EFFECT OF FOLIAR APPLICATION OF ZINC ON THE GROWTH AND DEVELOPMENT OF WHEAT

MOST. NAZNIN AKTER

DEPARTMENT OF SOIL SCIENCE
SHER-E-BANGLA AGRICULTURAL UNIVERSITY
DHAKA-1207

DECEMBER, 2015

EFFECT OF FOLIAR APPLICATION OF ZINC ON THE GROWTH AND DEVELOPMENT OF WHEAT

BY

MOST. NAZNIN AKTER

REG. NO. : 14-06323

A Thesis
Submitted to the Faculty of Agriculture
Sher-e-Bangla Agricultural University, Dhaka
in partial fulfilment of the requirements
for the degree
of

MASTER OF SCIENCE (MS)
IN
SOIL SCIENCE

SEMESTER: JULY-DECEMBER, 2015

Approved by:

Prof. Dr. Alok Kumar Paul	**Prof. Dr. Md. Asaduzzaman Khan**
Department of Soil Science	Department of Soil Science
Supervisor	**Co-Supervisor**

Mohammad Mosharraf Hossain
Chairman
Examination Committee
Department of Soil Science

DEPARTMENT OF SOIL SCIENCE
Sher-e-Bangla Agricultural University
Sher-e-Bangla Nagar, Dhaka-1207

CERTIFICATE

This is to certify that the thesis entitled **'Effect of Foliar Application of Zinc on the Growth and Development of Wheat'** submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **Master of Science in Soil Science**, embodies the result of a piece of *bona fide* research work carried out by **Most. Naznin Akter**, Registration number: **14-06323** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

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

Dated:
Dhaka, Bangladesh

Prof. Dr. Alok Kumar Paul
Department of Soil Science
Sher-e-Bangla Agricultural University
Dhaka-1207

DEDICATED

TO

MY BELOVED PARENTS

ACKNOWLEDGEMENTS

All praises are due to the Omnipotent Allah, the Supreme Ruler of the universe who enables the author to complete this present piece of work. The author deems it a great pleasure to express her profound gratefulness to her respected parents, who entiled much hardship inspiring for prosecuting her studies, receiving proper education.

The author feels proud to express her heartiest sence of gratitude, sincere appreciation and immense indebtedness to her supervisor Professor Dr. Alok Kumar Paul, Department of Soil Science, Sher-e-Bangla Agricultural University (SAU), Dhaka, for his continuous scholastic and intellectual guidance, cooperation, constructive criticism and suggestions in carrying out the research work and preparation of thesis, without his intense co-operation this work would not have been possible.

The author feels proud to express her deepest respect, sincere appreciation and immense indebtedness to her co-supervisor Professor Dr. Md. Asaduzzaman Khan, Department of Soil Science, SAU, Dhaka, for his scholastic and continuous guidance, constructive criticism and valuable suggestions during the entire period of course and research work and preparation of this thesis.

The author expresses her sincere respect and sence of gratitude to Chairman Mohammad Mosharraf Hossain, Associate Professor, Departement of Soil Science, SAU, Dhaka for valuable suggestions and cooperation during the study period. The author also expresses her heartfelt thanks to all the teachers of the Department of Soil Science, SAU, for their valuable teaching, suggestions and encouragement during the period of the study.

The author expresses her sincere appreciation to her colleages, relatives, well wishers and friends for their inspiration, help and encouragement throughout the study.

The Author

EFFECT OF FOLIAR APPLICATION OF ZINC ON THE GROWTH AND DEVELOPMENT OF WHEAT[1]

By

MOST. NAZNIN AKTER[2]

ABSTRACT

The experiment was conducted during the period from November 2014 to March 2015 in rabi season at the experimental field of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka to find out the effect of foliar application of zinc on the growth and development of wheat. The seeds of wheat variety 'BARI Gom 26' were used as test crop. The experiment comprised of the following treatments- T_0: Control (no zinc fertilizer), T_1: Spraying of 0.02% Zn solution once in growing season, T_2: Spraying 0f 0.02% Zn solution twice in growing season, T_3: Spraying of 0.04% Zn solution once in growing season, T_4: Spraying of 0.04% Zn solution twice in growing season, T_5: Spraying of 0.06% Zn solution once in growing season, T_6: Spraying of 0.06% Zn solution twice in growing season and T_7: Application of Zn in the soil as per recommended dose (2.5 kg Zn/ha). The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Statistically significant variation was observed for different parameters that were recorded. At 40, 50, 60, 70 DAS and harvest, the tallest plants (44.96, 64.73, 79.82, 90.17 and 97.01 cm, respectively) were recorded from T_6, while the shortest plant (39.27, 53.87, 69.26, 76.42 and 81.17 cm, respectively) was observed from T_0. The maximum number of effective tillers plants^{-1} (5.13), maximum number of filled grains spike^{-1} (46.07), highest grain yield (3.97 t ha^{-1}) and highest straw yield (5.10 t ha^{-1}) was attained from T_6, while the minimum number of effective tillers plants^{-1} (3.87), minimum number of filled grains spike^{-1} (40.43), lowest grain yield (3.08 t ha^{-1}) lowest straw yield (4.44 t ha^{-1}) and was observed from T_0.But incase of effective tiller, length of flag leaf,spikelet/spike,filled grain,yield of grain under T_6 treatment were statistically identical with T_3 , T_4,T_5 treatment.So we can choose T_3 for yield contributing characters and yield attributes. The maximum uptake of N (27.02 kg ha^{-1}), P (10.62 kg ha^{-1}) and K (14.07 kg ha^{-1}) by wheat grain were found from T_5 but the maximum uptake of Zn (0.214 kg ha^{-1}) from T_7, while the minimum values of uptake of N (19.40 kg ha^{-1}), P (7.66 kg ha^{-1}), K (10.29 kg ha^{-1}) and Zn (0.073 kg ha^{-1}) were found from T_0.The highest amount of available Zn of post harvest soil (3.53 ppm) was found from T_7, whereas the lowest available Zn in post harvest soil (2.01 ppm) was observed from T_0. Among the different treatments of foliar spray of Zn, spraying of 0.06% Zn solution twice in growing season induced superior growth, yield contributing characters and yield of wheat.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER I

INTRODUCTION

Wheat (*Triticum aestivum* L.) is an important food crop and primarily grown across the exceptionally diverse range of environments (WRC, 2009). Generally wheat supplies carbohydrate (69.60%), protein (12%), fat (1.72%), minerals (16.20%) and also other necessary nutrients in trace amount (BARI, 1997). Importance of wheat crop may be understood from the fact that it covers about 42% of total cropped area in rice-wheat system in South Asia (Iqbal *et al.,* 2002). The largest area of wheat cultivation in the warmer climates exists in the South-East Asia including Bangladesh, India and Nepal (Dubin and Ginkel, 1991). It contributes to the national economy by reducing the volume of import of cereals for fulfilling the food requirements of the country (Razzaque *et al.*, 1992). In Bangladesh, wheat is the second most important cereal crop (FAO, 1997). It occupies above 4% of the total cropped area and 11% of the area cropped in rabi and contributes 7% to the total output of food cereals (Anon., 2008).

Bangladesh had become highly dependent on wheat imports while dietary preferences were changing such that wheat was becoming a highly desirable food supplement to rice. Domestic wheat production rose to more than 1 million tons per year, but was still only 7-9% of total food grain production (BARI, 2010). Wheat cultivation has been increased manifolds to meet up the food shortage in the country. But, in spite of its importance, the yield of the crop in the context of our country is low (2.2 t ha^{-1}) in comparison to other wheat growing countries of the world (FAO, 1997). The area, production and yield of wheat have been increasing dramatically based on the demand of over increasing population of Bangladesh during the last two decades, but its present yield is too low in comparison to some developed countries like Japan, France, Germany and UK producing 3.76, 7.12, 7.28, and 8.00 t ha^{-1}, respectively (FAO, 2000). At present about 706.33 thousand hectares of land in Bangladesh is covered by wheat with the annual production of 1,592 thousand tons (BBS, 2014).

Yield of wheat is very low in Bangladesh and the low yield of wheat however is not an indication of low yielding potentiality of this crop, but may be attributed to a number of reasons viz. unavailability of quality seeds of high yielding varieties, delayed sowing after the harvest of transplanted aman rice, fertilizer management, disease and insect infestation and improper or limited irrigation facilities. Among the factors, different micronutrients especially application of zinc is the major reasons of yield reduction in Bangladesh. Zinc is essential plant micronutrient which is involved in many physiological functions, protein and carbonhydrate synthesis (Yadavi, *et al*., 2014). The nutritional requirement of zinc is specific to each culture, but cereals are more responsive. For wheat crop studies involving foliar Zn application are incipient in Bangladesh. The decreases of zinc on plant have been associated with the drought stress caused by decreases in soil water and consequently, restriction of root growth (Zafar *et al*., 2014). Zinc deficiency is a worldwide problem in crop production and a serious problem, especially in wheat croplands of Asia (Tisdale *et al*., 1997).

Usually, soil application of zinc sulphate heptahydrate 25.0-50.0 kg ha^{-1} is done to correct the deficiency; however, the availability of soil applied Zn is very poor and declines with time (Srivastava *et al*., 2008). As well documented by plant physiologists, zinc exerts a great influence on basic plant life processes, such as (i) nitrogen metabolism-uptake of nitrogen and protein quality; (ii) photosynthesis-chlorophyll synthesis, carbon anhydrase activity; (iii) resistance to abiotic and biotic stresses – protection against oxidative damage (Cakmak, 2008). Zinc 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 also plays an important role in the production of biomass (Kaya and Higgs, 2002). Furthermore, zinc may be required for chlorophyll synthesis, pollen function and fertilization (Kaya and Higgs, 2002). Low solubility of Zn in soils rather than low total amount of Zn is the major reason for the widespread occurrence of Zn deficiency problem in crop plants (Cakmak, 2008).

Different methods are used for micronutrient application such as seed priming, soil application and fortification, but foliar application is more beneficial. Significant increases in grain yield with foliar Zn application have been reported in other crops such as rice (Cakmak, 2008), triticale (Cakmak *et al*., 1997), and maize (Potarzycki and Grzebisz, 2009). Rehm and Albert (2006) reported that foliar spray of ferrous sulphate for the correction of Fe-chlorosis in wheat was found better than the soil application. Both macronutrients and micronutrients are foliar applied in combination with each other, then there is a significant increase in wheat production (Arif *et al*., 2006; Ali *et al*., 2008). Bameri *et al*. (2012) reported that root growth in wheat was improved by spraying micronutrients which led to increase in uptake of macro and micronutrients. Moreover, there is an increase in protein percentage of seed and yield components due to foliar application (Boorboori *et al*., 2012). Foliar application of zinc greatly affects plant growth and crop production. It is, therefore, important to study the efficiency of foliar application of zinc on yield of wheat under water stressed condition at different growth stages of the crop. The present study was, therefore, undertaken a) to know the effect of foliar application of zinc on yield of wheat. So, in the context of the above mentioned situation in respect of wheat cultivation in Bangladesh, the present piece of work was undertaken with the following objectives-

i. To observe the effect of foliar application of Zn on growth and yield of wheat;

ii. To compare the effect of soil and foliar application of Zinc with proper irrigation in wheat and

iii. To find out the optimum foliar dose of Zinc for higher yield of wheat.

CHAPTER II

REVIEW OF LITERATURE

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops in Bangladesh. A good number of research works have been done in Bangladesh and different countries of the world on various aspects of wheat production. Zinc is a micronutrient which is required relatively in a smaller amount for plant growth and development and also for the yield and yield attributes of wheat. Zinc plays a significant role in yield, yield attributes and soil nutrient status but the efficiency of zinc fertilizer depends on time and methods of application. Very limited research works have been carried out in home and abroad related to the yield, yield attributes and soil nutrient status due to the application of zinc in wheat. The research work so far done in Bangladesh is not adequate and conclusive. However, some of the important and informative research findings related to the yield, yield attributes and soil nutrient status, so far been done at home and abroad, reviewed below under the following headings:

2.1 Role of zinc and application methods on wheat

A field experiment was conducted by Cao *et al*. (2010) to investigate the effects of different Zn application methods (soil application or foliar spray) on grain Zn concentration and Zn bioavailability of 5 winter wheat cultivars in potentially zinc (Zn)-deficient calcareous soil. The results show that there are little effects of applying Zn fertilizer on grain yield of wheat, while the grain Zn concentration is significantly increased under certain methods of Zn application. Compared with the control treatment (no Zn application), the grain Zn concentrations are increased by 6.1%, 63.9% and 82.6% under the methods of soil application, foliar spray and soil+foliar application of Zn fertilizers, and the grain Zn uptakes are increased by 3.6%, 69% and 83%, respectively. In conclusion, comparing with the 3 Zn application methods, the foliar application of Zn fertilizer to wheat at the late growth stage (for example, the milk and dough stage) is an economical and effective method to attain high Zn concentration and bioavailability, and to improve the Zn quality of wheat grain in potentially Zn-deficiency calcareous soil.

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. Four Zn fertilizer levels including Z_0 (no zinc fertilizer), Zn_1 (5 kg Zn ha^{-1} in soil + 300 g Zn ha^{-1} in foliar application), Zn_2 (10 kg Zn ha^{-1} in soil + 600 g Zn ha^{-1} in foliar application) and Zn_3 (15 kg Zn ha^{-1} in soil + 900 g Zn ha^{-1} in foliar application) both from $ZnSO_4$ source have been applied in planting and booting stage in soil and as foliar application. Zn had increasing effects on grain yield, total dry matter, yield, 1000-grain weight, number of tiller, grain Zn content, flag leaf Zn content, plant height, number of node, protein content and grain Fe content. 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 the application of zinc and for obtaining optimum production and quality of crops application of zinc with other nutrients should be advised particularly for wheat cultivation (Riffat *et al.,* 2007).

Genc *et al.* (2006) reported that zinc has vast numbers of functions in plant metabolism and consequently zinc deficiency has a multitude of effects on plant growth. Zinc sulphate increased the Leaf Area Index, the total number of fertile tillers m^{-2}, number of spikelets $spike^{-1}$, spike length, grain $spike^{-1}$, thousand grain weight, grain yield, straw yield and biological yield and decreased harvest index.

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. 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. Eleven parameters including quantitative parameters and qualitative ones were measured. 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.

Ozturk *et al.,* (2006) reported that in general zinc application appears to improve the overall field performance of wheat plants. The most of the seed-zinc located in embryo and aleurone layer, whereas the endosperm is very low in Zn concentration. According to a Zn-staining study in wheat seed, Zn concentrations were found to be around 150 mg kg^{-1} in the embryo and aleurone layer and only 15 mg kg^{-1} in the endosperm.

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 Indol acetic acid (IAA) synthesis. Dwivedi and Tiwari (1992) also reported that application of zinc increased zinc uptake in grain and straw.

Hemantaranjan and Grag (1988) observed that optimum utilization of Zn and Fe significantly increased thousand grain weights in wheat. Zinc is a micronutrient which is required for plants growth relatively in a smaller amount but in appropriate time. The normal concentration range for Zn in dry matter of plants is 25 to 150 mg g^{-1}. Roots absorb Zn in the form of Zn^{2+}. Zinc is involved in a diverse range of enzymatic activities. The role of Zn include; auxin metabolism, influence on the activities of dehydrogenase and carbonic anhydrase, enzymes, synthesis of cytochrome 'C' and the stabilization of ribosomal fraction.

2.2 Effect of zinc on yield and yield contributing characters of wheat

A field experiment was conducted by Arshad *et al*. (2016) to find out the "interactive effect of phosphorus and zinc on wheat crop" at New Developmental farm, the University of Agriculture Peshawar, Pakistan. Four zinc levels (0, 5, 10 and 15 kg ha^{-1}) were applied to plots with three different levels of phosphorus (45, 90 and 135 kg ha^{-1}). Zn application had significantly increased wheat spike length (10.78 cm), 1000 grains weight (49.36 g) total dry matter (8200 kg ha^{-1}) and grain yield (4426 kg ha^{-1}) in the plots which were treated with 10 kg Zn ha^{-1}, while the maximum straw yield (4000 kg ha^{-1}) was recorded at 5 kg Zn ha^{-1}. These results indicated that agronomic characteristics of wheat crop showed more significant response in plots which were treated with 10 kg Zn ha^{-1}.

A field experiment was carried out by Sultana *et al*. (2016) at micronutrient experimental field of Soil Science Division, BARI, Joydebpur, Gazipur to study the effect of foliar application of zinc on yield of wheat (BARI gom-25) grown by skipping irrigation at different growth stages of the crop. The experiment was designed in a split plot design on sixteen treatments comprising four irrigation treatments (regular irrigation, skipped irrigation at crown root initiation, skipped irrigation at booting stage and skipped irrigation at grain filling stages of wheat growth) and four foliar application of zinc (0.0%, 0.02%, 0.04% and 0.06% of zinc). Zinc Sulphate Monohydrate ($ZnSO_4$. H_2O) was used as a source of Zn. The highest yield (5.59 t ha^{-1}) was recorded in normal irrigation which was identical with skipping irrigation at flowering and heading stage with 0.06% foliar application of zinc. Skipping irrigation at crown root initiation stage had the most negative effect on growth and yield. Skipping irrigation at flowering and heading stage of wheat with 0.04% foliar application of zinc gave the identical yield in regular irrigation with 0.04% and 0.06% foliar application of zinc. Thus, foliar application of zinc played a major role on yield and yield components of wheat at later stages of growth. The response of foliar application of Zn was positive and quadrate in nature. The optimum dose was appeared as 0.04% foliar application of zinc for grain yield of wheat in the study area of Joydebpur, Gazipur (AEZ-28).

Ahmadi and David (2016) conducted a field experiment during *Rabi* season to study the effect of Nitrogen and Zinc on Yield of Wheat *(Triticum aestivitm* L.) at the research farm of department of Soil Science. Three levels of nitrogen [0, 60 and 120] kg ha^{-1}], three levels of zinc [0, 15 and 30 kg ha^{-1}], respectively were applied. The treatment combination T8 - [@ 120 kg Nitrogen ha^{-1} +@ 30 kg Zinc ha^{-1}] gave the best results with respect to plant height 101.2 cm, it gave highest yield 5.600 t ha^{-1}, straw yield 7.570 t ha^{-1}

A field experiment was carried out by Singh *et al*. (2015) 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.) during the winter (Rabi) season in two consecutive years at the Allahabad agricultural Institute – Deemed University, Allahabad. The treatments comprised three levels of zinc (0, 3.5 and 7 kg ha^{-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) as borax, making 12 treatment combinations, each replicated three times. 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 crop.

To assess the possible role of micronutrients in improving wheat yield, an experiment was conducted by Zain *et al.* (2015) to evaluate the wheat performance by foliar application of micronutrients. Treatments consist of T_1 = No spray, T_2 = Spraying plants with tube well water (control), T_3 = Spraying plants with 1.6 kg FeSO4/100 L water/acre, T_4= Spraying plants with 3 kg $ZnSO_4$ (21%)/100 L water/acre, T_5 = Spraying plants with 1 kg $MnSO_4$/100 L water/acre, T_6 = Spraying plants with ($FeSO_4$ + $MnSO_4$), T_7 = Spraying plants with ($FeSO_4$ + $ZnSO_4$), T_8 = Spraying plants with ($ZnSO_4$ + $MnSO_4$), and T_9 = Spraying plants with ($FeSO_4$ + $ZnSO_4$ + $MnSO_4$). Results showed that foliar application of micronutrients substantially improved plant height, spike length cm, spikelets/spike, grains/spike, test weight, Tillers m^{-2}, grain and biological as well as harvest index of wheat.

A field experiment was conducted by Singh *et al*. (2013) for rabi season at the cultivator field in order to find out the effect of zinc on wheat crop. A field experiment was undertaken to evaluate the effect of graded levels of zinc sulphate (0, 7.5, 15.0, 22.5 and 30.0 kg/ha) on the flag leaf, yield content and uptake of nutrient in wheat. Application of 22.5 kg Zn ha^{-1} gave significantly higher flag leaf and yield.

To study the effect of potassium sulfate and zinc fertilizers on wheat drought resistance under water stress conditions, an experiment was conducted in the fall of 2011 in Dehloran region. In this test, a split factorial in a randomized complete block design with three replications. Factors examined include the normal irrigation and supplemental irrigation in main plots were performed and potassium fertilizers concentrations of zero, 60, 120 and 180 kg ha potassium sulfate source and zinc concentrations zero and 25 kg ha of zinc sulfate source factorial subplots were performed. At the end of the experiment seed yield, number of grains per spike, number of spikelets per spike, 1000 seed weight and the amount of protein, potassium, zinc and nitrogen on grain measured. The result revealed that the height, number of grains per spike, grain weight and grain yield of wheat greatly influenced by the application of zinc.

A field investigation was conducted by Keram *et al*. (2012) during winter (rabi) season in Vertisol to study the response of wheat yield, nutrient uptake, protein content and effect on soil properties to zinc application. The recommended doses of N, P and K were applied @ 120 N: 60 P_2O_5: 40 K_2O kg ha^{-1} in combination with Zn @ 0, 1.25, 2.50, 5, 10 and 20 kg ha^{-1} as zinc sulphate at the time of sowing in all the treatments. Pooled analysis of data revealed that yield, harvest index increased significantly with the application of recommended NPK+Zn @ 20 kg ha^{-1} by wheat as compare to NPK alone. In general, yield and harvest index increased up to highest level of Zn. The maximum yield (grain- 4.66 and straw- 5.44 kg ha^{-1}) and harvest index (46.07) was achieved by the application of 20 kg Zn ha^{-1} with recommended NPK as compare to control and other treatments.

Tiago *et al*. (2012) carried out an experiment with aimed to evaluate the effect of foliar application of zinc in agronomic characteristics and yield of wheat. Treatments consisted of four doses of zinc (0, 54, 108 and 216g ha^{-1} Zn), divided into two foliar applications, the first at tillering (18 days after plant emergence) and the second at the boot stage (65 days after emergence). Foliar application of zinc increased the number of fertile tillers and yield of wheat, however, have little effect on the agronomic characteristics of no-tilled crop with high nutrient content in soil.

A field experiment was conducted by Habib (2009) on clay-loam soil in Moghan region 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 concentration were evaluated. Results showed that foliar application of Zn increased seed yield and its quality compared with control.

A field experiment was conducted by Abbas *et al*. (2009) for two years, at Government Adaptive Research Farm Karor Lal Eason, District-Layyah, to study the effect of added zinc on growth and yield parameters, zinc uptake, soil zinc status and also the effect of added zinc in soil. Wheat variety Bhakkar- 2002 was sown during Rabi season, with the recommended doses of N, P and K were applied @ 150: 100: 60 kg N: P_2O_5: K_2O ha^{-1} in all treatments. Zn was applied @, 4, 8, 12 and 16 kg ha^{-1} as zinc sulphate at the time of sowing in the all treatments except control (recommended NPK). Combined Zn and NPK application significantly improved growth and yield parameters of wheat.

A field experiment was conducted by Khan *et al*. (2008) to investigate the effect of soil application of zinc fertilizer on yield and yield components of wheat (*Triticum aestivum* L. cv. Pak-81) grown on calcareous soil in Pakistan. The levels of zinc sulphate were 0 (control), 5, 10, 15, 20, 25 and 30 kg ha^{-1} and the zinc sulphate was combine-drilled at the time of sowing. Zinc sulphate increased the Leaf Area Index, the total number of fertile tillers m^2, number of spikelets $spike^{-1}$, spike length, grain $spike^{-1}$, thousand grain weight, grain yield, straw yield and biological yield and decreased harvest index.

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

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

A field experiment was conducted by Khan *et al*. (2007) on wheat and rice to study the response of Zinc application in wheat-rice system. Two levels of zinc 5 and 10 kg ha^{-1} with control were studied with the basal dose of N, P_2O_5, K_2O as

120-90-60 kg ha^{-1} in the form of urea, TSP, SOP and zinc sulphate during both the crops. Zn application, significantly affected wheat grain yield, ranged from 2.7 to 3.5 t ha^{-1}, giving highest increase of 31.6% over control from 5 kg Zn ha^{-1}. The number of tillers, spike m^{-2}, spike length, plant height and 1000 grain weight of wheat were also significantly affected over control with the same treatment.

Jain and Dahama (2007) conducted field trials during the winter (rabi) seasons, 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, 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 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.

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 6 kg Zn ha^{-1} increased the grain and straw yields by 19.4 and 16.8% over the no use of Zn.

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 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 $ZnSO_4ha^{-1}$. However, it was statistically at par with 30 kg $ZnSO_4ha^{-1}$.

Ozkutlu *et al*. (2006) reported that 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.

Parihar *et al*. (2005) carried out 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 vermicompost ha^{-1}) were studied on wheat for yield and reported that the application of Zn up to 10 kg ha^{-1} increased the grain yield by 7.2 per cent over control.

Razvi *et al*. (2005) reported that the soil application of $ZnSO_4$ at 10 kg ha^{-1} recorded significantly higher grain yield (27.72 q ha^{-1}), straw yield (44.07 q ha^{-1}), HI (0.366) and DMP at harvest (202.72 g m^{-1} row length) over the rest of the treatments.

Dewal and Pareek (2004) conducted a field experiment was conducted during the winter (rabi) 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 revealed that he growth parameters, yield attributes and yield increased significantly with application of 5 kg Zn ha^{-1}.

Singh (2004) was carried out a field experiment on wheat during the rabi season 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}.

Chandrakuma *et al.* (2004) was conducted a field experiment in Raichur, Karnataka, India during the rabi season to investigate the effects of organic, and 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.

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

Imtiaz *et al*. (2003) reported that zinc deficiency has been reported to cause stunted plant growth and as shown here, the impact of zinc stress on wheat growth in zinc deficient calcareous soil can be mitigated by zinc fertilization.

Sundar and Choudhary (2002) reported that a pot experiment was carried out during rabi season to study the effect of P, Zn, and soil type on yield and its interaction effect on wheat (cv. Raj. 1555) nutrient uptake. Treatments consisted of Zn (0, 5, 10, and 15 kg ha^{-1} as zinc sulfate) application on sandy clay loam and clay loam soil. Wheat responded significantly to the addition of P and Zn and to soil type. The highest straw and grain yields, number of grains per ear, and test weight were recorded with the application of 10 kg Zn ha^{-1} on clay loam soil.

Zeidan and Nofal (2002) showed that the 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.

Sharma *et al.* (2000) conducted a study 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.

2.3 Effect of zinc on nutrient status of wheat grain, straw and soil

A field experiment was conducted by Singh *et al*. (2013) for rabi season at the cultivator field in order to find out the effect of zinc on wheat crop. A field experiment was undertaken to evaluate the effect of graded levels of zinc sulphate (0, 7.5, 15.0, 22.5 and 30.0 kg/ha) and reported that application of 22.5 kg Zn/ha gave significantly higher Zn content and Zn uptake.

A field investigation was conducted by Keram *et al*. (2012) during winter (rabi) season in Vertisol to study the response of wheat yield, nutrient uptake, protein content and effect on soil properties to zinc application. The recommended doses of N, P and K were applied @ 120 N: 60 P_2O_5: 40 K_2O kg ha^{-1} in combination with Zn @ 0, 1.25, 2.50, 5, 10 and 20 kg ha^{-1} as zinc sulphate at the time of sowing in all the treatments. Pooled analysis of data revealed that nutrient (N, K and Zn) uptake and quality increased significantly with the application of recommended NPK+Zn @ 20 kg ha^{-1} by wheat as compare to NPK alone. Total nutrient uptake (N-123.19 kg ha^{-1}, K-90.86 kg ha^{-1} and Zn-327.74 g ha^{-1}) and total carbohydrate (70.37 per cent) content was achieved by the application of 20 kg Zn ha^{-1} with recommended NPK as compare to control and other treatments, while the total P uptake was decline with increasing levels Zn. There is no appraisal change in soil pH, EC, organic carbon and $CaCO_3$, but the status of DTPA-extractable Zn of soil was improved remarkably due to rational Zn fertilization combined with recommended NPK.

A field experiment was conducted by Cao *et al*. (2010) to investigate the effects of different Zn application methods (soil application or foliar spray) on grain Zn concentration and Zn bioavailability of 5 winter wheat cultivars in potentially zinc (Zn)-deficient calcareous soil. Compared with the control treatment (no Zn application), the grain Zn concentrations are increased by 6.1%, 63.9% and 82.6% under the methods of soil application, foliar spray and soil+foliar application of Zn fertilizers, and the grain Zn uptakes are increased by 3.6%, 69% and 83%, respectively.

A field experiment was conducted by Abbas *et al*. (2009) for two years, at Government Adaptive Research Farm Karor Lal Eason, District-Layyah, to study the effect of added zinc on growth and yield parameters, zinc uptake, soil zinc status and also the effect of added zinc in soil. Wheat variety Bhakkar-2002 was sown during Rabi season, with the recommended doses of N, P and K were applied @ 150: 100: 60 kg N: P_2O_5: K_2O ha^{-1} in all treatments. Zn was applied @, 4, 8, 12 and 16 kg ha^{-1} as zinc sulphate at the time of sowing in the all treatments except control (recommended NPK). Application of Zn increased its total uptake by wheat crop and also resulted in a built-up of Zn in the upper 15 cm layer to be available for next crop. Increasing the dose of Zn showed a little increase in the uptake of Manganese (Mn). The uptake of iron (Fe) increased by applying Zn upto 8 kg ha^{-1}, while high Zn doses resulted in reduced Fe uptake.

Jain and Dahama (2007) conducted field trials during the winter (rabi) seasons, 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 N, P, K and Zn uptake, and available zinc status after harvest.

In order to study the yield and yield contributing characters, zinc concentrations and its uptake by wheat, surface soils of six different locations of Bangladesh were collected and the experiment was performed by Shaheen *et al*. (2007) in pots in net house. The results obtained indicated the 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. 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.

A field experiment was conducted by Khan *et al*. (2007) on wheat to study the response of Zinc application in wheat-rice system. Two levels of zinc 5 and 10 kg ha^{-1} with control were studied with other nutrients. The concentration of zinc in soil and leaves was significantly affected by the application of zinc in wheat ranged from 0.47-1.37, 22.6-367.37 mg kg^{-1} in (soil and leaves). The highest concentration in soil and leaves was recorded by the cumulative application of 10 kg Zn ha^{-1} while lowest from control.

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.

Singh (2004) was carried out a field experiment on wheat during the rabi season 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 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.

Sundar and Choudhary (2002) reported that a pot experiment was carried out during rabi season to study the effect of P, Zn, and soil type on yield and its interaction effect on wheat (cv. Raj. 1555) nutrient uptake. Treatments consisted of Zn (0, 5, 10, and 15 kg ha^{-1} as zinc sulfate). The uptake of P, Zn, and Fe by grain and straw was significantly influenced due to P and Zn application and soil type. The uptake of these nutrients was higher with P and Zn application.

The above cited reviews revealed that zinc ferlilizer greatly affect the growth and as well as the yield and nutrients status of soil. But the literatures on the effects of foliar application of zinc on wheat have not been well defined and have no definite conclusion in these aspects under the agro climatic condition of Bangladesh.

CHAPTER III

MATERIALS AND METHODS

The experiment was conducted to find out the effect of foliar application of zinc on the growth and development of wheat. The details of the materials and methods i.e. location of experimental site, soil and climate condition of the experimental plot, materials used, design of the experiment, data collection and procedure of data analysis those were used or followed in this experiment have been presented below under the following headings:

3.1 Description of the experimental site

3.1.1 Experimental period

The experiment was conducted during the period from November 2014 to March 2015 in rabi season.

3.1.2 Site description

The present piece of research work was conducted in the experimental field of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka. The location of the site is $23^0 74^/$N latitude and $90^0 35^/$E longitude with an elevation of 8.2 meter from sea level.

3.1.3 Climatic condition

The climate of experimental site is subtropical, characterized by three distinct seasons, the rabi season from November to February and the pre-monsoon period or hot season from March to April and the monsoon period from May to October. The monthly average temperature, humidity and rainfall during the crop growing period were collected from Weather Yard, Bangladesh Meteorological Department, and presented in Appendix I. During the experimental period the maximum temperature (27.1^0C) was recorded from February, 2015 and the minimum temperature (12.4^0C) from January, 2015, highest relative humidity (78%) was observed from November, 2014, whereas the lowest relative humidity (67%) and highest rainfall (30 mm) was recorded in February, 2015.

3.1.4 Soil characteristics of the experimental plot

The soil of the experimental field belongs to the Tejgaon series under the Agroecological Zone, Madhupur Tract (AEZ- 28) and the General Soil Type is Deep Red Brown Terrace Soils. A composite sample was made by collecting soil from the field at a depth of 0-15 cm before the initiation of the experiment. The collected soil was air-dried, ground and passed through 2 mm sieve and analyzed for important physical and chemical parameters. The initial physical and chemical characteristics of soil are presented in the Table 1 and 2 (UNDP and FAO, 1988).

Table 1. Morphological characteristics of the experimental field

Morphology	Characteristics
Locality	SAU farm, Dhaka
Agro-ecological zone	Madhupur Tract (AEZ 28)
General Soil Type	Deep Red Brown Terrace Soil
Parent material	Madhupur Terrace
Topography	Fairly level
Drainage	Well drained
Flood level	Above flood level

Table 2. Initial physical and chemical characteristics of the soil (0-15 cm depth)

Characteristics	Value
Mechanical fractions:	
% Sand (2.0-0.02 mm)	18.60
% Silt (0.02-0.002 mm)	45.40
% Clay (<0.002 mm)	36.00
Textural class	Silty Loam
Consistency	Granular and friable when dry
pH (1: 2.5 soil- water)	5.8
Organic Matter (%)	1.187
Total N (%)	0.06
Exchangeable K (mmol kg^{-1})	0.12
Available P (mg kg^{-1})	19.85
Available S (mg kg^{-1})	14.40

3.2 Experimental details

3.2.1 Treatment of the experiment

The experiment comprised of the following treatments

T_0: Control (no zinc fertilizer)

T_1: Spraying of 0.02% Zn solution once in growing season

T_2: Spraying 0f 0.02% Zn solution twice in growing season

T_3: Spraying of 0.04% Zn solution once in growing season

T_4: Spraying of 0.04% Zn solution twice in growing season

T_5: Spraying of 0.06% Zn solution once in growing season

T_6: Spraying of 0.06% Zn solution twice in growing season

T_7: Application of Zn in the soil as per recommended dose (2.5 kg Zn/ha)

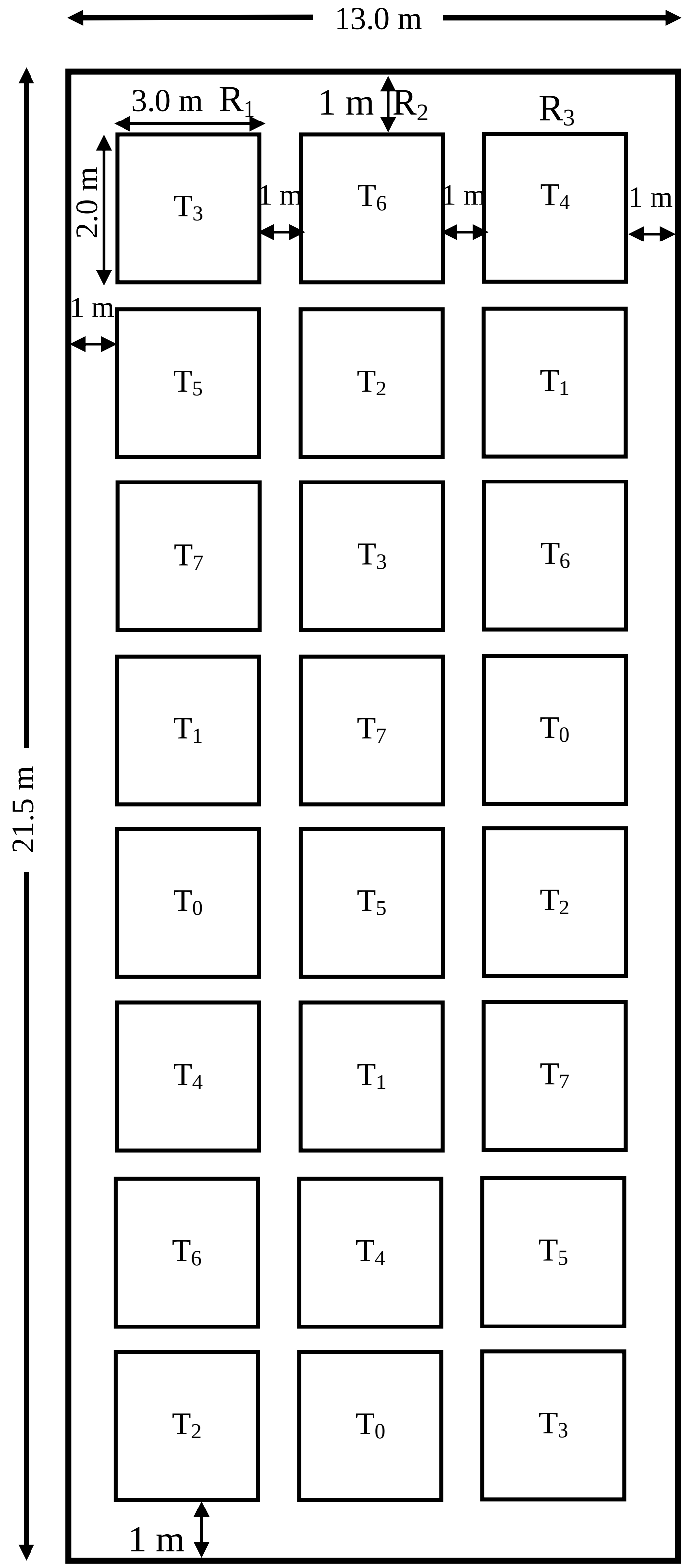
3.2.2 Experimental design and layout

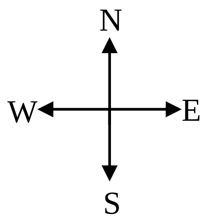
The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications, where the experimental area was divided into three blocks representing the replications to reduce soil heterogenetic effects. Each block was divided into 8 unit plots as treatments demarked with raised bunds. Thus the total numbers of plots were 24. The unit plot size was 3.0 m × 2.0 m. The distance maintained between two blocks and two plots were 1.0 m and 0.5 m, respectively. The layout of the experiment is shown in Figure 1.

3.3 Growing of crops

3.3.1 Seed collection

The seeds of wheat variety ‘BARI Gom 26’ were collected from Bangladesh Agricultural Research Institute (BARI), Joydevpur, Gazipur. The variety was released in 2010 as a high yielding variety (BARI, 2012). The variety was developed by Wheat Research Centre, BARI through crossing among 3 wheat variety imported from aboard and subsequently different selection process. After approval as a high yielding variety from the trial of different research centre and field condition it was released as BAW 1064.





Plot size: 3.0 m × 2.0 m

Plot spacing: 50 cm

Between replication: 1.0 m

<u>Treatment</u>

T_0: Control (no zinc fertilizer)

T_1: Spraying of 0.02% Zn solution once in growing season

T_2: Spraying 0f 0.02% Zn solution twice in growing season

T_3: Spraying of 0.04% Zn solution once in growing season

T_4: Spraying of 0.04% Zn solution twice in growing season

T_5: Spraying of 0.06% Zn solution once in growing season

T_6: Spraying of 0.06% Zn solution twice in growing season

T_7: Application of Zn in the soil as per recommended dose (2.5 kg Zn/ha)

Figure 1. Layout of the experimental plot

3.3.2 Preparation of the main field

The piece of land selected for the experiment was opened in the November 06, 2014 with a power tiller, and was exposed to the sun for a week after which the land was harrowed, ploughed and cross-ploughed several times followed by laddering to obtain a good tilth. Weeds and stubble were removed and finally a desirable tilth of soil was obtained for sowing of seeds. Fertilizers and manures as indicated below in 3.3.4 were mixed with the soil of plot.

3.3.3 Seeds sowing

Furrows were made for sowing the wheat seeds when the land was in proper joe condition and seeds were sown at 16 November, 2014. Seeds were sown continuously maintaining 20 cm line to line distance and plant to plant 5 cm. After sowing, seeds were covered with soil and slightly pressed by hand.

3.3.4 Application of fertilizers and manure

The fertilizers N, P, K, S and Zn in the form of Urea, TSP, MoP, Gypsum and Zinc, respectively were applied. Cowdung was applied 15 days before seeds sowing. The entire amount of TSP, MoP and Gypsum and 1/3rd of urea were applied at final land preparation. Rest of urea was top dressed in two splits after 1^{st} &2^{nd}irrigation at 21 &60days after sowing (DAS). Zinc Sulphate Monohydrate ($ZnSO_4.H_2O$) was used as a source of Zn. The mixture of 200 g Zn in 10 liter water called 0.02% Zn solution and similarly 400 g and 600 g Zn in 10 liter of water is called 0.04% and 0.06% Zn solution, respectively. 1^{st} and 2^{nd} foliar spraying of Zn solution was done at 30 DAS and 45 DAS, respectively as per treatment. The dose and method of application of fertilizers are presented below in Table 3 (BARI, 2014).

Table 3. Doses and method of application of fertilizers in wheat field

Fertilizers	Dose (per ha)
Cowdung	10 ton
Urea	220 kg
TSP	180 kg
MP	50 kg
Gypsum	120 kg
Zinc Sulphate Monohydrate	As per treatment

Source: BARI, 2014, Krishi Projukti Hatboi

3.3.5 After care

After the germination of seeds, various intercultural operations such as irrigation and drainage, weeding, top dressing of fertilizer and plant protection measures were accomplished for better growth and development of the wheat seedlings.

3.3.5.1 Irrigation and drainage

Three flood irrigations at early stage of crop growth (21 DAS), panicle initiation stage (60 DAS) and grain formation stage (80 DAS) were provided. Proper drainage system was also developed for draining out excess water.

3.3.5.2 Weeding

Weedings were done to keep the plots free from weeds which ultimately ensured better growth and development of wheat seedlings. The newly emerged weeds were uprooted carefully. The rotary weeder was used starting from 30 DAS, three times, an interval of 15 days. One manual weeding was taken up once at peak tillering stage to remove weeds around the clumps.

3.3.5.3 Plant protection

The crop was attacked by different kinds of insects during the growing period. Triel-20 ml was applied on 11 January and sumithion-40 ml/20 litre of water was applied on 31 January as plant protection measure. During the entire growing period the crop was observed carefully to take protection measures.

3.4 Harvesting, threshing and cleaning

The crop was harvested manually on 5^{th} March, 2015. The harvested crop of each plot was bundled separately, properly tagged and brought to threshing floor. Enough care was taken during threshing and cleaning period of wheat grain. Fresh weight of wheat grain and straw were recorded plot wise. The grains were dried, cleaned and weighed for individual plot. The weight was adjusted to a moisture content of 12%. Yields of wheat grain and straw per plot were recorded and converted to t ha^{-1} for estimation of per hectare yield of wheat.

3.5 Data collection

3.5.1 Plant height

The height of plant was recorded in centimeter (cm) at 40, 50, 60 and 70 DAS and at harvest as the average of 10 plants selected at random from the inner rows of each plot that were tagged earlier. The height was measured from the ground level to the tip of the plant by a meter scale.

3.5.2 Days to starting of ear emergence

Days to starting of ear emergence was recorded by calculating the number of days from sowing to starting of ear emergence by keen observation of the experimental plots during the experimental period.

3.5.3 Days to starting of maturity

Days to starting of maturity was recorded by calculating the number of days from sowing to starting of maturity as spikes become brown color by keen observation of the experimental plot.

3.5.4 Length of flag leaf

The length of flag leaf was measured as the average of 10 plants selected at random from the inner rows of each plot. The length was measured from the base to tip of the flag leaf.

3.5.5 Effective tillers plant^{-1}

The total number of effective tillers plant^{-1} was counted as the number of panicle bearing tillers plant^{-1}. Data on effective tillers plant^{-1} were counted from 10 selected plants at harvest and average value was recorded.

3.5.6 Non-effective tillers plant^{-1}

The total number of non-effective tillers plant^{-1} was counted as the number of tiller plant^{-1} without spike. Data on non-effective tillers plant^{-1} were counted from 10 selected plants at harvest and average value was recorded.

3.5.7 Total tillers plant^{-1}

The total number tillers plant^{-1} was recorded by adding effective and sterile tillers plant^{-1}. Data on total tillers plant^{-1} were counted from 10 selected plants at harvest and average value was recorded.

3.5.8 Ear length

The length of ear was measured with a meter scale from 10 selected panicles and the average value was recorded.

3.5.9 Spikelets spike^{-1}

The total number of spikelets spike^{-1} was counted as the number of spikelets from 10 randomly selected spikes from each plot and average value was recorded.

3.5.10 Fertile florets spikelet^{-1}

The number of fertile floret spikelet^{-1} was counted from 10 randomly selected spikelets from each plot and average value was recorded.

3.5.11 Filled grains spike^{-1}

The total number of filled grains spike^{-1} was counted as number of filled grains from 10 randomly selected spikes from each plot and average value was recorded.

3.5.12 Unfilled grains spike^{-1}

The total number of unfilled grains spike^{-1} was counted as number of unfilled grains from 10 randomly selected spikes from each plot and average value was recorded.

3.5.13 Total grains spike^{-1}

The total number of grains spike^{-1} was counted by adding number of filled and unfilled grains spike from each plot and average value was recorded.

3.5.14 Weight of 1000-seeds

One thousand seeds were counted randomly from the total cleaned harvested seeds of each individual plot and then weighed in grams and recorded.

3.5.15 Grain yield ha^{-1}

Grains obtained from each unit plot were sun-dried and weighed carefully. The dry weight of grains of each plot was used to record grain yield of each unit plot. Grains obtained from each unit plot were converted into t ha^{-1} grain yield.

3.5.16 Straw yield ha^{-1}

Straw obtained from each unit plot were sun-dried and weighed carefully. The dry weight of straws of each plot was used to record straw yield of each unit plot. Straw obtained from each unit plot were converted into t ha^{-1} straw yield.

3.5.17 Biological yield

Grain yield and straw yield together were regarded as biological yield of wheat. The biological yield was calculated with the following formula:

Biological yield = Grain yield + Straw yield.

3.5.18 Harvest index

Harvest index was calculated from per hectare grain and straw yield that were obtained from each unit plot and expressed in percentage.

$$HI = \frac{\text{Economic yield (grain weight)}}{\text{Biological yield (Total dry weight)}} \times 100$$

3.6 Chemical analysis of plant samples

3.6.1 Collection of plant samples

Grain and straw samples were collected after threshing and finely ground by using a Wiley-Mill with stainless contact points to pass through a 60-mesh sieve. The samples were stored in plastic vial for analyses of N, P, K, S and Zn.

3.6.2 Preparation of plant samples

The plant samples were dried in an oven at 70^0C for 72 hours and then ground by a grinding machine to pass through a 20-mesh sieve. The grain and straw samples were analyzed for determination of N, P, K, S and Zn concentrations as follows:

3.6.3 Digestion of plant samples with sulphuric acid for N

For the determination of nitrogen an amount of 0.2 g oven dry, ground sample were taken in a micro kjeldahl flask. 1.1 g catalyst mixture (K_2SO_4: $CuSO_4$. $5H_2O$: Se in the ratio of 100: 10: 1), and 5 ml conc. H_2SO_4 were added. The flasks were heating at 120^0C and added 2.5 ml 30% H_2O_2 then heated was continued at 180^0C until the digests became clear and colorless. After cooling, the content was taken into a 100 ml volumetric flask and the volume was made up to the mark with de-ionized water. A reagent blank was prepared in a similar manner. Nitrogen in the digest was estimated by distilling the digest with 10 N NaOH followed by titration of the distillate trapped in H_3BO_3 indicator solution with 0.01N H_2SO_4.

3.6.4 Digestion of plant samples with nitric-perchloric acid for P, K, S and Zn

A sub sample weighing 0.5 g was transferred into a dry, clean 100 ml digestion vessel. Ten ml of di-acid (HNO_3: $HClO_4$ in the ratio 2:1) mixture was added to the flask. After leaving for a while, the flasks were heated at a temperature slowly raised to 200^0C. Heating were stopped when the dense white fumes of $HClO_4$ occurred. The content of the flask were boiled until they became clean and colorless. After cooling, the content was taken into a 100 ml volumetric flask and the volume was made up to the mark with de-ionized water. P, K, S and Zn were determined from this digest.

3.6.5 Determination of P, K, S and Zn from plant samples

3.6.5.1 Phosphorus

Phosphorus in the digest was determined by using 1 ml for grain sample and 2 ml for straw sample from 100 ml extract was then determined by Vanado molybdate method and the color intensity were measured colorimetrically at 660 nm wavelength and readings were calibrated with the standard P curve (Page *et al*., 1982).

3.6.5.2 Potassium

Five milli-liter of digest sample for the grain and 10 ml for the straw were taken and diluted 50 ml volume to make desired concentration so that the absorbance of sample were measured within the range of standard solutions. The absorbance was measured by atomic absorption spectrometer.

3.6.5.3 Sulphur

Sulphur content was determined from the digest of the plant samples (grain and straw) with $CaCl_2$ (0.15%) solution as described by (Page *et al*., 1982). The digested S was determined by developing turbidity by adding acid seed solution (20 ppm S as K_2SO_4 in 6N HCl) and $BaCl_2$ crystals. The intensity of turbidity was measured by atomic absorption spectrophotometer at 420 nm wavelengths (Hunter, 1984).

3.6.5.4 Zinc

Zinc content was determined from the digest of the grain and straw samples by developing turbidity by adding $BaCl_2$ seed solution. The intensity of turbidity was measured by atomic absorption spectrophotometer at 420 nm wavelengths (Hunter, 1984).

3.7 Nutrient uptake

After chemical analysis of grain and straw samples the nutrient contents were calculated and from the value of nutrient contents, nutrient uptakes were also calculated by following formula:

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{Nutrient content (\%)} \times \text{Yield (kg ha}^{-1}\text{)}}{100}$$

3.8 Post harvest soil sampling

After harvest of crop, soil samples were collected from each plot at a depth of 0 to 15 cm. Soil samples of each plot was air-dried, crushed and passed through a two mm (10 meshes) sieve. The soil samples were kept in plastic container to determine the physical and chemical properties of soil.

3.9 Soil analysis

Soil samples were analyzed for both physical and chemical characteristics viz. pH, organic matter S, and Zn contents. The soil samples were analyzed by the following standard methods as follows:

3.9.1 Soil pH

Soil pH was measured with the help of a glass electrode pH meter, the soil water ratio being maintained at 1: 2.5 as described by Page *et al.*, 1982.

3.9.2 Organic matter

Organic carbon in soil sample was determined by wet oxidation method (Page *et al.*, 1982). The underlying principle was used to oxidize the organic matter with an excess of 1N $K_2Cr_20_7$ in presence of conc. H_2SO_4 and conc. H_3PO_4 and to titrate the excess $K_2Cr_20_7$ solution with 1N $FeSO_{4.}$ To obtain the content of organic matter was calculated by multiplying the percent organic carbon by 1.73 (Van Bemmelen factor) and the results were expressed in percentage.

3.9.3 Total nitrogen

Total N content of soil were determined followed by the Micro Kjeldahl method. One gram of oven dry ground soil sample was taken into micro kjeldahl flask to which 1.1 gm catalyst mixture (K_2SO_4: $CuSO_4$. $5H_2O$: Se in the ratio of 100:10:1), and 6 ml H_2SO_4 were added. The flasks were swirled and heated 200^0C and added 3 ml H_2O_2 and then heating at 360^0C was continued until the digest was clear and colorless. After cooling, the content was taken into 100 ml volumetric flask and the volume was made up to the mark with distilled water. A reagent blank was prepared in a similar manner. These digests were used for nitrogen determination (Page *et al.*, 1982).

Then 20 ml digest solution was transferred into the distillation flask, Then 10 ml of H_3BO_3 indicator solution was taken into a 250 ml conical flask which is marked to indicate a volume of 50 ml and placed the flask under the condenser outlet of the distillation apparatus so that the delivery end dipped in the acid. Add sufficient amount of 10N-NaOH solutions in the container connecting with distillation apparatus. Water runs through the condenser of distillation apparatus was checked. Operating switch of the distillation apparatus collected the distillate. The conical flask was removed by washing the delivery outlet of the distillation apparatus with distilled water. Finally the distillates were titrated with standard 0.01 N H_2SO_4 until the color changes from green to pink. The amount of N was calculated using the following formula:

$$\% N = (T-B) \times N \times 0.014 \times 100/S$$

Where,

T = Sample titration (ml) value of standard H_2SO_4

B = Blank titration (ml) value of standard H_2SO_4

N = Strength of H_2SO_4

S = Sample weight in gram

3.9.4 Available phosphorus

Available P was extracted from the soil with 0.5 M $NaHCO_3$ solutions, pH 8.5 (Olsen *et al.*, 1954). Phosphorus in the extract was then determined by developing blue color with reduction of phosphomolybdate complex and the color intensity were measured colorimetrically at 660 nm wavelength and readings were calibrated with the standard P curve (Page *et al*., 1982).

3.9.5 Exchangeable potassium

Exchangeable K was determined by 1N NH_4OAc (pH 7) extraction methods and by using flame photometer and calibrated with a standard curve (Page *et al*., 1982).

3.9.6 Available Zinc

Available Zn content was determined by developing turbidity by adding $ZnCl_2$ solution. The intensity of turbidity was measured by atomic absorption spectrophotometer at 420 nm wavelengths (Hunter, 1984).

3.10 Statistical Analysis

The data obtained for different characters were statistically analyzed using MSTAT software to observe the significant difference among the different treatments. The mean values of all the characters were calculated and analysis of variance was performed. The significance of the difference among the treatment means was estimated by the Duncan Multiple Range Test (DMRT) at 5% level of probability (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

The experiment was conducted to find out the effect of foliar application of zinc on the growth and development of wheat. Data on different yield contributing characters & yield, nutrient content in grain & straw, nutrient uptake by grain & straw and characteristics of post harvest soil was recorded. The analyses of variance (ANOVA) of the data on different parameters are presented in Appendix II-XI. The results have been presented and possible interpretations given under the following headings:

4.1 Yield contributing characters and yield of wheat

4.1.1 Plant height

Plant height of wheat showed statistically significant variation due to the foliar application of Zinc at 40, 50, 60, 70 DAS (days after sowing) and harvest (Appendix II). At 40, 50, 60, 70 DAS and harvest, the longest plant (44.96, 64.73, 79.82, 90.17 and 97.01 cm, respectively) was recorded from T_6 (Spraying of 0.06% Zn solution twice in growing season) which was statistically similar to other treatment except T_0 (control condition), at the same DAS, while the shortest plant (39.27, 53.87, 69.26, 76.42 and 81.17 cm, respectively) was observed from T_0 at 40, 50, 60, 70 DAS and harvest (Table 4). Plant height is a genetical character but different management practices influences it. From the data it was revealed that all the treatments produced significantly taller plants compared to the control treatment. Sultana *et al*. (2016) reported that foliar application of zinc gave the identical plant height with 0.04% and 0.06% foliar application of zinc. Ahmadi and David (2016) reported that 30 kg Zinc ha^{-1} gave the best results with respect to plant height 101.2 cm. Singh *et al*. (2015) observed that 7 kg ha^{-1} zinc was found superior over all other treatments in relation to plant height. Tiago *et al*. (2012) reported that foliar application of zinc has little effect on the agronomic characteristics of no-tilled crop with high nutrient content in soil.

Table 4. Effect of foliar application of zinc on plant height at different days after sowing (DAS) of wheat

Treatments	Plant height (cm) at				
	40 DAS	50 DAS	60 DAS	70 DAS	Harvest
T_0	39.27 b	53.87 b	69.26 b	76.42 b	81.17 b
T_1	42.38 ab	60.39 ab	76.03 a	86.68 a	92.23 a
T_2	42.33 ab	61.63 a	76.73 a	87.10 a	93.94 a
T_3	42.87 a	62.50 a	77.38 a	87.43 a	93.33 a
T_4	43.00 a	63.20 a	78.25 a	88.33 a	94.80 a
T_5	44.93 a	64.29 a	79.23 a	89.84 a	96.87 a
T_6	44.96 a	64.73 a	79.82 a	90.17 a	97.01 a
T_7	41.73 ab	59.37 ab	74.88 ab	83.73 a	90.31 a
$LSD_{(0.05)}$	3.190	6.315	5.879	7.071	8.482
Level of significance	0.05	0.05	0.05	0.05	0.05
CV(%)	4.27	5.89	7.39	4.68	5.24

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

T_0: Control (no zinc fertilizer)

T_1: Spraying of 0.02% Zn solution once in growing season

T_2: Spraying 0f 0.02% Zn solution twice in growing season

T_3: Spraying of 0.04% Zn solution once in growing season

T_4: Spraying of 0.04% Zn solution twice in growing season

T_5: Spraying of 0.06% Zn solution once in growing season

T_6: Spraying of 0.06% Zn solution twice in growing season

T_7: Application of Zn in the soil as per recommended dose (2.5 kg Zn/ha)

4.1.2 Days required for starting of ear emergence

Foliar application of Zinc showed statistically non-significant differences in terms of days required for starting of ear emergence of wheat (Appendix III). The maximum days required for starting of ear emergence (63.67) was observed from T_6, while the minimum days required for starting of ear emergence (61.00) was found from T_0 treatment (Table 5).

4.1.3 Days required for starting of maturity

Days required for starting of maturity of wheat showed statistically non-significant variation due to the foliar application of Zinc (Appendix III). The maximum days required for starting of maturity (91) was found from T_0, while the minimum days required for starting of maturity (82) was observed from T_6 treatment (Figure 2).

4.1.4 Number of effective tillers plant^{-1}

Statistically significant variation was recorded in terms of number of effective tillers plants^{-1} of wheat sdue to the foliar application of Zinc (Appendix III). The maximum number of effective tillers plants^{-1} (5.13) was attained from T_6 which was statistically similar (5.07, 5.00, 4.93, 4.77 and 4.73) to T_5, T_4, T_3, T_2 and T_1, respectively, while the minimum number of effective tillers plants^{-1} (3.87) was observed from T_0 which was statistically similar (4.20) to T_7 (Table 5). Tiago *et al*. (2012) reported that foliar application of zinc has little effect on the agronomic characteristics as number of effective tillers plant^{-1}.

4.1.5 Number of non-effective tillers plants^{-1}

Number of non-effective tillers plants^{-1} of wheat showed statistically significant variation due to the foliar application of Zinc (Appendix III). The maximum number of non-effective tillers plants^{-1} (0.27) was found from T_0 which was statistically similar (0.20 and 0.13) to T_5, T_6, T_4 and T_7, respectively, while the minimum number of non-effective tillers plants^{-1} (0.03) was observed from T_3 which was statistically similar (0.07 and 0.10) to T_1 and T_2 (Table 5). Similar findings also reported by Sultana *et al*. (2016) from their earlier experiment.

Table 5. Effect of foliar application of zinc on days required for starting of ear emergence, maturity and number of tillers plant^{-1} of wheat

Treatments	Days required for starting of ear emergence	Number of tillers plant^{-1}		
		Effective	Non-effective	Total
T_0	61.00	3.87 c	0.27 a	4.13 c
T_1	61.33	4.73 ab	0.07 bc	4.80 abc
T_2	62.00	4.77 ab	0.10 bc	4.87 ab
T_3	62.33	4.93 a	0.03 c	4.97 ab
T_4	62.67	5.00 a	0.13 abc	5.13 a
T_5	63.33	5.07 a	0.20 ab	5.27 a
T_6	63.67	5.13 a	0.20 ab	5.33 a
T_7	62.67	4.20 bc	0.13 abc	4.33 bc
$LSD_{(0.05)}$	--	0.619	0.124	0.646
Level of significance	NS	0.01	0.05	0.01
CV(%)	4.56	7.50	9.91	7.60

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

T_0: Control (no zinc fertilizer)

T_1: Spraying of 0.02% Zn solution once in growing season

T_2: Spraying 0f 0.02% Zn solution twice in growing season

T_3: Spraying of 0.04% Zn solution once in growing season

T_4: Spraying of 0.04% Zn solution twice in growing season

T_5: Spraying of 0.06% Zn solution once in growing season

T_6: Spraying of 0.06% Zn solution twice in growing season

T_7: Application of Zn in the soil as per recommended dose (2.5 kg Zn/ha)

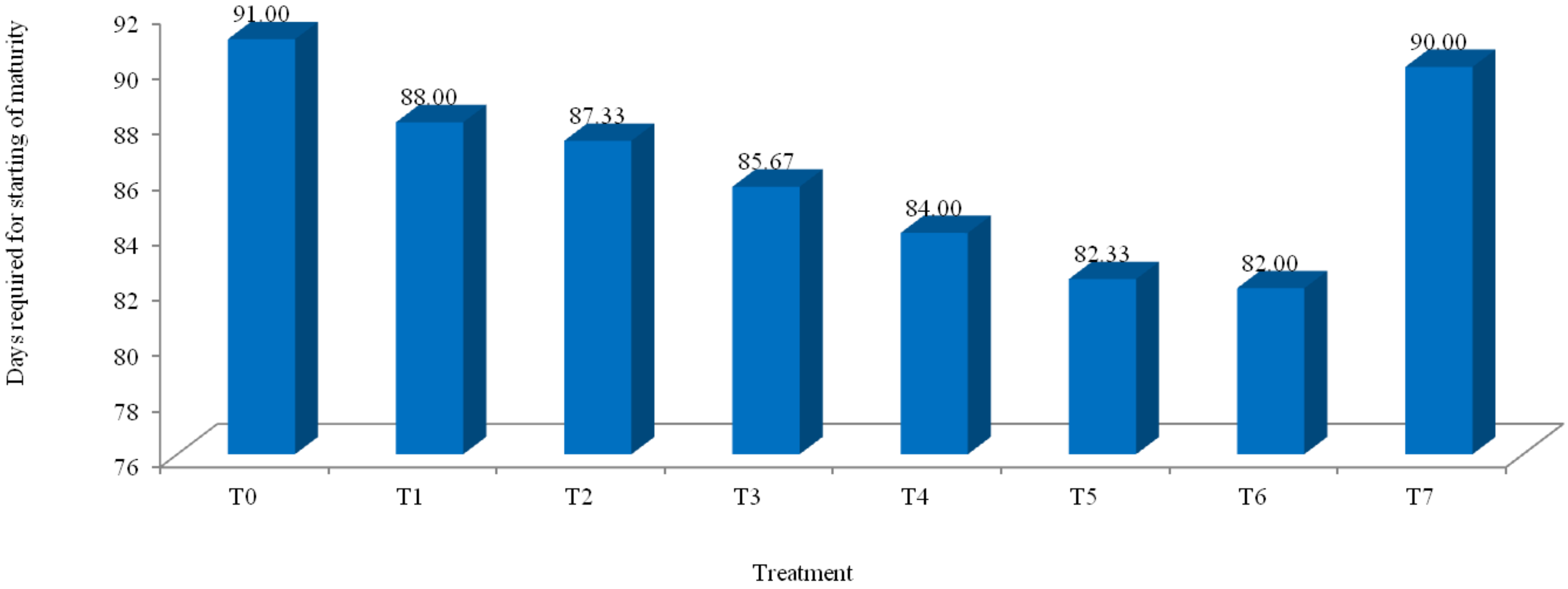


Figure 2. Effect of foliar application of zinc on days required for starting maturity of wheat

4.1.6 Number of total tillers plants^{-1}

Number of total tillers plants^{-1} of wheat showed statistically significant variation due to the foliar application of Zinc (Appendix III). The maximum number of total tillers plants^{-1} (5.33) was observed from T_6 which was statistically similar (5.27, 5.13, 4.97, 4.87 and 4.80) to T_5, T_4, T_3, T_2 and T_1, respectively, while the minimum number of total tillers plants^{-1} (4.13) was found from T_0 which was statistically similar (4.33) to T_7 (Table 5). Genc *et al.* (2006) reported that zinc sulphate increased the total number of fertile tillers m^{-2} of wheat.

4.1.7 Length of flag leaf

Length of flag leaf of wheat showed statistically significant variation due to the foliar application of Zinc (Appendix IV). The longest length of flag leaf (20.23 cm) was recorded from T_6 which was statistically similar with other treatments except T_0 and the shortest length of flag leaf (17.35 cm) was observed from T_0 (Table 6).

4.1.8 Ear length

Significant variation was recorded in terms of ear length wheat showed due to the foliar application of Zinc (Appendix IV). The longest ear (14.92 cm) was found from T_6 which was statistically similar with other treatments except T_0 and T_7 and the shortest ear (13.93 cm) was attained from T_0 which was statistically similar (14.06 cm) to T_7 (Table 6). Arshad *et al*. (2016) reported that Zn application had significantly increased wheat spike length (10.78 cm).

4.1.9 Number of spikelets spike^{-1}

Number of spikelets spike^{-1} of wheat showed statistically significant variation due to the foliar application of Zinc (Appendix IV). The maximum number of spikelets spike^{-1} (22.07) was found from T_6 which was statistically similar with other treatments except T_0 and T_7 and the minimum number of spikelets spike^{-1} (19.27) was observed from T_0 which was statistically similar (20.30) to T_7 (Table 6). Genc *et al.* (2006) reported that zinc sulphate increased the number of spikelets spike^{-1} of wheat.

Table 6. Effect of foliar application of zinc on length of flag leaf, ear length, spikelets spike^{-1} and fertile floret spikelet^{-1} of wheat

Treatments	Length of flag leaf (cm)	Ear length (cm)	Spikelets spike^{-1}	Fertile floret spikelet^{-1}
T_0	17.35 b	13.93 c	19.27 c	2.03 d
T_1	19.12 a	14.24 abc	20.80 abc	2.20 cd
T_2	19.33 a	14.41 abc	20.97 ab	2.38 bc
T_3	19.49 a	14.38 abc	21.17 ab	2.50 ab
T_4	19.78 a	14.66 ab	21.53 ab	2.64 ab
T_5	20.05 a	14.76 a	21.83 ab	2.69 a
T_6	20.23 a	14.92 a	22.07 a	2.74 a
T_7	18.79 a	14.06 bc	20.30 bc	2.13 cd
$LSD_{(0.05)}$	1.391	0.627	1.527	0.260
Level of significance	0.01	0.05	0.05	0.01
CV(%)	4.12	5.48	4.15	6.12

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

T_0: Control (no zinc fertilizer)

T_1: Spraying of 0.02% Zn solution once in growing season

T_2: Spraying 0f 0.02% Zn solution twice in growing season

T_3: Spraying of 0.04% Zn solution once in growing season

T_4: Spraying of 0.04% Zn solution twice in growing season

T_5: Spraying of 0.06% Zn solution once in growing season

T_6: Spraying of 0.06% Zn solution twice in growing season

T_7: Application of Zn in the soil as per recommended dose (2.5 kg Zn/ha)

4.1.10 Number of fertile floret spikelet^{-1}

Statistically significant variation was recorded in terms of number of fertile floret spikelets^{-1} of wheat due to the foliar application of Zinc (Appendix IV). The maximum number of fertile floret spikelets^{-1} (2.74) was observed from T_6 which was statistically similar (2.69, 2.64 and 2.50) with T_5, T_4 and T_3, while the minimum number of fertile floret spikelets^{-1} (2.03) was recorded from T_0 which was statistically similar (2.13 and 2.20) to T_7 and T_1 (Table 6).

4.1.11 Number of filled grains spike $^{-1}$

Number of filled grains spike^{-1} of wheat showed statistically significant variation due to the foliar application of Zinc (Appendix V). Data revealed that the maximum number of filled grains spike^{-1} (46.07) was recorded from T_6 which was statistically similar with other treatments except T_0, while the minimum number of filled grains spike^{-1} (40.43) was observed from T_0 (Table 7).

4.1.12 Number of unfilled grains spike $^{-1}$

Foliar application of Zinc varied significantly in terms of number of unfilled grains spike^{-1} of wheat (Appendix V). The maximum number of unfilled grains spike^{-1} (5.30) was found from T_0 which was statistically similar (4.80 and 4.63) with T_7 and T_2, whereas the minimum number of unfilled grains spike^{-1} (3.40) was observed from T_5 (Table 7).

4.1.13 Number of total grains spike $^{-1}$

Number of total grains spike^{-1} of wheat showed statistically significant variation due to the foliar application of Zinc (Appendix V). The maximum number of total grains spike^{-1} (50.20) was observed from T_6 which was statistically similar with other treatments except T_0 and T_1, while the minimum number of total grains spike^{-1} (45.73) was recorded from T_0 which was statistically similar (46.47) to T_1 (Table 7). Genc *et al.* (2006) reported that zinc sulphate increased the grain spike^{-1}, of wheat.

Table 7. Effect of foliar application of zinc on number of filled and unfilled grains spike^{-1} and weight of 1000-seeds of wheat

Treatments	Filled grains spike^{-1} (No.)	Unfilled grains spike^{-1} (No.)	Total grains spike^{-1} (No.)	Weight of 1000-seeds (g)
T_0	40.43 b	5.30 a	45.73 c	43.36 c
T_1	42.37 ab	4.10 bcd	46.47 bc	45.20 abc
T_2	43.90 ab	4.63 abc	48.53 abc	45.36 abc
T_3	45.13 a	4.03 bcd	49.17 ab	45.79 ab
T_4	45.27 a	3.67 cd	48.93 ab	46.22 ab
T_5	45.67 a	3.40 d	49.07 ab	46.87 a
T_6	46.07 a	4.13 bcd	50.20 a	46.92 a
T_7	42.37 ab	4.80 ab	47.17 abc	44.15 bc
$LSD_{(0.05)}$	3.340	0.907	2.803	2.111
Level of significance	0.05	0.01	0.05	0.05
CV(%)	4.34	12.15	3.32	4.65

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

T_0: Control (no zinc fertilizer)

T_1: Spraying of 0.02% Zn solution once in growing season

T_2: Spraying 0f 0.02% Zn solution twice in growing season

T_3: Spraying of 0.04% Zn solution once in growing season

T_4: Spraying of 0.04% Zn solution twice in growing season

T_5: Spraying of 0.06% Zn solution once in growing season

T_6: Spraying of 0.06% Zn solution twice in growing season

T_7: Application of Zn in the soil as per recommended dose (2.5 kg Zn/ha)

4.1.14 Weight of 1000-seeds

Statistically significant variation was recorded on weight of 1000-seeds of wheat due to the foliar application of Zinc (Appendix V). The highest weight of 1000-seeds (46.92 g) was recorded from T_6 which was statistically similar with other treatments except T_0 and T_7, while the lowest weight of 1000-seeds (43.15 g) was observed from T_0 which was statistically similar (44.15 g) to T_7 (Table 7). Genc *et al.* (2006) reported that zinc sulphate increased the thousand grain weight of wheat. Arshad *et al*. (2016) reported that Zn application had significantly increased wheat 1000 grains weight (49.36 g).

4.1.15 Grain yield

Grain yield of wheat varied significantly due to the foliar application of Zinc (Appendix VI). The highest grain yield (3.97 t ha^{-1}) was found from T_6 which was statistically similar with other treatments except T_0 and T_7, whereas the lowest grain yield (3.08 t ha^{-1}) was observed from T_0 which was statistically similar (3.32 t ha^{-1}) to T_7 (Table 8). Yield varied for different varieties might be due to genetical and environmental influences as well as management practices also. Application of Zn fertilizer ensured the suitable growth and development for wheat plant for that reasons highest yield was recorded than the control condition. Arshad *et al*. (2016) reported that Zn application had significantly increased wheat grain yield (4426 kg ha^{-1}). Sultana *et al.* (2016) reported that foliar application of zinc gave the identical yield with 0.04% and 0.06% foliar application of zinc.

4.1.16 Straw yield

Straw yield of wheat varied significantly due to the foliar application of Zinc (Appendix VI). The highest straw yield (5.10 t ha^{-1}) was observed from T_6 which was statistically similar with other treatments except T_0, T_7 and T_1, while the lowest straw yield (4.44 t ha^{-1}) was recorded from T_0 which was statistically similar (4.59 and 4.62 t ha^{-1}) to T_7 and T_1 (Table 8).

Table 8. Effect of foliar application of zinc on grain yield, straw yield and harvest index of wheat

Treatments	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
T_0	3.08 c	4.44 d	40.94
T_1	3.55 ab	4.62 bcd	43.36
T_2	3.62 ab	4.82 abcd	42.91
T_3	3.77 a	4.87 abc	43.61
T_4	3.85 a	4.92 abc	43.89
T_5	3.91 a	5.03 ab	43.72
T_6	3.97 a	5.10 a	43.78
T_7	3.32 bc	4.59 cd	41.99
$LSD_{(0.05)}$	0.388	0.384	--
Level of significance	0.01	0.05	NS
CV(%)	6.08	4.59	4.43

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

T_0: Control (no zinc fertilizer)

T_1: Spraying of 0.02% Zn solution once in growing season

T_2: Spraying 0f 0.02% Zn solution twice in growing season

T_3: Spraying of 0.04% Zn solution once in growing season

T_4: Spraying of 0.04% Zn solution twice in growing season

T_5: Spraying of 0.06% Zn solution once in growing season

T_6: Spraying of 0.06% Zn solution twice in growing season

T_7: Application of Zn in the soil as per recommended dose (2.5 kg Zn/ha)

4.1.17 Biological yield

Statistically significant variation was recorded in terms of biological yield of wheat due to the foliar application of Zinc (Appendix VI). The highest biological yield (9.07 t ha^{-1}) was recorded from T_6 which was statistically similar (8.94, 8.78 and 8.63 t ha^{-1}) to T_5, T_4 and T_3, whereas the lowest biological yield (7.52 t ha^{-1}) was observed from T_0 which was statistically similar (7.91 t ha^{-1}) to T_7 (Figure 3). Management practices influenced biological yield although it was governed by genetical and environmental influences. Genc *et al.* (2006) reported that zinc sulphate increased the biological yield of wheat.

4.1.18 Harvest index

Harvest index of wheat varied non-significantly due to the foliar application of Zinc (Appendix VI). The highest harvest index (43.89%) was recorded from T_4 and the lowest harvest index (40.94%) was found from T_0 (Table 8). Data revealed that the control condition provided lowest harvest index.

4.2 N, P, K, Zn concentration in grain and straw

4.2.1 N, P, K and Zn concentration in grain

Statistically non-significant variation was recorded for N, P and K concentration in grain of wheat and significant variation was observed for Zn concentration in grain due to the foliar application of Zinc (Appendix VII). The maximum concentration in grain for N (0.688%), P (0.271%) and K (0.355%) were observed from T_7, whereas the minimum concentration in grain for N (0.630%), P (0.235%) and K (0.334%) were recorded from T_0 (Table 9). In case of Zn concentration in grain, the maximum concentration of Zn was recorded in T_7 (0.0064%) which was statistically similar with T_6 (0.0050%), T_5 (0.0050%), T_4 (0.0049%), T_3 (0.0047%) and T_2 (0.0046%), while the minimum concentration was observed in T_0 (0.0024%) which was followed by T_1 (0.0044%). Singh *et al*. (2013) reported that application of 22.5 kg Zn/ha gave significantly higher Zn content in grain.

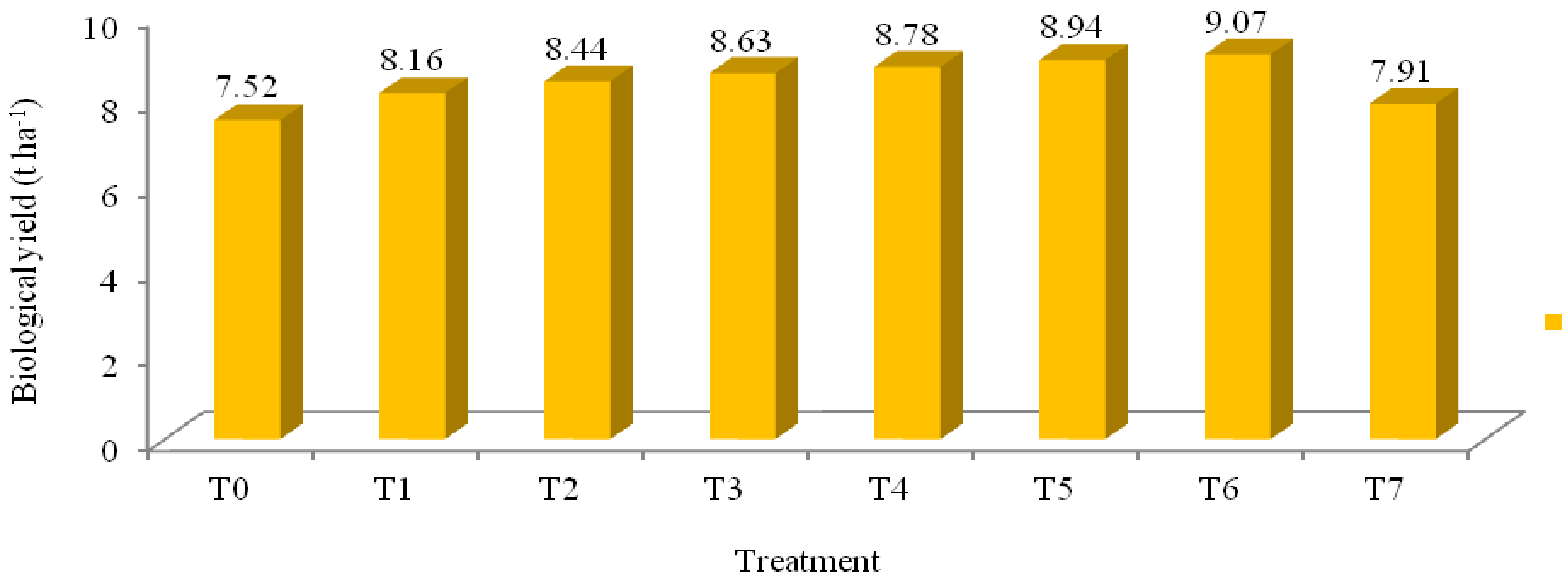


Figure 3. Effect of foliar application of zinc on biological yield of wheat

Table 9. Effect of foliar application of zinc on N, P, K and Zn concentrations in grain of wheat

Treatments	Concentration (%) in grain			
	N	P	K	Zn
T_0	0.630	0.235	0.334	0.0024 c
T_1	0.639	0.249	0.335	0.0044 b
T_2	0.668	0.250	0.339	0.0046 ab
T_3	0.637	0.247	0.344	0.0047 ab
T_4	0.657	0.255	0.351	0.0049 ab
T_5	0.681	0.262	0.338	0.0050 ab
T_6	0.680	0.267	0.354	0.0050 ab
T_7	0.688	0.271	0.355	0.0064 a
$LSD_{(0.05)}$	--	--	--	0.0018
Level of significance	NS	NS	NS	0.01
CV(%)	4.71	6.45	3.17	3.85

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

T_0: Control (no zinc fertilizer)

T_1: Spraying of 0.02% Zn solution once in growing season

T_2: Spraying 0f 0.02% Zn solution twice in growing season

T_3: Spraying of 0.04% Zn solution once in growing season

T_4: Spraying of 0.04% Zn solution twice in growing season

T_5: Spraying of 0.06% Zn solution once in growing season

T_6: Spraying of 0.06% Zn solution twice in growing season

T_7: Application of Zn in the soil as per recommended dose (2.5 kg Zn/ha)

4.2.2 N, P, K and Zn concentration in straw

Statistically non-significant variation was recorded for N, P and K concentration in straw of wheat and significant variation was observed for Zn concentration in straw due to the foliar application of Zinc (Appendix VIII). The maximum concentration in straw for N (0.446%), P (0.077%) and K (1.178%) were recorded from T_7, while the minimum concentration in straw for N (0.412%), P (0.074%), K (1.043%) was recorded from T_0 (Table 10). But for Zn concentration in straw, the maximum concentration of Zn was recorded in T_7 (0.0071%) which was statistically similar with T_6 (0.0061%), T_5 (0.0059%), T_4 (0.0056%) and T_3 (0.0054%), while the minimum concentration was recorded in T_0 (0.0031%) which was followed by T_1 (0.0049%) and T_2 (0.0051%) and they were statistically similar.

4.3 N, P, K and Zn uptake by grain and straw

4.3.1 N, P, K and Zn uptake by grain

N, P and K and Zn uptake by grain varied significantly due to the foliar application of Zinc (Appendix IX). The maximum uptake by grain for N (27.02 kg ha^{-1}), P (10.62 kg ha^{-1}) and K (14.07 kg ha^{-1}) were found from T_5 but the maximum uptake of Zn (0.214 kg ha^{-1}) were recorded from $T_{7,}$ while the minimum uptake by grain for N (19.40 kg ha^{-1}), P (7.66 kg ha^{-1}), K (10.29 kg ha^{-1}) and Zn (0.073 kg ha^{-1}) were found from T_0 (Table 11). Singh *et al*. (2013) reported that application of 22.5 kg Zn/ha gave significantly higher Zn uptake by grain.

4.3.2 N, P, K and Zn uptake by straw

Significant variation was recorded for N, P and K and Zn uptake by straw due to the foliar application of Zinc (Appendix X). The maximum uptake by straw for N (22.34 kg ha^{-1}), P (3.84 kg ha^{-1}) and K (59.18 kg ha^{-1}) were found from $T_{6,}$ whereas the maximum uptake of Zn (0.327 kg ha^{-1}) were recorded from T_7, while the minimum uptake by straw for N (18.32 kg ha^{-1}), P (3.30 kg ha^{-1}), K (48.33 kg ha^{-1}) and Zn (0.138 kg ha^{-1}) from T_0 (Table 12).

Table 10. Effect of foliar application of zinc on N, P, K and Zn concentrations in straw of wheat

Treatments	Concentration (%) in straw			
	N	P	K	Zn
T_0	0.412	0.074	1.043	0.0031 c
T_1	0.431	0.071	1.069	0.0049 b
T_2	0.444	0.075	1.070	0.0051 b
T_3	0.423	0.074	1.063	0.0054 ab
T_4	0.431	0.074	1.125	0.0056 ab
T_5	0.426	0.075	1.088	0.0059 ab
T_6	0.444	0.076	1.071	0.0061 ab
T_7	0.446	0.077	1.178	0.0071 a
$LSD_{(0.05)}$	--	--	--	0.0018
Level of significance	NS	NS	NS	0.05
CV(%)	5.54	4.63	5.65	3.78

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

T_0: Control (no zinc fertilizer)

T_1: Spraying of 0.02% Zn solution once in growing season

T_2: Spraying 0f 0.02% Zn solution twice in growing season

T_3: Spraying of 0.04% Zn solution once in growing season

T_4: Spraying of 0.04% Zn solution twice in growing season

T_5: Spraying of 0.06% Zn solution once in growing season

T_6: Spraying of 0.06% Zn solution twice in growing season

T_7: Application of Zn in the soil as per recommended dose (2.5 kg Zn/ha)

Table 11. Effect of foliar application of zinc on N, P, K and Zn uptake by grain of wheat

Treatments	Uptake by grain (kg ha^{-1})			
	N	P	K	Zn
T_0	19.40 c	7.66 c	10.29 e	0.073 f
T_1	22.80 bc	8.41 bc	11.88 cd	0.155 e
T_2	24.20 ab	9.05 abc	12.28 bcd	0.165 de
T_3	23.99 ab	9.32 abc	12.98 abc	0.176 cd
T_4	25.34 ab	9.84 ab	13.53 ab	0.188 bc
T_5	27.02 a	10.62 a	14.07 a	0.197 ab
T_6	26.57 ab	10.57 a	13.88 a	0.197 ab
T_7	22.86 bc	8.70 bc	11.24 de	0.214 a
$LSD_{(0.05)}$	3.708	1.694	1.378	0.018
Level of significance	0.01	0.05	0.01	0.01
CV(%)	8.81	10.44	6.29	7.90

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

T_0: Control (no zinc fertilizer)

T_1: Spraying of 0.02% Zn solution once in growing season

T_2: Spraying 0f 0.02% Zn solution twice in growing season

T_3: Spraying of 0.04% Zn solution once in growing season

T_4: Spraying of 0.04% Zn solution twice in growing season

T_5: Spraying of 0.06% Zn solution once in growing season

T_6: Spraying of 0.06% Zn solution twice in growing season

T_7: Application of Zn in the soil as per recommended dose (2.5 kg Zn/ha)

Table 12. Effect of foliar application of zinc on N, P, K and Zn uptake by straw of wheat

Treatments	Uptake by straw (kg ha^{-1})			
	N	P	K	Zn
T_0	18.32 b	3.30 b	48.33 c	0.138 f
T_1	19.89 ab	3.25 b	49.36 bc	0.226 e
T_2	21.51 a	3.60 ab	51.55 bc	0.247 d
T_3	20.54 ab	3.60 ab	51.68 bc	0.261 cd
T_4	21.24 a	3.65 ab	55.35 ab	0.277 c
T_5	21.71 a	3.80 a	53.16 abc	0.300 b
T_6	22.34 a	3.84 a	59.18 a	0.305 b
T_7	20.45 ab	3.51 ab	49.25 bc	0.327 a
$LSD_{(0.05)}$	2.216	0.367	5.875	0.018
Level of significance	0.05	0.05	0.05	0.01
CV(%)	6.10	5.88	6.42	6.23

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

T_0: Control (no zinc fertilizer)

T_1: Spraying of 0.02% Zn solution once in growing season

T_2: Spraying 0f 0.02% Zn solution twice in growing season

T_3: Spraying of 0.04% Zn solution once in growing season

T_4: Spraying of 0.04% Zn solution twice in growing season

T_5: Spraying of 0.06% Zn solution once in growing season

T_6: Spraying of 0.06% Zn solution twice in growing season

T_7: Application of Zn in the soil as per recommended dose (2.5 kg Zn/ha)

4.4 pH, organic matter and total N, available P, exchangeable K and available Zn in post harvest soil

4.4.1 pH

Statistically non-significant variation was recorded for pH in post harvest soil due to the foliar application of Zinc (Appendix XI). The highest pH of post harvest soil (5.95) was found from T_2 and the lowest pH in post harvest soil (5.80) was observed from T_4 (Table 13). Keram *et al*. (2012) reported that there is no appraisal change in soil pH due to rational Zn fertilization.

4.4.2 Organic matter

Statistically non-significant variation was observed for organic matter in post harvest soil due to the foliar application of Zinc (Appendix XI). The highest organic matter of post harvest soil (1.260%) was found from T_6 and the lowest organic matter in post harvest soil (1.200%) was recorded from T_4 (Figure 4).

4.4.3 Total N

Total N in post harvest soil showed statistically non-significant variation due to the foliar application of Zinc (Appendix XI). The highest total N of post harvest soil (0.043%) was found from T_1 and the lowest total N in post harvest soil (0.040%) was found from T_2 (Figure 5). Bameri *et al*. (2012) reported that root growth in wheat was improved by spraying micronutrients which led to increase in uptake of macro and micronutrients.

4.4.4 Available P

Statistically non-significant variation was recorded for available P in post harvest soil due to the foliar application of Zinc (Appendix XI). The highest available P of post harvest soil (23.89 ppm) was observed from T_0 and the lowest available P in post harvest soil (22.36 ppm) was found from T_4 (Table 13).

Table 13. Effect of foliar application of zinc on the nutrient content of post harvest soil

Treatments	pH	Available P (ppm)	Exchangeable K (me %)	Available Zn (ppm)
T_0	5.83	23.89	0.144 b	2.01 c
T_1	5.92	23.03	0.142 b	3.07 b
T_2	5.95	23.66	0.141 b	3.09 b
T_3	5.87	22.48	0.146 b	3.10 b
T_4	5.80	22.36	0.145 b	3.11 b
T_5	5.85	23.26	0.142 b	3.12 b
T_6	5.85	22.42	0.143 b	3.29 b
T_7	5.90	23.05	0.154 a	3.53 a
$LSD_{(0.05)}$	--	--	0.006	0.222
Level of significance	NS	NS	0.01	0.01
CV(%)	2.61	3.43	1.97	3.97

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

T_0: Control (no zinc fertilizer)

T_1: Spraying of 0.02% Zn solution once in growing season

T_2: Spraying 0f 0.02% Zn solution twice in growing season

T_3: Spraying of 0.04% Zn solution once in growing season

T_4: Spraying of 0.04% Zn solution twice in growing season

T_5: Spraying of 0.06% Zn solution once in growing season

T_6: Spraying of 0.06% Zn solution twice in growing season

T_7: Application of Zn in the soil as per recommended dose (2.5 kg Zn/ha)

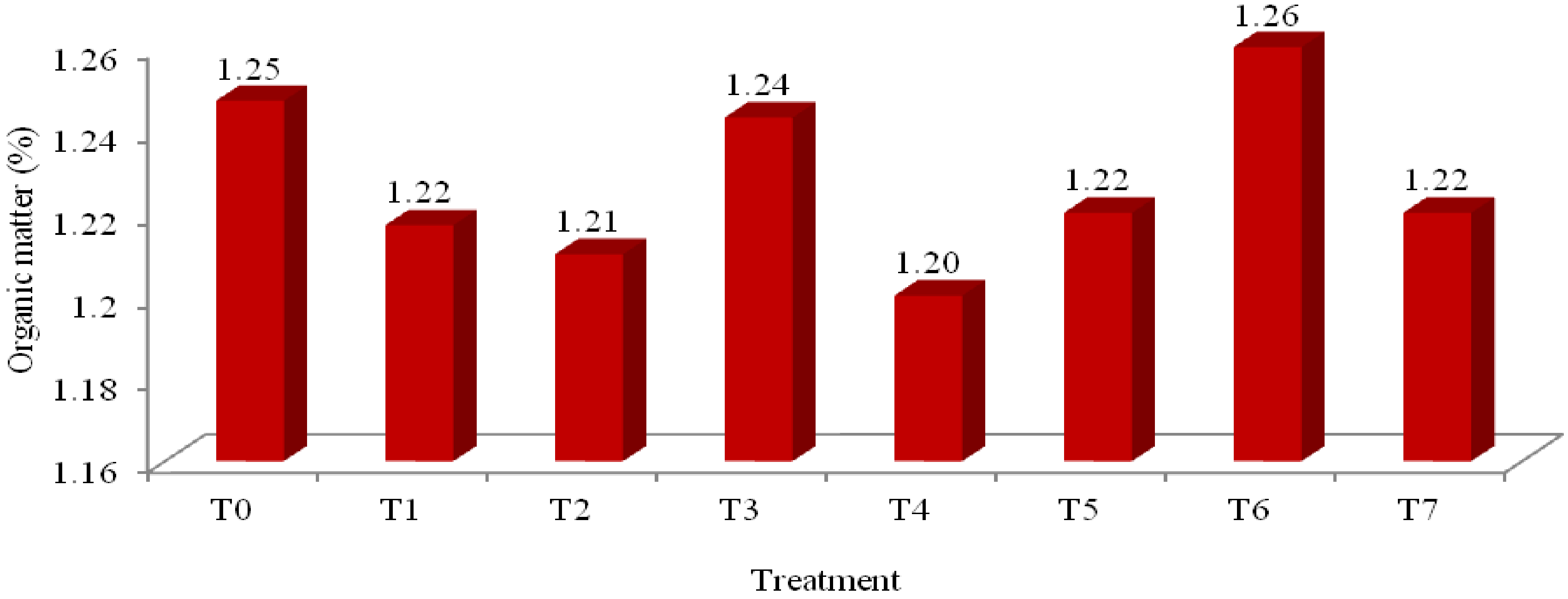


Figure 4. Effect of foliar application of zinc on organic matter content in post harvest soil of wheat

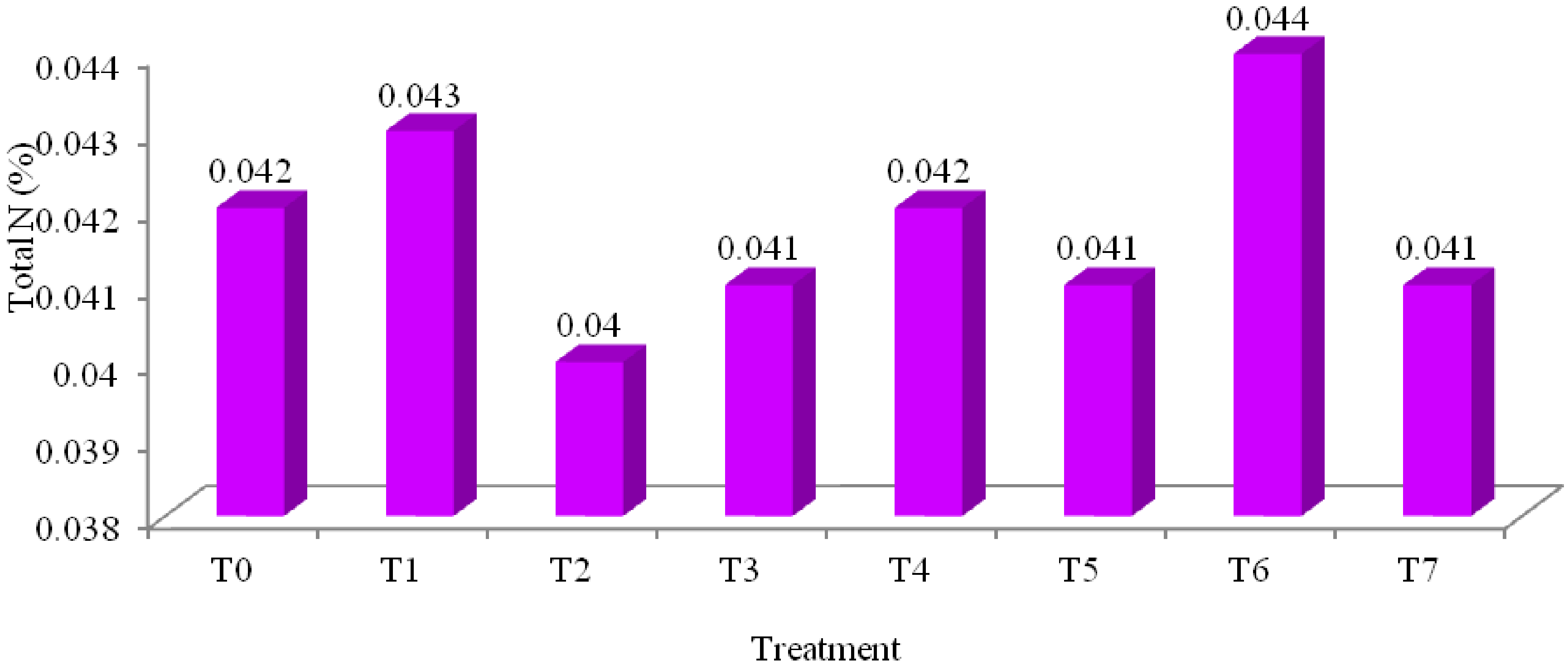


Figure 5. Effect of foliar application of zinc on total N in post harvest soil of wheat

4.4.5 Exchangeable K

Statistically significant variation was recorded for exchangeable K in post harvest soil due to the foliar application of Zinc (Appendix XI). The highest exchangeable K of post harvest soil (0.154 me%) was found from T_7, while the lowest exchangeable K in post harvest soil (0.141 me%) was observed from T_2 which was statistically similar with other treatments except T_7 (Table 13).

4.4.6 Available Zn

Available Zn in post harvest soil showed statistically significant variation due to the foliar application of Zinc (Appendix XI). The highest available Zn of post harvest soil (3.53 ppm) was found from T_7 which was closely followed by the other treatments except T_0, whereas the lowest available Zn in post harvest soil (2.01 ppm) was observed from T_0 which was statistically different from all other treatments (Table 13). Bameri *et al*. (2012) reported that root growth in wheat was improved by spraying micronutrients which led to increase in uptake of macro and micronutrients. Jain and Dahama (2007) observed that zinc interaction had significant effect on available zinc status after harvest.

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was conducted during the period from November 2014 to March 2015 in rabi season in the experimental field of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka to find out the effect of foliar application of zinc on the growth and development of wheat. The seeds of wheat variety 'BARI Gom 26' were used as test crop. The experiment comprised of the following treatments- T_0: Control (no zinc fertilizer), T_1: Spraying of 0.02% Zn solution once in growing season, T_2: Spraying 0f 0.02% Zn solution twice in growing season, T_3: Spraying of 0.04% Zn solution once in growing season, T_4: Spraying of 0.04% Zn solution twice in growing season, T_5: Spraying of 0.06% Zn solution once in growing season, T_6: Spraying of 0.06% Zn solution twice in growing season and T_7: Application of Zn in the soil as per recommended dose (2.5 kg Zn/ha). The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Data on different yield contributing characters & yield, nutrient content in grain & straw, nutrient uptake by grain & straw and characteristics of post harvest soil was recorded and variation was observed for most o the characters.

At 40, 50, 60, 70 DAS and harvest, the longest plant (44.96, 64.73, 79.82, 90.17 and 97.01 cm, respectively) was recorded from T_6, while the shortest plant (39.27, 53.87, 69.26, 79.42 and 81.17 cm, respectively) was observed from T_0. The maximum days required for starting of ear emergence (63.67) was observed from T_6, while the minimum days (61.00) was found from T_0. The maximum days required for starting of maturity (110.33) was found from T_6, while the minimum days (104.33) was observed from T_0. The maximum number of effective tillers plants^{-1} (5.13) was attained from T_6, while the minimum number (3.87) was observed from T_0. The maximum number of non-effective tillers plants^{-1} (0.27) was found from T_0, while the minimum number (0.03) was observed from T_3. The maximum number of total tillers plants^{-1} (5.33) was observed from T_6, while the minimum number (4.13) was found from T_0. The longest length of flag leaf (20.23 cm) was recorded from T_6 and the shortest length of flag leaf (17.35 cm) was observed from T_0. The longest ear (14.92 cm) was found from T_6 and the shortest ear (13.93 cm) from T_0. The maximum number of spikelets spike^{-1} (22.07) was found from T_6 and the minimum number (19.27) was observed from T_0. The maximum number of fertile floret spikelets^{-1} (2.74) was observed from T_6, while the minimum number (2.03) was recorded from T_0. The maximum number of filled grains spike^{-1} (46.07) was recorded from T_6, while the minimum (40.43) was observed from T_0. The maximum number of unfilled grains spike^{-1} (5.30) was found from T_0, whereas the minimum number (3.40) was observed from T_5. The maximum number of total grains spike^{-1} (50.20) was observed from T_6, while the minimum number (45.73) was recorded from T_0. The highest weight of 1000-seeds (46.92 g) was recorded from T_6, while the lowest weight (43.15 g) was observed from T_0. The highest grain yield (3.97 t ha^{-1}) was found from T_6, whereas the lowest (3.08 t ha^{-1}) was observed from T_0. The highest straw yield (5.10 t ha^{-1}) was observed from T_6, while the lowest (4.44 t ha^{-1}) was recorded from T_0. The highest biological yield (9.07 t ha^{-1}) was recorded from T_6, whereas the lowest (7.52 t ha^{-1}) was observed from T_0. The highest harvest index (43.89%) was recorded from T_4 and the lowest harvest index (40.94%) was found from T_0.

The maximum concentration in grain for N (0.688%), P (0.271%), K (0.355%) and Zn (0.0064%) were observed from T_7, whereas the minimum concentration in grain for N (0.630%), P (0.235%), K (0.334%) and Zn (0.0024%) were recorded from T_0. The maximum concentration in straw for N (0.446%), P (0.077%), K (1.178%) and Zn (0.0071%) were recorded from T_7, while the minimum concentration in straw for N (0.412%), P (0.074%), K (1.043%) and Zn (0.0031%) were observed from T_0. The maximum uptake by grain for N (27.02 kg ha^{-1}), P (10.62 kg ha^{-1}) and K (14.07 kg ha^{-1}) were found from T_5 but the maximum uptake of Zn (0.214 kg ha^{-1}) were recorded from $T_{7,}$ while the minimum uptake by grain for N (19.40 kg ha^{-1}), P (7.66 kg ha^{-1}), K (10.29 kg ha^{-1})

and Zn (0.073 kg ha^{-1}) were found from T_0. The maximum uptake by straw for N (22.34 kg ha^{-1}), P (3.84 kg ha^{-1}) and K (59.18 kg ha^{-1}) were found from T_6, whereas the maximum uptake of Zn (0.327 kg ha^{-1}) were recorded from T_7, while the minimum uptake by straw for N (18.32 kg ha^{-1}), P (3.30 kg ha^{-1}), K (48.33 kg ha^{-1}) and Zn (0.249 kg ha^{-1}) from T_0.

The highest pH of post harvest soil (5.95) was found from T_2 and the lowest (5.80) was observed from T_4. The highest organic matter of post harvest soil (1.260%) was found from T_6 and the lowest (1.200%) was recorded from T_4. The highest total N of post harvest soil (0.043%) was found from T_1 and the lowest (0.040%) was found from T_2. The highest available P of post harvest soil (23.89 ppm) was observed from T_0 and the lowest (22.36 ppm) was found from T_4). The highest exchangeable K of post harvest soil (0.154 me %) was found from T_7, while the lowest (0.141 me %) was observed from T_2. The highest available Zn of post harvest soil (3.53 ppm) was found from T_7, whereas the lowest (2.01 ppm) was observed from T_0.

Conclusion

Among the different foliar spray of Zn, spraying of 0.06% Zn solution twice in growing season induced superior growth, yield contributing characters, yield of wheat.

Considering the situation of the present experiment, further studies in the following areas may be suggested:

1. Another micro and macro nutrients with different doses and other management practices may be used in future study.

2. Another higher level of Zn needs to be considered in different agro-ecological zones of Bangladesh for regional trial before final recommendation.

REFERENCES

Abbas, G., Khan, M.Q., Jamil, M., Tahir, M. and Hussain, F. (2009). Nutrient uptake, growth and yield of wheat (*Triticum aestivum*) as affected by zinc application rates. *Intl. J. Agric. Biol.*, **11**(4): 389-396.

Ahmadi, S.A. and David, A.A. (2016). Effect of nitrogen and zinc on yield of wheat (*Triticum aestivum* L.). *Intl. J. Multidisciplinary Res. & Dev.*, **3**(5): 291-293.

Ali, S., Khan, A.R., Mairaj, G., Arif, M., Fida, M. and Bibi, S. (2008). Assessment of Different Crop Nutrients Management Practices for Improvement of Crop Yield. *Australian J. Crop Sci.*, **2**: 150-157.

Ananda, N., Patil, B.N. (2007). Effect of zinc, iron and split application of nitrogen on growth, yield of durum wheat (*Triticum durum* Desf.) and on available nutrient status in soil. Department of Agronomy, College of Agriculture, Dharwad -580 005 (Kamataka), India. Hisar, India: *Gaurav Soc. Agri. Res. Info.*, **8**(3): 515-519.

Anonymous. (2008). Statistical year book of Bangladesh-2006. Bangladesh Bureau of Statistics, Planning Division, Ministry of Planning, Government of the People’s Republic of Bangladesh. www.bbs.gov.bd (4 November 2012).

Arif, M., Chohan, M.A., Ali, S., Gul, R. and Khan, S. (2006). Response of wheat to foliar application of nutrients. *J. Agric. Biol. Sci.* **1**: 30-34.

Arshad, M., Adnan, M., Ahmed, S., Khan, A.K., Ali, I., Ali, M., Ali, A., Khan, A., Kamal, M.A., Gul, F. and Khan, M.A. (2016). Integrated Effect of Phosphorus and Zinc on Wheat Crop. *American-Eurasian J. Agric. & Environ. Sci.*, **16**(3): 455-459.

Bameri, M., Abdolshahi, R., Mohammadi-Nejad, G., Yousefi, K. and Tabatabaie, S.M. (2012). Effect of Different Microelement Treatment on Wheat (*Triticum aestivum*) Growth and Yield. *International Research Journal of Basic and Applied Science*s, **3**: 219-223.

BARI (Bangladesh Agricultural Research Institute). (2010). Wheat production in Bangladesh: a success story. ttp://www.bari.gov. bd/index.

BARI (Bangladesh Agricultural Research Institute). (2012). Wheat varieties released by Bangladesh Agricultural Research Institute. http://www.bari. gov.bd/index.

BARI (Bangladesh Agricultural Research Institute). (2014). Krishi Projukti Hat Boi. BARI. Joydevpur, Gazipur. p. 18.

BARI. (1997). Increase wheat cultivation and decrease irrigation cost (A folder in Bengali). Wheat Res. Centre. Bangladesh Agril. Res. Inst. Nashipur, Dinajpur. p. 12-15.

BBS (Bangladesh Bureau of Statistics). (2014). Yearly Statistical Book. Bangladesh Bureau of Statistics, Dhaka Bangladesh. 153 p.

Boorboori, M.R., Eradatmand Asli, D. and Tehrani, M. (2012) The Effect of Dose and Different Methods of Iron, Zinc, Manganese and Copper Application on Yield Components, Morphological Traits and Grain Protein Percentage of Barley Plant (*Hordeum vulgare* L.) in Greenhouse Conditions. *J. Adv. Env. Biol.*, **6**: 740-746.

Brown, P.H., Cakmak, I. and Zhang, Q. (1993). Form and function of zinc in plants. Kluwar Academic Publishers. Dordecht, the Netherlands. Robson (Ed). pp. 93-16.

Cakmak, I. (2008). Enrichment of cereal grains with zinc: Agronomic or genetic biofortification? *Plant Soil.* **302:** 1–17.

Cakmak, I., Chohan, M.A. and Omheld, V.R. (1997). Zinc deficiency induced impairments of cellular functions in plants. *Plant Soil.* **193:** 71–83.

Cao, Y., Tian, X., Yang, X, Lu, X., Chen, H., Nan, X. and Li, X. (2010). Effects of soil and foliar applications of Zn on winter wheat grain Zn concentration and bioavailability. *Acta Metallurgica Sinica*, **16**(6): 1394-1401.

Chandrakumar, K., Halepyati, A.S., Desai, B.K. and Pujari, B.T. (2004). Influence of organics, macro, micronutrients and methods of application on yield and yield attributes of wheat under irrigation. Dharwad, India: University of Agricultural Sciences. *Karnataka J. Agrl. Sci.* **17** (1): 5-9. Dewal and Pareek (2004)

Dubin, Y.P. and Ginkel, P.M. (1991). Wheat cultivation in the warmer climates exists in the South-East Asia including Bangladesh. *Indian J. Agril. Sci*., **58**(1): 131-135.

Dwivedi, B.S. and Tiwari, K.N. (1992). Effect of native and fertilizer zinc on dry matter yield and zinc uptake by wheat (*Triticum aestivum* L.) in Udic Ustochrespts. *Trop. Agric.*, **69**(4): 357-361.

FAO. (1997). Production Year Book. Food and Agricultural Organization of the United Nations Rome, Italy. **49**: 201-212.

FAO. (2000). Production Year Book. Food and Agricultural Organization of the United Nations Rome, Italy. **54**: 176-186.

Genc, Y., McDonald, G.K. and Graham, R.D. (2006). Contribution of different mechanisms to zinc efficiency in bread wheat during early vegetative stage. *Plant and Soil.* **281**: 353–367.

Gomez, K.A. and Gomez, A.A. (1984). Statistical Procedure for Agricultural Research (2nd edn.). Int. Rice Res. Inst., A Willey Int. Sci., p. 28-192.

Grotz, N. and Guerinot, M.L. (2006). Molecular aspects of Cu, Fe and Zn homeostasis in plants. Biochim. *Biophys. Acta.* **1763:** 595–608.

Habib, M. (2009). Effect of foliar application of Zn and Fe on wheat yield and quality. *African J. Biotech*., **8**(24): 6795-6798.

Hemantaranjan, A. and Grag, O.K. (1988). Iron and zinc fertilization with reference to the grain quality of *Triticum aestiuvm* L. *J. Plant Nutr.* **11**(6-11): 1439-1450.

Hunter, A.H. (1984). Soil Fertility Analytical Service in Bangladesh. Consultancy Report BARC, Dhaka.

Imtiaz, M., Alloway, B.J., Shah, K.H., Siddique, S.H., Memon, M.Y., Aslam, M. and Khan, P. (2003). Zinc nutritious of wheat: Growth and zinc uptake. *Asian J. Plant Sci*., **2**: 152–155.

Iqbal, M., Khan, M.A., Anwar, M.Z. (2002). Zero-tillage technology and farm profits: a case study of wheat growers in the rice zone of Punjab. *Pakistan Dev. Rev.*, **41**: 665-682.

Jain, N.K. and Dahama, A.K. (2006). Direct and residual effects of phosphorus and zinc fertilization on productivity of wheat (*Triticum aestivum*)-pearl millet (*Pennisetum glaucum*) cropping system. College of Agriculture, Rajasthan Agricultural University, Bikaner 334 006, India. New Delhi, India: Indian Society of Agronomy. *Indian J. Agron.*, **51**(3): 165-169.

Jain, N.K. and Dahama, A.K. (2007). Effect of phosphorus and zinc on yield, nutrient uptake and quality of wheat (*Triticum aestivum*). New Delhi, India: Indian Council of Agricultural Research. *Indian J. Agric. Sci.*, **77**(5): 310-313.

Kaya, Y., Kaya, Y., Arisoy, R.Z. and Gocmen, A. (2002). Variation in grain yield and quality traits of bread wheat genotypes by zinc fertilization. *Pakistan J. Agron*., **1**: 142–144.

Keram, K.S., Sharma, B.L. and Sawarkar, S.D. (2012). Impact of Zn application on yield, quality, nutrients uptake and soil fertility in a medium deep black soil (vertisol). *Intl. J. Sci. Env. Tech*., **1**(5): 563-571.

Khan M.A., Fuller, M.P. and Baloch, F.S. (2008). Effect of soil applied zinc sulphate on wheat (*Triticum aestivum* L.) grown on a calcareous soil in Pakistan. *Cereal Res. Comm*., **36**(4): 571-582.

Khan, R., Gurmani, A.R., Khan, M.S. and Gurmani, A.H. (2007). Effect of zinc application on rice yield under wheat rice system. *Pakistan J. Biol Sci*., **10**(2): 235-239.

Mahendra S. and Yadav, B.L. (2006). Effect of organic materials and zinc on growth and yield of wheat (*Triticum aestivum* L.) under irrigation with high RSC water. Agricultural Research Station, Fatehpur-Shekhawati, Sikar, India. *Haryana J. Agron.*, **22**(2): 142-144.

Ozkutlu, F., Torun, B. and Cakmak, I. (2006). Effect of zinc humate on growth of soybean and wheat in zinc-deficient calcareous soils. *Comm. Soil Sci. and Plant Analysis*. **37**: 2769–2778.

Page, A.L., Miller, R.H. and Keeney, D.R. (1982). Methods of analysis part 2, Chemical and Microbiological Properties, Second Edition American Society of Agronomy, Inc., Soil Science Society of American Inc. Madson, Wisconsin, USA. pp. 403-430.

Parihar, N.S., Saini, R.S and Pathan, A.R.K. (2005). Effect of sulphur, zinc and organic manures on yield and nutrient uptake of wheat in Typic ustipsamment soil. New Delhi, India: Indian Society of Agricultural Science. *Annals of Agric. Res.*, **26**(1): 64-68.

Potarzycki, J. and Grzebisz, W. (2009). Effect of Zinc Foliar Application on Grain Yield of Maize and Its Yielding Components. *Plant Soil & Env.*, **55**: 519-527.

Rajendra K., Singh, N.P. and Gyan S. (2007). Study on the application of micronutrients in a rice-wheat cropping system. Indian Agricultural Statistics Research Institute, New Delhi - 110 012, India. *Bhartiya-Krishi-Anusandhan-Patrika*. **22**(1): 28-34.

Ranjbar, G.A. and Bahmaniar, M.A. (2007). Effects of soil and foliar application of Zn fertilizer on yield and growth characteristics of bread wheat (*Triticum aestivum* L.) cultivars. The University of Mazandaran, Agricultural Campus of Sari, Km 9 Darya Boulevard, Sari, Iran. *Asian J. Plant Sci*. **6**(6): 1000-1005.

Razvi, M.R., Halepyati, A.S., Pujari, B.T. and Koppalkar, B.G. (2005). Influence of graded levels of fertilizers applied to green manure and wheat on biomass production of sunnhemp and grain yield of wheat under irrigation. Department of Agronomy, College of Agriculture, Raichur - 584 101, India. *Karnataka J. Agric. Sci*., **18**(1): 4-7.

Razzaque, A., Das, N. and Roy, S. (1992). Wheat is the most important cereal crop that contributes to the national economy. *Indian J. Agron*., **26**(1): 35-39.

Rehm, G. and Albert, S. (2006). Micronutrients and Production of Hard Red Spring Wheat. *Minnesota Crop e News*, 7 March 2006, 1-3.

Riffat S., Samim, M.K. and Mahmud, R. (2007). Effect of zinc on yield and zinc uptake by wheat on some soils of Bangladesh. *J. Soil. Nature.* **1**(1): 07-14.

Schmidt, R. and Szakal, P. (2007). Zn fertilization of wheat. Higher protein, lower carbohydrate content. Faculty of Agricultural and Food Sciences, University of West Hungary, Mosonmagyarovar, Hungary. *Cereal Res. Comm*., **35**(2): 1041-1044.

Seilsepour, M. (2006). Study of zinc effects on quantitative and qualitative traits of winter wheat in saline soil condition. Iran Desert Research Center, University of Tehran. *BIABAN*. **11**(2): 17-23.

Shaheen, R., Samim, M.K. and Mahmud. R. (2007). Effect of zinc on yield and zinc uptake by wheat on some soils of Bangladesh. *J. Soil. Nature.* **1**(1): 07-14.

Sharma, P.K., Yadav, G.L., Sharma, B.L. and Sudesh, K. (2000). Response of wheat (*Triticum aestivum*) to nitrogen and zinc fertilization. New Delhi, India: Indian Society of Agronomy. *Indian J. Agron.* **45** (1): 124-127.

Shrivastava, R.B., Singh, V.P. and Singh, D. (2008). Component characters of grain yield and harvest index in wheat. *Indian J. Agric. Res*., **12**(1): 35-43.

Singh, L.B., Yadav, R. and Abraham. T. (2015). Studies on the effect of zinc levels and methods of boron application on growth, yield and protein content of wheat (*Triticum aestivum* L.). *Bull. Env. Pharmacol. Life Sci*., **4**(2): 108-113.

Singh, P., Prakash, D., Singh. Y.V. and Singh, S. (2013). Effect of zinc application on yield and benefit/cost (B/C) ratio of wheat in western Uttar Pradesh. *Crop Res*., **45**(1,2&3): 39-41.

Singh, Y.P. (2004). Effect of nitrogen and zinc on wheat irrigated with alkali water. *Annals of Agric. Res*., **25**: 233-236.

Sultana, S., Naser, H.M.. Shil, N.C., Akhter, S. and. Begumm R.A. (2016). Effect of foliar application of zinc on yield of wheat grown by avoiding irrigation at different growth stages. *Bangladesh J. Agril. Res*., **41**(2): 323-334.

Sundar, S. and Choudhary, S.S. (2002). Phosphorus, zinc and soil interaction on the uptake of zinc and iron by wheat (*Triticum durum*). Hisar, India: Gaurav Society of Agricultural Research Information Centre. *Res. On Crops.* **3**(2): 363-368.

Sundar, S., Dave, P.V. and Choudhary, S.S. (2003). Interaction effect of phosphorus, zinc and soil on uptake of phosphorus and copper by wheat and their individual effect on yield. Hyderabad, India: Acharya N.G. Ranga Agricultural University. *J. Res. ANGRAU.* **31**(3): 117-121.

Tiago, Z., Steiner, F., Fey, R., Castagnara, D.D., Seidel, E.P. (2012). Response of wheat to foliar application of zinc. *Central Rural Santa Maria*. **42**(5): 784-787.

Tisdale, S.L., Nelson, W.L., Beaton, J.D. and Havlin, J.L. (1997). Soil fertility and fertilizer, 5th edn. Prentice hall, New Delhi

UNDP and FAO. (1988). Land Resources Appraisal of Bangladesh for Agricultural Development, Report-2. Agro-ecological regions of Bangladesh. BARC/UNDP. New Airport Road, Farmgate, Dhaka-1201. pp. 212-221.

WRC (Wheat Research Center). (2009). Annual Report, 2008–09. Wheat Research Center, Nashipur, Dinajpur, Bangladesh, p. 181.

Yadavi, A., Aboueshaghi, R.S., Dehnavi, M.M. and Balouchi, H. (2014). Effect of micronutrıents foliar application on grain qualitative characteristics and some physiological traits of wheat under drought stress. *Indian J. Fundamental App. Life Sci*., **4**(4):124-131.

Zafar, S., Nasri, M., Moghadam, H.R.T. and Zahedi, H. (2014). Effect of zinc and sulfur foliar applications on physiological characteristics of wheat under water deficit stress. *Intl. J. Bio-Sci.*, **5**(12): 87-96.

Zain, M., Khan, I., Qadri, R.W.K., Ashraf, U. Sajid Hussain, S., Sajid Minhas, S., Siddique, A., Jahangir, M.M. and Bashir, M. (2015). Foliar Application of Micronutrients Enhances Wheat Growth, Yield and Related Attributes. *American J. Plant Sci*., **6**: 864-869

Zeidan, M.S. and Nofal, O.A. (2002). Effect of urea on the efficiency of spraying iron, manganese, zinc and copper on wheat. Cairo, Egypt: National Information and Documentation Centre (NIDOC). *Egyptian J. Agron.*, **24**: 121-131.

APPENDICES

Appendix I. Monthly record of air temperature, relative humidity, rainfall and sunshine hour of the experimental site during the period from November 2014 to March 2015

Month	*Air temperature (ºc)		*Relative humidity (%)	Total Rainfall (mm)	*Sunshine (hr)
	Maximum	Minimum			
November, 2014	25.8	16.0	78	00	6.8
December, 2014	22.4	13.5	74	00	6.3
January, 2015	24.5	12.4	68	00	5.7
February, 2015	27.1	16.7	67	30	6.7
March, 2015	28.1	19.5	68	00	6.8

* Monthly average,

* Source: Bangladesh Meteorological Department (Climate & weather division) Agargoan, Dhaka – 1212

Appendix II. Analysis of variance of the data on plant height at different days after sowing (DAS) and harvest of wheat as influenced by foliar application of zinc

Source of variation	Degrees of freedom	Mean square				
		Plant height (cm) at				
		40 DAS	50 DAS	60 DAS	70 DAS	Harvest
Replication	2	0.192	9.848	0.335	3.895	0.479
Treatment	7	9.922*	36.734*	33.274*	59.114*	77.490*
Error	14	3.319	13.002	11.270	16.303	23.460

**: Significant at 0.01 level of probability; *: Significant at 0.05 level of probability

Appendix III. Analysis of variance of the data on days required for starting of ear emergence, maturity and number of tillers plant^{-1} of wheat as influenced by foliar application of zinc

Source of variation	Degrees of freedom	Mean square				
				Number of tillers plant^{-1}		
		Days required for starting of ear emergence	Days required for starting of maturity	Effective	Non-effective	Total
Replication	2	0.125	3.292	0.016	0.002	0.020
Treatment	7	2.518	12.851	0.607**	0.018*	0.550**
Error	14	2.554	9.101	0.125	0.005	0.136

**: Significant at 0.01 level of probability; *: Significant at 0.05 level of probability

Appendix IV. Analysis of variance of the data on length of flag leaf, ear length, spikelets spike^{-1} and fertile floret spikelet^{-1} of wheat as influenced by foliar application of zinc

Source of variation	Degrees of freedom	Mean square			
		Length of flag leaf (cm)	Ear length (cm)	Spikelets spike^{-1}	Fertile floret spikelet^{-1}
Replication	2	0.020	0.048	0.002	0.010
Treatment	7	2.487**	0.353*	2.434*	0.220**
Error	14	0.631	0.128	0.760	0.022

**: Significant at 0.01 level of probability; *: Significant at 0.05 level of probability

Appendix V. Analysis of variance of the data on number of filled and unfilled grains spike^{-1} and weight of 1000-seeds of wheat as influenced by foliar application of zinc

Source of variation	Degrees of freedom	Mean square			
		Filled grains spike^{-1} (No.)	Unfilled grains spike^{-1} (No.)	Total grains spike^{-1} (No.)	Weight of 1000-seeds (g)
Replication	2	0.116	0.000	0.112	0.311
Treatment	7	11.968*	1.156**	7.062*	4.734*
Error	14	3.638	0.268	2.562	1.453

**: Significant at 0.01 level of probability; *: Significant at 0.05 level of probability

Appendix VI. Analysis of variance of the data on grain, straw, biological yield and harvest index of wheat as influenced by foliar application of zinc

Source of variation	Degrees of freedom	Mean square			
		Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
Replication	2	0.013	0.004	0.010	1.015
Treatment	7	0.285**	0.157*	0.852**	3.298
Error	14	0.049	0.049	0.097	3.636

**: Significant at 0.01 level of probability; *: Significant at 0.05 level of probability

Appendix VII. Analysis of variance of the data on N, P, K and Zn concentrations in grain of wheat as influenced by foliar application of zinc

Source of variation	Degrees of freedom	Mean square			
		Concentration (%) in grain			
		N	P	K	Zn
Replication	2	0.002	0.0001	0.0001	0.000001
Treatment	7	0.002	0.0001	0.0001	0.0001**
Error	14	0.001	0.0001	0.0001	0.000001

**: Significant at 0.01 level of probability;

Appendix VIII. Analysis of variance of the data on N, P, K and Zn concentrations in straw of wheat as influenced by foliar application of zinc

Source of variation	Degrees of freedom	Mean square			
		Concentration (%) in straw			
		N	P	K	Zn
Replication	2	0.0001	0.0001	0.003	0.000001
Treatment	7	0.0001	0.0001	0.006	0.0001**
Error	14	0.0001	0.0001	0.004	0.000001

**: Significant at 0.01 level of probability;

Appendix IX. Analysis of variance of the data on N, P, K and Zn uptake by grain of wheat as influenced by foliar application of zinc

Source of variation	Degrees of freedom	Mean square			
		Uptake by grain (kg ha^{-1})			
		N	P	K	Zn
Replication	2	5.742	0.686	0.152	0.0001
Treatment	7	17.770**	3.246*	5.385**	0.006**
Error	14	4.483	0.936	0.619	0.0001

**: Significant at 0.01 level of probability; *: Significant at 0.05 level of probability

Appendix X. Analysis of variance of the data on N, P, K and Zn uptake by straw of wheat as influenced by foliar application of zinc

Source of variation	Degrees of freedom	Mean square			
		Uptake by straw (kg ha^{-1})			
		N	P	K	Zn
Replication	2	1.235	0.011	4.608	0.0001
Treatment	7	4.722*	0.133*	39.404*	0.011**
Error	14	1.601	0.044	11.255	0.0001

**: Significant at 0.01 level of probability; *: Significant at 0.05 level of probability

Appendix XI. Analysis of variance of the data on nutrient content of post harvest soil as influenced by foliar application of zinc

Source of variation	Degrees of freedom	Mean square		
		pH	Organic matter (%)	Total N (%)
Replication	2	0.006	0.002	0.0001
Treatment	7	0.007	0.001	0.0001
Error	14	0.023	0.002	0.0001

Appendix XI. Cont'd

Source of variation	Degrees of freedom	Mean square		
		Available P (ppm)	Exchangeable K (me %)	Available Zn (ppm)
Replication	2	0.118	0.0001	0.022
Treatment	7	0.994	0.0001**	0.085*
Error	14	0.624	0.00001	0.016

**: Significant at 0.01 level of probability; *: Significant at 0.05 level of probability