cu (4.20 ppm) in wheat grain were obtained from were obtained from Zn_2 treatment (6 kg ha^{-1} Zn). On the other hand, the shortest plant (65.58 cm), minimum grain yield (150 g m^{-2})/(1.50 t ha^{-1}) and the lowest concentration of Zn (27.58 ppm) and Cu (3.85 ppm) in wheat grain were observed when Zn was not applied (Zn_0 treatment). In contrast, plant height (66.60 cm) and grain yield (180.88 g m^{-2})/(1.8 t ha^{-1}) were the highest when Cu_2 treatment (4 kg ha^{-1} Cu) was imposed. The highest concentration Zn (36.12 ppm) was obtained from Cu_1 treatment (2 kg ha^{-1} Cu) and Cu (4.66 ppm) obtained from Cu_2 treatment (4 kg ha^{-1} Cu) in wheat grain. The shortest plant height (66.03 cm), the lowest grain yield (167.22 g m^{-2})/(1.67 t ha^{-1}) and the lowest concentration of Zn (32.22 ppm) and Cu (2.82 ppm) being recorded from the control treatment Cu_0. Among the interactions of Zn and Cu, the tallest plant (69.15 cm), the highest grain (222.66 g m^{-2})/(2.22 t ha^{-1}) were obtained from combined treatment Zn_2Cu_2. The highest concentration of Zn (46.90 ppm) was obtained from Zn_2Cu_1 treatment and Cu (5.10 ppm) was obtained from Zn_2Cu_2 treatment in wheat grain. On the contrary, the lowest performances for all the studied crop characters and the lowest concentration of Zn and Cu in wheat grain were obtained from the treatment combination Zn_0Cu_0 where Zn and Cu were not applied. The results showed that grain yield of wheat increased with increasing levels of both Zn and Cu up to Zn_2 treatment (6 kg ha^{-1} Zn) and Cu_2 treatment (4 kg ha^{-1} Cu), respectively. The effect of Zn was more prominent than with Cu on different yield components and yield of wheat.

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LIST OF ABBREVIATIONS

ABBREVIATIONS	FULL WORD
AEZ	Agro-Ecological Zone
@	At the Rate
BARI	Bangladesh Agricultural Research Institute
BAU	Bangladesh Agricultural University
BCR	Benefit Cost Ratio
BINA	Bangladesh Institute of Nuclear Agriculture
BBS	Bangladesh Bureau of Statistics
CGR	Crop Growth Rate
cm	Centimeter
^0C	Degree Celsius
cv.	Cultivar(s)
CV%	Percentage of Coefficient Variance
DAS	Days After Sowing
DMRT	Duncan's Multiple Range Test
et al.	And Others
FAO	Food and Agriculture Organization
(g)	Gram (s)
HI	Harvest Index
Kg ha^{-1}	Kg Per Hectare
K	Potassium
LER	Land Equivalent Ratio
LSD	Least Significant Difference
m	Meter
MoP	Muriate of Potash
OM	Organic Matter
N	Nitrogen
NS	Non-Significant
pH	Hydrogen Ion Concentration
ppm	Parts Per Million

ABBREVIATIONS	FULL WORD
P	Phosphorus
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^{-1}	Ton $Hectare^{-1}$
UNDP	United Nations Development Programme
%	Percent
i.e.	That is
e.g.	As for Example

CHAPTER I

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the leading cereal food grain crop cultivated in the world. It ranks first both in area (21,360 thousand hectares) and production (5,76,317 thousand metric ton) of the world (FAO, 2014) cereal crops accounting for 30% of all cereal food worldwide and is a staple food for over 10 billion people in as many as 43 countries of the World. Increasing rate of consumption of wheat is 3% per year (Roy and Pandit, 2007). In the developing world, need for wheat will be increased 60% by 2050 (Rosegrant and Agcaoili, 2010). The International Food Policy Research Institute projections revealed that world demand for wheat will increase from 552 million tons in 1993 to 775 million tons by 2020 (Rosegrant *et al*.,1997). Wheat grain is the main staple food for about two third of the total population of the world (Hanson *et al*., 1982).Wheat 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 2016, world production of wheat was 749 million tonnes, making it the second most produced cereal after maize (Wikipedia). Since 1960, world production of wheat and other grain crops has tripled and is expected to grow further through the middle of the 21st century . Globally, wheat is the leading source of plant protein in human food, having a higher protein content than other major cereals, maize (corn) or rice. It provides about 20% of the total food calories for the human race. Wheat grain is rich in food value containing 12% protein, 1.72% fat, 69.60% carbohydrate and 27.20% minerals (BARI, 2006). Wheat ranks second in Bangladesh accounting for 20% of all cereal food of Bangladesh and is cultivated on large scale in the country. Wheat has now become an indispensable food item of the people of Bangladesh and it continues to fill the food gap caused by possible failure of rice crop. Within a period of 30 years of time, wheat has been firmly established as a secure crop in Bangladesh, mainly due to stable market price and two million farmers are currently involved in wheat production (Karim *et al*., 2010). 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). Bangladesh is a small country with large population and its population has an increasing trend. Increasing grain yield and improving quality are of great importance for the increasing human population (Curtis and Halford, 2014). 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. Wheat is grown under different environmental condition ranging from humid to arid, sub tropical to temperate zone (Saari, 1998). It is grown under a wide range of climatic and soil conditions. It, however, grows well in clayey loam soils. In Bangladesh, it is a crop of Rabi season, requires dry weather and bright sunlight. Well distributed rainfall between 40 and 110 cm is congenial for its growth. It is cool-loving crop and adopted for cultivation in regions with cooler climatic conditions. Its grain growth and development rely on temperature range of 150 /100 to 180 /150 (Throne *et al*., 1968), the best time of wheat sowing is the second half of November that needed around 110-120 days to complete its life cycle. 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 important 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 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). 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 Cu are considered to be the most important in order to obtain optimum production in case of wheat. Wheat is a relatively sensitive crop to copper (Brown & Clark, 1977) and zinc (Hamid & Ahmad, 2001) deficiencies. Application of Cu and Zn to wheat in soils significantly increased crop growth and wheat nutrient quality. Copper application increased Zn concentrations in wheat suggesting its higher tendency towards binding sites, subsequently making Zn more available to plants.

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. Zinc, a micro nutrient element, is required for plant growth relatively to a smaller amount. The total zinc content of soil ranges from less than 10 to 1000 ppm. Zinc has been found useful in improving yield and yield components of wheat (Cakmak*et al*., 1996; Modaihsh, 1997; Kaya *et al*., 2002; Singh, 2004) and adequately applied zinc has been shown to improve the water use efficiency of wheat plants (Bagci*et al*., 2007). 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 important for membrane integrity and most importantly phytochrome activities (Shkolnik, 1984). 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 copper is one of them. Copper as an essential micronutrient for normal growth and metabolism of plants is well documented (Sharma and Agarwal, 2005; Singh *et al*., 2007). This element plays role in protein and carbohydrate metabolism as well as enzymatic systems. Copper is an essential micronutrient required for the growth of wheat (Brown and Clark, 1977) with crucial roles throughout the plant including chlorophyll formation, enzymatic reactions and pollen formation (Graham, 1975;Sauchelli, 1969). Copper mobilises from old leaves to younger parts of the plant to some extent with the degree of mobilisation greater when Cu is more available to the plant and movement is related to leaf senesce (Hill *et al*., 1978; Loneragan, 1981). It is involved in numerous physiological functions as a component of several enzymes, mainly those which participate in electron flow, catalyze redox reactions in mitochondria and chloroplasts (Lolkema and Vooijs, 1986). Copper as essential to wheat because it is involved in a number of plant functions, such as electron transfers, chlorophyll production, protein synthesis and respiration. Among the micronutrients, zinc and copper deficiency are prominent in Bangladesh soils. Due to the deficiency of zinc, plants show symptoms such as little leaf, mottle rosette, die-back, browning, yellowing, brown spot. Zinc deficient plant make 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. In excessive quantities Cu becomes toxic as it interferes with photosynthetic and respiratory processes, protein synthesis and development of plant organelles (Wainwright and Woolhouse, 1977; Sandmann and Boger, 1980; Baszynski *et al*., 1982; Ouzounidou *et al*., 1992, 1993; Agarwala *et al*., 1995). Copper deficiency in wheat produces characteristic symptoms of yellowing and curling of young leaves, pigtailing of leaf tips, limpness or wilting, delay in heading, aborted heads and spikelets, head and stem bending, as well as stem melanosis disease in certain wheat cultivars. Wheat deficient in Cu during the vegetative phase appears wilted and progresses to plants being short and thin-stemmed with twisted leaf-tips that senesce (Grundon, 1987;Wurst *et al.*, 2010). Mature plants deficient in Cu have delaying heading, and empty or partially-filled heads due to lack of viable pollen and also senesce (Graham, 1975).

The prevailing situation underscores the need for investigation whether Zn and Cu 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 Zn and Cu on the yield and quality 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 compare the yield and quality performance of wheat by using different doses of Zn and Cu.
- To find out the optimum dose of Zn and Cu on the yield and nutrient content of wheat.
- To show the interaction effect between Zn and Cu on the yield and accumulation of Zn and Cu in wheat under different doses.

CHAPTER II

REVIEW OF LITERATURE

This chapter has presented a comprehensive review of literature related to the effect of Zn and Cu on the yield and quality of wheat. Wheat (*Triticum aestivum* L.) is one of the major cereal crops in Bangladesh. At home and abroad a good number of research works on wheat cultivar have been done in various aspects for its successful production and still more modern and most sophisticated research are in progress all over the world. The production 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 Copper are the most important micronutrient elements those play a significant role in crop production. 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). Copper is important for physiological redox processes, pollen viability and lignification (Marschner, 1995). In this chapter, an attempt has been made to review the available information related to the present study is summarized to find out some important information to support the present piece of work. However, the research work so far done at home and abroad regarding the performance of wheat under different levels of zinc and copper fertilizers along with other pertinent information are reviewed below:

Zinc and Copper on Wheat

2.1 Forms of Zinc in Soils

Zinc is a micronutrient since it is required relatively smaller in amount than macronutrients. The forms of Zn in soils are: solution Zn^{2+}, adsorbed Zn^{2+} (on clay surface, organic matter, carbonates and oxide minerals), organically complexed Zn^{2+} and Zn^{2+} substitued for Mg^{2+} in the crystal lattices of clay mineralsand Zn in primary and secondary minerals.

2.2 Effect of Zinc on Wheat

Zinc (Zn) is a micronutrient which is need for plant growth and development relatively to a smaller amount and 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. Zinc is an important essential element involved in a diverse range of enzymatic activities.

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 grainyield, 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 Zn deficiency has a multitude of effects on plant growth. Zn 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 Zn 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).

The most of the seed-Zn 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 phytatein seeds could be sinks for Zn. According to a Zn-staining study in wheat seed, Zn concentrations were found to be 150 mg 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).

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.

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 ovantoat 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 oflocations.

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 mg l^{-1}) and three Zn levels (0, 0.1 and 10 mg l^{-1}). Results showed that supply of Fe (5 mg l^{-1}) and Zn (0.1 mg l^{-1}) increased plant dry weight and leaf chlorophyll content compared to the Fe or Zn deficient (0 mg l^{-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- andstem-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.

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 andits quality compared with control. Among treatments, application of (Fe + Zn) obtainedhighest 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.

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, UgarKhurd, 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}) an 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 at10 t ha^{-1}+$ZnSO_4$ soil application at 10 kg ha^{-1} showed higher yield (38.65qha^{-1}) compared to the other treatment combinations.

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).

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.

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.

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.

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.

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.

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.

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 of3233 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 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.

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}.

Rerkasem and Longeragan (1990) stated that zinc deficiency could depress wheat yield through the failure of grain setting. The highest grain yield was obtained by wheat plants from soil fertilized only by NO_3-N during the reproductive stage combined with foliar spraying with zinc.

Mitra and Jana (1991) found that number of effective tillers/plant, number of grains/ panicle and 1000 grain weight were significantly increased by zinc application up to 6kg Zn/ha and thereafter a negative effect was noticed.

Jahiruddin *et al*. (1992) conducted a study with four field trials in two AEZs of Bangladesh to examine the effect of zinc on grain set of wheat. Of the agronomie parameters studied, the two components viz., number of grains/spike and grain yield 11 increased significantly due to zinc treatment. Crop response to zinc varied between locations.

Ahmed *et al*. (1991) carried out a fertilizer trial in Old Brahmaputra Floodplain soil to examine the effect of magnesium, zinc and magnesium on the growth, yield and nutrient content of wheat (cv. Kanchan). They observed that the grain yield of wheat responded significantly to zinc treatments. The addition of Mg alone resulted in a 38.5% yield increase over control as against the yield increment of 42.1 % by the combined treatment of magnesium, zinc. The grain yield of wheat was positively dependent on the number of grains/spike, indicating that the added nutrients especially zinc had a considerable influence on grain set which in turn resulted in higher grain yield. Magnesium played a significant role in improving the protein content of grain.

Mandal (1993) carried out an experiment with 21 wheat varieties in the Tarai region of India in order to find out the effect of zinc application on grain yield and other yield components of wheat. Most of the varieties showed positive response to zinc with respect to grain yield , number of grain/spike and spike length. Grain yield was increased basically through the increase in number of grains/spike. However, varieties like BAU 2076, H 1968, BR 350 and BW 121 showed very small response or no response to zinc for most of the trials.

Rawson (1999) found from reciprocal transfers of wheat plants between adequate and zero zinc root media at different development stages, that the period during which florets are sterilized by zinc 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 zinc 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 zinc to the reproductive growth centers. It appeared that a prior period in adequate zinc had a different effect on sterility amongst genotypes.

Wei and Zuo (1996 a) reported that application of zinc to the zinc deficient soil in Yiduhe village in the suburbs of Beijing, China resulted in significant positive effects on winter wheat production. They reported that foliar application of zinc increased the yield of winter wheat by 20% and rate of nitrogen use by 13.9%.

Wei and Zuo (1996 b) reported that basal application of zinc significantly increased the number of spikelet's on the main stem, leaf area, photosynthesis, 1000 grain weight and N. P and K uptake. They also found that utilization efficiency of nitrogen and phosphoric acid by plants was improved by foliar application of zinc (18 and 7.5% higher, respectively than control).

Hossain *et al.* (1997) conducted an experiment to evaluate the performance of wheat cultivars Kanchan, Aghrani and Akbar with or without application of 0 or 3 kg Zn/ha. They found the highest yield in Kanchan and zinc application increased it.

Mandal and Ray (1999) conducted a field trial in 1999-2000 at Cooehbehar. West Bengal, India with 13 wheat cultivars which were given 0, 10, or 15 kg Zn/ha. Nine cultivars showed significant response to applied zinc for major yield components. Cv. BW-36, HP1376 and BR-2094 were non responsive to Zn. Sonalika was non responsive to zinc at the lower dose and its yield significantly decreased at the higher dose.

Mandal (2000) carried out an experiment with different local high yielding bread wheat varieties originating from Mexican, Semi-dwarf parents to determine the response of zinc (0, and 6 kg Zn /ha) with respect to yield and its component characters during the winter season of 1993-94 in west Bengal, India. He reported that most of the varieties responded well to zinc for yield and important yield component characters.

Kataki *et al*. (2001) conducted a field experiment during 2002-2003 and 2004-2005 at the Naldung rice wheat site of Kavre district of Nepal to study the effect of Zn and N on sterility in wheat cultivars. The soil application of Zn at sowing reduced sterility b y more than 50% and doubled wheat yields by increasing seed set. They found that application of Zn could double wheat yields in Zn-deficient areas of the mid-hill region of Nepal. Mete ci aL (2005) conducted an experiment during the winter season to study the effect of zinc and lime on the growth and yield of wheat (Tri/icumaestivum cv. HP173 1). The application of zinc (5 or 10 kg Zn/ha) alone and in combination with lime (0.5 or 1.0 I/ha) to both soils significantly enhanced the 1000-grain weight and zinc content of wheat plants. The number of grains/spike and plant height was significantly increased with the application of zinc and lime whet_ier singly or in combination. The application of lime (1.0 i/ha) with zinc (1 kg Za/ha) to both fields resulted in the highest wheat grain yields.

Lakshman *et al*. (2005) conducted a field experiment to evaluate the zinc deficiency causing grain set failure and yield loss. This study evaluated the performance of ten cultivars of bread wheat (*Triticum aestivum* L.) in zinc deficient (Zn_0) and zinc supplemented conditions (Zn_2). Observations were recorded for plant height (cm), days to 50% flowering, number of filled grains per spike, chatTy grain (%), 1000-grain weight and yield/plant (g). Significant genetic variability for zinc efficiency was observed for number tilled grains/spike, chaffy grain (%) and yield/plant. DBW14 yielded the maximum mean values for yield/plant at both Zn2 and Zn0levels, while the mean values were lowest for HP 1731 at Zn0 and Sonalika at Zn2. The high response to zinc was found in DBWI4, P8W343, HD2285, HD2643 and NWI0I4, whereas Sonalika showed least response to zinc application in respect to yield. The rest of the cultivars showed moderate response to zinc.

Wrobel *et al*. (2006) conducted a pot experiment in 2001-2003 at the Department of Soil Tillage and Fertilization Techniques, Jelcz-Laskowice. Poland, to investigate the effect of zinc (Zn) fertilizer application on spring wheat grown in light soil, deficient in Zn and subjected to periodic drought stress. Deficit in available zinc in the soil revealed deficient amounts of zinc in wheat grain, which decreased the quality of wheat grain as foodstuff or fodder. Application of zinc fertilizer increased the grain weight and straw yields of spring wheat. This study demonstrated that zinc is 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 the wheat grain.

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.

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.

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 inthe 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.

2.3 Forms of Copper in Soils

Copper is an micronutrient component of enzymes, some of which are important to lignin formation in cell walls. It is also involved in photosynthesis, respiration, and processes within the plant involving nitrogen. Copper is taken up as Cu^{2+} (cupric ion). Soluble copper and organic matter complexes known as chelates.

2.4 Effect of Copper on Wheat

Copper is an important micronutrient for plants.Copper is more tightly bound to organic matter than the other micronutrients.Copper deficiencies can occur in organic soils.Copper-containing minerals can dissolve and supply Zn to the soil solution. Copper can be immobilized by microorganisms, taken up by plants, or exchanged on soil particle surfaces. Copper may also form chelates with soluble organic matter. Organic copper must be mineralized before it is available for plant uptake.The important Cu containing minerals are Chalcopyrite ($CuFeS_2$), Chalcocite (Cu_2S), Covellite(CuS),Cuprite(Cu_2O), Bornite ($2Cu_2S{\cdot}CuS{\cdot}FeS$). Copper participates a numerous physiological processes and an essential cofactor for many metalloproteins.

Karamanos *et al*. (2003) carried out an extensive study that included 115 site-years in order to arrive at a uniform critical concentration of DTPA extractable Cu (DTPA-Cu) for prairie soils. The authors reported statistically significant grain yield responses in 87% of trials carried out on soils containing Cu of wheat grown on soils containing DTPA-Cu in a marginal range that extends between 0.4 and 1.2 mg DTPA-Cu kg^{-1} soil was obtained in less than 15% of trials.

Common foliar fertilizer forms include $CuSO_4$, copper oxide (CuO) and chelated forms that are applied at various rates depending on crop and fertilizer form (Martens and Westermann, 1991).

Foliar applications especially as solutions of inorganic salts, can cause leaf burn; however, damage can be minimized by keeping application rates at 0.25 to 0.5 kg Cu ha^{-1} (Mortvedt and Cox, 1985). This may necessitate a second foliar application (Varvel *et al*., 1983).

Earlier limited research on the prairies (Karamanos *et al*. 1986; Penney *et al*. 1993) has found foliar applications to be either erratic or less effective than the best soil treatments.

Malhi *et al*. (1989) found that foliar application of 2–4 kg Cu ha^{-1} as Cu-chelate or 10–20 kg Cu ha^{-1} as $CuSO_4$ resulted in phytotoxicity and delayed maturity; nevertheless, it did reduce stem melanosis in Park wheat and increased grain yield as effectively as equivalent rates of soil-incorporated Cu in one of two experiments.

Karamanos *et al*. (2003), carried out an experiment on soils containing less than and those containing DTPA-Cu greater than 0.4 mg Cu kg^{-1}. Significant ($P < 0.05$, except one case of $P < 0.1$) grain yield increases to either soil and/or foliar applications were obtained in all trials in the former category, whereas no statistically significant grain yield increases were obtained in any of the trials in the latter.

Broadcast and incorporation of Cu in the form of $CuSO_4{\cdot}5H_2O$ resulted in maximum grain yield in all instances, thus confirming earlier observations (Kruger *et al*., 1985; Karamanos *et al*., 1986; Malhi *et al*., 1989; Penney *et al*., 1993) that soil application of at least 4 kg $CuSO_4{\cdot}5H_2O$-Cu ha^{-1} provided maximum grain yield by correcting a Cu deficiency.

Graham (1976), Karamanos *et al*. (1986) and Penney *et al.* (1993), who found that performance of a foliar application was influenced by both timing of application and environmental conditions. Foliar application of Cu resulted in significant ($P < 0.05$) grain yield increase in 7 of the 10 trials that were characterized as Cu deficient. A weaker response ($P < 0.1$) was obtained in an additional two soils. However, grain yield increases with foliar application were not as high as the corresponding broadcast and incorporated soil Cu application at 4 kg ha^{-1} in the form of $CuSO_4{\cdot}5H_2O$. A large number of Cu experiments have been carried out in controlled environments (Baszynski *et al.*, 1988; Lidon *et al*., 1993; Ouzounidou *et al*., 1993; Ouzounidou 1994).

Copper accumulation in the leaves of wheat plants grown with elevated levels of Cu was in the range as toxic (20 mg kg^{-1}) (Allaway, 1968)

Uptake of Cu in vivo by higher plants can affect some of their physiological and metabolic processes. In chloroplasts it can alter the architecture of the thylakoid membranes which in turn affects some light reaction processes especially those associated with PSII (Baszynski *et al*., 1988; Eleftheriou and Karataglis, 1989; Ouzounidou *et al*., 1992). These disturbances are correlated with lipid peroxidation and changes of the thylakoid membrane polypeptide patterns, which influence the reactions of electron transport mainly on the water oxidation side (Maksymiec *et al*., 1992; Baron *et al*., 1995).

Copper stress reduced the whole plant height as well as the length of ear almost by half. These decreases are consistent with the decreases in the contents of starch, soluble sugars, and lipids in the ore plants (Lanaras *et al*. 1993), which resulted from reduced photosynthesis and CO_2 assimilation.

The impact of elevated Cu level on mesophyll capacity in turn depends among other things, on the activity of Rubisco and the capacity for photosynthetic electron transport (Radoglou *et al*., 1992; Moustakas *et al.*, 1994; Ouzounidou 1994). The plants at low copper had decreased height and profuse tillering which could be attributed to the loss of apical dominance of the main stem. Similar effects of low Cu have also been described in different plants (Agarwala and Sharma, 1976; Agarwala and Sharma, 1979; Marschner, 1995).

Shoot fresh and dry matter yield and percent dry matter were minimum in the control plants and increased with an increase in Cu application rate to a maximum at 1.5 mg kg^{-1} Cu at 80 days of growth . At levels higher than 1.5 mg kg^{-1} Cu, the shoot dry matter yield decreased slightly in wheat plants (Kumar *et al*., 1990).

The application of Cu significantly reduced the Fe content in the leaves and the magnitude of reduction was 10.3% with the application of 2.5 mg kg^{-1} Cu over control. Brar and Sekhon (1978) was observed that excess Cu antagonistically affect the translocation of Fe from stem to the leaves.

The concentration of Mn in leaves, grain and straw was higher at lower levels of Cu and insignificantly decreased at higher levels of Cu. Hulagur and Dangarwala (1982) have reported a decrease in Mn uptake on Cu application in plants grown in a loamy sand soil.

The application of Cu did not affect the concentration of Zn in the leaves of wheat plants at lower levels of Cu but at higher levels of Cu (2.0 and 2.5 mg kg^{-1}), the Zn concentration decreased significantly. The antagonistic effect of Cu and Zn on plant growth has been well documented (Arora and Sekhon, 1982; Dangarwala, 2001). However, no such effect was observed in Zn concentrations of grain and straw of earlier at plants.

Copper was relatively more harmful than nickel to both seed germination and seedling growth of *Raphanus sativus* L. var. Pusachetki (Gupta *et al*., 2001). The similar effect of Cu containing textile, dye and printing industry effluent on germination and growth performance of two Rabi crops namely, wheat and chickpea was studied by Kaushik *et al*. (2005) and Kumawat Singh *et al.* (2001)

The sensitivity of wheat to the toxicity of the copper and cadmium pollutants was in the order of root elongation > shoot elongation > germination rate (Wang and Zhou, 2005 and Smirnoval *et al*., 2006). Effect of copper on catalase activity, peroxidase activity, protein and sugar content in wheat *(Triticum aestivum).*

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.

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.

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.

Effect of Other Chemical Fertilizers on Wheat:

Renu *et al*. (2005) also found that the number of tillers per plant was less where no fertilizer was applied as compared to phosphorus fertilizer application in case of wheat crop.

Khan *et al*. (2010) laid out a field experiment with a view to find out the effect of different phosphatic fertilizers on growth attributes of wheat. Phosphorus was applied at the rate of 40 and 80 kg P ha^{-1} in the form of SSP, TSP, NP and DAP. It was concluded from the study that phosphorus application at the rate of 80 kg P ha^{-1} as single super phosphate (SSP) showed better results as compared to triple super phosphate (TSP), nitrophos (NP) and diammonium phosphate (DAP) on phosphorus deficient soil .The results showed that the maximum plant height (91.67 cm) was recorded in treatment T_6 (80 kg P ha^{-1} as SSP), while it was minimum (75.33 cm) in treatment T_1 (control). Plant height was significantly affected among all the various P sources application. It also increased linearly with the increased level of phosphorus application.

Renata *et al*. (2013) laid out a field experiment with a view to find out the effect of differentiated phosphorus fertilization on winter wheat yield and quality. The effects of differentiated rates of phosphorous applied together with a fixed level of nitrogen and magnesium fertilization were investigated. Correlation analysis on relationships between grain yield and nutrient content in wheat leaves at the beginning of stem elongation stage (BBCH31) showed significant relationships for phosphorous, calcium, magnesium, zinc and manganese. Regression analysis proved that the content of zinc in leaves at the BBCH31 stage was the main factor which determined winter wheat grain yield. Furthermore, mineral fertilization significantly increased the content of protein and gluten when compared with the control objects, whereas no significant differences were observed among the fertilized objects. Statistically significant relationships were found between leaf content of N, P, Mg, Zn and Mn at BBCH31 and the accumulation of protein and gluten in wheat grain. Protein and gluten in grain depended on the content of magnesium in leaves at the beginning of stem elongation stage. Weather conditions as a factor significantly influenced grain size uniformity while mineral fertilization had no influence on this trait.

Awasthi and Bhan (1993) noticed through an experiment that plant height of wheat increased significantly with increasing rates of nitrogen up to 60 kg ha^{-1} .

Poulsen *et al*. (2005) recommended that the phosphatic fertilizer application enhanced significantly higher number of grains per spike which ultimately increased the grain and straw yields. DAP and SSP had produced more number of grains per spike as compared to other P containing fertilizers.

Mondal (2014) conducted a field experiment at Sher-e-Bangla Agricultural University, Dhaka to evaluate the response of wheat variety by different levels of nitrogen. The experiment included three varieties viz. BARI gom 23, BARI gom 24, and BARI gom 25 and four levels of nitrogen viz. 75, 100, 125 and 150 kg N ha^{-1} . Result demonstrated that the variety BARI gom 24 with application of 125 kg N ha^{-1} produced the maximum grain yield (4.71t ha^{-1}) and harvest index (49.37 %).

Rahman (2005) found that most of the yield components of wheat as well as straw yield were significantly higher at 125 kg N ha^{-1} .

Ahmed and Hossain (1992) executed that application of N at the rate of 135 kg ha^{-1} produced the highest seed yield ranging from 2.2 to 2.6 t ha^{-1} .

Meneses and Ivan (1992) reported that plant height increased significantly with 0 to 200 kg N ha^{-1} .

Akter (2005) conveyed an experiment with four nitrogen levels viz. 0 (control), 50, 100 and 150 kg ha^{-1} and from that he has found that 100 kg N ha^{-1} gave the highest number of total tillers $plant^{-1}$.

Chaudhry *et al*. (1989) reported from years experimental result that application of N @ 150 kg $ha^{–1}$ resulted in highest (408.0 and 416.0) number of tillers m^{-2} in both the year.

Wilhelm (1998) reported that nitrogen plays a very vital role in the process of grain filling (Green, 1984), increase leaf area of the crop and may result in increased dry matter production by intercepting more sun light.

Akter (2005) carried a field experiment to study the effect of nitrogen levels under rainfed and irrigated conditions on yield and seed quality of wheat. The experiment was involved with four nitrogen levels viz. 0 (control), 50, 100 and 150 kg ha^{-1} . From the experiment, it was noted that increasing nitrogen levels also increased the seed yield. He also found that increasing the nitrogen level up to 100 kg ha^{-1} the straw yield also increased.

Liaqat *et al*. (2003) executed that nitrogen @ 150 kg ha^{-1} gave grain yield of 4330 and 5160 kg ha^{-1} during Rabi 2000–01 and 2001–02, respectively. Increasing N rates further resulted in reduction in grain yield during both the years.

Islam *et al*. (2002) steered out an experiment and reported that the plots are fertilized with 170 kg N ha^{-1} had the maximum number of grains per spike.

Maqsud *et al*. (2002) found that the application of 150 kg N ha^{-1} gave the maximum number of grains per spike.

Mozumder (2001) carried out an experiment to investigate the response the wheat at different of levels of nitrogen. Treatments of nitrogen in that experiment were 0, 30, 60, 90, and 120 kg ha^{-1} . He proposed that the effect of N on straw yield was significant. The highest straw yield was recorded from N at the rate of 120 kg ha^{-1} .

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).

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.

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.

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.

Kharu and Dhillon conducted a field experiment in Karnal, Haryana, India. during 2003- 07 to study the effects of magnesium application on the yield and quality of wheat (*Triticum aestivum*). Wheat yield increased significantly with the application of Cosavet (80% water soluble magnesium) compared to gypsum and the control.The highest yield (5.96 t/ha) was obtained with 12.0 kg Mg/ha (Cosavet) applied in two splits, i.e. at 21 and 40 days after sowing, closely followed by 8.0 kg Mg/ha (5.91 t/ha). Yield increases of 8.61 and 2.9% over the control were obtained with Cosavet (12 kg S/ha) and gypsum (25 kg S/ha), respectively.The protein content increased by 7.1-11.2 and 7.1% with the application of Cosavet and gypsum, respectively, over the control. The highest protein contents were also obtained with Cosavet applied at 8 and 6+6 kg Mg/ha. The number of effective tillers, number of grains per spike, and biomass were greater with Cosavet than with gypsum and the control.

Alam (1995) conducted a field experiment in Mymensingh on wheat (Variety Kanchan, Akbar and Aghrani) with 100 kg nitrogen, 80 kg phosphorus, 30 kg potassium, 24 kg sulphur, 4 kg Zinc, 2 kg boron and 12 kg magnesium $ha^{-1}$and observed that Mg gave 2.71 t ha^{-1} grain yield among the treatments.

From the above review of literatures we can conclude that zinc and copper have a remarkable effect on yield and yield contributing characters and quality of wheat. Some studies revealed that zinc and copper above certain levels increased the yield and yield parameters and quality of wheat. So, there is still scope for zinc and copper 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 copper fertilizers for wheat cv. BARI Gom-30 under a typical agro-climatic situation of Sher-e-Bangla Nagar, Dhaka, Bangladesh (AEZ-28).

CHAPTER III

MATERIALS AND METHODS

The field experiment was conveyed to achieve the objectives of the study and executed following standard procedures and methods. This chapter 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 conducted at the experimental field of Sher-e-Bangla Agricultural University (SAU), Sher-e-Bangla Nagar, Dhaka-1207, Bangladesh, during the period from November 2015 to March 2016 to study the effect of Zn and Cu on the yield and quality of wheat. The field was located at the southwest part of the main academic building. The following map in the Fig. 3.1 shows the specific area of experimental site.

3.2 Location of the Study

3.2.1 Geographical Location

The experimental area was situated at $23^{0}74'$ N latitude and $90^{0}35'$E longitude at an altitude of 8.6 meter above the sea level (Anon, 2004).

3.2.2 Agro-Ecological Region

The experimental field belongs to the Agro-ecological zone of ―The Modhupur Tract, AEZ-28‖ (Anon, 2003a). This was a region of complex relief and soils developed over the Modhupur clay, where floodplain sediments buried the dissected edges of the Modhupur Tract leaving small hillocks of red soils as 'islands' surrounded by floodplain (Anon, 2003b). The experimental site was shown in the map of AEZ of Bangladesh in Fig. 3.1.

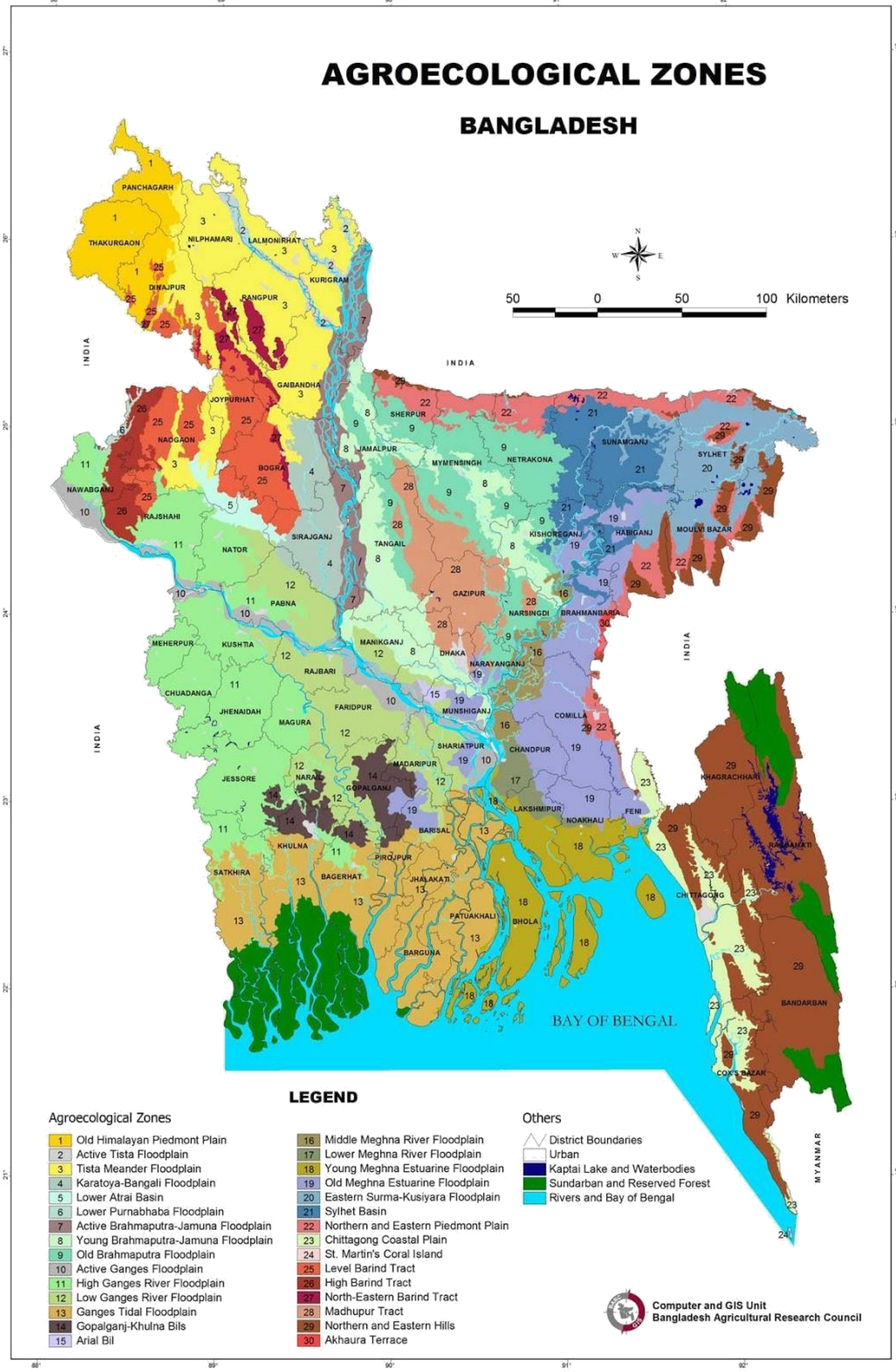


Fig: 3.1 The Map of Agro-ecological Zones of Bangladesh

3.2 Soil

The experiment was conducted in a typical wheat growing soil of Sher-e-Bangla Agricultural University (SAU) Farm, Dhaka, during Robi season of 2015. The farm belongs to the General soil type, ―Deep Red Brown Terrace Soil‖ under Tejgaon Series. Top soils were clay loam in texture and olive-gray with common fine to medium distinct dark yellowish brown mottles. The experimental field was flat having available irrigation and drainage system. The soil of the research field is slightly acidic in reaction with low organic matter content. 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 (April to September) and scanty in Rabi season (October to March). In Rabi season temperature is generally low and there is plenty of sunshine. The atmospheric temperature tends to increase from February as the season proceeds towards kharif. Rainfall was almost nil during the period from November to March and scanty from February to March. The weather conditions of crop growth period such as monthly mean rainfall (mm), mean temperature (^{o}C), sunshine hours and humidity (%) are recorded by the Weather Station of SAU, Sher-e-Bangla Nagar, Dhaka, have been presented in Appendix 2.

3.4 Planting Materials

Wheat (*Triticum aestivum* L.) variety BARI Gom-30 was used as plant material. Bangladesh Agriculture Research Institute (BARI), Gazipur, Bangladesh, developed this variety and released in 2014. It is newly developed a short duration, drought-tolerant and high-yielding wheat variety and has started gaining popularity among farmers of the drought-prone Barind tract. This variety attains a height of 95-100 cm. It is resistant to leaf rust and leaf spot disease (blight) and also heat tolerant. The number of tillers plant $^{-1}$ is 4-5, 55-60 days require for spike initiation, crop duration 102-108 days, spike broad, grain spike^{-1} 45-50, grain white, bright and medium, 1000 grain weight 44-48g, tiller straight in seedling, plant deep green, very few hair present in upper node of culm. Its yield is 4-5 t ha^{-1}. The seeds of this variety were collected from Bangladesh Agricultural Research Institute (BARI), Gazipur.

3.5 Land Preparation

The land of the experimental field was first opened on November 7, 2015 with the tractor drawn disc plough. Then it was exposed to the sunshine for 7 days prior to the next ploughing. Then soil was brought into desirable fine tilth by ploughing and harrowing with country plough and ladder. Deep ploughing was done to produce a good tilth, which was necessary to get better yield of the crop. Laddering was done in order to break the soil clods into small pieces followed by each ploughing. All the weeds and stubbles were removed from the experimental field. 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. The soil was treated with insecticides at the time of final ploughing. Insecticides, Furadan 5G was used @ 8 kg ha^{-1} to protect young plants from the attack of mole cricket, ants, and cutworms.

Table 1. Morphological characteristics of the experimental field

Morphological features	Characteristics
Location	Sher-e-Bangla Agricultural University (SAU) 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

Table 2. Physical and chemical properties of the initial soil sample

Characteristics	Value
Particle size analysis	
% Sand	22
% Silt	30
% Clay	48
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 Zinc	3.32 µg/g soil
Available Copper	1.93 µg/g soil

3.6 Fertilizer Application

The unit plots were fertilized with 120 kg N, 30 kg P, 60 kg K and 10 kg S ha^{-1} respectively. Urea, triple super phosphate (TSP),muriate of potash (MoP) and Gypsum were used as source of nitrogen, phosphorus, potassium and sulpher, respectively. Zinc and Copper were applied as per experimental specification through Zinc sulphate and copper sulphate soil application. The whole amount of TSP, MoP, gypsum, zinc sulphate, copper sulphate 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 at crown root initiation stage (21 DAS) and spike initiation stage (55 DAS) the seed.

3.7 Treatments of the Experiment

The experiment consisted of two factors with three levels of Zn and three levels of Cu.

3.7.1 Factor A: Zn Levels

The following Zn levels were imposed in the experiment

Zn_0= Control (No Zn application)

Zn_1= 3 kg ha^{-1}

Zn_2= 6 kg ha^{-1}

3.7.2 Factor B: Copper Levels

The following Cu levels were imposed in the experiment

Cu_0= Control (No Cu application)

Cu_1= 2 kg ha^{-1}

Cu_2= 4 kg ha^{-1}

3.7.3 Combining Two Factors, 9 Treatment Combinations were Obtained

Zn_0Cu_0 Zn_1Cu_0 Zn_2Cu_0

Zn_0Cu_1 Zn_1Cu_1 Zn_2Cu_1

Zn_0Cu_2 Zn_1Cu_2 Zn_2Cu_2

3.8 Experimental Design and Layout

The field experiment was laid out in a Randomized Complete Block Design (RCBD). Each treatment was replicated three times. There was 27 plots and the size of a unit plot was 3m in length and 2.25m in breadth. The distance between two adjacent replications (block) was 0.75m and row-to-row distance was 0.45m. The inter block and inter row spaces were used as footpath and irrigation/ drainage channels. Layout of the experiment was done on November 14, 2015.

3.9 Seed Treatment

Wheat seeds were treated with Vitavex-200 @ 0.25% before sowing to prevent seeds from the attack of soil borne disease.

3.10 Sowing of Seeds in the Field

The seeds of wheat were sown in rows made by hand plough on 15 November, 2016 @ 120 kg ha^{-1}. The seeds were sown in solid rows in the furrows having a depth of 2-3 cm from the soil surface and row to row distance was 20 cm. After sowing, the wheat seeds were covered with soil and lightly pressed by hand. Two guards were appointed everyday from early morning to evening to protect the wheat seeds from birds.

3.11 Intercultural Operations

Intercultural operations were done to ensure normal growth of the crop. The following intercultural operations were followed:

3.11.1 Irrigation

Three irrigations were applied during the entire growing period , the first irrigation after 21 days of sowing at crown root initiation (CRI) stage, the second irrigation after 45 days at heading stage and the third irrigation after 62 days at grain filling stage. During the irrigation proper care was taken so that water could not flow from one plot to another or overflow the boundary of the plot. Excess water of the experimental field was drained out.

3.11.2 Thinning

Emergence of seedling was completed within 10 days after seed sowing. Overcrowded seedlings were thinned out for two times for better yield. First thinning was done after 15 days of seed sowing which was done to remove unhealthy and lineless seedlings. The second thinning was done 10 days after first thinning keeping healthy seedlings in each hill.

3.11.3 Weeding

Weeding was done in the field to keep the plots free from weeds which ultimately ensured better growth and development of wheat seedlings. Weeding was done two times during the whole growing period, the first weeding was done 18 DAS (Days after sowing) and the second other after 40 days after sowing. Thedemarcation boundaries and drainage channels were also kept free from weed. Identified weeds were kakpayaghash (*Dactyloctenium aegyptium* L.), Shama (*Echinocloa crussgalli*), Durba (*Cynodondactylon*), Arail (*Leersiabexandra*), Mutha (*Cyperusrotundus* L.)

Bathua(*Chenopodium album*) Shaknatey (*Amaranthus viridis*), Foska begun *(Physalis beterophylls*), Titabegun (*Solanum torvum*).

3.11.4 Protection Against Insect and Pest

The wheat crop was attacked by different kinds of insects (cereal aphid and grass hopper) during the growing period. The experimental plot was sprayed at 35 days with Diazinon to control the attack of Aphids. Insecticides were applied to the eachplots after irrigation at afternoon. Sumithion-40 ml/20 liter of water was applied as plant protection measure to control the leaf blight of wheat. Two guards were appointed to protect the wheat grain from birds especially pigeons from mid January to harvest.

3.12 Harvesting and Post-harvest Operation

The crop was harvested at the date 15/2/2016, manually from each plot depending upon the maturity of plant and the maturity of crop was determined when 90% of the spike became golden yellow in color. One meter area of each plot was harvested for yield data and it was converted to t ha^{-1}. The harvested crops of each plot was bundled separately, properly tagged and brought to threshing floor carefully. Then the crops were sun dried by spreading on the threshing floor. Proper care was taken during threshing and cleaning of wheat grain.The grains were cleaned and fresh weight of wheat grain was recorded plot wise.Thegrain weight was adjusted to a moisture content of 14%. The straw was sun dried and the yield of wheat straw $plot^{-1}$ was recorded and converted to t ha^{-1}.

3.13 Crop Sampling and Data Collection

The crop sampling was done at the time of harvest and harvesting date was 15/2/2016. At each harvest, ten plants were selected randomly from each plot. The selected wheat plants of each plot were cut carefully at the soil surface level.

The data on the following parameters of ten plants were recorded at each harvest:

1) The plant heights (cm)
2) Effective tiller number hill^{-1}
3) Non-effective tiller number hill^{-1}
4) Panicle length (cm)
5) Number of filled grain panicle^{-1}
6) Number of unfilled grain panicle^{-1}
7) 1000 grain weight (g)
8) Straw yield(t ha^{-1})
9) Grain yield (t ha^{-1})

Grain and straw samples were analyzed for N, P, K, Zn, and Cu to find their concentration.

3.14 Procedure of Data Collection

3.14.1: The Plant Height (cm)

The heights of ten 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.

3.14.2: Effective and Non-effective Tillers Number Hill^{-1}

The tillers which can produce the spike with filled grains can be termed as effective tillers and the tillers having no spike was regarded as non-effective tillers . Ten plants were selected from each plot randomly and the number of effective tillers and non-effective tillers from 10 plants were counted and averaged then to have number of effective and non-effective tillers hill^{-1}.

3.14.3: Panicle Length (cm)

The length of panicle was measured by using a meter scale and the measurement was taken from the base to tip of the panicle. Average length of panicle was taken from 10 randomly selected panicles from inner row plants of each plot. Data was recorded at harvest time and mean data was expressed in centimeter (cm).

3.14.4: Number of Filled Grains and Unfilled Grains Panicle^{-1}

The total number of filled and unfilled grains from randomly selected ten panicles were counted and average of which gave the number of filled and unfilled grains panicle^{-1}. If any food material presents in the grains considered as filled grain.

3.14.5: 1000 Grain Weight (g)

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

3.14.6: Straw Yield (t ha^{-1})

The grains, straws were sun dried and then the yield of straw was determined from the central 1m^{2}area of each plot. Straw weighed to determine the straw yield plot^{-1} and was expressed in t ha^{-1}.

3.14.7: Grain Yield (t ha^{-1})

Yield of Wheat grain was determined from the central 1m^{2} area of each plot and expressed as t ha^{-1} on 14% moisture content basis. Grain moisture content was measured by using a digital moisture tester.

3.15 Analyses of Data

The data collected from each plot on different parameters were statistically analyzed to obtain the level of significance using the MSTAT-computer package program. The Duncan multiple range (LSD) test at 5 % level of significance was used to compare the mean difference among the treatments.

3.16 Collection and Preparation of Initial Soil Sample

The initial soil samples were collected from experimental field 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 all samples thoroughly to make a composite sample. After collection of soil samples, the plant roots, leaves, weeds etc. were picked up and removed. Then the samples were air-dried and sieved through a 10-mesh sieve and then stored in a clean plastic container for physical and chemical analysis.

3.17 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, Bangladesh. The properties studied included soil texture, soil-pH, soil organic matter content, total N, available P, exchangeable K and available S. The chemical properties of post harvest soil samples have been presented in Appendix-1. The soil was analyzed by standard methods:

3.17.1 Particle Size Analysis

For the analysis of particle size of soil, Hydrometer Method was used 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.

3.17.2 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 which described by (Jackson, 1962).

3.17.3 Organic Carbon and Organic Matter

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 (Piper, 1950) and the result was expressed in percentage.

3.17.4 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).

3.17.5 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 nm wave length by Spectrophotometer and available P was calculated with the help of standard curve.

3.17.6 Exchangeable Potassium

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

3.17.7 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 nm wave length.

3.18 Methods for Grain Analysis

For determination of total Zn and Cu contents in grain the samples were first digested with diacid mixture (HNO_3 and $HClO_4$ in the ratio of 2:1). The amount of the Zn and Cu in the digest was estimated by using Atomic Absorption Spectro-photometer.

CHAPTER IV

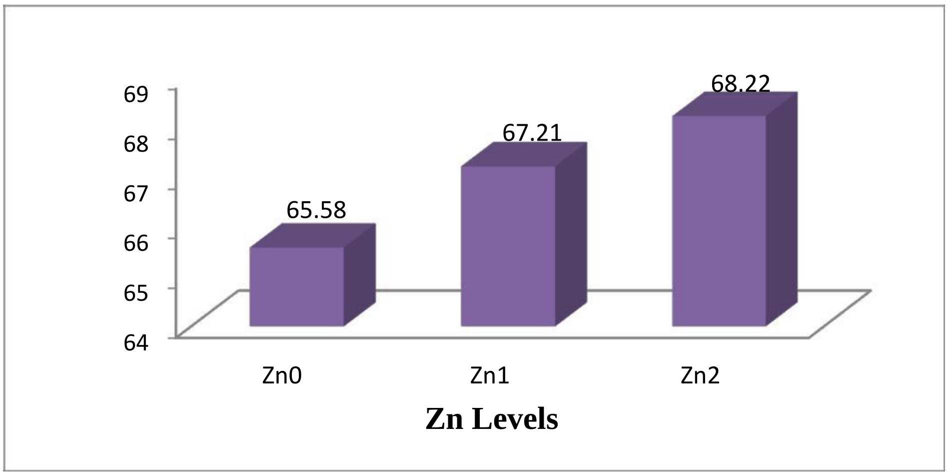
RESULTS AND DISCUSSION

The experiment was conducted to study the effect of Zn and Cu on the growth and yield of wheat. The results attained from present study for crop characters, yields attributes 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

According to the present study, plant height was not significantly influenced by the application of different levels of zinc (Fig. 1). Results stated that the tallest plant (68.22 cm) was achieved from the treatment Zn_2 (6 kg ha^{-1} Zn) where the shortest plant (65.58 cm) was obtained from the treatment Zn_0 (control) (Table 3). Here, it was noticed that zinc had a contribution for higher plant growth and Zn_2 (6 kg ha^{-1} Zn) showed the best result where no application of zinc treatment showed shortest plant height. Mekkei and El-Haggan Eman (2014) attained similar results and they noticed that combination of micronutrients (Zn) produced the highest grades of plant height.

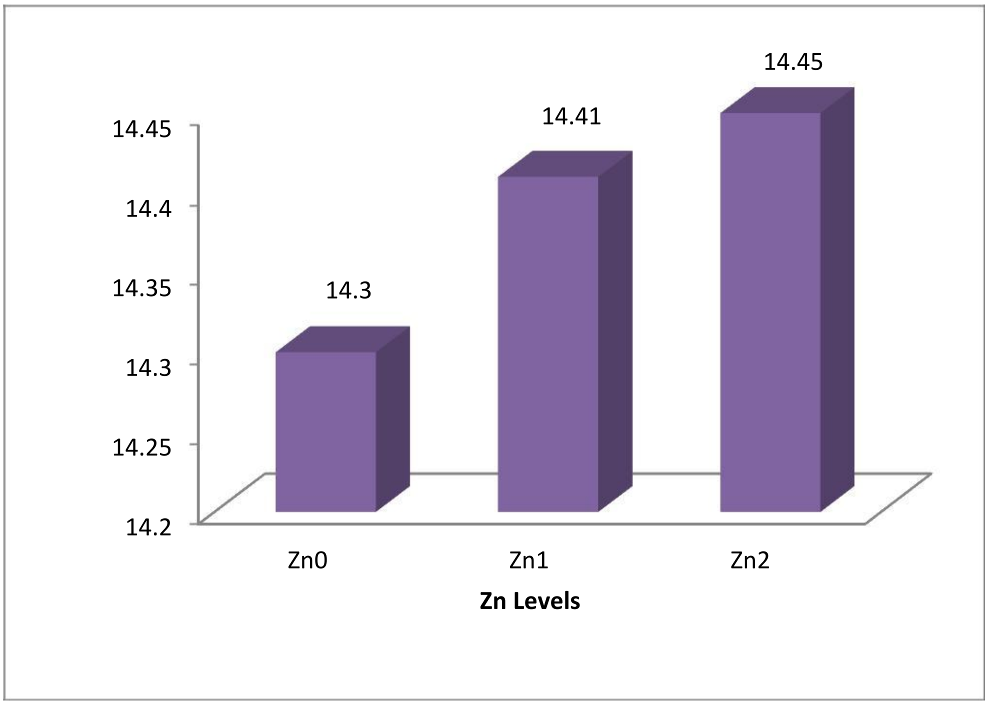


Zn_0 = 0 (control), Zn_1 = 3 kg ha^{-1} Zn, Zn_2 = 6 kg ha^{-1} Zn

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

4.1.2 Panicle Length

Non-significant variation was noticed for wheat panicle length and influenced by the application of different levels of zinc (Fig. 2). Results stated that the longest panicle length (14.45cm) was achieved from Zn_2 (6 kg ha^{-1} Zn) and the shortest panicle length (14.30 cm) was obtained from Zn_0 (control) treatment (Table 3). Panicle length increased with the increasing rates of Zn. Here, it can be stated that zinc had a contribution for longer panicle length and Zn_2 (6 kg ha^{-1} Zn) showed the best result where no application of zinc (Zn_0) showed little panicle length. Mekkei and El- Haggan Eman (2014) viewed that combination of micronutrients (Cu+ Fe+ Mn+ Zn) produced the highest grades of panicle length, number of grains $panicle^{-1}$. Other workers have also reported that Zinc application improved panicle length and shortest from control (Dewal and Pareek, 2004 and Islam *et al.,* 1999).

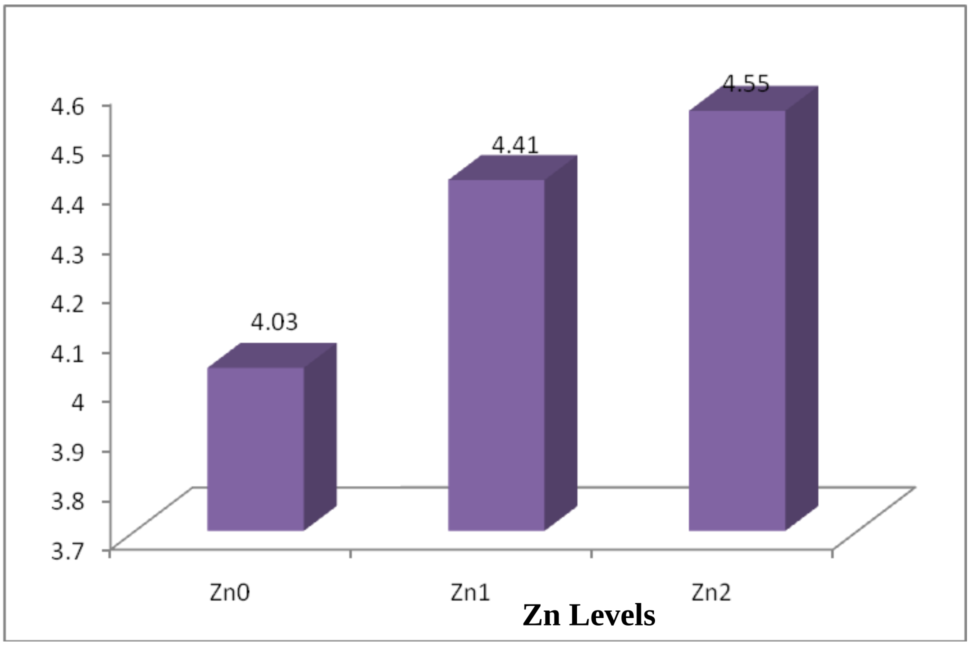


Zn_0 = 0 (control), Zn_1 = 3 kg ha^{-1} Zn, Zn_2 = 6 kg ha^{-1} Zn

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

4.1.3 Number of Effective Tillers Hill^{-1}

Non-significant variation was observed with different doses of zinc in respect of number of effective tillers hill^{-1} (Table 3) and (Fig 3). Among the different doses of fertilizers, Zn_0 (control) showed the lowest number of effective tillers hill^{-1} (4.03) and Zn_2 (6 kg Zn ha^{-1}) showed the highest number of effecitve tillers hill^{-1} (4.55). The result attained by Mitra and Jana (1991) with an experiment found that number of effective tillers hill^{-1} were significantly increased by zinc application up to 10kg Zn ha^{-1} and thereafter a positive effect was noticed.

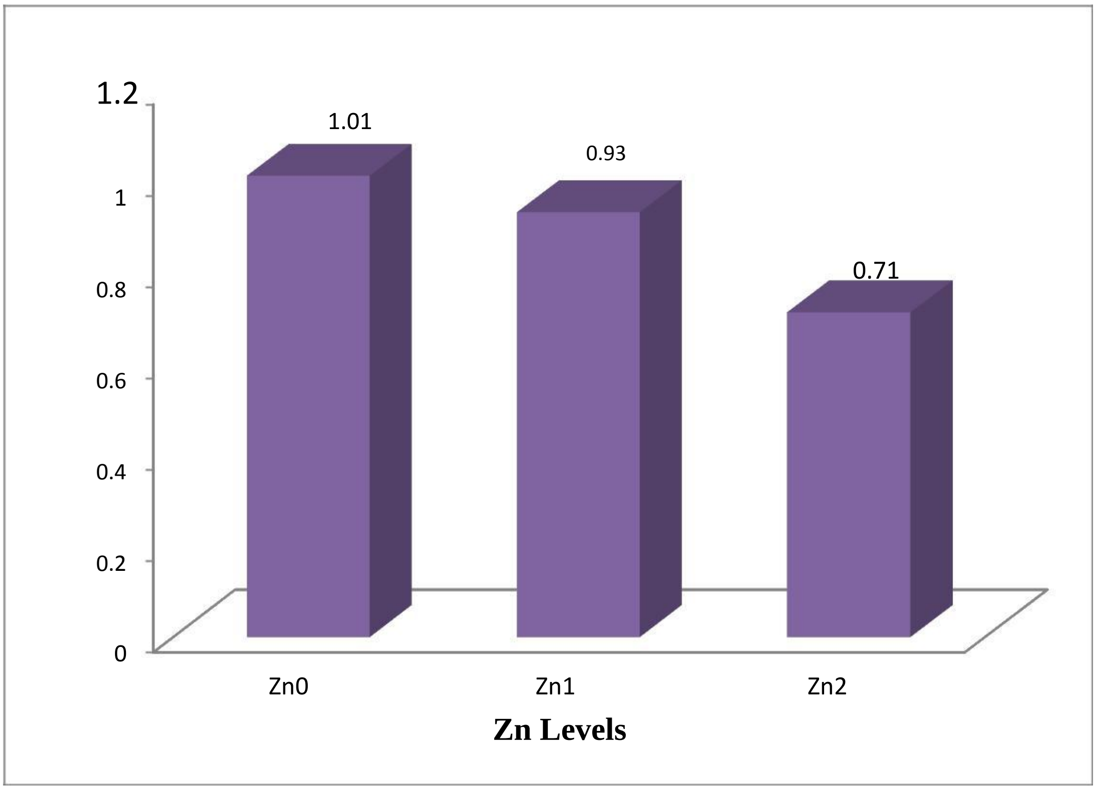


Zn_0 = 0 (control), Zn_1 = 3 kg ha^{-1} Zn, Zn_2 = 6 kg ha^{-1} Zn

Fig.3: Effect of Zn levels on the number of effective tillers hill^{-1} of wheat

4.1.4 The Number of Non-effective Tillers Hill^{-1}

Non-significant variation was observed with different doses of zinc in respect of number of non-effective tillers hill^{-1} (Table 3) and (Fig 4). Among the different doses of fertilizers, Zn_0 (control) showed the highest number of non-effective tillers hill^{-1} (1.01) and Zn_2 (6 kg Zn ha^{-1}) showed the lowest number of non-effecitve tillers hill^{-1} (0.71). Genc *et al.* (2006) observed that the zinc increased the total number of fertile tillers m^{-2}, thus decreased the total number of non-effective tillers m^{-2}.

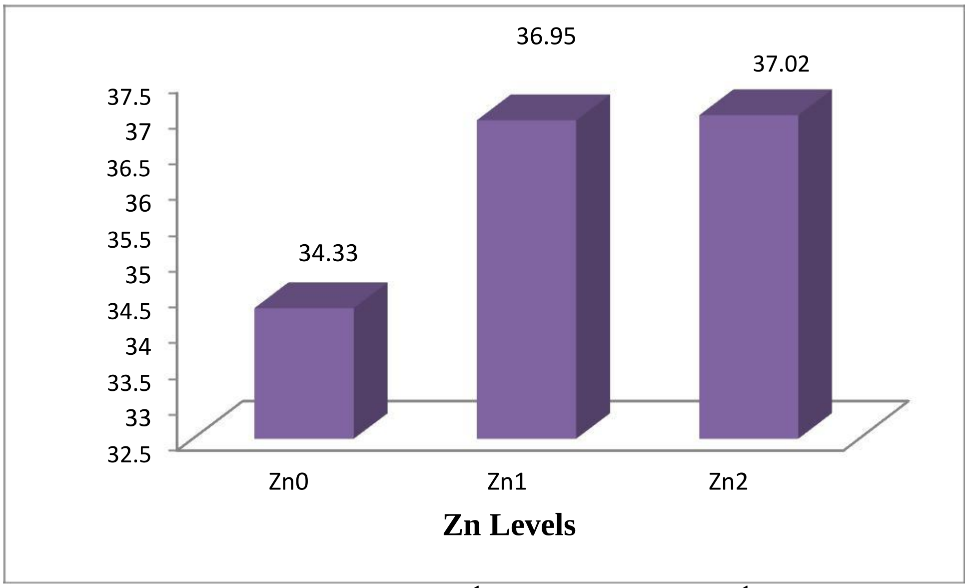


Zn_0 = 0 (control), Zn_1 = 3 kg ha^{-1} Zn, Zn_2 = 6 kg ha^{-1} Zn

Fig.4: Effect of Zn levels on the number of non-effective tillers hill^{-1} of wheat

4.1.5 Number of Filled Grains Panicle^{-1}

The influence of Zn on the number of filled grains panicle^{-1} was not statistically significant (Fig. 5). Within the present study, number of filled grains panicle^{-1} was not significantly influenced by the application of zinc at different doses (Table 3). It was found that the maximum number of filled grains panicle^{-1} (37.02) was achieved from the treatment Zn_2 (6 kg ha^{-1} Zn). Again, the minimum number of filled grains panicle^{-1} (34.33) was obtained from the treatment Zn_0 (control). Number of filled grains panicle^{-1} increased with the increase of Zn up to Zn_2 treatment (6 kg ha^{-1} Zn). Mekkei and El-Haggan Eman (2014) appreciated that application with combination of micronutrients (Cu+ Fe+ Mn+ Zn) produced the highest number of grains panicle^{-1}. Gul *et al*. (2011) also indicated 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 least number of grains (29) spike^{-1}.

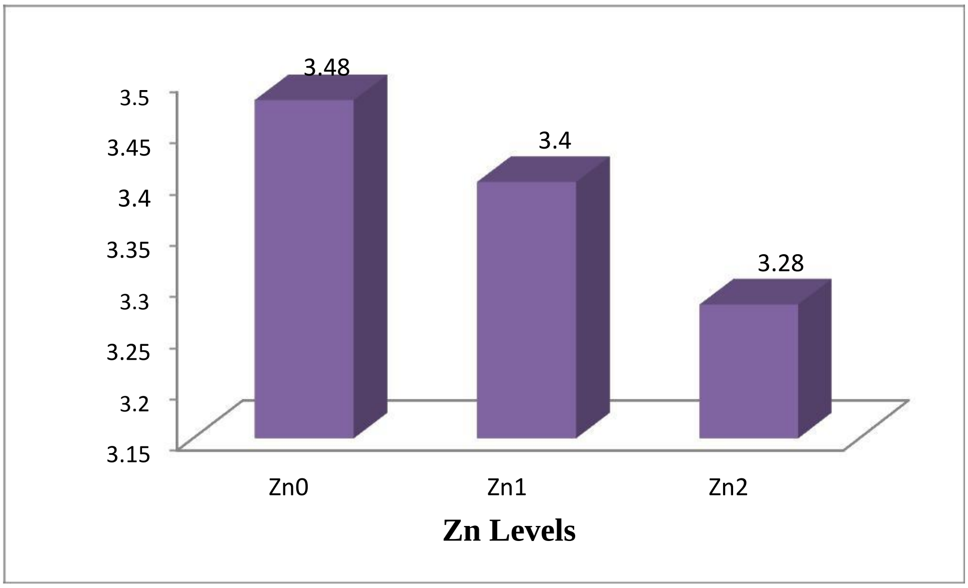


Zn_0 = 0 (control), Zn_1 = 3 kg ha^{-1} Zn, Zn_2 = 6 kg ha^{-1} Zn

Fig.5: Effect of Zn levels on the number of filled grains panicle^{-1} of wheat

4.1.6 Number of Unfilled Grains Panicle^{-1}

Different doses of zinc fertilizers showed non-significant variations in respect on number of unfilled grains panicle^{-1} of wheat (Table 3) and (Fig 6). Among the different doses of fertilizers, Zn_2 (6 kg ha^{-1} Zn) showed the lowest number of unfilled grains panicle^{-1} (3.28). On the contrary, the highest number of unfilled grains panicle^{-1} (3.48) was observed with Zn_0, where no zinc fertilizer was applied.

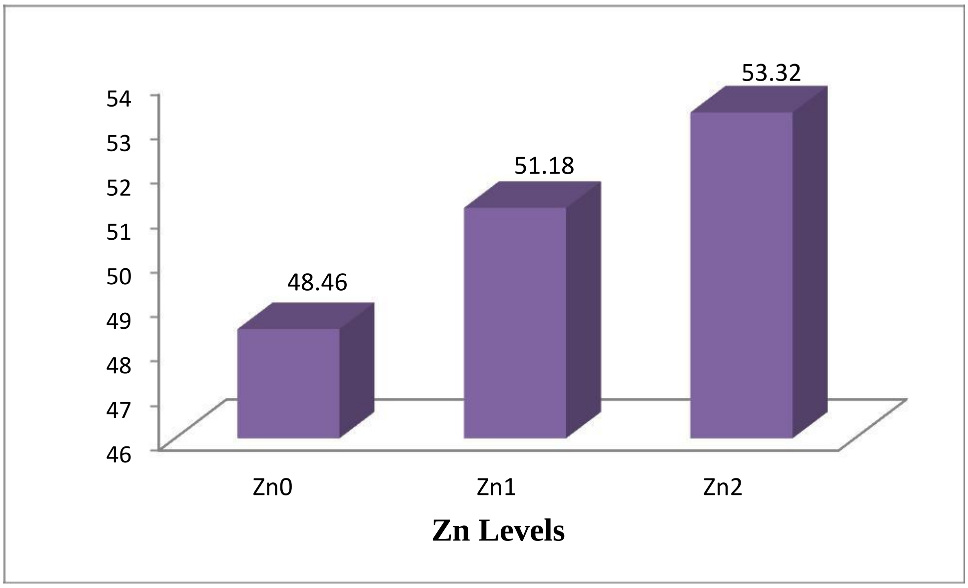


Zn_0 = 0 (control), Zn_1 = 3 kg ha^{-1} Zn, Zn_2 = 6 kg ha^{-1} Zn

Fig.6: Effect of Zn levels on the number of unfilled grains panicle^{-1} of wheat

4.1.7 Weight of 1000 grain

Weight of 1000 grain is an important yield contributing character. Higher 1000 grain weight indicates more pure seeds and resulted higher grain yield ha^{-1}. Here, application of different levels of zinc fertilizer to the wheat crop pretended non-significant difference on 1000 grain weight (Table 3).The highest 1000 grain weight (53.32g) was observed with Zn_2 (6 kg ha^{-1} Zn) treatment where as the lowest (48.46g) was with Zn_0 treatment (Control) (Fig. 7). Zeidan *et al*. (2010) reported that 1000 grains weight was significantly increased with application of foliar application of Zn. Mekkei and El-Haggan Eman (2014) also showed similar results. Positive effects of Zn application on 1000 grain weight were also observed by Ananda and Patil (2007). Kenbaev and Sade (2002) and Hosseini (2006) that yield components increased with the increase in Zinc application.

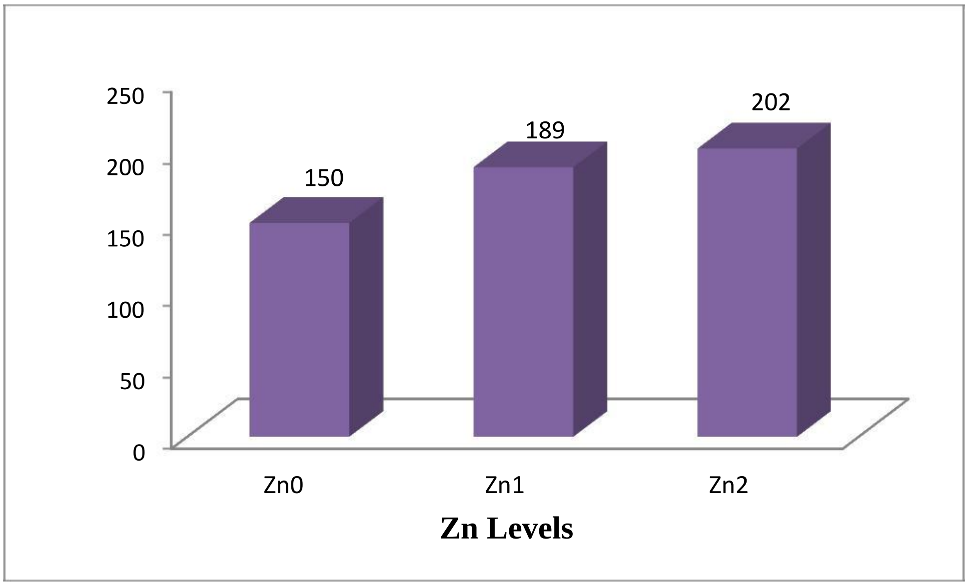


Zn_0 = 0 (control), Zn_1 = 3 kg ha^{-1} Zn, Zn_2 = 6 kg ha^{-1} Zn

Fig.7: Effect of Zn levels on the weight of 1000 grains of wheat

4.1.8 Grain Yield of Wheat

Grain yield is the primary achievement of a crop production. Application of zinc played a effective role on the yield and yield components of wheat (Table 3). Yield components were influenced effectively due to application of zinc. The grain yield of wheat increased significantly due to added zinc up to the treatment Zn_2 (6 kg ha^{-1} Zn). The highest grain yield (202 g m^{-2})/(2.02 t ha^{-1}) was achieved from Zn_2 treatment (6 kg ha^{-1} Zn). The lowest grain yield (150 g m^{-2})/(1.5 t ha^{-1}) was obtained from the treatment Zn_0 (control; no Zn application). Zinc is an 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 observed that increased wheat production with application of zinc over control. Many authors also reported that grain yield increased significantly with increasing Zn levels (El-Majid *et al.*, 2000 and Seilsepour, 2007).

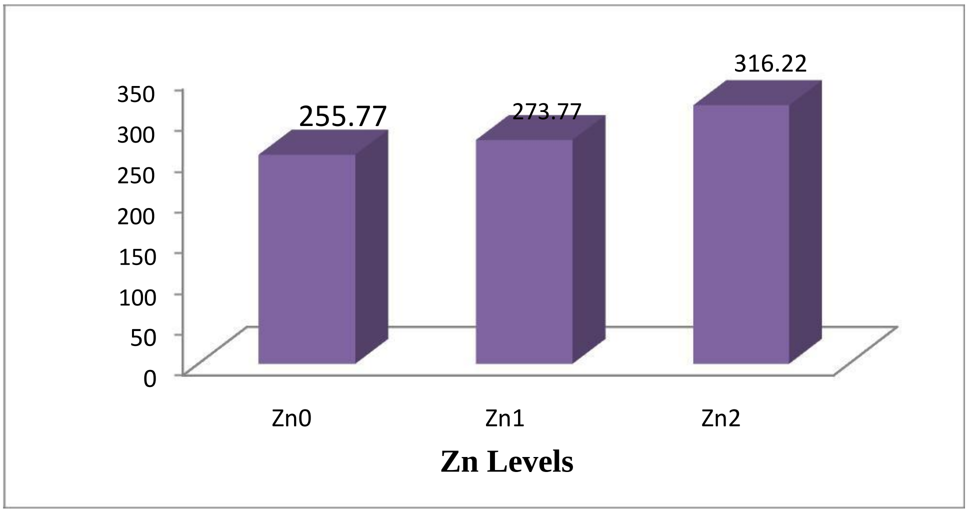


Zn_0 = 0 (control), Zn_1 = 3 kg ha^{-1} Zn, Zn_2= 6 kg ha^{-1} Zn

Fig.8: Effect of Zn levels on grain yield of wheat

4.1.9 Straw Yield of Wheat

Wheat plants showed significant variation in respect of straw yield of wheat when zinc fertilizer in different doses was applied (Table 3). Among the different fertilizer doses, Zn_2 (6 kg Zn ha^{-1}) showed the highest straw yield (316.22 g m^{-2})/(3.16 t ha^{-1}). On the other hand, the lowest straw yield (255.77 g m^{-2})/(2.55 t ha^{-1}) was observed in the treatment where no zinc fertilizer was applied.



Zn_0 = 0 (control), Zn_1 = 3 kg ha^{-1} Zn, Zn_2= 6 kg ha^{-1} Zn

Fig.9: Effect of Zn levels on straw yield of wheat

Table 3. Effect of Zn levels on the growth and yield of wheat

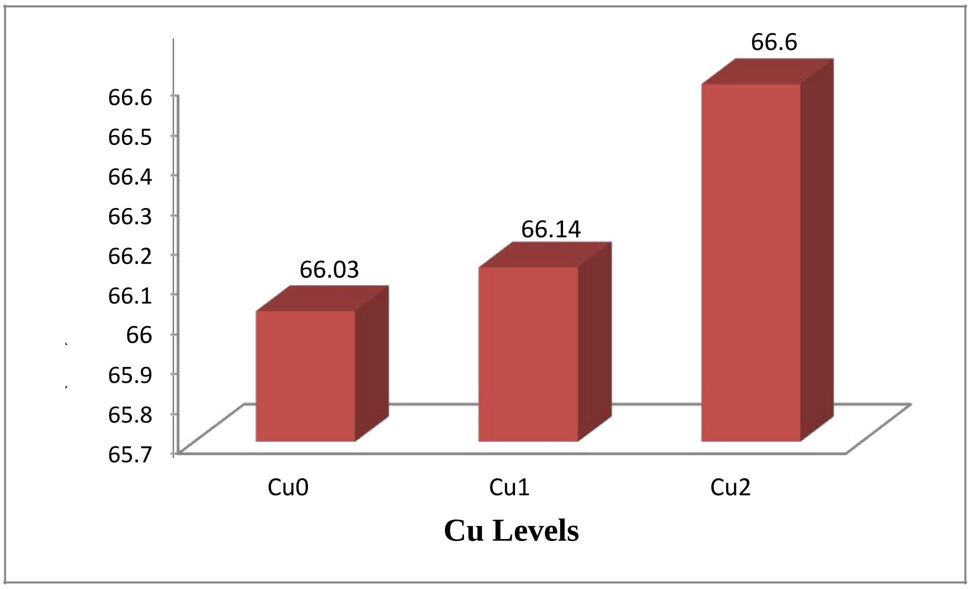
Treatments	Plant Height (cm)	Panicle Length (cm)	Number of Effective Tillers Hill^{-1}	Number of Non-effective Tillers Hill^{-1}	Numer of Filled Grains Panicle^{-1}	Number of Un-filled Grains Panicle^{-1}	1000 Seeds Weight (g)	Grain Yield (g m^{-2})	Straw Yield (g m^{-2})
Zn_0 (Control)	65.58	14.30	4.03	1.01	34.33	3.48	48.46	150b	255.77b
Zn_1 (3 kg Zn ha^{-1})	67.21	14.41	4.41	0.93	36.95	3.40	51.18	189ab	273.77ab
Zn_2 (6 kg Zn ha^{-1})	68.22	14.45	4.55	0.71	37.02	3.28	53.32	202a	316.22a
SE(±)	NS	NS	NS	NS	NS	NS	NS	5.1644	5.5035

In a column figures having similar letter(s) do not differ significantly at 5% level whereas figures with dissimilar letter(s) differ significantly as per DMRT

4.2 Effect of Copper on the Growth and Yield of Wheat

4.2.1 Plant Height

According to the present study, plant height was not significantly influenced by the application of copper (Fig. 10). Results stated that the tallest plant (66.60 cm) was achieved from the treatment Cu_2 (4 kg ha^{-1} Cu) where the shortest plant (66.03 cm) was obtained from the treatment Cu_0 (control) (Table 4). Here, it was noticed that copper had a contribution for higher plant growth and Cu_2 (4 kg ha^{-1} Cu) showed the best result where no application of copper treatment showed shortest plant height. Copper stress reduced the whole plant height as well as the length of ear almost by half and these decreases are consistent with the decreases in the contents of starch, soluble sugars, and lipids in the ore plants (Lanaras *et al*., 1993).

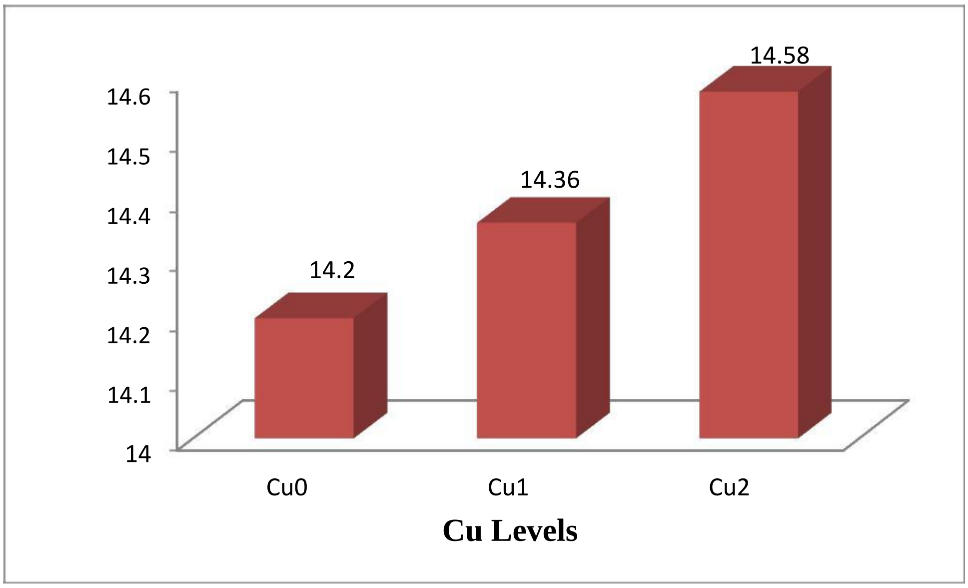


Cu_0 = 0 (control), Cu_1 = 2 kg ha^{-1} Cu, Cu_2 = 4 kg ha^{-1} Cu

Fig.10: Effect of Cu levels on plant height (cm) of wheat

4.2.2 Panicle Length

Non-significant variation was noticed for panicle length and influenced by the application of different levels of copper (Fig. 11). Results stated that the longest panicle length (14.58cm) was achieved from Cu_2 (4 kg ha^{-1} Cu) and the shortest panicle length (14.20 cm) was obtained from Cu_0 (control) treatment (Table 4). Panicle length increased with the increasing rates of Cu. Here, it can be stated that copper had a contribution for longer panicle length and Cu_2 (4 kg ha^{-1} Cu) showed the best result where no application of copper (Cu_0) showed little panicle length. Mekkei and El-Haggan Eman (2014) viewed that combination of micronutrients (Cu+ Fe+ Mn+ Zn) produced the highest grades of panicle length, number of grains $panicle^{-1}$.

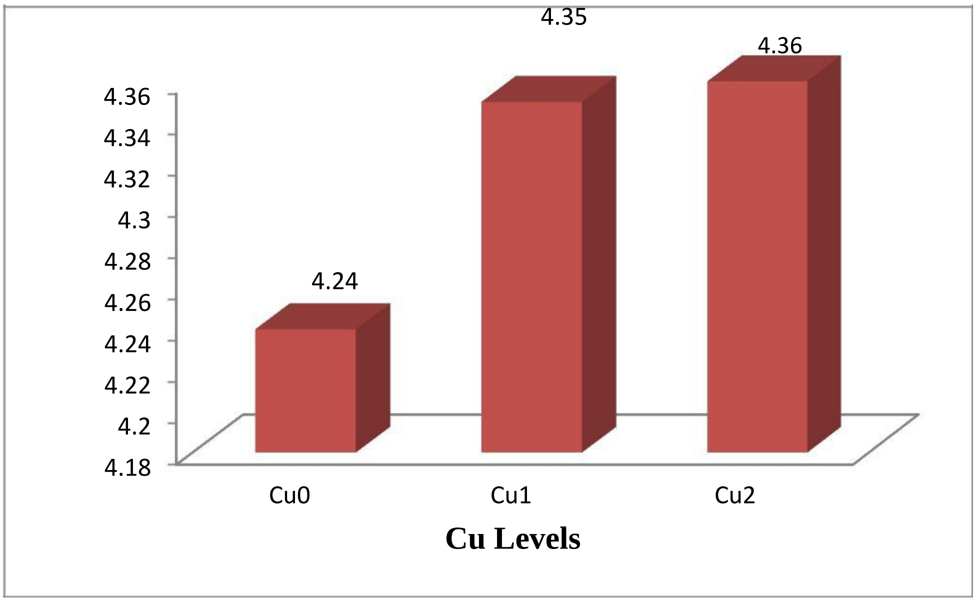


Cu_0 = 0 (control), Cu_1 = 2 kg ha^{-1} Cu, Cu_2 = 4 kg ha^{-1} Cu

Fig.11: Effect of Cu levels on panicle length (cm) of wheat

4.2.3 Number of Effective Tillers Hill^{-1}

Non-significant variation was observed with different doses of copper in respect of number of effective tillers hill^{-1} (Table 4) and (Fig 12). Among the different doses of fertilizers, Cu_0 (control) showed the lowest number of effective tillers hill^{-1} (4.24) and Cu_2 (4 kg Cu ha^{-1}) showed the highest number of effecitve tillers hill^{-1} (4.36). Nadim *et al.* (2013) reported that the combinations of micronutrients (Zn, Cu, Fe, Mn and B) increased the number of tillers plant^{-1}. Mekkei and El- Haggan Eman (2014) viewed that combination of micronutrients (Cu+ Fe+ Mn+ Zn) produced the highest number of tillers plant^{-1}.

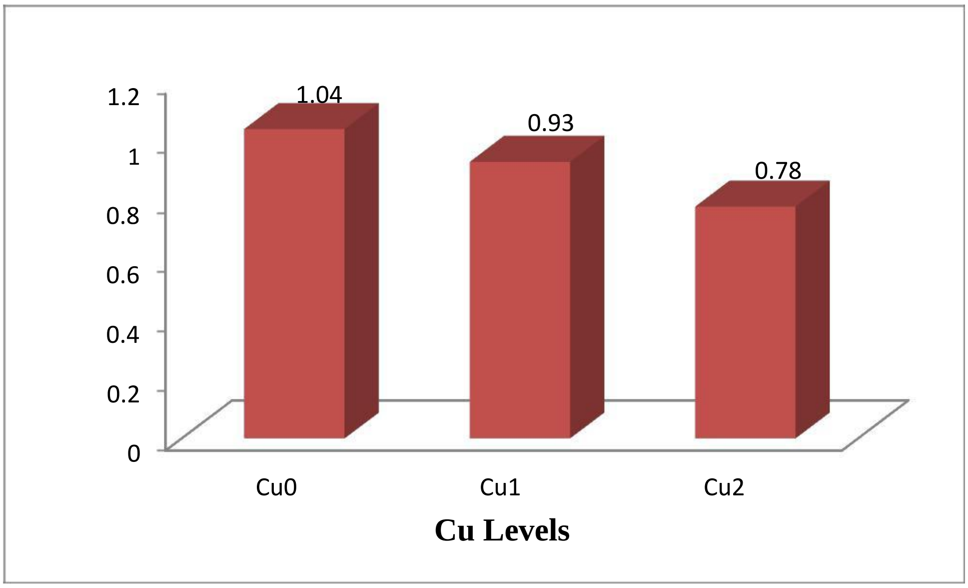


Cu_0 = 0 (control), Cu_1 = 2 kg ha^{-1} Cu, Cu_2 = 4 kg ha^{-1} Cu

Fig.12: Effect of Cu levels on the number of effective tillers hill^{-1} of wheat plant

4.2.4 The Number of Non-effective Tillers Hill^{-1}

Significant variation was observed with different doses of copper in respect of number of non-effective tillers hill^{-1} (Table 4). Among the different doses of fertilizers, Cu_0 (control) showed the highest number of non-effective tillers hill^{-1} (1.04) and Cu_2 (4 kg Cu ha^{-1}) showed the lowest number of effecitve tillers hill^{-1} (0.78). So, increasing the rate of Cu decreasing the number of non-effective tiller hill^{-1}.

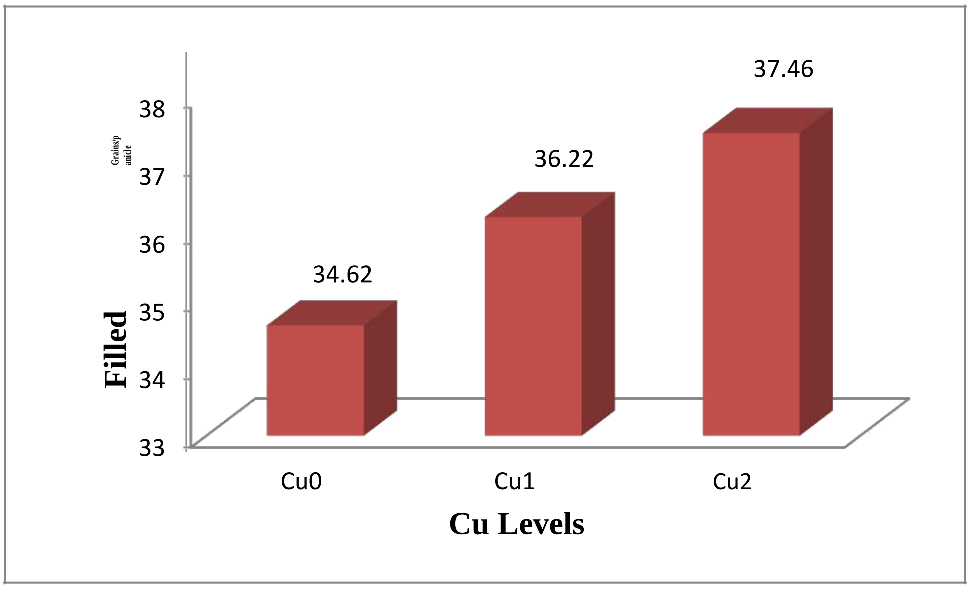


Cu_0 = 0 (control), Cu_1 = 2 kg ha^{-1} Cu, Cu_2 = 4 kg ha^{-1} Cu

Fig.13: Effect of Cu levels on the number of non-effective tillers hill^{-1} of wheat plant

4.2.5 Number of Filled Grains Panicle^{-1}

The influence of Cu on the number of filled grains panicle^{-1} was statistically significant (Fig. 14). Within the present study, number of filled grains panicle^{-1} was significantly influenced by the application of copper at different doses (Table 4). It was found that the maximum number of filled grains panicle^{-1} (37.46) was achieved from the treatment Cu_2 (4 kg ha^{-1} Cu). Again, the minimum number of filled grains panicle^{-1} (34.62) was obtained from the treatment Cu_0 (control). Number of filled grains panicle^{-1} increased with the increase of Cu up to Cu_2 treatment (4 kg ha^{-1} Cu). Mekkei and El-Haggan Eman (2014) appreciated that application with combination of micronutrients (Cu+ Fe+ Mn+ Zn) produced the highest grades of number of grains panicle^{-1}. Broadcast and incorporation of Cu increases the grain yield (Kruger *et al*. 1985; Karamanos *et al*. 1986; Malhi *et al*. 1989; Penney *et al*. 1993). Nadim *et al.* (2013) reported that the combinations of micronutrients (Zn, Cu, Fe, Mn and B) increased the number of grains panicle^{-1}.

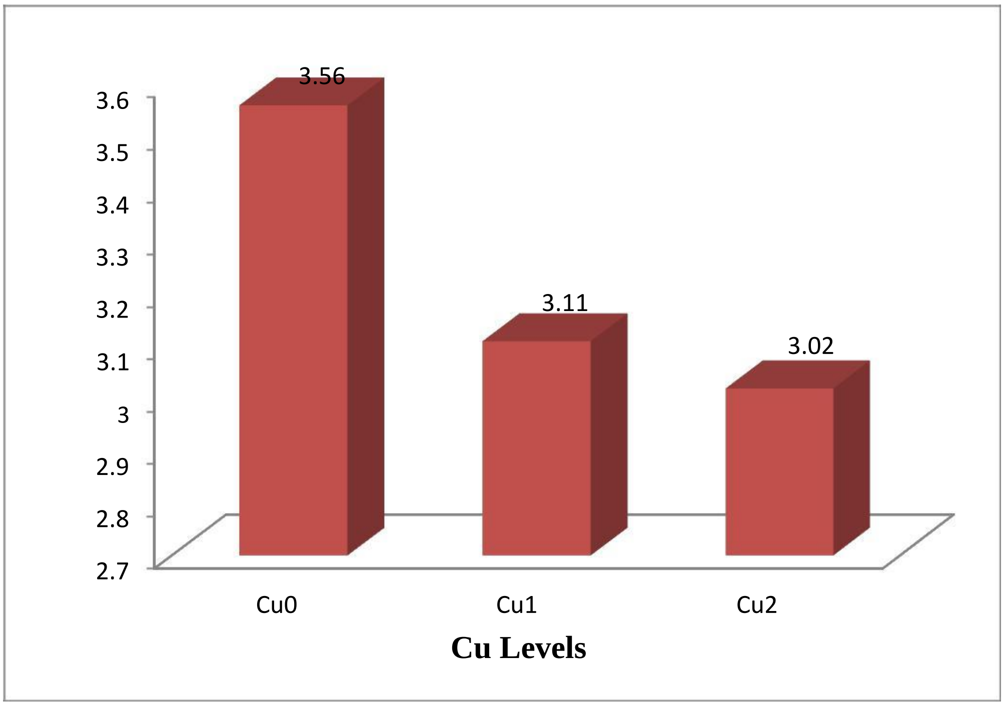


Cu_0 = 0 (control), Cu_1 = 2 kg ha^{-1} Cu, Cu_2 = 4 kg ha^{-1} Cu

Fig.14: Effect of Cu levels on the number of filled grains panicle^{-1}

4.2.6 Number of unfilled grain panicle^{-1}

Different doses of copper fertilizers showed non-significant variations in respect on number of unfilled grains panicle^{-1} of wheat (Table 4) and (Fig 15). Among the different doses of fertilizers, Cu_2 (4 kg ha^{-1} Cu) showed the lowest number of unfilled grains panicle^{-1} (3.02). On the contrary, the highest number of unfilled grains panicle^{-1} (3.56) was observed with Cu_0, where no copper fertilizer was applied.

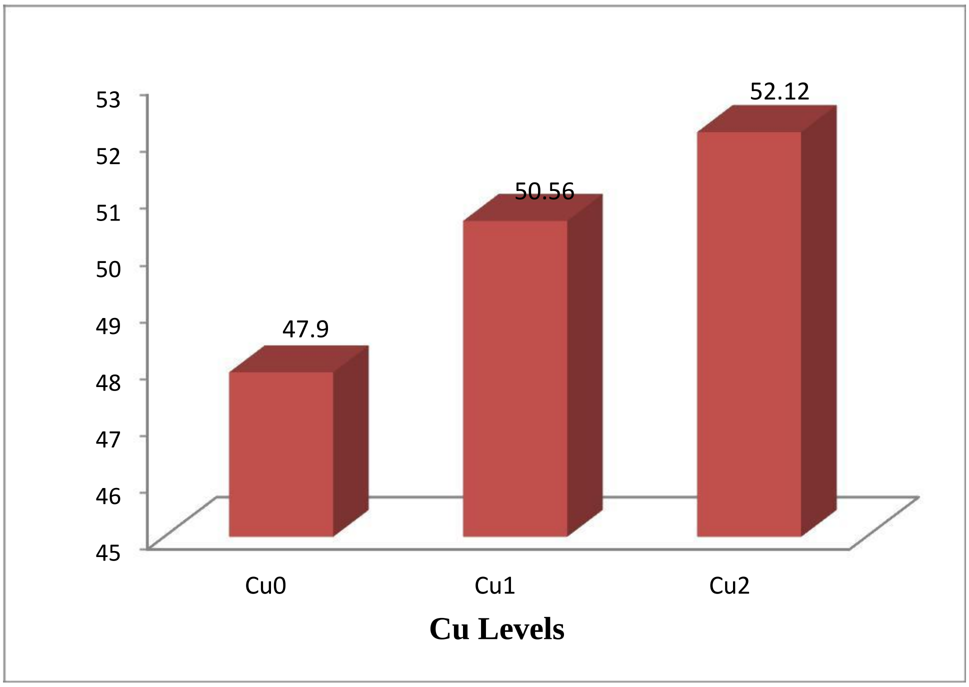


Cu_0 = 0 (control), Cu_1 = 2 kg ha^{-1} Cu, Cu_2 = 4 kg ha^{-1} Cu

Fig.15: Effect of Cu levels on the number of unfilled grains panicle^{-1}

4.2.7 Weight of 1000 Grain

Application of different levels of copper fertilizer to the wheat crop pretended non-significant difference on 1000 grain weight (Table 4). The highest 1000 grain weight (52.12 g) was observed with Cu_2 (4 kg ha^{-1} Cu) treatment where as the lowest (47.90 g) was with Cu_0 treatment (Control) (Fig. 16). Mekkei and El-Haggan Eman (2014) also showed similar results that mixture of micronutrients with Cu increased 1000 grain weight.

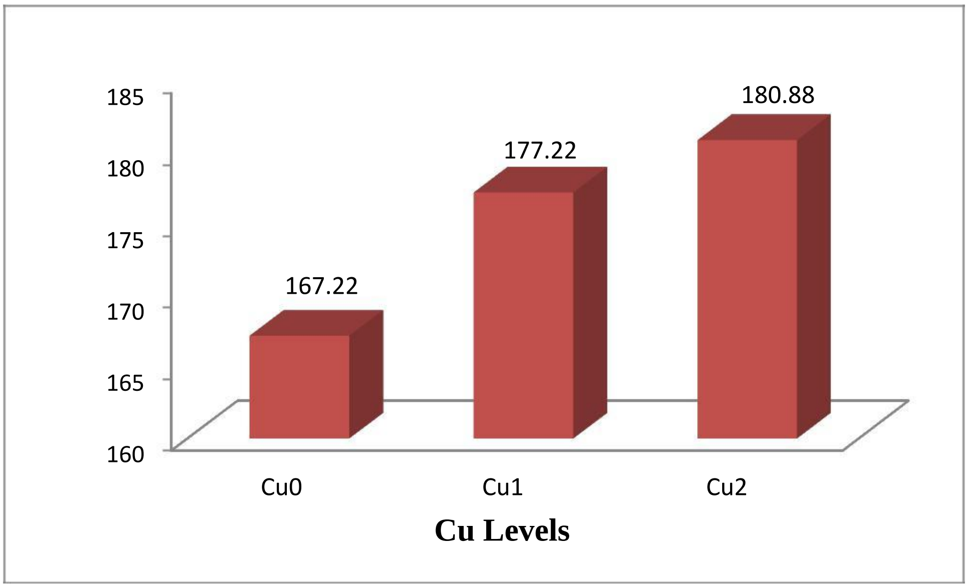


Cu_0 = 0 (control), Cu_1 = 2 kg ha^{-1} Cu, Cu_2 = 4 kg ha^{-1} Cu

Fig.16: Effect of Cu levels on the weight of 1000 grains (g)

4.2.8 Grain Yield of Wheat

Application of copper played an effective role on the yield and yield components of wheat (Table 4). Yield components were influenced effectively due to application of copper. The grain yield of wheat increased non-significantly due to added copper up to the treatment Cu_2 (4 kg ha^{-1} Zn). The highest grain yield (180.88 g m^{-2})/(1.8 t ha^{-1}) was achieved from Cu_2 treatment (4 kg ha^{-1} Cu). The lowest grain yield (167.22 g m^{-2})/(1.67 t ha^{-1}) was obtained from the treatment Cu_0 (control; no Cu application). Malhi *et al*. (1989) found that foliar application of Cu increased grain yield. Graham (1976), Karamanos *et al*. (1986) and Penney *et al.* (1993), also found that performance of a foliar application of Cu increased grain yield.

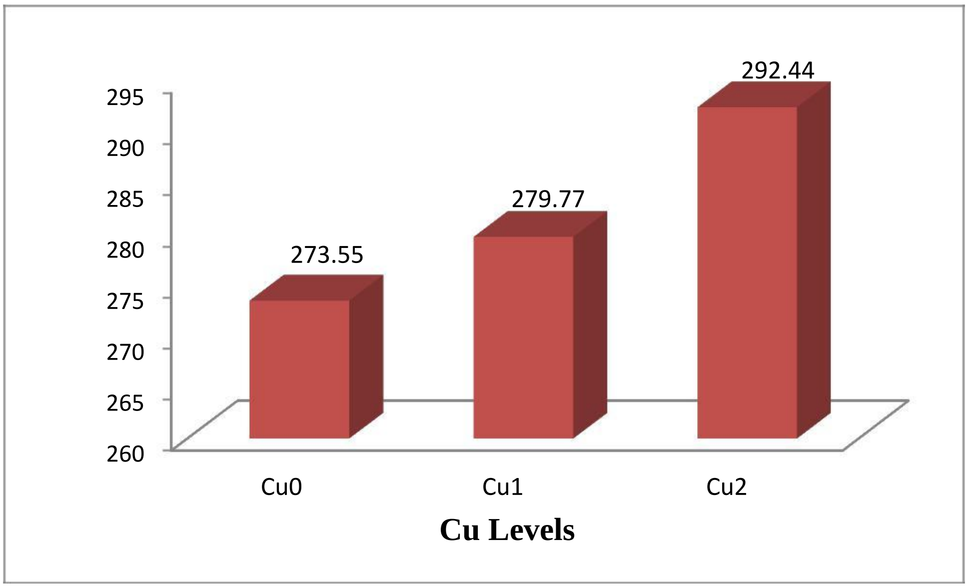


Cu_0 = 0 (control), Cu_1 = 2 kg ha^{-1} Cu, Cu_2 = 4 kg ha^{-1} Cu

Fig.17: Effect of Cu levels on the grain yield of wheat (g m^{-2})

4.2.9 Straw Yield of Wheat

Wheat plants showed non-significant variation in respect of straw yield of wheat when copper fertilizer in different doses was applied (Table 4). Among the different fertilizer doses, Cu_2 (4 kg Zn ha^{-1}) showed the highest straw yield (292.44 g m^{-2})/(2.92 t ha^{-1}). On the other hand, the lowest straw yield (273.55 g m^{-2})/(2.73 t ha^{-1}) was observed in the treatment where no copper fertilizer was applied. Kumar *et al*. (1990) was noticed that shoot dry matter decreased when no copper wa applied. Mekkei and El-Haggan Eman (2014) was reported similar result that Cu concentration increased straw yield.



Cu_0 = 0 (control), Cu_1 = 2 kg ha^{-1} Cu, Cu_2 = 4 kg ha^{-1} Cu

Fig.18: Effect of Cu levels on the straw yield of wheat (g m^{-2})

Table 4. Effect of Cu levels on the growth and yield of wheat

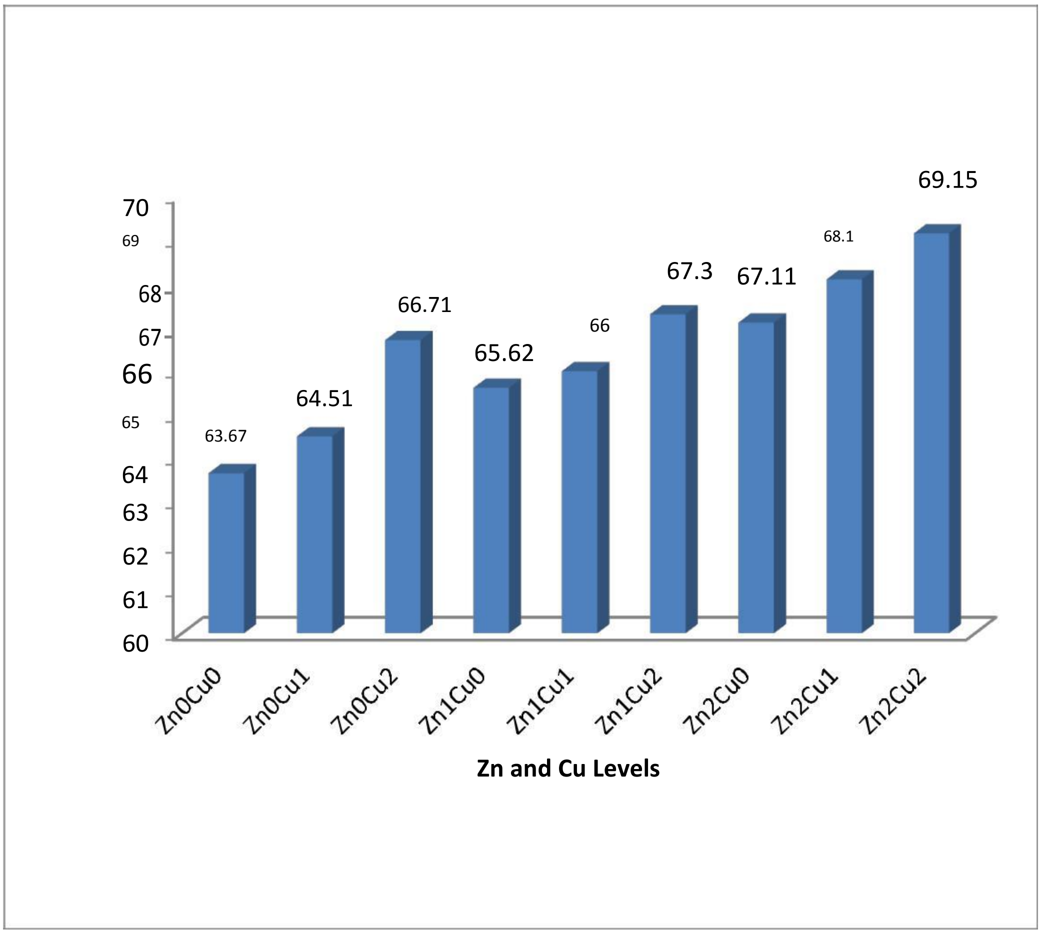
Treatments	Plant Height (cm)	Panicle Length (cm)	Number of Effective Tillers $Hill^{-1}$	Number of Non-effective Tillers $Hill^{-1}$	Number of Filled Grains	Number of Un-filled Grains	1000 Seeds Weight (g)	Grain Yield (g)	Straw Yield (g)
Cu_0 (Control)	66.03	14.20	4.24	1.04	34.62	3.56	47.90	167.22	273.55
Cu_1 (2 kg Cu ha^{-1})	66.14	14.36	4.35	0.93	36.22	3.11	50.56	177.22	279.77
Cu_2(4 kg Cu ha^{-1})	66.60	14.58	4.36	0.78	37.46	3.02	52.12	180.88	292.44
SE(±)	NS	NS	NS	0.0610	0.5874	NS	NS	NS	NS

In a column figures having similar letter(s) do not differ significantly at 5% level whereas figures with dissimilar letter(s) differ significantly as per DMRT

4.3 Interaction Effect of Zn and Cu Levels on the Growth and Yield of Wheat

4.3.1 Plant Height

The plant height was not significantly affected by the interaction effects of different levels of Zn and Cu (Table 5). The tallest plant (69.15 cm) was found at Zn_2Cu_2 treatments combination and the shortest plant (63.67 cm) was found under Zn_0Cu_0 treatments combination (Fig. 19). Present results indicated that plant height increased with the increasing levels of Zn and Cu.



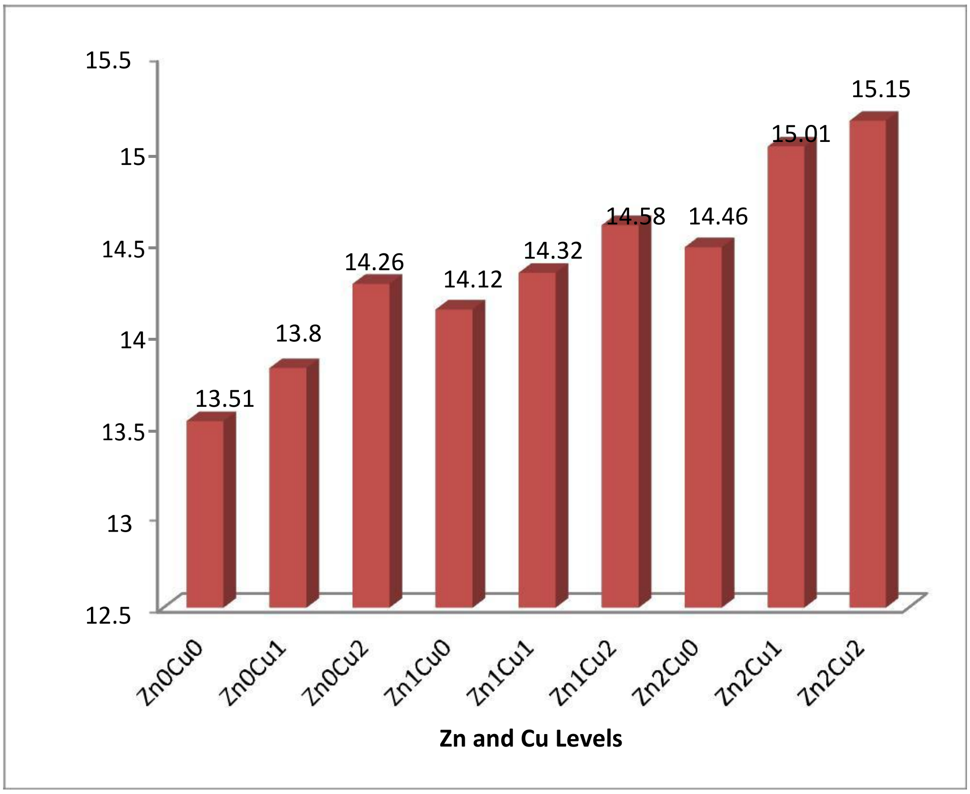
Zn_0 = 0 (control), Zn_1 = 3 kg ha^{-1} Zn, Zn_2 = 6 kg ha^{-1} Zn

Cu_0 = 0 (control), Cu_1 = 2 kg ha^{-1} C u , Cu_2 = 4 kg ha^{-1} Cu

Fig. 19: Interaction effect of Zn and Cu levels on plant height (cm) of wheat

4.3.2 Panicle Length

The combined effects of Zn and Cu on panicle length were significant (Table 5). However, the longest panicle (15.15 cm) was observed with Zn_2Cu_2 treatments combination which was statistically similar to all other treatmant combinations except Zn_0Cu_0 and the shortest value (13.51 cm) was in control Zn_0Cu_0 treatments combination. (Fig.20). From the above findings, it is concluded that the panicle length was enhanced by Zn and Cu interaction. This result is agreed with that of Mekkei and El-Haggan Eman (2014).

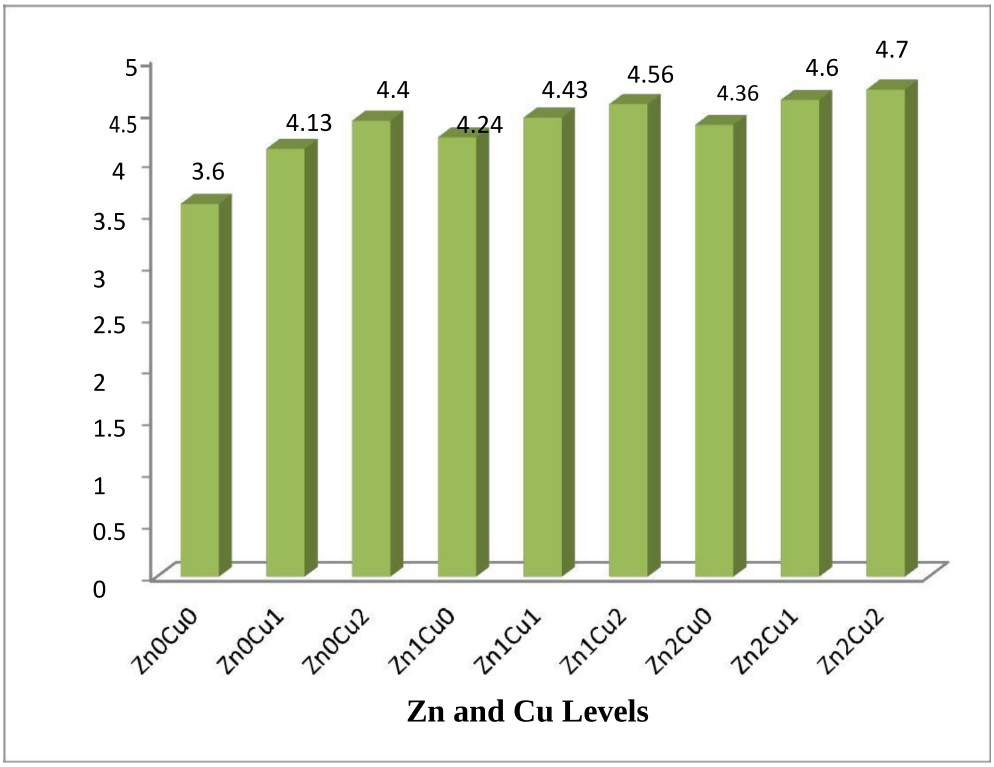


Zn_0 = 0 (control), Zn_1 = 3 kg ha^{-1} Zn, Zn_2 = 6 kg ha^{-1} Zn
Cu_0 = 0 (control), Cu_1 = 2 kg ha^{-1} C u , Cu_2 = 4 kg ha^{-1} Cu

Fig. 20: Interaction effect of Zn and Cu levels on plant height (cm) of wheat

4.3.3 Number of Effective Tillers Hill^{-1}

Combined application of different doses of zinc and copper had significant effect on number of effective tillers/hill of wheat (Table 5). It was observed that the highest number of effective tillers/hill (4.70) was recorded with Zn_2Cu_2 treatment which was statistically similar to all other treatment combinations except Zn_0Cu_0. The lowest number of effective tillers/hill (3.60) was observed in the treatment combination of Zn_0Cu_0. The results obtained from the rest of the treatment showed significant variation compared to the highest and lowest number of effective tillers/hill. The result obtained in another experiment conducted by Tahir *et al*., (2009) was similar with the present findings.

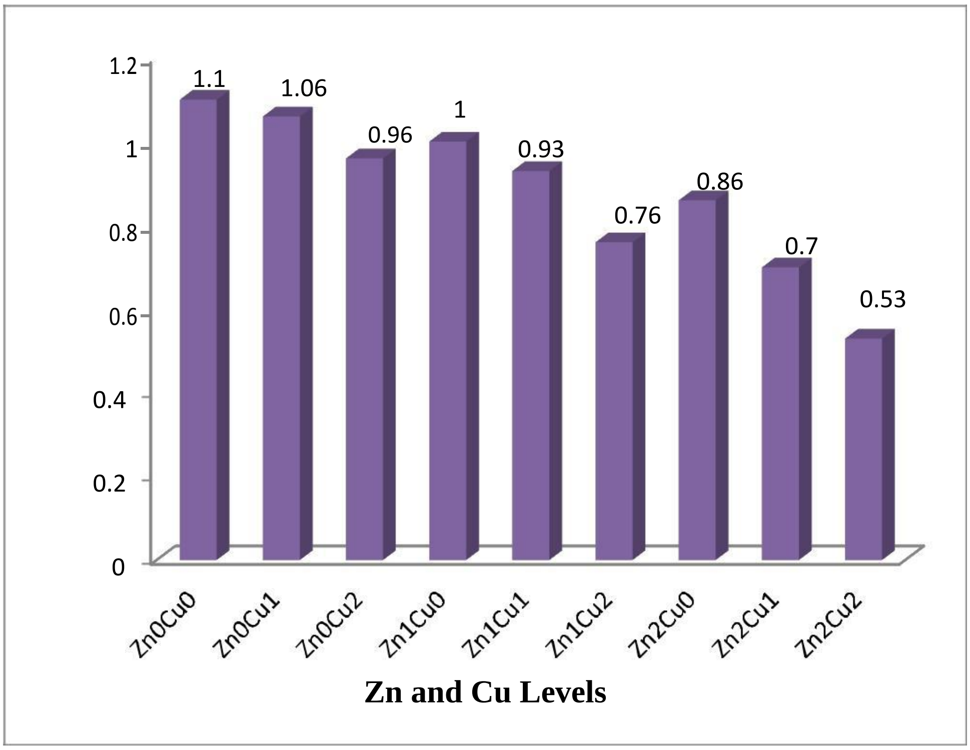


Zn_0 = 0 (control), Zn_1 = 3 kg ha^{-1} Zn, Zn_2 = 6 kg ha^{-1} Zn
Cu_0 = 0 (control), Cu_1 = 2 kg ha^{-1} C u , Cu_2 = 4 kg ha^{-1} Cu

Fig. 21: Interaction effect of Zn and Cu levels on the number of effective tillers hill^{-1} of wheat

4.3.4 Number of Non-effective Tillers Hill^{-1}

Combined application of different doses of zinc and copper had non-significant effect on number non-effective tillers/hill of wheat (Table 5). It was observed that the highest number of non-effective tillers/hill (1.1) was recorded with Zn_0Cu_0 treatment. On the other hand, the lowest number of non-effective tillers/hill (0.53) was observed in the treatment combination of Zn_2Cu_2.

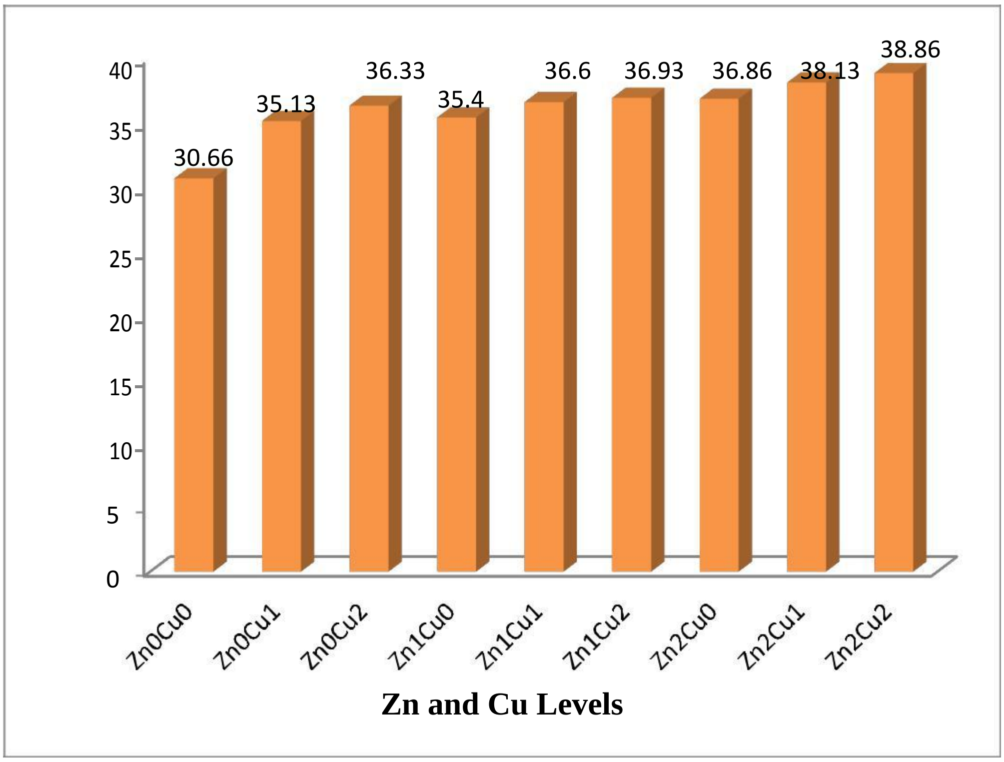


Zn_0 = 0 (control), Zn_1 = 3 kg ha^{-1} Zn, Zn_2 = 6 kg ha^{-1} Zn
Cu_0 = 0 (control), Cu_1 = 2 kg ha^{-1} C u , Cu_2 = 4 kg ha^{-1} Cu

Fig. 22: Interaction effect of Zn and Cu levels on the number of non-effective tillers hill^{-1} of wheat

4.3.5 Number of Filled Grains Panicle^{-1}

Interaction effects of Zn and Cu showed significant variation on the number of filled grains panicle^{-1} (Table 5). The number of filled grains panicle^{-1} varied from 30.66 to 38.86 depending on the various treatments used. Zn_2Cu_2 treatments combination produced the maximum number of grains panicle^{-1} (38.86) which was statistically similar to all other treatment combinations except Zn_0Cu_0 and the minimum (30.66) was obtained from control Zn_0Cu_0 treatments combination (Fig. 23). The combined positive effect of Zn and Cu interaction on number of grains panicle^{-1} of wheat was reported by Ali *et al*. (2009).

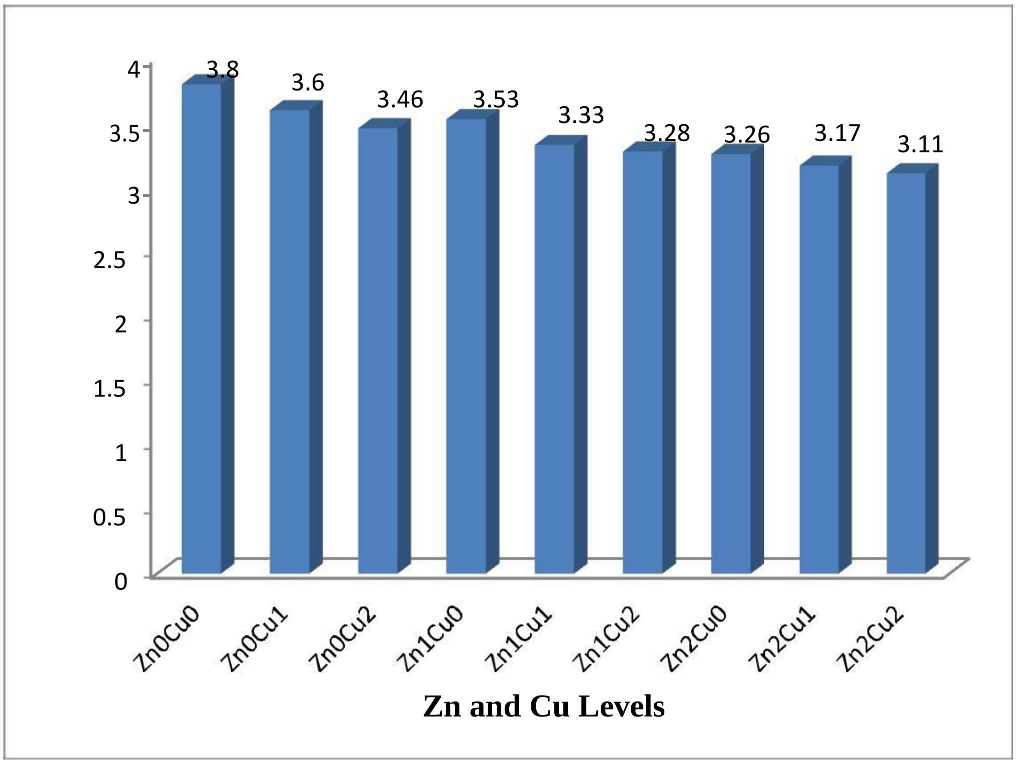


Zn_0 = 0 (control), Zn_1 = 3 kg ha^{-1} Zn, Zn_2 = 6 kg ha^{-1} Zn
Cu_0 = 0 (control), Cu_1 = 2 kg ha^{-1} C u , Cu_2 = 4 kg ha^{-1} Cu

Fig. 23: Interaction effect of Zn and Cu levels on the number of filled grains panicle^{-1} of wheat plant

4.3.6 Number of Unfilled Grains Panicle^{-1}

Combined application of different doses of zinc and copper fertilizers had effect on the number of unfilled grains panicle^{-1} of wheat (Table 5). It was observed that the lowest number of unfilled grains panicle^{-1} was (3.11) in Zn_2Cu_2 treatment. The highest number of unfilled grains panicle^{-1} (3.8) was recorded in the treatment combination of Zn_0Cu_0 (without zinc and copper).

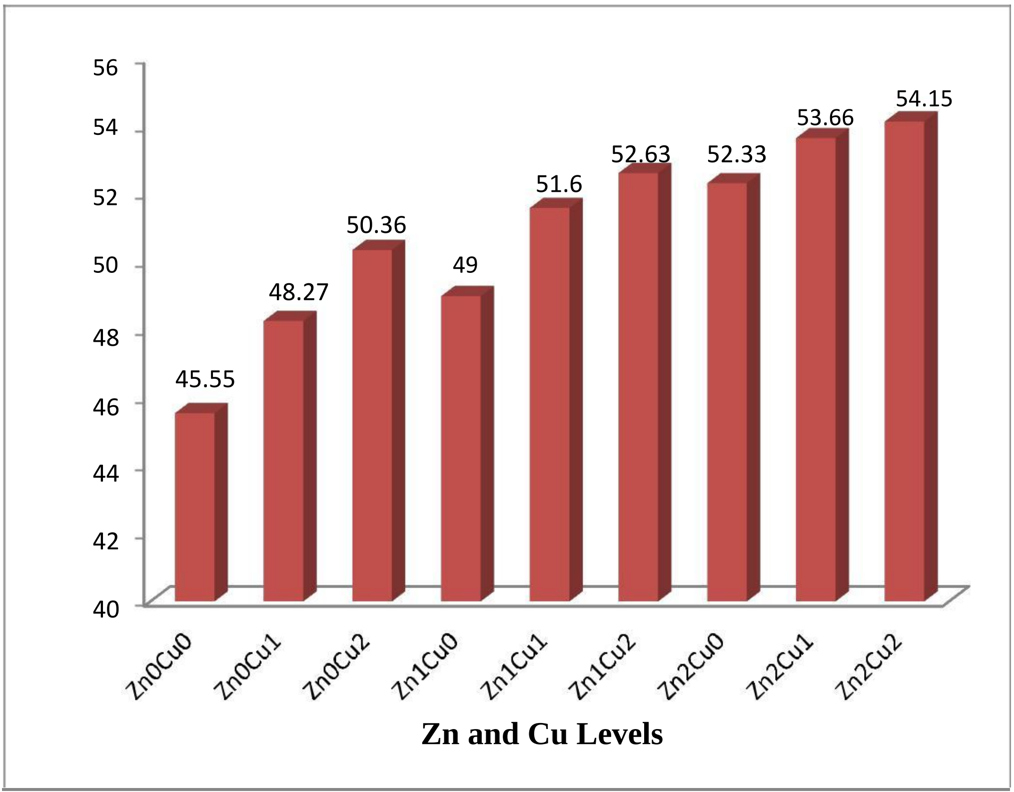


Zn_0 = 0 (control), Zn_1 = 3 kg ha^{-1} Zn, Zn_2 = 6 kg ha^{-1} Zn
Cu_0 = 0 (control), Cu_1 = 2 kg ha^{-1} C u , Cu_2 = 4 kg ha^{-1} Cu

Fig. 24: Interaction effect of Zn and Cu levels on the number of unfilled grains panicle^{-1} of wheat plant

4.3.7 1000 grain weight

The analysis of variance showed that the interaction effects of Zn and Cu were not significant for 1000 grain weight (Table 5). The highest 1000 grain weight (54.15 g) was obtained from Zn_2Cu_2 treatments combination, while the lowest 1000 grain weight (45.55 g) was found from control Zn_0Cu_0 treatments combination (Fig. 25). The above results indicate that the 1000 grain weight was enhanced by Zn and Cu interaction. This combined positive effect of Zn and Cu interaction on 1000 grain weight of wheat was also reported by Mekkei and El-Haggan Eman (2014).

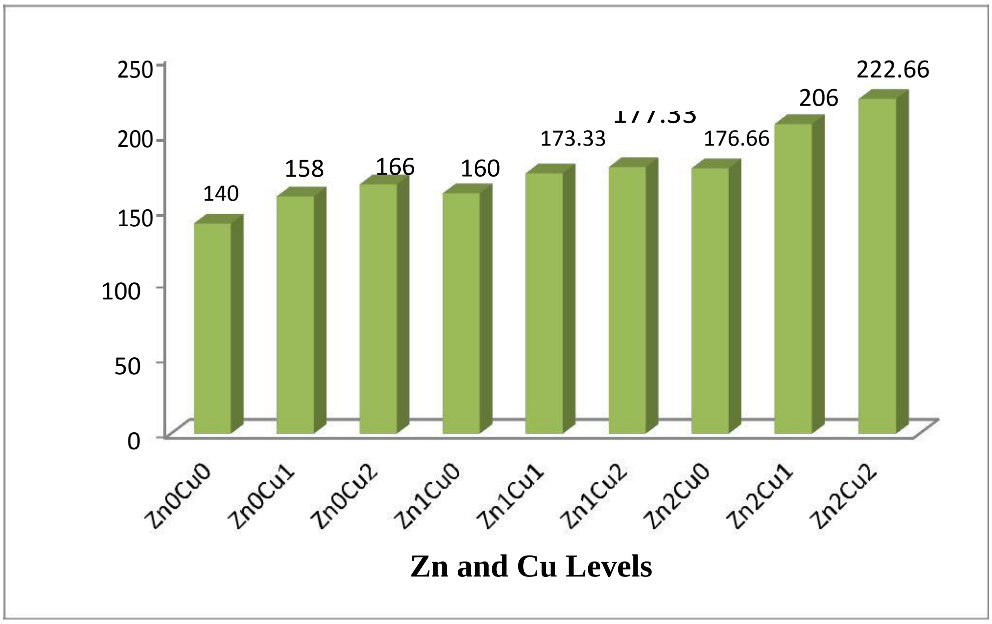


Zn_0 = 0 (control), Zn_1 = 3 kg ha^{-1} Zn, Zn_2 = 6 kg ha^{-1} Zn
Cu_0 = 0 (control), Cu_1 = 2 kg ha^{-1} Cu, Cu_2 = 4 kg ha^{-1} Cu

Fig. 25: Interaction effect of Zn and Cu levels on the weight of 1000 grains (g) of wheat plant

4.3.8 Grain Yield of Wheat

The combined interaction effect of different levels of Zn and Cu fertilizer was significant regarding grain yield (Table 5). The highest grain yield (222.66 g m^{-2})/(2.22 t ha^{-1}) was recorded at a Zn_2Cu_2 treatments combination which was statistically similar to Zn_2Cu_1 and the lowest grain yield (140 g m^{-2})/(1.4 t ha^{-1}) was recorded from Zn_0Cu_0 treatments combination (Fig.26). Zn in conjunction with Cu 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. Boorboori and Tehrani (2011) also showed the same result.



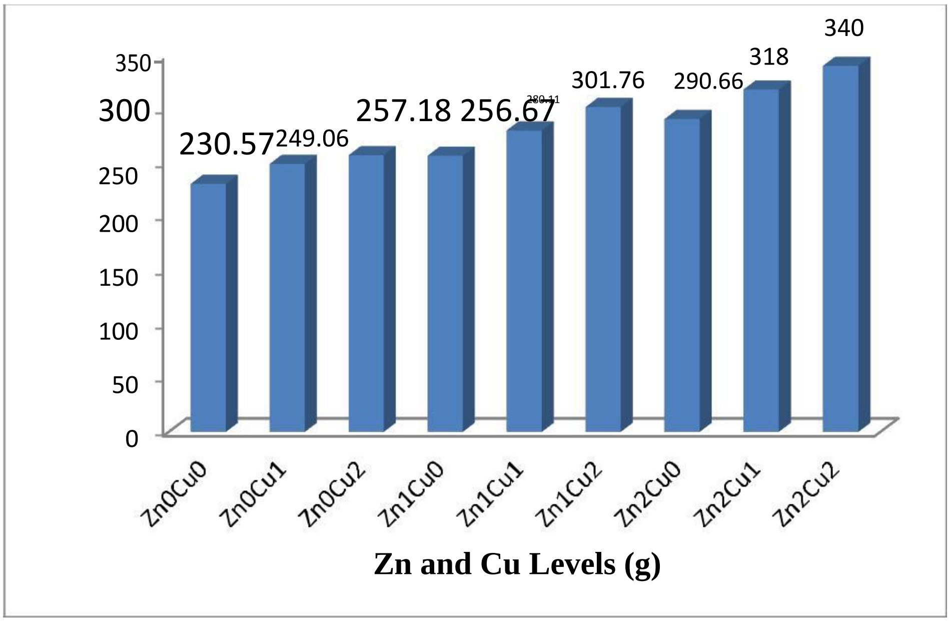
Zn_0 = 0 (control), Zn_1 = 3 kg ha^{-1} Zn, Zn_2 = 6 kg ha^{-1} Zn

Cu_0 = 0 (control), Cu_1 = 2 kg ha^{-1} C u , Cu_2 = 4 kg ha^{-1} Cu

Fig.26: Interaction effect of Zn and Cu levels on the grain yield (g m^{-2}) of wheat plant

4.3.9 Straw Yield of Wheat

Combined application of different doses of zinc and copper fertilizers had significant effect on straw yield of wheat (Table 5). It was observed that the highest straw yield (340 g m^{-2})/(3.4 t ha^{-1}) was recorded with Zn_2Cu_2 treatment which was statistically similar to Zn_2Cu_1, Zn_2Cu_0 and Zn_1Cu_2 treatment combinations. On the other hand, the lowest straw yield (230.57 g m^{-2}) /(2.3 t ha^{-1}) was observed in the treatment combination of Zn_0Cu_0 (without zinc and copper) and significantly different from all other treatments. The results obtained from the rest of the treatment showed significant variation compared to the highest and lowest straw yield of wheat. The result obtained with another experiment conducted by (Boorboori and Tehrani, 2011) was similar with the present findings.



Zn_0 = 0 (control), Zn_1 = 3 kg ha^{-1} Zn, Zn_2 = 6 kg ha^{-1} Zn

Cu_0 = 0 (control), Cu_1 = 2 kg ha^{-1} C u , Cu_2 = 4 kg ha^{-1} Cu

Fig. 27: Interaction effect of Zn and Cu levels on the grain yield (g m^{-2}) of wheat plant

Table 5. Effect of Interaction of Zn and Cu Levels on the Growth and Yield of Wheat

Treatments	Plant Height (cm)	Panicle Length (cm)	Number of Effective Tillers Hill^{-1}	Number of Non-effective Tillers Hill^{-1}	Number of Filled Grains	Number of Un-filled Grains	1000 Seeds Weight (g)	Grain Yield (g)	Straw Yield (g)
Zn_0Cu_0	63.67	13.51b	3.6b	1.1	30.66b	3.8	45.55	140c	230.57d
Zn_0Cu_1	64.51	13.80ab	4.13ab	1.06	35.13a	3.6	48.27	158bc	249.06cd
Zn_0Cu_2	66.71	14.26ab	4.40a	0.96	36.33a	3.46	50.36	166b	257.18cd
Zn_1Cu_0	65.62	14.12ab	4.24ab	1.00	35.40a	3.53	49	160bc	256.67cd
Zn_1Cu_1	66.0	14.32ab	4.43a	0.93	36.60a	3.33	51.60	173.33b	280.11bcd
Zn_1Cu_2	67.30	14.58ab	4.56a	0.76	36.93a	3.28	52.63	177.33b	301.76abc
Zn_2Cu_0	67.11	14.46ab	4.36a	0.86	36.86a	3.26	52.33	176.66b	290.66abc
Zn_2Cu_1	68.1	15.01ab	4.6a	0.70	38.13a	3.17	53.66	206a	318ab
Zn_2Cu_2	69.15	15.15a	4.7a	0.53	38.86a	3.11	54.15	222.66a	340a
SE(+)	NS	0.3416	0.1670	NS	1.0174	NS	NS	6.2578	12.7396

In a column figures having similar letter(s) do not differ significantly at 5% level whereas figures with dissimilar letter(s) differ significantly as per DMRT

Table 6. Effect of Zn on the Zn Concentration in Wheat Grain

Treatments	Zn Concentration (ppm)
Zn_0 (0, Control)	27.58b
Zn_1 (3 kg ha^{-1} Zn)	32.72b
Zn_2 (6 kg ha^{-1} Zn)	42.20a
SE (±)	0.708

The Zn concentration in wheat grain was significantly influenced by the application of Zn (Table 6). It was observed that the highest concentration of Zn (42.20 ppm) was recorded in wheat grain with Zn_2 (6 kg ha^{-1} Zn) treatment. The lowest concentration of Zn (27.58 ppm) was recorded in wheat grain with Zn_0 (control) treatment.

Table 7. Effect of Cu on the Zn Concentration in Wheat Grain

Treatments	Zn Concentration (ppm)
Cu_0 (0, Control)	32.55
Cu_1 (2 kg ha^{-1} Cu)	36.12
Cu_2 (4 kg ha^{-1} Cu)	33.82
SE (±)	NS

The Zn concentration in wheat grain was not significantly influenced by the single effect of Cu (Table 7). It was observed that the highest concentration of Zn (36.12 ppm) was recorded in wheat grain with Cu_1 (2 kg ha^{-1} Cu) treatment. The lowest concentration of Zn (32.55 ppm) was recorded in wheat grain with Cu_0 (control) treatment.

Table 8. Interaction Effect of Zn and Cu on the Zn Concentration in Wheat Grain

Treatment Combinations	Zn Concentration (ppm)
Zn_0Cu_0	26.66
Zn_0Cu_1	27.33
Zn_0Cu_2	28.75
Zn_1Cu_0	31.95
Zn_1Cu_1	34.15
Zn_1Cu_2	32.08
Zn_2Cu_0	39.05
Zn_2Cu_1	46.90
Zn_2Cu_2	40.65
SE(±)	NS

The Zn concentration in wheat grain was not significantly influenced by the interaction effect of Zn and Cu (Table 8). It was observed that the highest concentration of Zn (46.90 ppm) was recorded in wheat grain with Zn_2Cu_1 treatment combination and it was almost similar with Zn_2Cu_2, and Zn_2Cu_0 treatment combinations. The lowest concentration of Zn (26.66 ppm) was recorded in wheat grain with Zn_0Cu_0 treatment and it was almost similar with Zn_0Cu_1 and Zn_0Cu_2 treatment combinations.

Table 9. Effect of Zn on the Cu Concentration in Wheat Grain

Treatments	Cu Concentration (ppm)
Zn_0 (0, Control)	3.85
Zn_1 (3 kg ha^{-1} Zn)	3.90
Zn_2 (6 kg ha^{-1} Zn)	4.24
SE (±)	NS

The Cu concentration in wheat grain was not significantly influenced by the application of Zn (Table 9). It was observed that the highest concentration of Cu (4.24 ppm) was recorded in wheat grain with Zn_2 (6 kg ha^{-1} Zn) treatment. The lowest concentration of Cu (3.85 ppm) was recorded in wheat grain with Zn_0 (control) treatment.

Table 10. Effect of Cu on the Cu Concentration in Wheat Grain

Treatments	Cu Concentration (ppm)
Cu_0 (0, Control)	2.82b
Cu_1 (2 kg ha^{-1} Cu)	4.51a
Cu_2 (4 kg ha^{-1} Cu)	4.66a
SE (±)	0.110

The Cu concentration in wheat grain was significantly influenced by the single effect of Cu (Table 10). It was observed that the highest concentration of Cu (4.66 ppm) was recorded in wheat grain with Cu_2 (4 kg ha^{-1} Cu) treatment. The lowest concentration of Cu (2.82 ppm) was recorded in wheat grain with Cu_0 (control) treatment.

Table 11. Interaction Effect of Zn and Cu on the Cu Concentration in Wheat Grain

Treatment Combinations	Cu Concentration (ppm)
Zn_0Cu_0	2.70c
Zn_0Cu_1	4.83a
Zn_0Cu_2	4.03b
Zn_1Cu_0	2.80c
Zn_1Cu_1	4.03b
Zn_1Cu_2	4.86a
Zn_2Cu_0	2.96c
Zn_2Cu_1	4.6ab
Zn_2Cu_2	5.10a
SE($\pm$)	0.190

The interaction effect of Zn and Cu on the wheat grain Cu concentration was significantly different (Table 11). It was observed that the highest concentration of Cu (5.10 ppm) was recorded in wheat grain with Zn_2Cu_2 treatment combination and it was statistically similar with Zn_2Cu_1, Zn_1Cu_2 and Zn_0Cu_1 treatment combinations. The lowest concentration of Cu (2.70 ppm) was recorded in wheat grain with Zn_0Cu_0 treatment and it was statistically similar with Zn_1Cu_0 and Zn_2Cu_0 treatment combinations.

CHAPTER V

SUMMARY AND CONCLUSION

An experiment was conducted at the research field of Sher-e-Bangla Agricultural University (SAU) farm, Dhaka-1207 to evaluate the effect of three levels of zinc viz., 0 (Control), 3 kg ha^{-1} Zn, 6 kg ha^{-1} Zn and copper viz., 0 (Control), 2 kg ha^{-1} Cu, 4 kg ha^{-1} Cu on grain yield and yield attributes of wheat (BARI Gom-30) during the period from November 2015 to February 2016. The experiment was laid out in a randomized complete block design with three replications. There were 27 unit plots and the size of the plot was (3m × 2.25m). There were 9 treatments combination. Wheat seed of cv. (BARI Gom-30) was sown as test crop. The results revealed that yield and yield contributing characters were influenced by different levels of zinc, copper and the interaction effects of different levels of Zn and Cu .

The tallest plant (68.22 cm), the highest grain yield (202 g m^{-2})/(2.02 t ha^{-1}) and the highest concentration of Zn (42.20 ppm) and Cu (4.20 ppm) in wheat grain were obtained from were obtained from Zn_2 treatment (6 kg ha^{-1} Zn). In contrast, the shortest plant (65.58 cm), minimum grain yield (150 g m^{-2})/(1.50 t ha^{-1}) and the lowest concentration of Zn (27.58 ppm) and Cu (3.85 ppm) in wheat grain were observed when Zn was not applied (Zn_0 treatment).

On the other hand, plant height (66.60 cm) and grain yield (180.88 g m^{-2})/(1.8 t ha^{-1}) were the highest when Cu_2 treatment (4 kg ha^{-1} Cu) was imposed.The highest concentration Zn (36.12 ppm) was obtained from Cu_1 treatment (2 kg ha^{-1} Cu) and Cu (4.66 ppm) obtained from Cu_2 treatment (4 kg ha^{-1} Cu) in wheat grain. The shortest plant height (66.03 cm), the lowest grain yield (167.22 g m^{-2})/(1.67 t ha^{-1}) and the lowest concentration of Zn (32.22 ppm) and Cu (2.82 ppm) being recorded from the control treatment Cu_0.

Among the interactions of Zn and Cu, the tallest plant (69.15 cm), the highest grain (222.66 g m^{-2})/(2.22 t ha^{-1}) were obtained from combined treatment Zn_2Cu_2. The highest concentration of Zn (46.90 ppm) was obtained from Zn_2Cu_1 treatment and Cu (5.10 ppm) was obtained from Zn_2Cu_2 treatment in wheat grain. On the contrary, the lowest performances for all the studied crop characters and the lowest concentration of Zn and Cu in wheat grain were obtained from the treatment combination Zn_0Cu_0 where Zn and Cu were not applied. The results showed that grain yield of wheat increased with increasing levels of both Zn and Cu up to Zn_2 treatment (6 kg ha^{-1} Zn) and Cu_2 treatment (4 kg ha^{-1} Cu), respectively.

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 (6 kg ha^{-1} Zn)and Cu_2 treatment (4 kg ha^{-1}

Cu) as soil application. However, before making conclusion concerning the appropriate dose of Zn and Cu, 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

Appendix 1. Monthly records of air temperature, relative humidity, rainfall and sunshine hours during the period from November 2015 to February 2016

Month	Year	Monthly average air temperature (^{0}C)			Average relative humidity (%)	Total rainfall (mm)	Total sunshine (hours)
		Maximum	Minimum	Mean			
Nov	2015	28.52	16.30	22.41	68.92	Trace	216.50
Dec.	2015	27.19	14.91	21.05	70.05	Trace	212.50
Jan.	2016	25.23	18.20	21.80	74.90	4.0	195.00
Feb.	2016	31.35	19.40	25.33	68.78	3.0	225.50

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