EFFECT OF SULPHUR AND ZINC ON THE GROWTH AND YIELD OF WHEAT

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CERTIFICATE

This is to certify that the thesis entitled “**EFFECT OF S AND ZN ON THE GROWTH AND YIELD OF WHEAT (BARI GOM-29)**” submitted to the Department of **SOIL SCIENCE**, 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 **KHONDOKAR FEROZ MAHMUD**, Registration No. **10-04053** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

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

Dated: June, 2016
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Dedicated To

My Beloved Parents

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The Author

Effect of S and Zn on the growth and yield of wheat (BARI Gom-29)

ABSTRACT

An experiment was carried out at the research field of Sher-e-Bangla Agricultural University, Dhaka to evaluate the effect of S and Zn on the growth and yield of wheat (BARI Gom-29) during the period from December 2015 to March 2016. Four levels of Sulphur*viz*. (i) S_0 = 0 kg S ha^{-1} (Control), (ii) S_1 = 10 kg S ha^{-1}, (iii) S_2 = 15 kg S ha^{-1} and (iv) S_3 = 20 kg S ha^{-1} and three levels of boron *viz*. (i) Zn_0 = 0 kg Zn ha^{-1} (Control), (ii) Zn_1 = 1.3 kg Zn ha^{-1} and (iii) Zn_2 = 1.6 kg Zn ha^{-1} were used as experimental treatments. The experiment was laid out in a randomized complete block design with three replications. Data on different growth and yield parameters were recorded and analyzed statistically. Sulphur and zinc individually and also in association gave significant effect on growth and yield of wheat. S_2 (15 kg S ha^{-1}) gave the highest number of tillers $plant^{-1}$ (3.71), dry weight $plant^{-1}$ (33.53 g), spike length (9.86 cm), number of grain $spike^{-1}$ (32.37), grain yield (4.23 t ha^{-1}), stover yield (5.59 t ha^{-1}) and the highest harvest index (43.08%). Again, Zn_1 (1.3 kg Zn ha^{-1}) highest number of tillers $plant^{-1}$ (3.73), dry weight $plant^{-1}$ (5 31.41 g),spike length (9.93 cm), number of grain $spike^{-1}$ (31.16), grain yield (4.23 t ha^{-1}), stoveryield (5.56 t ha^{-1}) and harvest index (43.21%). In terms of combination of sulphur with zinc, the highest number of tillers $plant^{-1}$ (4.05), highest dry weight $plant^{-1}$ (34.89 g a), highest spike length (12.40 cm), highest number of grain $spike^{-1}$ (38.25), highest grain yield (4.46 t ha^{-1}), highest stover yield (5.80 t ha^{-1}) and harvest index (43.47%) were obtained from S_2Zn dose. Finally, all the growth, yield and yield attributing characters were found lowest in control treatments.

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ABBREVIATIONS AND ACRONYMS

AEZ = Agro-Ecological Zone
BBS = Bangladesh Bureau of Statistics
BCSRI = Bangladesh Council of Scientific Research Institute
cm = Centimeter
CV % = Percent Coefficient of Variation
DAS = Days After Sowing
DMRT = Duncan’s Multiple Range Test
et al., = And others
e.g. = exempli gratia (L), for example
etc. = Etcetera
FAO = Food and Agricultural Organization
g = Gram (s)
i.e. = id est (L), that is
Kg = Kilogram (s)
LSD = Least Significant Difference
m^2 = Meter squares
ml = MiliLitre
M.S. = Master of Science
No. = Number
SAU = Sher-e-Bangla Agricultural University
var. = Variety
^{o}C = Degree Celceous
% = Percentage
NaOH = Sodium hydroxide
GM = Geometric mean
mg = Miligram
P = Phosphorus
K = Potassium
Ca = Calcium
L = Litre
μg = Microgram
USA = United States of America
WHO = World Health Organization

CHAPTER I

INTRODUCTION

Wheat (*Triticumaestivum*) is one of the leading cereals in the world. It belongs to the family poeaceae and it is the world's most widely cultivated cereal crop which ranks first followed by rice. It is preferable to rice for its higher seed protein content. It ranks first both in acreage and production among the grain crops of the world (FAO, 2008). About one third of the world population lives on wheat grains for their subsistence (FAO, 2007). Wheat grain is rich in food value containing 12% protein, 1.72% fat, 69.60% carbohydrate and 27.20% minerals (BARI, 2006).

Bangladesh is an over populated country. Increasing agricultural production per unit area of land is becoming most important step to cope with the present population growth in Bangladesh. Wheat can be a good supplement of rice and it can play a vital role to feed this vast population. From nutritional point of view, wheat is superior to rice for its higher protein content.

Bangladesh produces 1302998 metric tons of wheat per annum from 1061602 acres of land with an average yield of 3.03 t ha^{-1} (BBS, 2014) and it can be increased up to 6.8 t ha^{-1} (RARS, 2002). So, there is an ample opportunity to increase production of wheat per unit area through adoption of modern and improved agronomic practices such as optimum seed rate, timely sowing and judicious application of irrigation, fertilizer and other inputs.

Fertilizers are indispensable for the crop production system of modern agriculture. It plays a very important role in utilizing the soils for an efficient crop production. The elements essential for plants are C, H, O, N, P, K, Ca, Mg, S, Fe, Cu, B, Mn, Mo, Zn, Cl. Out of these 16 elements, 9 essential elements have been classified as "macronutrients" as these are required in relatively large amount by the plants. These elements include C, H, O, N, P, K, C Mg, S. The remaining of the elements (B, Cu, Fe, Cl, Mn, Mo and Zn) are called "trace elements" (Alloway, 1990; Brady and Weil, 2002). Essential trace elements are often called "micronutrients" because they are required in small, but in critical concentrations by living organisms.

Among different macro and micro nutrients, S and Zn are the most important nutrients for wheat growth and development.

Sulfur (S) is one of the essential nutrients for plant growth. It is required in similar amount as that of phosphorus (De Kok*et al*., 2002; Ali *et al*., 2008). It is a building block of protein and a key ingredient in the formation of chlorophyll (Duke and Reisenauer, 1986).

Deficiency of S significantly affect the production and quality of wheat (McGrath, 2003; Gyori, 2005). Without adequate S, crops can’t reach their full potential regarding yield, quality or protein content; nor can they make efficient use of other applied nutrients (Sahota, 2006).

The sulphur requirements of cereal crops are lower in comparison to root crops, rapes and legumes (Motowicka-Terelak, Terelak 2000). However, due to decreasing sulphur emission to the atmosphere and application of sulphur-free mineral fertilizer the deficiency of this element in cereal crops has been lately observed (Grzebisz 2003, Stern 2005). Plants absorb sulphur from the soil through their root system in the sulfate form and transport it to the chloroplasts of leaf cells, where sulfate are reduced to sulphide and built into organic compounds (Hell, Rennenberg 1998). Elemental form of sulphur is not directly available for plants and has to be transformed in the soil into sulfate form.

Elemental sulphur in the finely ground form can also be used for foliar fertilization because it undergoes oxidation on the leaf surface and is included in the processes of plant metabolism (Legris-Delaporte*et al*. 1987). Application of sulphur fertilizers may increase the yield and quality of agricultural crops (Tabatabai 1984).

Sulphur does not affect only nitrogen utilization and grain quality, but it also plays an important part in the formation of the baking quality (Ryant and Hrivna, 2004). Reproductive growth of wheat appears to be more sensitive to sulphur deficiency than vegetative growth, with decreased grain size under sulphur-limiting conditions. In addition to the effects on yields, the sulphur status of wheat grain is an important parameter for the quality of wheat products (Honermeier and Simioniuc, 2004).

Sulphur deficiency in crop plants has been recognized as a limiting factor not only for crop growth and seed yield but also for poor quality of products, because sulphur is a constituent of several essential compounds such as cysteine, methionine, coenzymes, thioredoxine and sulfolipids. It was shown that sulphur application altered the amino acid composition with a greater proportion of sulphur containing cysteine and methionine (Singh, 2003).

As a plant nutrient the role of zinc in crop production, including wheat cultivation, has been well established (Kanwar and Randhawa, 1974). The functional role of zinc includes auxin metabolism. It influences the activities of hydrogenase and carbonic anhydrase, synthesis of cytochrome and the stabilization of ribosomal fractions (Tisdale *et al*., 1984). Due to the deficiency of zinc, plants show symptoms such as little leaf, mottle rosette, die-back, browning, yellowing, brown spot. The visual symptoms of zinc deficiency vary with the species, variety, soil, water regime, fertilizer use, planting method, growth stage and season. In general, zinc deficient plants make poor growth and interveinal leaf chlorosis and necrosis of lower leaves. Reddish or brownish spot often occurs on the older leaves, and seed production is strikingly reduced due to its deficiency (Throne, 1957).

Hence, Application of Zn fertilizer is a promising short-term approach to improve Zn concentrations in seeds and can also contribute to alleviation of Zn deficiency related health problems in the developing world (Aslam*et al*., 2014). Zinc, in addition, is reported to be having possible role in reducing the toxic effects of excessive boron (Singh *et al*., 1990). Deficiency of and response to zinc and sulphur in wheat have been reported from various parts of the world. Bangladesh soils are not exception to this. Zinc and sulphur, plant nutrient elements, are required for plant growth relatively to a smaller amount.

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

Objectives:

1. To compare the growth and yield performance of wheat by using different doses of sulphur and zinc.
2. To know the interaction effect of sulphur and zinc on nutrient content and uptake by plant and seed of wheat.
3. To identify the suitable dose of sulphur and zinc for better yield of wheat

CHAPTER II

REVIEW OF LITERATURE

An effort has been completed in this chapter to present a brief review of research in relation to Effect of S and Zn on the growth and yield of wheat (BARI Gom-29). Sulphur and Zinc are important plant nutrient for growth and yield of wheat. The sulphur requirements of cereal crops are lower in comparison to root crops, rapes and legumes (Motowicka-Terelak, Terelak 2000). But application of sulphur fertilizers may increase the yield and quality of agricultural crops both cereal and root crops (Tabatabai 1984). Zinc is a micronutrient which is required for plant growth relatively in a smaller amount. It plays a key role in pollination and seed set processes; so that its deficiency can cause to decrease in seed formation and subsequent yield reduction (Ziaeyan and Rajaiea 2009). However, the research work so far done at home and abroad regarding the performance of wheat under different levels of sulphur and zinc fertilizers along with other pertinent information are reviewed below.

2.1 Effect of sulphur (S)

Sulphur deficiency significantly effects the production and quality of winter wheat (Gyori, 2005). Without adequate sulphur, crops can’t reach their full potential in terms of yield, quality or protein content; nor can they make efficient use of applied nitrogen (Sahota, 2006). At high nitrogen fertilization levels significant responses to sulphur fertilization were found which emphasized the need for precision application of sulphur in intensive wheat production systems. Continued use of nitrogen fertilizer without supplemental sulphur on low sulphur soils will reduce flour quality (Flaete*et al.*, 2005).

Sulphur does not affect only nitrogen utilisation and grain quality, but it also plays an important part in the formation of the baking quality (Ryant and Hrivna, 2004). Reproductive growth of wheat appears to be more sensitive to sulphur deficiency than vegetative growth, with decreased grain size under sulphur-limiting conditions. In addition to the effects on yields, the sulphurstatus of wheat grain is an important parameter for the quality of wheat products (Honermeier and Simioniuc, 2004).

Sulphur deficiency in crop plants has been recognized as a limiting factor not only for crop growth and seed yield but also for poor quality of products, because sulphur is a constituent of several essential compounds such as cysteine, methionine, coenzymes, thioredoxine and sulfolipids. It was shown that sulphur application altered the amino acid composition with a greater proportion of sulphur containing cysteine and methionine (Singh, 2003).

Responses of the breadmaking quality of wheat to sulphur are more common than responses in terms of grain yield. Sulphur application did not affect grain protein concentration directly, but tended to increase gel protein weight in flour and the proportion of polymeric proteins. Dough extensibility was increased by sulphur. Correlation and regression analyses showed that grain protein concentration was a poor indicator of loaf volume, whereas grain sulphur status (sulphur concentration and N : S ratio) was more influential (Zhao *et al*., 1999c).

Sulphur deficiency decreases grain size and baking quality because of formation of disulfide bonds formed from the sulphydryl groups of cysteine. This effects the viscoelasticity of dough (Gyori, 2005). The baking quality of wheat was improved by sulphur application, showing high correlation between loaf volume and the sulphur content of grain and thus improving rheological properties (extensibility) of dough (Singh, 2003). Sulphur deficit may result in harder grain; the dough made from such grain is usually stiff and is not elastic (Ryant and Hrivna, 2004).

A synergistic effect between the applied nitrogen and sulphur fertilizers appears to increase nitrogen and sulphur assimilation in wheat grain and may improve breadmaking qualities. When nitrogen and sulphur fertilizers were applied simultaneously, flour protein content and dough strength, swelling and extensibility were increased (Tea *et al*., 2007).

Jarvan*et al*. (2008) conducted trials to identify the effect of sulphur fertilization on the yield of winter wheat (*Triticumaestivum* L.) on some of the quality indices of yield and protein quality, including the content of nonreplaceable amino acids, and on the baking properties of flour. In the field trials the effect of N and NS fertilization was compared on the nitrogen background of N60 + N40 kg ha^{-1}. Due to sulphur (in two top dressings in total S10 kg ha^{-1}) the yield of winter wheat 'Lars' increased, depending on the weather and soil conditions, in field trials 0.47–1.48 t ha^{-1}, i.e. 7.7–43.0% and in production trials 1.35–2.44 t ha^{-1}, i.e. 39.8–45.5%. Sulphur had also a great impact on yield parameters. Increased yield was observed by increasing tiller number and dry matter production.

Moss *et al.* (1981) conducted a field experiment with wheat (cv Olympic) using 5 levels of S (0, 6, 12.5, 25 and 50 kg S/ha) and found that the grain-S concentration increased significantly due to its application.

Ali *et al.* (1982) reported on an experiment in Grey Floodplain soil of Jamalpur that 30 kg S/ha increased the plant height, tiller number and grain yield of Sonalika wheat to 30l7 kg/ha from 2815 kg/ha.

Ali *et al.,* (1983) carried out a field experiment on silt loam soils at Mymensingh, Jamalpur, Ishurdi and Madhupur to study the response of wheat (cv. Sonalika) to various fertilizer nutrients. They reported that addition of 30 kg S/ha significantly increased the grain yield with a record of 2430 kg/ha yield in S added plot and 1960 kg/ha in control.

Mahler and Maples (1986) carried out an experiment on the response of wheat to sulphur fertilization and observed significant increase in grain yield of wheat.

Islam *et al.* (1986) conducted a field study throughout the countries and have also demonstrated the significant positive yield increase due to added sulphur for wheat.

Reneau*et al.* (1986) conducted an experiment with winter wheat on Kenansville loams sand soil in the coastal plain region of Virginia in the

Eastern United States and found that S application did not significantly influence the yield of wheat.

Kuligod*et al.* (1994) carried out an experiment on wheat cv. Kiran grown on a deep black soil (TypicChromusterts) in 1991-92 and reported that application of 30 kg S/ha increased 18% grain yield.

Dai *et al.* (1995) conducted an experiment on wheat grown in the field in 1991-92, with applying 61.78 kg $ZnS0_4$/ha. The S concentration in shoots was highest (0.406% with applied S and 0.364% in control) at the booting stage. The S content in plants was highest (about 10-11 mg/plant) at the milk stage, while S accumulation rate was highest (0.40 mg plant per d) between stem elongation and booting. Application of S fertilizer had significant effect on growth parameters and also showed increased grain yield. The amount of S needed for production of 100 kg grain was 0.154-0.222 kg. Alter stem elongation, more S was accumulated in stems than in leaves, while in later growth stages S mainly accumulated in spikes.

Khajanchi*et at* (1997) conducted a greenhouse experiment in a well drained sandy soil with wheat (cv. HD-2329) using 15 or 30 mg S per kg soil as 35S-labelled gypsum. They found that uptake of both total and fertilizer S increased significantly and synergistically with addition of 60mg N and 30mg S per kg soil, fertilizer S utilization percentage ranged from 6.6 to 6.1 and increased with successive rates of N but decreased with increase in S levels from 15 to 30 mg per kg soil.

Kaushik and Sharma (1997) conducted a field trial at Rajsthan Agricultural University with wheat cv. Raj 3077 using 10. 20. 40 or 00kg S/ha and found that grain yield increased significantly with up to 20 kg S. Tiller number, spike length, grain/spike and 1000 grain weight was also increased significantly with up to 20 kg S.

Ruiter*et al.* (2001) studied the use of S containing fertilizers (0 and 50 kg S/ha) with four wheat cultivars for yield potential and dough rheological properties.

There was little effect of S fertilizer on grain yield and S concentration or uptake. Sulphur treatment reduced the N:S ratio in grain. There was significant reduction in work input following S fertilizer application.

Kulczycki (2010) carried a field experiment to study the effect of sulphur fertilization on the yield and chemical composition of winter wheat. Elemental sulphur was applied through soil and foliar application. The soil applied sulphur significantly increased grain yield and also straw yield with a dose of 80 kg S ha^{-1}. Fertilizing with elemental sulphur significantly increased the overall sulphur content during the wheat vegetation when the highest doses were used. Tiller number, panicle length, 1000 grain weight were also obtained as highest with a dose of 80 kg S ha^{-1}.

Erekul*et al*. (2012) conducted studies on the influence of S-fertilization on grain yield and bread-making quality of wheat (*Triticumaestivum* L.). S-fertilization had positive effects on grain yield and some quality parameters under Mediterranean conditions; however, significant differences were rather rare. Particularly the gluten-index and the sedimentation value promoted by S fertilization were among the tested parameters. Therefore, S-fertilization in improving bread-making quality of wheat in the region should not be disregarded.

Jarvan*et al*. (2012) investigated the effect of sulphur application on winter wheat yield and yield components. Sulphur was applied at the rate of 10 kg ha^{-1} accompanied with N 100 kg ha^{-1}, which effect was compared to effect of ammonium nitrate at the same rate of N. The rates of fertilizers were divided into two portions and applied at the growth stages 21–22 and 25–30. The effect of sulphur fertilization on the formation of wheat yield varied on a quite large scale depending on soil and weather conditions of trial locations. The yield components were closely related: when one component was changed, the other components sometimes compensated for grain yield. The application of sulphur increased the number of ears per unit area by an average of 14.0% and the number of grains per ear by an average of 18.6%. At the same time, sulphurdecreased the 1000-grain weight. As a final result, sulphur application increased the wheat yield by 1.16 t ha^{-1} on average, i.e. by 23.0%.

Rai*et al*. (2016) conducted an investigation to study the Effect of sulphur levels on physico-chemical properties of soil and performance of wheat. They observed that sulphur is essential for synthesis of proteins, vitamins and sulphur containing essential amino acids and is also associated with nitrogen metabolism. Sulphur improves both yield and quality of crops. Sulphur deficiency in soil is the increase with intensification of agriculture. The fertilizers responsive varieties have accelerated the depletion of sulphur increases in soil, even from lower soil depth. The continuous use of sulphur free fertilizers have resulted in wide spread deficiency of sulphur in Indian soils and become more beneficial in light textured soils which low in organic matter.

Hayat *et al*. (2015) set an experiment and observed that applications of 140 kg N ha^{-1} at sowing alongside applications of 20 kg S ha^{-1} at anthesis was helpful in increasing 1000 grain weight and grain yields in wheat varieties. It was therefore recommended that foliar S should be included as an important input, alongside N, in the production technology of wheat crop.

Klikocka*et al*. (2016) conducted a study to evaluate the effect of nitrogen (N) and sulphur (S) fertilizer on grain yield of spring wheat and its technological quality. The experiment included 2 factors: N fertilization (0, 40, 80, 120 kg/ha) and S fertilization (0, 50 kg/ha). The experiment showed that S fertilization increased grain yield by 3.58%. S had also positive influence on growth parameters like plant height, tiller number, dry matter production. Grain/panicle and 1000 grain weight were also increased significantly by S fertilization at 50 kg/ha. Positive correlation was found between the content of S in grain and grain yield (r = 0.73).

2.2 Effect of zinc (Zn)

Zinc has been reported elsewhere as being effective in increasing dry matter production in wheat plants and it appears that its application acts like nitrogen addition to nutrient rich soil, stimulating greater biomass productivity at a greater proportion to the decrease in harvest index. Zinc deficiency has been reported to cause stunted plant growth and as shown here, the impact of Zinc stress on wheat growth in Zn deficient calcareous soil can be mitigated by Zn fertilization (Imtiaz*et al*., 2003). Zinc is a micronutrient which is required for plants growth relatively in a smaller amount. The normal concentration range for Zn in dry matter of plants is 25 to 150 mg g^{-1}. Roots absorb Zn in the form of Zn2+. Zinc is involved in a diverse range of enzymatic activities.

Sultana *et al.* (2016) carried out a field experiment at 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. Zinc Sulphate Monohydrate ($ZnSO_4$. H_2O) was used as a source of Zn. The interaction effect of irrigation and foliar application of zinc significantly influenced the yield and yield components of wheat. 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).

A field experiment was conducted by Ahmadi*et al.* (2016) to study the Effect of Nitrogen and Zinc on Yield of Wheat (*Triticumaestivitm* L.). Laid out in factorial with 3x3 randomized block design with three levels of Nitrogen (0, 60 and 120) kg ha^{-1}, three levels of Zinc (0, 15 and 30 kg ha^{-1}), respectively. The treatment combination (Nitrogen @ 120 kg ha^{-1} + Zinc @ 30 kg ha^{-1}) gave the best results with respect to plant height 101.2 cm. It also gave highest yield 5.60 t ha^{-1}, straw yield 7.57 t ha^{-1} and test weight 44 g 1000 seed g^{-1}. The economical point of view, the same treatment combination gave the maximum profit of Rs = 63395 ha^{-1} with C:B ratio of 1:2.77.

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

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

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

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

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

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

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

Mekkei and El-HagganEman (2014) conducted two field experiments to study the effect of Cu, Fe, Mn, Zn foliar application on yield and quality of four wheat cultivars (Sids 13, Sakha 94, Misr 1 and Gemeiza 7). Results showed that foliar application by all micronutrients gave significant effect on yield traits and protein content in both seasons compared with control treatment.

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

Ali *et al*. (2013) conducted a field study to evaluate the effect of boron (B) and zinc (Zn) fertilizer alone and in combination on yield, yield components and nutrient concentration in various plant parts. Results showed that combined addition of 2.0 kg B and 5 kg Zn ha^{-1} produced significant impact on the grain yield and its components i.e., number of tillers m^{-2}, spike length, number of grains spike^{-1}and 1000-grain weight. The improvement in dry matter production and grain yield was 14.5% and 9.4%, over control, respectively, by the combined application of 2.0 kg B ha^{-1} and 5.0 kg Zn ha^{-1}. There was substantial increase in B concentration in grains i.e., 129.6% and 47.6% by individual addition of 2.0 kg B and 5.0 kg Zn ha^{-1} over control, respectively. The level of Zn content was raised from 15.2 to 37.4 mg kg^{-1} by application of 10.0 kg Zn ha^{-1}. Thus, substantial improvement in wheat productivity could be harvested with simultaneous increased concentration of Zn nutrient in grain for alleviation of syndrome caused due to Zn deficiency across rural and peri-urban communities.

An experiment was carried by Monjezi*et al.*(2013) to study the effect of drought stress, iron and zinc spray on the yield and yield components of wheat. Influencing the seed filling process, in interaction with iron, which is an important leaf's chlorophyll cation, zinc increased the seed yield. The drought stress reduced the thousand kernels weight (TKW) and the number of seeds per spike increased about 24% and 8.5% more than the one of control treatment, respectively. Zinc spray increased seed yield and thousand kernels weight. The results obtained from the present research showed that zinc spray has fairly improved the effects caused by drought stress.

An experiment was conducted by Mohammadi Sultana *et al.* (2013) to study the effect of potassium sulfate and zinc fertilizers on wheat drought resistance under water stress conditions. 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. Geight, number of grains per spike, grain weight, grain yield and zinc concentration were affected seedling fresh weight. Finally, the amount of 120 kg potassium per ha and 25 kg zinc sulfate per ha for the cultivation of this wheat is recommended.

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

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

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

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

Abbas *et al.* (2010) investigated the effect of Zn as Zinc sulphate on wheat crop cultivar ‘AS-2002’. Levels of $ZnSO_4$ (33%) applied were 0, 7.5, 15, 22.5 and 30 kg ha^{-1}. As evidenced by the grain yield successive increase in grain yield was witnessed with each incremental dose of Zn reaching the threshold level of $ZnSO_4$ at 22.5 kg ha^{-1}. But, for the economic gains in terms of each Rupee invested in Zinc, 7.5 kg $ZnSO_4$ coupled with recommended dose of NPK generated the maximum return (1:4.08). The Zn application at 22.5 kg ha^{-1} having the mean CBR of 2.93 emerged as the next remunerative treatment in the studies. Thus, in the light of our findings it is recommended that along with the recommended dose of NPK at 114-84-62 kg NPK ha^{-1}, $ZnSO_4$ 33% may be applied with the first irrigation either at 7.5 or 22.5 kg ha^{-1} for the highest economic returns in wheat production.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Sundar*et al*. (2003) reported that Potted wheat plants grown on sandy clay loam (S1) and clay loam soils (S2) were treated with 0, 10 and 20 kg P ha^{-1}, 0, 5, 10 and 15 kg Zn ha^{-1} sandy clay loam (S1) and clay loam (S2). Grains per ear, test weight, grain and straw yields increased significantly only up to 10 kg Zn ha^{-1}; beyond this level, adverse effects on the yield were observed. Grains per ear, test weight, grain and straw yields were influenced by the soils and were highest with the application of 10 kg Zn ha^{-1}.

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

Prasad *et al*. (2002) did a field experiment in Bihar, India for five years to study the optimal frequency of zinc application on zinc deficient soil in the rice-wheat cropping system. 'The treatments were soil and foliar application of Zn sulfate at different doses. The results indicated that the pooled yield of rice

(32.5 q ha^{-1}) was higher than that of wheat grain (15.8 g ha^{-1}). The frequency of Zn application, based on 10 cropping systems, indicated that the use of 25 kg Zn sulfate ha^{-1} as soil application after a two crop interval was found to be optimal. The rates of increase in yields of rice and wheat were 52.4 and 21.0 kg Zn sulfate ha^{-1}, respectively and the per cent increase in yield of rice was 46.6 and wheat 38.1. The rice and wheat yields in the cropping system were significantly correlated with Zn removal.

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

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

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

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

2.3 Sulphur and zinc in interaction

Orman and Huseyin (2012) carried a pot experiment to evaluate the effects of sulphur (S) and zinc (Zn) on soil pH and electrical conductivity (EC), nitrogen (N), S, iron (Fe), Zn, N:S ratio; and straw and grain dry weight of wheat grown in a calcareous clay loam soil. Sulphur was applied at 0, 10, 50, 250 mg S kg^{-1} (as $CaSO_4.2H_2O$) and zinc at 0, 5 mg $Znkg^{-1}$ (as $ZnSO_4.7H_2O$) to the soil. The soil pH decreased by S alone. The soil EC increased due to increase in sulphur with zinc. The straw S concentration increased by sulphur alone. In the 250 mg Skg^{-1} application to soil, the straw S concentration increased by 28.13% when compared with 0 mg Skg^{-1} treatment. The grain Zn concentration was significantly increased by sulphur with zinc. In the 250 mg S kg^{-1} with 5 mg Zn kg^{-1} application to the soil, the grain Zn concentration increased 38.47% when compared with no sulphur and zinc treatment to soil. The zinc treatment led to a significantly reduced straw Fe concentration. The straw dry weight was significantly affected by sulphur alone and it increased from 2.53 to 3.86%. The grain dry weight was significantly affected by zinc alone and it decreased by 12.18%. But, the grain zinc concentration increased 25% by increasing the zinc. The results suggest that application of sulphur and zinc could be a good approach for the nutrition of wheat plants.

CHAPTER III

MATERIALS AND METHODS

The experiment was conducted at the Soil Science field of Sher-e-Bangla Agricultural University, Dhaka during the period from December 2015 to March 2016. This chapter deals with a brief description on experimental site, climate, soil, land preparation, layout, experimental design, intercultural operations, data recording and their analyses.

3.1 Experimental site

The experiment was conducted at the Sher-e-Bangla Agricultural University farm, Dhaka, under the Agro-ecological zone of Modhupur Tract, AEZ-28 during the Rabi season of 2015. The land area is situated at 23°41′N latitude and 90°22′E longitude at an altitude of 8.6 meter above sea level. The experimental site is shown in the AEZ Map of Bangladesh in Appendix I.

3.2 Climate

The experimental area is under the sub-tropical climate that is characterized by high temperature, high humidity and heavy rainfall with occasional gusty winds in kharif season (April-September) and less rainfall associated with moderately low temperature during the Rabi season (October-March). The weather data during the study period of the experimental site is shown in Appendix II.

3.3 Soil

The farm belongs to the General soil type, Shallow Red Brown Terrace Soils under Tejgaon Series. Top soils were clay loam in texture, olive-gray with common fine to medium distinct dark yellowish brown mottles. The experimental area was flat having available irrigation and drainage system. The land was above flood level and sufficient sunshine was available during the experimental period. Soil samples from 0-15 cm depths were collected from experimental field. The analyses were done by Soil Resources and Development Institute (SRDI), Dhaka. The physicochemical properties of the soil are presented in Appendix III.

3.4 Planting material

Wheat (*Triticumaestivum* L.) variety BARI Gom-29 was used as plant material. BARI developed this variety and released in 2014. It is a most popular variety now due to its high yielding potentials and suitable for early and late planting (up to second week of December). This variety attains a height of 80-85cm and it resistant to leaf rust disease. The number of tillers plant^{-1} is 3-4 and the leaves are wide and deep green in color. It requires 60-63 days to heading. Grains are amber in color and bright. Its yield is 4-5 t ha^{-1} and 1000 grain weight is 48-52 g. The seeds of this variety were collected from Bangladesh Agricultural Research Institute (BARI), Gazipur.

3.5 Land preparation

The land was first opened with the tractor drawn disc plough. Ploughed soil was then brought into desirable fine tilth by 4 operations of ploughing and harrowing with country plough and ladder. The stubble and weeds were removed. The first ploughing and the final land preparation were done on 22 November and 28 November 2015, respectively. Experimental land was divided into unit plots following the design of experiment. The plots were spaded one day before seed sowing and the basal dose of fertilizers was incorporated thoroughly before seed sowing.

3.6 Fertilizer application

The unit plots were fertilized with 150 kg N, 125 kg P, 67 kg K and S 80 kg respectively. Urea, triple super phosphate (TSP) and muriate of potash (MoP) were used as source of nitrogen, phosphorus and potassium, respectively. Zinc and Sulpher were applied as per experimental specification through Zinc sulphate (60% Zn) and gypsum soil application. The whole amount of TSP, MoP, gypsum, boric acid and one third of the urea were applied at the time of final land preparation prior to sowing. The remaining two-thirds of urea were top-dressed in two equal splits on 20 and 55 days after sowing (DAS) the seed.

3.7 Fertilizer dose and methods of application

At the time of first ploughingcowdung was applied. The experimental area was fertilized with urea, triple super phosphate (TSP), muriate of potash (MoP), gypsum and $ZnSO_4$ as source of N, P, K, S and Zn respectively. The following doses of fertilizers were applied:

Fertilizers and manure		Amount (kg ha^{-1})
Urea	=	250
TSP	=	155
MoP	=	45
Gypsum	=	As per treatment
ZnO		As per treatment
Cowdung	=	10000

The whole amount of TSP, MoP and one third of the urea were applied at the time of final land preparation prior to sowing. The remaining two-thirds of urea were top-dressed in two equal splits on 20 and 55 days after sowing (DAS) the seed. Sulphur and zinc were applied as per experimental specification through gypsum as soil application and zinc sulphate ..

3.8 Treatments of the experiment

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

Factor A: Sulphur – 4 levels:

1) S_0 = 0 kg S ha^{-1} (Control)
2) S_1 = 10 kg S ha^{-1}
3) S_2 = 15 kg S ha^{-1}
4) S_3 = 20 kg S ha^{-1}

Factor B: Zinc – 3 levels:

1) Zn_0 = 0 kg Zn ha^{-1} (Control)
2) Zn_1 = 1.3 kg Zn ha^{-1}
3) Zn_2 = 1.6 kg Zn ha^{-1}

Combination of S and Zn: 12 treatment combinations

S_0Zn_0, S_0Zn_1, S_0Zn_2, S_1Zn_0, S_1Zn_1, S_1Zn_2, S_2Zn_0, S_2Zn_1, S_2Zn_2, S_3Zn_0, S_3Zn_1, S_3Zn_2.

3.9 Experimental design and lay out

The experiment was laid out in a Randomized Complete Block Design (factorial). Each treatment was replicated three times. Thus the total number of unit plots was 3×4×3=36. The size of the unit plot was 3m × 2m. The distance maintained between two unit plots was 0.5m and that between blocks was 1m. The treatments were randomly assigned to the plots within each replication. The layout of the experiment field is shown in Appendix IV.

3.10 Sowing of seeds

Seeds were sown on 28th November, 2015 by hand. Seeds were sown in line and then covered properly with soil. The line to line distance for wheat was 20 cm and plant to plant distance was 4 - 5 cm.

3.11 Intercultural operations

3.11.1 Weeding

During plant growth period two hand weedings were done. First weeding was done at 20 days after sowing followed by second weeding at 15 days after first weeding. The weeds identified were kakpayaghash (*Dactylocteniumaegyptium* L.), Shama (*Echinocloacrussgalli*), Durba (*Cynodondactylon*), Arail (*Leersiabexandra*), Mutha (*Cyperusrotundus* L.) Bathua (*Chenopodium album*) Shaknatey (*Amaranthusviridis*), Foska begun (*Physalisbeterophylls*), Titabegun (*Solanumtorvum*), and Shetlomi (*Gnaphaliumluteolabum* L.)

3.11.1 Irrigation and weeding

Two times of irrigations were done at 20 and 55 DAS (Days after sowing).

3.11.3 Plant protection measures

The wheat crop was infested by Aphid and rodent. Therefore, contact insecticide (Malathion @ 22.2 mm per 10 litres of water) was given two times and 2% zinc sulphide was applied in some times because wheat field was highly infested by rodent.

3.11.4 General observation of the experimental field

The field was observed time to time to detect visual difference among the treatment and any kind of infestation by weeds, insects and diseases so that considerable losses by pest was minimized.

3.11.5 Harvesting and post harvest operation

Maturity of crop was determined when 90% of the grains became golden yellow in color. Ten plants per plot were preselected randomly from which different growth and yield attributes data were collected and 1 m^2 areas from middle portion of each plot was harvested separately and bundled, properly tagged and then brought to the threshing floor for recording grain and straw yield. Threshing was done by using pedal thresher. The grains were cleaned and sun dried to a moisture content of 12%. Straw was also sun dried properly.

3.12 Recording of data

Experimental data were recorded from 45 days of sowing and continued up to harvest. The following data were recorded during the experimentation.

3.12.1 Crop growth characters

a. Plant height (cm)
b. Number of tillers plant^{-1}
c. Total dry matter

3.12.2 Yield and yield components

a. Length of spike (cm)
b. Number of grains spike^{-1}
c. Weight of 1000 grains (g)
d. Grain yield (t ha^{-1})
e. Straw yield (t ha^{-1})
f. Harvest index (%)

3.13 Detailed procedures of recording data

3.13.1 Crop growth characters

3.13.1.1 Plant height

Plant height was measured at 15 days interval starting from 20 days after sowing (DAS) and continued up to harvest. The height of the plant was determined by measuring the distance from the soil surface to the tip of the leaf before heading, and to the tip of spike after heading. The collected data were finally averaged.

3.13.1.2 Number of tillers plant^{-1}

Number of tillers plant-1 were counted at 15 days interval starting from 45 DAS and up to harvest and finally averaged as their number plant-1.

3.13.1.5 Dry weight of plant

Five plants at different days after sowing (45, 60, 75 DAS and at harvest) were collected and dried at 70° C for 24 hours. The dried samples were then weighed and averaged.

3.13.2 Yield and yield contributing characters

3.13.2.1 Spike length

Spike length were counted from five plants from basal node of the rachis to apex of each spike and then averaged. This was taken at different days after sowing (DAS) separately.

3.13.2.2 Number of grains spike^{-1}

The number of grains spike-1 was counted from 10 spike and number of grains spike-1 was measured by the following formula

$$\text{Number of grains spike}^{-1} = \frac{\text{Total number of grains}}{\text{Number of spike}}$$

3.13.2.3 Weight of 1000 grains

One thousand cleaned dried grains were counted randomly from each plot and weighed by using a digital electric balance when the grains retained 12% moisture and the mean weight was expressed in gram.

3.13.2.4 Grain yield

Grain yield was determined from the central 1 m2 area of each plot and expressed as t ha^{-1} on 12% moisture basis. Grain moisture content was measured by using a digital moisture tester.

3.13.2.5 Straw yield

Straw yield was determined from the central 1 m2 area of each plot, after separating the grains. The sub-samples were oven dried to a constant weight and finally converted to t ha-1.

3.13.2.6 Harvest index (%)

It denotes the ratio of economic yield to biological yield and was calculated with the following formula.

$$\text{Harvest index (\%)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

Where, Biological yield = Grain yield + Stover yield

3.14 Statistical analysis

The data collected on different parameters were statistically analyzed with split plot design using the MSTAT computer package program developed. Least Significant Difference (LSD) technique at 5% level of significance was used by DMRT to compare the mean differences among the treatments (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSIN

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

4.1 Growth parameters

4.1.1 Plant height

Under the present study, plant height was significantly influenced by the application of sulphur (Fig. 1 and appendix V). Results revealed that the tallest plant (36.30, 49.90, 75.25 and 84.29 cm at 30, 50, 70 DAS and at harvest respectively) was achieved from the treatment of S_3 (20 kg S ha^{-1}) where the shortest plant (31.57, 45.58, 64.01 and 76.01 cm at 30, 50, 70 DAS and at harvest respectively) was obtained from the control treatment S_0 (0 kg S ha^{-1}) (Table 3). The results obtained from the treatment S_1 (10 kg S ha^{-1}) and S_2 (15 kg S ha^{-1}) was statistically different with S_3 (20 kg S ha^{-1}) treatment at all crop duration. Ali *et al.* (1982) found that S had significant effect on plant height, they observed that 30 kg S/ha increased the plant height. Similar results was also observed by Dai *et al.* (1995).

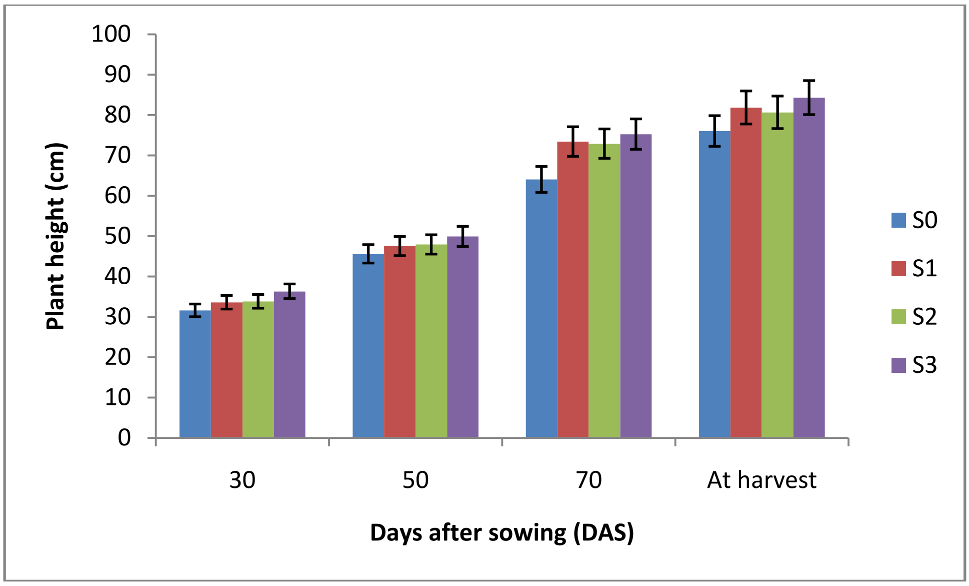

Fig.1. Plant height of wheat (BARI Gom-29) as influenced by S ($LSD_{0.05}$ = 1.052, 1.167, 1.314, 1.541)

S_0 (0 kg S ha^{-1}), S_1 (10 kg S ha^{-1}), S_2 (15 kg S ha^{-1}), S_3 (20 kg S ha^{-1})

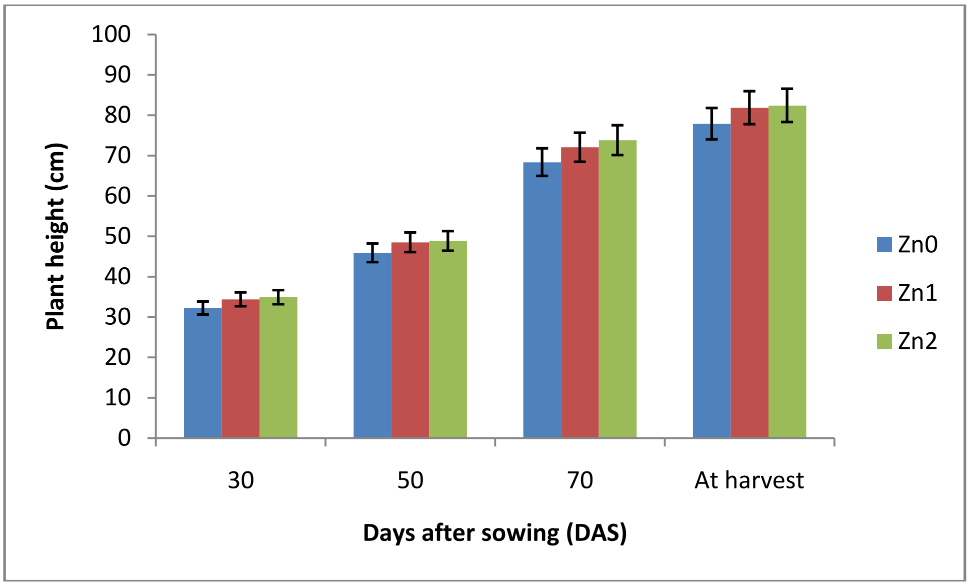

Fig. 2. Plant height of wheat (BARI Gom-29) as influenced by Zn ($LSD_{0.05}$ = 0.146, 0.237, 0.486, 0.511)

Zn_0 (0 kg Zn ha^{-1}), Zn_1 (1.3 kg Zn ha^{-1}), Zn_2 (1.6 kg Zn ha^{-1})

Plant height was significantly affected by the application of zinc (Fig. 2 and appendix V). Results revealed that the tallest plant (34.89, 48.82, 73.79 AND 82.40 cm at 30, 50, 70 DAS and at harvest respectively) was achieved from the treatment of Zn_2 (1.6 kg Zn ha^{-1}) which was closely followed by Zn_1 (1.3 kg Zn ha^{-1}) at all crop duration. The shortest plant (32.20, 45.87, 68.34 and 77.86 cm at 30, 50, 70 DAS and at harvest respectively) was obtained from the control treatment, Zn_0 (0 kg Zn ha^{-1}) (Table 1). Here, it was also observed that zinc had a contribution for higher plant growth and Zn_2 (1.6 kg Zn ha^{-1}) showed the best result where no application of zinc treatment showed shortest plant height. Mekkei and El-HagganEman (2014) obtained similar results and they observed that combination of micronutrients (Zn) produced the highest values of plant height. Bameri*et al.* (2012) found that plant height was significantly affected by the application of Zn and this result was also supported by Ahmadi*et al.* (2016) and Ranjbar and Bahmaniar (2007).

The interaction effect between sulphur and zinc were significant for the plant height at 30, 50, 70 DAS and at harvest (Appendix V and Table 1). It was observed that the tallest plant (38.11, 52.13, 79.26 and 88.85 cm at 30, 50, 70 DAS and at harvest respectively) was obtained with S_3Zn_1 which was statistically identical with S_3Zn_2 at 30 and 50 DAS but significantly different at 70 DAS and at harvest. S_3Zn_1 and S_2Zn_2 also gave comparatively higher plant height at all crop duration but significantly different from S_3Zn_1. The shortest plant (31.21, 44.87, 60.90 and 73.71 cm at 30, 50, 70 DAS and at harvest respectively) was obtained with S_0Zn_0 which was statistically identical with S_0Zn_1at 70 DAS and at harvest followed by S_0Zn_2, S_1Zn_0 an S_3Zn_0.

Table 1. Plant height of wheat (BARI Gom-29) as influenced by S and Zn donated on growth and yield

Treatment	Plant height (cm)			
	30 DAS	50 DAS	70 DAS	At harvest
S_0Zn_0	31.21 g	44.87 f	60.90 f	73.71 g
S_0Zn_1	31.52 fg	45.92 ef	62.22 f	74.63 g
S_0Zn_2	31.99 fg	45.95 ef	68.90 e	79.70 e
S_1Zn_0	32.54 ef	46.57 de	73.30 d	81.03 de
S_1Zn_1	33.67 cd	47.58 cd	72.60 d	81.73 cd
S_1Zn_2	34.53 c	48.34 c	74.31 cd	82.77 bc
S_2Zn_0	31.66 fg	45.75 ef	69.30 e	76.75 f
S_2Zn_1	34.12 cd	48.29 c	74.03 cd	82.11 cd
S_2Zn_2	35.62 b	49.68 b	75.30 bc	83.05 bc
S_3Zn_0	33.38 de	46.27 e	69.84 e	79.96 e
S_3Zn_1	38.11 a	52.13 a	79.26 a	88.85 a
S_3Zn_2	37.42 a	51.31 a	76.65 b	84.07 b
LSD$_{0.05}$	1.024	1.066	1.690	1.419
CV(%)	7.554	6.389	8.216	10.538

S_0 = 0 kg S ha^{-1}
S_1 = 10 kg S ha^{-1}
S_2 = 15 kg S ha^{-1}
S_3 = 20 kg S ha^{-1}

Zn_0 = 0 kg Zn ha^{-1}
Zn_1 = 1.3 kg Zn ha^{-1}
Zn_2 = 1.6 kg Zn ha^{-1}

4.1.2 Number of tillers plant^{-1}

Number of tillers plant^{-1} was significantly influenced by the application of sulphur (Fig. 3 and appendix VI). Results revealed that the highest number of tillers plant^{-1} (1.29, 2.83, 3.75 and 3.71 at 30, 50, 70 DAS and at harvest respectively) was achieved from the treatment of S_2 (15 kg S ha^{-1}) followed by S_1 (10 kg S ha^{-1}) and S_3 (20 kg S ha^{-1}). The lowest number of tillers plant^{-1} (1.04, 2.42, 3.22 and 3.17 at 30, 50, 70 DAS and at harvest respectively) was obtained from the control treatment S_0 (0 kg S ha^{-1}). Ali *et al.* (1982) found that S had significant effect on plant height, they observed that 30 kg S/ha increased the plant height. Similar results was also observed by Klikocka*et al*. (2016), Jarvan*et al*. (2008) and Kulczycki (2010).

Significant variation was found for number of tillers plant^{-1} affected by the application of zinc (Fig. 4 and appendix VI). Results revealed that the highest number of tillers plant^{-1} (1.29, 2.82, 3.76 and 3.73 at 30, 50, 70 DAS and at harvest respectively) was achieved from the treatment of Zn_1 (1.3 kg Zn ha^{-1}) followed by Zn_2 (1.6 kg Zn ha^{-1}) at all crop duration. The lowest number of tillers plant^{-1} (1.06, 2.47, 3.29 and 3.21 at 30, 50, 70 DAS and at harvest respectively) was obtained from the control treatment, Zn_0 (0 kg Zn ha^{-1}). Similar results were also observed by Ranjbar and Bahmaniar (2007), Genc*et al*. (2006) and Riffat*et al*., 2007. They found that Zn gave significantly higher tillers which is resulted highest yield.

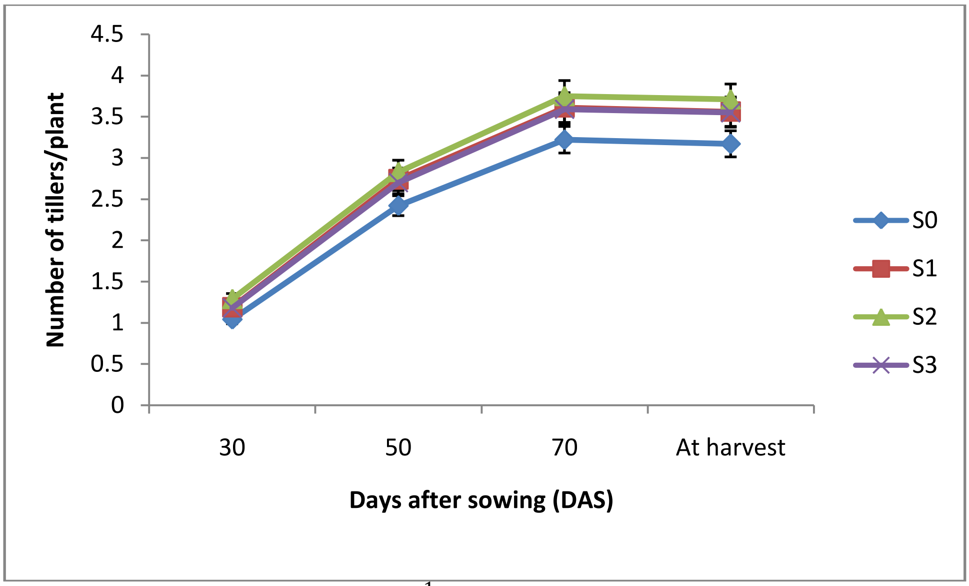

Fig. 3. Number of tillers plant^{-1} of wheat (BARI Gom-29) as influenced by S ($LSD_{0.05}$ = 0.059, 0.102, 0.122, 0.131)

S_0 (0 kg S ha^{-1}), S_1 (10 kg S ha^{-1}), S_2 (15 kg S ha^{-1}), S_3 (20 kg S ha^{-1})

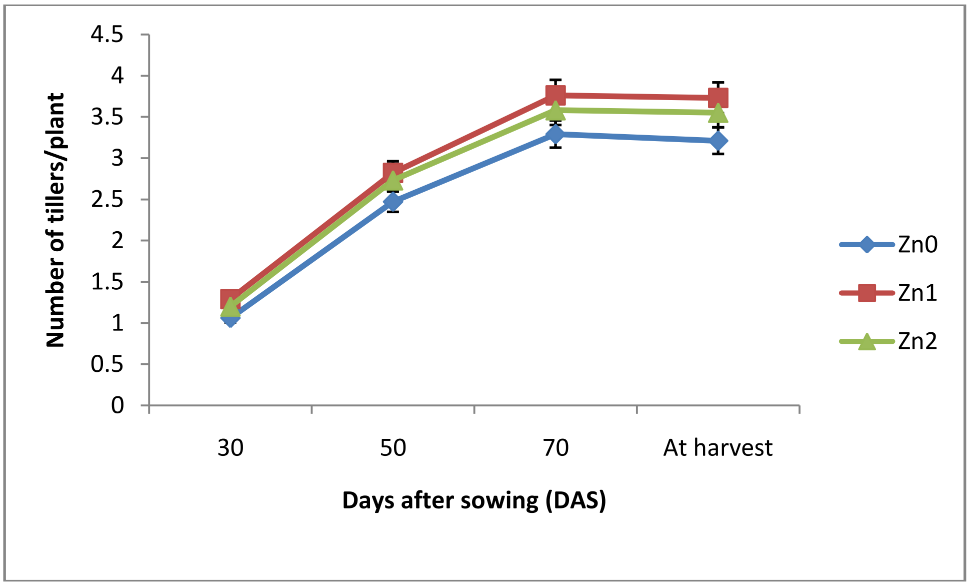

Fig. 4. Number of tillers plant^{-1} of wheat (BARI Gom-29) as influenced Zn ($LSD_{0.05}$ = 0.066, 0.087, 0.135, 0.138)

Zn_0 (0 kg Zn ha^{-1}), Zn_1 (1.3 kg Zn ha^{-1}), Zn_2 (1.6 kg Zn ha^{-1})

Combined effect of sulphur and zinc had varied influence on number of tillers plant^{-1} of wheat at 30, 50, 70 DAS and at harvest affected by combined effect of sulphur and zinc (Appendix VI and Table 2). It was observed that the highest number of tillers plant^{-1} (1.49, 3.09, 4.07 and 4.05 at 30, 50, 70 DAS and at harvest respectively) was obtained with S_2Zn_1 which was statistically identical with S_2Zn_2 and S_1Zn_1 at 70 DAS and at harvest followed by S_1Zn_1. The lowest number of tillers plant^{-1} (1.00, 2.29, 3.09 and 3.00 at 30, 50, 70 DAS and at harvest respectively) was obtained with S_0Zn_0 which was statistically similar with S_0Zn_1, S_1Zn_0 and S_2Zn_0.

Table 2. Number of tillers plant^{-1} of wheat (BARI Gom-29) as influenced by S and Zn donated on growth and yield

Treatment	Number of tillers plant^{-1}			
	30 DAS	50 DAS	70 DAS	At harvest
S_0Zn_0	1.00 e	2.29 g	3.09 g	3.00 e
S_0Zn_1	1.05 e	2.41 fg	3.24 fg	3.19 de
S_0Zn_2	1.07 de	2.55 ef	3.33 def	3.31 cd
S_1Zn_0	1.03 e	2.46 f	3.29 ef	3.24 de
S_1Zn_1	1.35 b	2.99 ab	3.94 ab	3.89 ab
S_1Zn_2	1.20 c	2.76 cd	3.60 c	3.51 c
S_2Zn_0	1.04 e	2.48 f	3.30 ef	3.22 de
S_2Zn_1	1.49 a	3.09 a	4.07 a	4.05 a
S_2Zn_2	1.35 b	2.93 b	3.89 ab	3.85 ab
S_3Zn_0	1.15 cd	2.63 de	3.47 cde	3.39 cd
S_3Zn_1	1.25 c	2.79 c	3.80 b	3.78 b
S_3Zn_2	1.16 cd	2.68 cde	3.51 cd	3.52 c
LSD$_{0.05}$	0.094	0.1312	0.186	0.245
CV(%)	6.117	7.364	6.589	6.436

S_0 = 0 kg S ha^{-1}
S_1 = 10 kg S ha^{-1}
S_2 = 15 kg S ha^{-1}
S_3 = 20 kg S ha^{-1}

Zn_0 = 0 kg Zn ha^{-1}
Zn_1 = 1.3 kg Zn ha^{-1}
Zn_2 = 1.6 kg Zn ha^{-1}

4.1.3 Dry weight plant^{-1}

Dry weight plant^{-1} varied significantly due to the application of different levels of sulphur (Fig. 5 and appendix VII). Results revealed that the highest dry weight plant^{-1} (5.91, 16.87, 27.90 and 33.53 g at 30, 50, 70 DAS and at harvest respectively) was achieved from the treatment of S_2 (15 kg S ha^{-1}) followed by S_1 (10 kg S ha^{-1}) and S_3 (20 kg S ha^{-1}). The lowest dry weight plant^{-1} (5.63, 14.56, 25.73 and 31.04 g at 30, 50, 70 DAS and at harvest respectively) was obtained from the control treatment S_0 (0 kg S ha^{-1}). Jarvan*et al.* (2008) and Klikocka*et al.* (2016) found that S application significantly increase dry matter production in wheat.

Significant variation was found for dry weight plant^{-1} affected by the application of different levels of zinc (Fig. 6 and appendix VII). Results revealed that the highest dry weight plant^{-1} (5.91, 16.95, 27.81 and 31.41 g at 30, 50, 70 DAS and at harvest respectively) was achieved from the treatment of Zn_1 (1.3 kg Zn ha^{-1}) followed by Zn_2 (1.6 kg Zn ha^{-1}) at all crop duration. The lowest dry weight plant^{-1} (5.68, 14.69, 25.96 and 31.41 g at 30, 50, 70 DAS and at harvest respectively) was obtained from the control treatment, Zn_0 (0 kg Zn ha^{-1}). Similar results were observed by Ranjbar and Bahmaniar (2007), Ali *et al*. (2013) and Ai-Qing *et al*. (2011), they found that Zn had great influence on dry matter production in wheat plants.

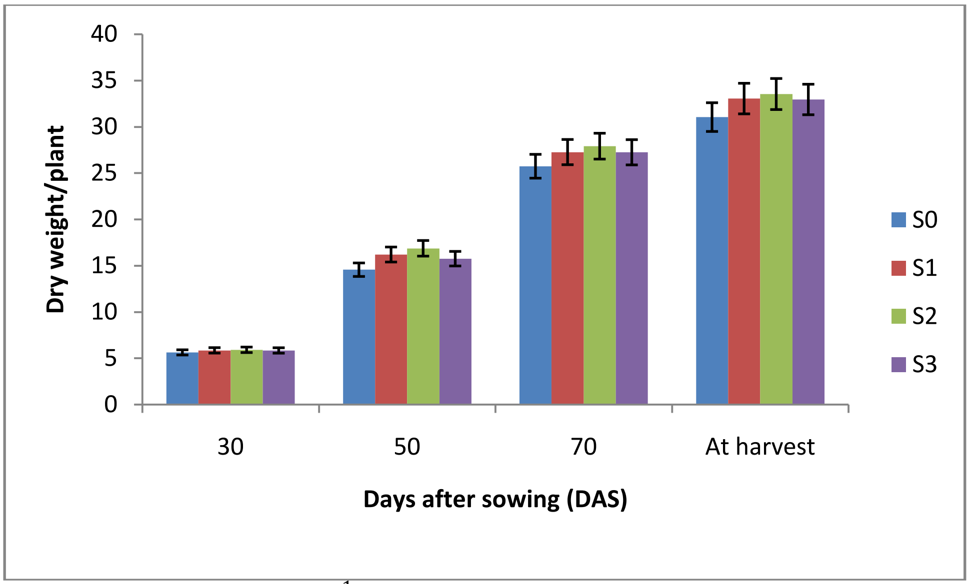

Fig. 5. Dry weight $plant^{-1}$ (BARI Gom-29) as influenced by S ($LSD_{0.05}$ = 0.049, 0.314, 0.416, 0.448)
S_0 (0 kg S ha^{-1}), S_1 (10 kg S ha^{-1}), S_2 (15 kg S ha^{-1}), S_3 (20 kg S ha^{-1})

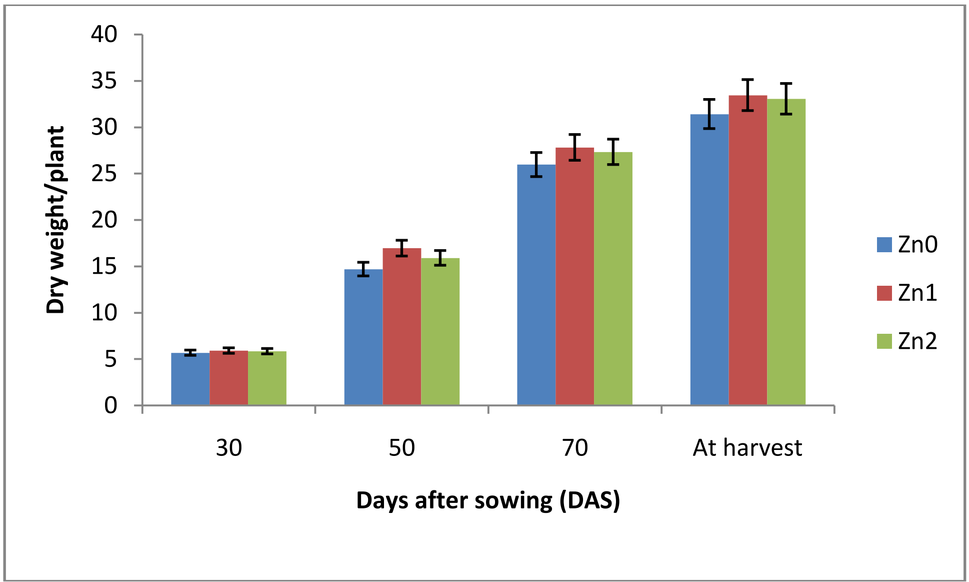

Fig. 6. Dry weight $plant^{-1}$ (BARI Gom-29) as influenced by Zn ($LSD_{0.05}$ = 0.063, 0.562, 0.466, 0.348)
Zn_0 (0 kg Zn ha^{-1}), Zn_1 (1.3 kg Zn ha^{-1}), Zn_2 (1.6 kg Zn ha^{-1})

Varied difference was observed for dry weight plant^{-1} of wheat at 30, 50, 70 DAS and at harvest (Appendix VII and Table 3). Results revealed that the highest dry weight plant^{-1} (6.11, 18.92, 29.41 and 34.89 g at 30, 50, 70 DAS and at harvest respectively) was obtained with S_2Zn_1 followed by S_1Zn_1, S_2Zn_2 and S_3Zn_1. The lowest dry weight plant^{-1} (5.57, 14.13, 25.04 and 30.11 g at 30, 50, 70 DAS and at harvest respectively) was obtained with S_0Zn_0 which followed by S_0Zn_1 and S_1Zn_0.

Table 3. Dry weight plant^{-1} (BARI Gom-29) as influenced by S and Zn donated on growth and yield

Treatment	Dry weight plant^{-1} (g)			
	30 DAS	50 DAS	70 DAS	At harvest
S_0Zn_0	5.57 f	14.13 h	25.05 i	30.11 h
S_0Zn_1	5.64 ef	14.64 gh	25.53 hi	30.90 g
S_0Zn_2	5.69 e	14.90 g	26.60 fg	32.12 ef
S_1Zn_0	5.69 e	14.72 gh	25.71 hi	31.27 g
S_1Zn_1	5.99 b	17.75 b	28.57 b	34.33 b
S_1Zn_2	5.88 cd	16.12 de	27.49 cde	33.21 d
S_2Zn_0	5.67 e	14.77 gh	26.17 gh	31.77 f
S_2Zn_1	6.11 a	18.92 a	29.41 a	34.89 a
S_2Zn_2	5.95 bc	16.92 c	28.12 bc	33.93 c
S_3Zn_0	5.79 d	15.12 fg	26.89 efg	32.50 e
S_3Zn_1	5.89 cd	16.47 cd	27.72 cd	33.69 c
S_3Zn_2	5.84 d	15.67 ef	27.10 def	32.93 d
$LSD_{0.05}$	0.093	0.6011	0.7124	0.3935
CV(%)	5.389	6.271	6.334	8.612

S_0 = 0 kg S ha^{-1}
S_1 = 10 kg S ha^{-1}
S_2 = 15 kg S ha^{-1}
S_3 = 20 kg S ha^{-1}

Zn_0 = 0 kg Zn ha^{-1}
Zn_1 = 1.3 kg Zn ha^{-1}
Zn_2 = 1.6 kg Zn ha^{-1}

4.2 Yield contributing parameters

4.2.1 Spike length

Significant influence was found in terms spike length of wheat affected by application of different sulphur levels (Fig. 7 and appendix VIII). Results indicated that the highest spike length (9.86 cm) was achieved from the treatment of S_2 (15 kg S ha^{-1}) followed by S_1 (10 kg S ha^{-1}). The lowest spike length (6.83 cm) was obtained from the control treatment S_0 (0 kg S ha^{-1}) followed by and S_3 (20 kg S ha^{-1}). Kaushik and Sharma (1997) observed that S fertilizer had influence on increased spike length which supported by the presenting.

Significant variation was observed for spike lengthaffected by the application of different levels of zinc (Fig. 8 and appendix VIII). Results revealed that the highest spike length (9.93 cm) was achieved from the treatment of Zn_1 (1.3 kg Zn ha^{-1}) followed by Zn_2 (1.6 kg Zn ha^{-1}) at the time of harvest. The lowest spike length (7.01 cm) was obtained from the control treatment, Zn_0 (0 kg Zn ha^{-1}). Similar results were also found by Gul*et al*. (2011) and Dewal and Pareek (2004)

Influence of combined effect of sulphur and zinc was found to be significant for spike length of wheat at the time of harvest (Appendix VIII and Table 4). It was observed that the highest spike length (12.40 cm) was obtained with S_2Zn_1 which was statistically identical with S_1Zn_1 followed by S_2Zn_2 and S_3Zn_1. Similarly, the lowest spike length (6.43 cm) was obtained with S_0Zn_0 followed by S_0Zn_1, S_0Zn_2 and S_1Zn_0.

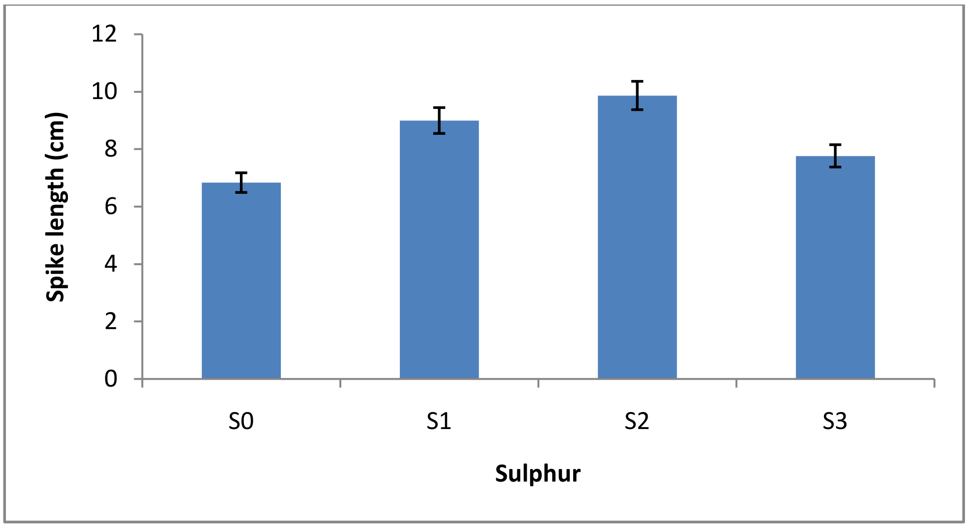

Fig. 7. Spike length of wheat (BARI Gom-29) as influenced by S ($LSD_{0.05}$ = 0.766)

S_0 (0 kg S ha^{-1}), S_1 (10 kg S ha^{-1}), S_2 (15 kg S ha^{-1}), S_3 (20 kg S ha^{-1})

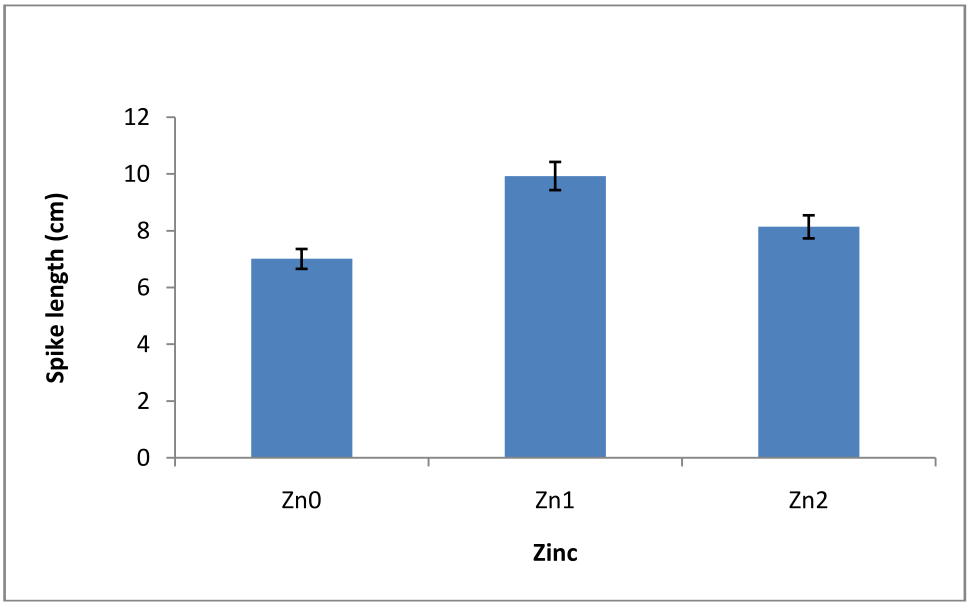

Fig. 8.Spike length of wheat (BARI Gom-29) as influenced by Zn ($LSD_{0.05}$ = 1.038)

Zn_0 (0 kg Zn ha^{-1}), Zn_1 (1.3 kg Zn ha^{-1}), Zn_2 (1.6 kg Zn ha^{-1})

4.2.2 Number of grain spike^{-1}

Number of grain spike^{-1} of wheat was significantly influenced by application of different sulphur levels (Fig. 9 and appendix VIII). Results demonstrated that the highest number of grain spike^{-1} (32.37) was achieved from the treatment of S_2 (15 kg S ha^{-1}) followed by S_1 (10 kg S ha^{-1}). The lowest number of grain spike^{-1} (24.46) was obtained from the control treatment S_0 (0 kg S ha^{-1})

followed by and S_3 (20 kg S ha^{-1}). Kaushik and Sharma (1997) also found that number of grain $spike^{-1}$ was significantly influenced by S.

Significant variation was observed for number of grain $spike^{-1}$ affected by the application of different levels of zinc (Fig. 10 and appendix VIII). Results revealed that the highest number of grain $spike^{-1}$ (31.16) was achieved from the treatment of Zn_1 (1.3 kg Zn ha^{-1}) followed by Zn_2 (1.6 kg Zn ha^{-1}) at the time of harvest. The lowest number of grain $spike^{-1}$ (25.38) was obtained from the control treatment, Zn_0 (0 kg Zn ha^{-1}). Gul*et al.* (2011) found that number of grain $spike^{-1}$ significantly by Zn.

Significant variation was found for number of grain $spike^{-1}$ of wheat at the time of harvest affected by combined effect of sulphur and zinc (Appendix VIII and Table 4). It was observed that the highest number of grain $spike^{-1}$ (38.25) was obtained with S_2Zn_1 followed by S_1Zn_1 and S_2Zn_2. Similarly, the lowest number of grain $spike^{-1}$ (23.03) was found from S_0Zn_0 which was statistically identical with S_0Zn_1 followed by S_1Zn_0.

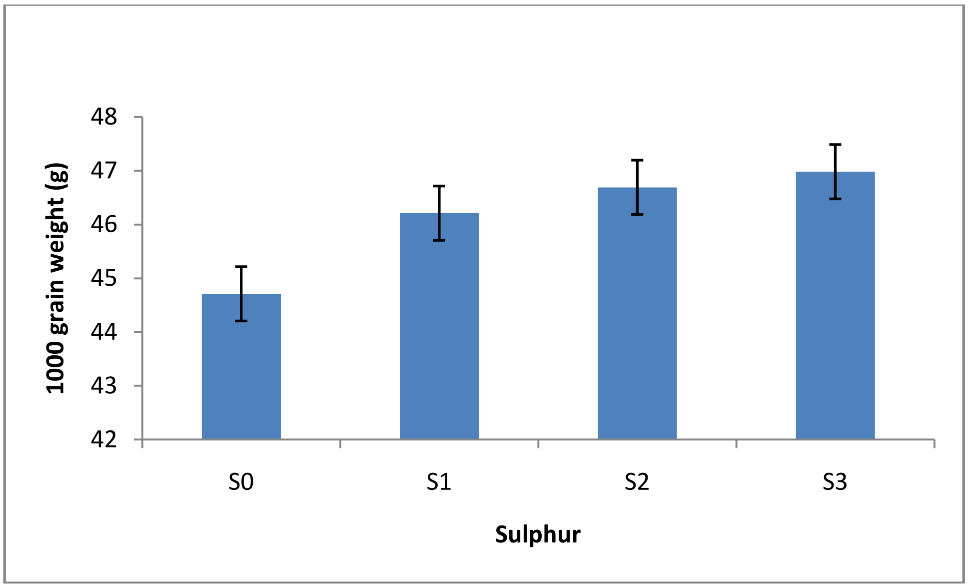

Fig. 9. Number of grain/spike of wheat (BARI Gom-29) as influenced by S ($LSD_{0.05}$ = 1.032)

S_0 (0 kg S ha^{-1}), S_1 (10 kg S ha^{-1}), S_2 (15 kg S ha^{-1}), S_3 (20 kg S ha^{-1})

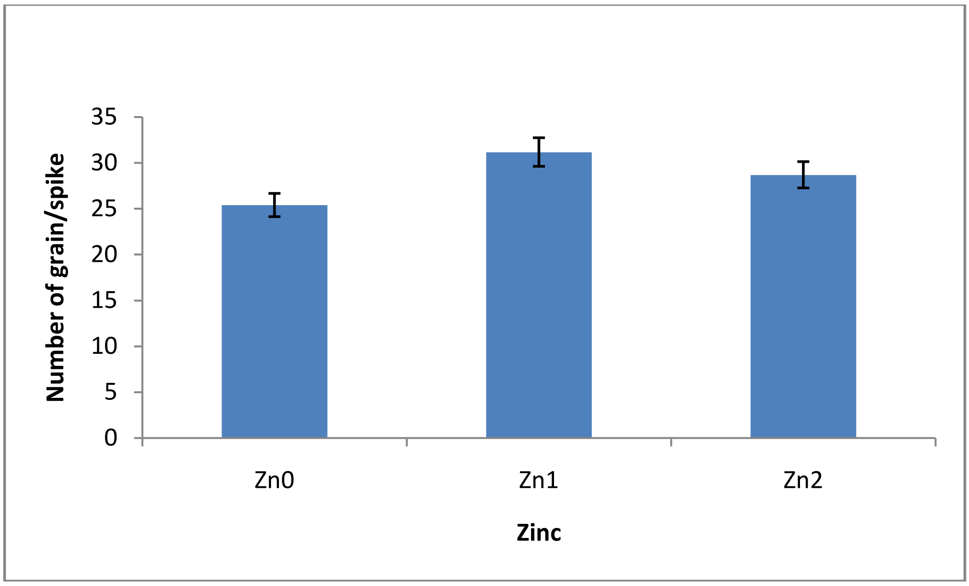

Fig. 10. Number of grain/spike of wheat (BARI Gom-29) as influenced by Zn ($LSD_{0.05}$ = 2.364)

Zn_0 (0 kg Zn ha^{-1}), Zn_1 (1.3 kg Zn ha^{-1}), Zn_2 (1.6 kg Zn ha^{-1})

4.2.3 Weight of 1000 grains

Significant influence was found in terms 1000 grain weight of wheat affected by application of different sulphur levels (Fig. 11 and appendix VIII). Results indicated that the highest 1000 grain weight (46.98 g) was attained from the treatment of S_3 (20 kg S ha^{-1}) followed by S_2 (15 kg S ha^{-1}). The lowest 1000 grain weight (44.71 g) was found from the control treatment S_0 (0 kg S ha^{-1}) followed by and S_1 (10 kg S ha^{-1}). Hayat *et al.* (2015) observed that applications of 20 kg S ha^{-1} was helpful in increasing 1000 grain weight in wheat varieties. Klikocka*et al.* (2016) also found similar result.

Significant variation was observed for 1000 grain weight affected by the application of different levels of zinc (Fig. 12 and appendix VIII). Results revealed that the highest 1000 grain weight (47.15 g) was achieved from the treatment of Zn_2 (1.6 kg Zn ha^{-1}) followed by Zn_1 (1.3 kg Zn ha^{-1}) at the time of harvest. The lowest 1000 grain weight (44.94 g) was obtained from the control treatment, Zn_0 (0 kg Zn ha^{-1}). Ahmadi*et al.* (2016) and Ranjbar and Bahmaniar (2007) found similar results with the present findings.

1000 grain weight of wheat at the time of harvest was significantly varied by combined effect of sulphur and zincr (Appendix VIII and Table 4). It was observed that the highest 1000 grain weight (48.42 g) was obtained with S_3Zn_2 which was statistically identical with S_2Zn_1 followed by S_2Zn_2. Similarly, the lowest 1000 grain weight (44.13 g) was found in S_0Zn_0 followed by S_0Zn_1, S_0Zn_2, S_1Zn_0 and S_2Zn_0.

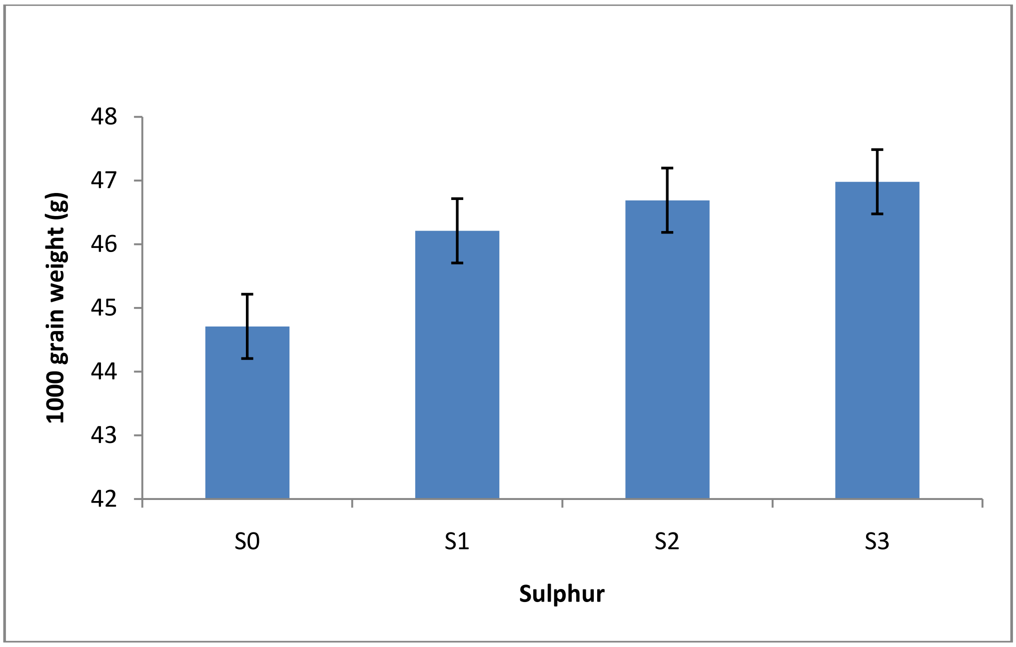

Fig. 11. 1000 grain weight of wheat (BARI Gom-29) as influenced by S ($LSD_{0.05} = 0.158$)

S_0 (0 kg S ha^{-1}), S_1 (10 kg S ha^{-1}), S_2 (15 kg S ha^{-1}), S_3 (20 kg S ha^{-1})

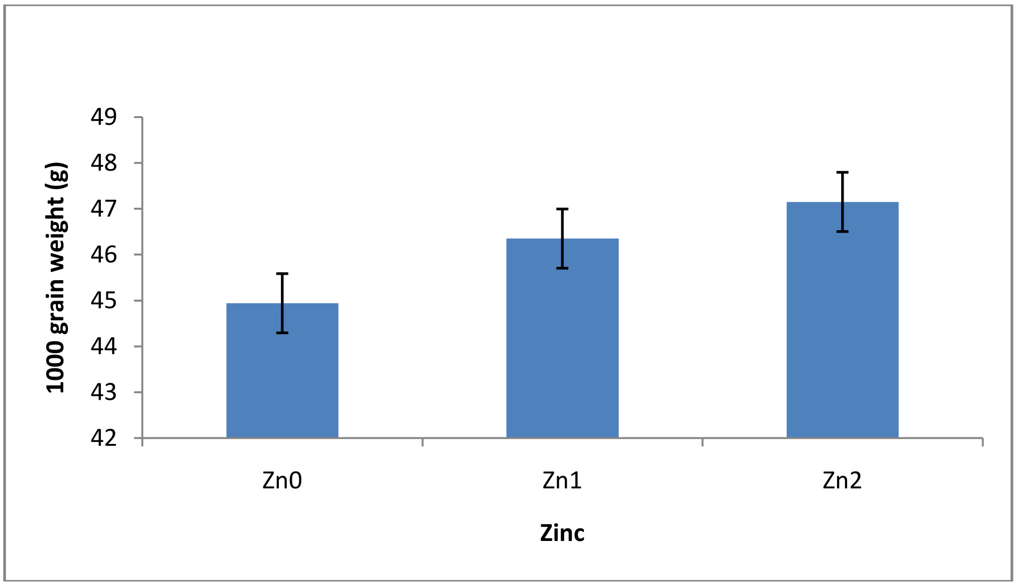

Fig. 12. 1000 grain weight of wheat (BARI Gom-29) as influenced by Zn($LSD_{0.05} = 0.719$)

Zn_0 (0 kg Zn ha^{-1}), Zn_1 (1.3 kg Zn ha^{-1}), Zn_2 (1.6 kg Zn ha^{-1})

Table 4. Yield contributing characters of wheat (BARI Gom-29) as influenced by S and Zn donated on growth and yield

Treatment	Yield contributing characters		
	Spike length (cm)	Number of grain spike^{-1}	1000 grain weight (g)
S_0Zn_0	6.43 g	23.03 g	44.13
S_0Zn_1	6.88 f	23.93 g	44.86
S_0Zn_2	7.18 ef	26.43 e	45.13
S_1Zn_0	7.02 f	25.23 f	45.25
S_1Zn_1	12.2 a	32.63 b	45.94
S_1Zn_2	7.73 d	28.44 d	46.61
S_2Zn_0	7.15 ef	26.43 e	44.81
S_2Zn_1	12.4 a	38.25 a	48.21
S_2Zn_2	10.0 b	32.43 b	47.72
S_3Zn_0	7.45 de	26.83 e	45.58
S_3Zn_1	8.21 c	29.83 c	47.10
S_3Zn_2	7.62 d	27.43 de	48.42
$LSD_{0.05}$	0.347	1.082	NS
CV(%)	6.792	8.539	

S_0 = 0 kg S ha^{-1}
S_1 = 10 kg S ha^{-1}
S_2 = 15 kg S ha^{-1}
S_3 = 20 kg S ha^{-1}

Zn_0 = 0 kg Zn ha^{-1}
Zn_1 = 1.3 kg Zn ha^{-1}
Zn_2 = 1.6 kg Zn ha^{-1}

4.3 Yield parameters

4.3.1 Grain yield

Grain yieldof wheat influenced significantly by application of different sulphur levels (Table 5 and appendix VIII). It was found that the highest grain yield (4.23 t ha^{-1}) was achieved from the treatment of S_2 (15 kg S ha^{-1}) followed by S_1 (10 kg S ha^{-1}) and S_3 (20 kg S ha^{-1}). Again, the lowest grain yield (3.62 t ha^{-1}) was obtained from the control treatment S_0 (0 kg S ha^{-1}). Hayat *et al*. (2015) observed that applications of 20 kg S ha^{-1} was helpful in increasing grain yields in wheat varieties. Similar results was also observed by Honermeier and Simioniuc, 2004, Jarvan*et al*. (2008) and Ali *et al.* (1982).

Significant variation was observed for grain yieldaffected by the application of different levels of zinc (Table 5 and appendix VIII). It was observed that the highest grain yield (4.23 t ha^{-1}) was achieved from the treatment of Zn_1 (1.3 kg Zn ha^{-1}) followed by Zn_2 (1.6 kg Zn ha^{-1}). The lowest grain yield (3.77 t ha^{-1}) was obtained from the control treatment, Zn_0 (0 kg Zn ha^{-1}). Sultana *et al.* (2016), Ahmadi*et al.* (2016) and Ranjbar and Bahmaniar (2007) also showed supported results with the present findings.

Varied difference was found for grain yield of wheat at the time of harvest affected by combined effect of sulphur and zinc (Appendix VIII and Table 5). It was observed that the highest grain yield (4.46 t ha^{-1}) was obtained with S_2Zn_1 which was statistically similar with S_1Zn_1 and S_2Zn_2 followed by S_3Zn_1. Similarly, the lowest grain yield (3.27 t ha^{-1}) was found from S_0Zn_0 which was followed by S_0Zn_1.

4.3.2 Stover yield

The stover yieldof wheat affected by different sulphur levels was found to be significant (Table 5 and appendix VIII). It was noticed that the highest stover yield (5.59 t ha^{-1}) was achieved from the treatment of S_2 (15 kg S ha^{-1}) which was closely followed by S_3 (20 kg S ha^{-1}). Again, the lowest stover yield (5.01 t ha^{-1}) was obtained from the control treatment S_0 (0 kg S ha^{-1}).

Significant effect was found for stover yieldaffected by the application of different levels of zinc (Table 5 and appendix VIII). It was claimed that the highest stover yield (5.56 t ha^{-1}) was achieved from the treatment of Zn_1 (1.3 kg Zn ha^{-1}) followed by Zn_2 (1.6 kg Zn ha^{-1}). The lowest stover yield (5.15 t ha^{-1}) was obtained from the control treatment, Zn_0 (0 kg Zn ha^{-1}). Gul*et al*. (2011) obtained the similar findings which supported the present study.

Significant differences was found for stover yield of wheat at the time of harvest by combined effect of sulphur and zinc (Appendix VIII and Table 5). It was observed that the highest stover yield (5.80 t ha^{-1}) was obtained with S_2Zn_1 which was statistically similar with S_1Zn_1, S_1Zn_2, S_2Zn_2 and S_3Zn_1. Similarly, the lowest stover yield (4.80 t ha^{-1}) was found from S_0Zn_0 which was statistically identical with S_0Zn_1 and S_1Zn_0.

4.3.3 Harvest index

Harvest indexof wheat was influenced significantly by application of different sulphur levels (Table 5 and appendix VIII). It was found that the highest harvest index (43.08%) was achieved from the treatment of S_2 (15 kg S ha^{-1}) which was statistically identical with S_1 (10 kg S ha^{-1}) followed by S_3 (20 kg S ha^{-1}). Again, the lowest harvest index (41.95%) was obtained from the control treatment S_0 (0 kg S ha^{-1}).

Significant variation was observed for harvest indexaffected by the application of different levels of zinc (Table 5 and appendix VIII). It was observed that the highest harvest index (43.21%) was achieved from the treatment of Zn_1 (1.3 kg Zn ha^{-1}) which was statistically identical with Zn_2 (1.6 kg Zn ha^{-1}). The lowest harvest index (42.26%) was obtained from the control treatment, Zn_0 (0 kg Zn ha^{-1}).

Significant influence was found for harvest index of wheat at the time of harvest affected by combined effect of sulphur and zinc (Appendix VIII and Table 5). It was observed that the highest harvest index (43.47%) was obtained with S_2Zn_1 which was statistically identical with S_1Zn_1, S_2Zn_2 and S_3Zn_2 and statistically similar with S_3Zn_1 and S_1Zn_0. Similarly, the lowest harvest index (40.52%) was found from S_0Zn_0 followed by S_0Zn_1.

Table 5. Yield parameters of wheat (BARI Gom-29) as influenced by S and Zn donated on growth and yield

Treatment	Yield parameters		
	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	Harvest index (%)
Effect of sulphur (S)			
S_0	3.62 b	5.01 b	41.95 c
S_1	4.19 a	5.54 a	43.06 a
S_2	4.23 a	5.59 a	43.08 a
S_3	4.16 a	5.57 a	42.75b
$LSD_{0.05}$	0.042	0.051	0.284
CV(%)	6.364	7.819	8.296
Effect of zinc (Zn)			
Zn_0	3.77 b	5.15 b	42.26 b
Zn_1	4.23 a	5.56 a	43.21 a
Zn_2	4.18 a	5.51 a	43.14 a
$LSD_{0.05}$	0.127	0.172	0.248
CV(%)	6.364	7.819	8.296
Combined effect of S and Zn			
S_0Zn_0	3.27 g	4.80 f	40.52 e
S_0Zn_1	3.54 f	4.84 f	42.24 d
S_0Zn_2	4.04 d	5.40 de	42.80 c
S_1Zn_0	3.78 e	4.98 f	43.15 a-c
S_1Zn_1	4.41 ab	5.75 ab	43.41 a
S_1Zn_2	4.28 bc	5.60 a-d	43.32 ab
S_2Zn_0	3.83 e	5.26 e	42.13 d
S_2Zn_1	4.46 a	5.80 a	43.47 a
S_2Zn_2	4.38 ab	5.72 ab	43.37 a
S_3Zn_0	4.18 c	5.55 b-d	42.96 bc
S_3Zn_1	4.31 bc	5.65 a-c	43.27 ab
S_3Zn_2	4.21 c	5.50 cd	43.36 a
$LSD_{0.05}$	0.131	0.185	0.3470
CV(%)	6.364	7.819	8.296

S_0 = 0 kg S ha^{-1}
S_1 = 10 kg S ha^{-1}
S_2 = 15 kg S ha^{-1}
S_3 = 20 kg S ha^{-1}

Zn_0 = 0 kg Zn ha^{-1}
Zn_1 = 1.3 kg Zn ha^{-1}
Zn_2 = 1.6 kg Zn ha^{-1}

4.4 Nutrient status in post harvest soils

4.4.1 % organic matter

Percent (% organic matter) in post harvest soil was not influenced significantly by application of different sulphur levels (Table 6 and appendix IX). But it was found that the highest % organic matter (0.57%) was achieved from the treatment of S_2 (15 kg S ha^{-1}) and the lowest % organic matter (0.50%) was obtained from the control treatment S_0 (0 kg S ha^{-1}).

Percent (% organic matter) in post harvest soil was not also influenced significantly by application of different Zn levels (Table 6 and appendix IX). But it was found that the highest % organic matter (0.59%) was achieved from the treatment of Zn_1 (1.3 kg Zn ha^{-1}) and the lowest % organic matter (0.51%) was obtained from the control treatment Zn_0 (0 kg Zn ha^{-1}).

Significant influence was not also found in postharvest soil after wheat harvest (Appendix IX and Table 6). But it was observed that the highest % organic matter (0.70%) was obtained with S_2Zn_1 and the lowest % organic matter (0.46%) was found from S_0Zn_0.

4.4.2 Available S

Available S in post harvest soil was influenced significantly by application of different sulphur levels (Table 6 and appendix IX). It was found that the highest available S (19.28 µ gm/gm) was achieved from the treatment of S_3 (20 kg S ha^{-1}) and the lowest available S (9.98µ gm/gm) was obtained from the control treatment S_0 (0 kg S ha^{-1}).

Available S in post harvest soil was not influenced significantly by application of different Zn levels (Table 6 and appendix IX). But it was observed that the highest available S (15.23µ gm/gm) was achieved from the treatment of Zn_2 (1.6 kg Zn ha^{-1}) and the lowest available S (14.45µ gm/gm) was obtained from the control treatment Zn_0 (0 kg Zn ha^{-1}).

Significant influence was found in postharvest soil after wheat harvest (Appendix IX and Table 6). It was observed that the highest available S (19.62µ gm/gm) was obtained with S_2Zn_1 which was statistically identical with S_3Zn_1

and the lowest available S (9.88µ gm/gm) was found from S_0Zn_0 which was statistically identical with S_0Zn_1.

4.4.2 Available Zn

Available Zn in post harvest soil was not influenced significantly by application of different sulphur levels (Table 6 and appendix IX). But it was found that the highest available Zn (3.18µ gm/gm) was achieved from the treatment of S_2 (15 kg S ha^{-1}) and the lowest available Zn (3.01µgm/gm) was obtained from the control treatment S_0 (0 kg S ha^{-1}).

Available Zn in postharvest soil was not influenced significantly by application of different Zn levels (Table 6 and appendix IX). But it was observed that the highest available Zn (3.19 µ gm/gm) was achieved from the treatment of Zn_2 (1.6 kg Zn ha^{-1}) and the lowest available Zn (3.03 µ gm/gm) was obtained from the control treatment Zn_0 (0 kg Zn ha^{-1}).

Significant influence was found for Zn in postharvest soil after wheat harvest by combined effect of Zn and Zn (Appendix IX and Table 6). It was observed that the highest available Zn (3.38 µgm/gm) was obtained with S_2Zn_2which was statistically identical with S_1Zn_2 and the lowest available Zn (2.85 µgm/gm) was found from S_0Zn_0 which was statistically identical with S_1Zn_0.

Table 6. Nutrient status in post harvest soils as influenced by S and Zn donated on growth and yield

Treatment	Yield parameters		
	% Organic matter	Available S (µ gm/gm)	Available Zn (µg g^{-1})
Effect of sulphur (S)			
S_0	0.50	9.98 d	3.01
S_1	0.60	14.00 c	3.26
S_2	0.57	16.01 b	3.18
S_3	0.53	19.28 a	3.09
$LSD_{0.05}$	NS	1.116	NS
CV(%)			
Effect of zinc (Zn)			
Zn_0	0.51	14.45	3.03
Zn_1	0.59	14.78	3.18
Zn_2	0.56	15.23	3.19
$LSD_{0.05}$	NS	NS	NS
CV(%)			
Combined effect of S and Zn			
S_0Zn_0	0.46	9.88 h	2.85 e
S_0Zn_1	0.49	9.93 h	3.14 b
S_0Zn_2	0.55	10.14 g	3.04bc
S_1Zn_0	0.61	13.86 f	2.88 e
S_1Zn_1	0.55	13.70 f	3.08 bc
S_1Zn_2	0.65	14.44 e	3.37 a
S_2Zn_0	0.48	15.40 d	2.96 d
S_2Zn_1	0.70	15.88 d	3.12 cd
S_2Zn_2	0.52	16.75 c	3.38 a
S_3Zn_0	0.50	18.64 b	2.98 d
S_3Zn_1	0.58	19.57 a	3.17 b
S_3Zn_2	0.51	19.62 a	3.20 b
$LSD_{0.05}$	NS	0.127	0.075
CV(%)	5.637	7.831	6.448

S_0 = 0 kg S ha^{-1}

S_1 = 10 kg S ha^{-1}

S_2 = 15 kg S ha^{-1}

S_3 = 20 kg S ha^{-1}

Zn_0 = 0 kg Zn ha^{-1}

Zn_1 = 1.3 kg Zn ha^{-1}

Zn_2 = 1.6 kg Zn ha^{-1}

CHAPTER V

SUMMARY AND CONCLUSION

An experiment was conducted at the research field of Sher-e-Bangla Agricultural University, Dhaka to evaluate the effect of S and Zn on the growth and yield of wheat (BARI Gom-29). The unit plots were fertilized with 150 kg, N, 125 kg TSP, 67 kg MoP and Gypsum 80 kg ha^{-1} respectively. Zinc and Boron were applied as per experimental specification through Zinc sulphate (60% Zn) and boric acid (17% B) respectively.

The experiment was two factorials with four levels of S and three levels of Zn. Four levels of sulphur*viz*. (i) S_0 = 0 kg S ha^{-1} (Control), (ii) S_1 = 10 kg S ha^{-1}, (iii) S_2 = 15 kg S ha^{-1} and (iv)S_3 = 20 kg S ha^{-1} and three levels of boron *viz*. (i) Zn_0 = 0 kg Zn ha^{-1} (Control), (ii) Zn_1 = 1.3 kg Zn ha^{-1} and (iii) Zn_2 = 1.6 kg Zn ha^{-1} were used as experimental treatments. The experiment was laid out in a randomized complete block design with three replications. There were 36 unit plots and the size of the plot was 2m × 2m i.e. 4 m^2. There were 12 treatments combination. Wheat seed of cv. BARI Gom-29 was sown as test crop. Data on different growth and yield parameters were recorded and analyzed statistically.

Sulphur had great influence on growth, yield and yield contributing parameters of wheat under the present study. Results revealed that the tallest plant (84.29 cm) and highest 1000 grain weight (46.98 g) was attained from S_3 (20 kg S ha^{-1}) where the highest number of tillers plant^{-1} (3.71), dry weight plant^{-1} (33.53 g), spike length (9.86 cm), number of grain spike^{-1} (32.37), grain yield (4.23 t ha^{-1}), stover yield (5.59 t ha^{-1}) and the highest harvest index (43.08%) were achieved from the treatment of S_2 (15 kg S ha^{-1}). But the lowest plant height (76.01 cm), number of tillers plant^{-1} (3.17), dry weight plant^{-1} (31.04 g), spike length (6.83 cm), number of grain spike^{-1} (24.46), 1000 grain weight (44.71 g), grain yield (3.62 t ha^{-1}), stover yield (5.01 t ha^{-1}) and lowest harvest index (41.95%) were obtained from the control treatment S_0 (0 kg S ha^{-1})

In case of Zn application, the tallest plant (82.40 cm) and highest 1000 grain weight (47.15 g) was achieved from the treatment of Zn_2 (1.6 kg Zn ha^{-1}) where the highest number of tillers $plant^{-1}$ (3.73), dry weight $plant^{-1}$ (5 31.41 g),spike length (9.93 cm), number of grain $spike^{-1}$ (31.16), grain yield (4.23 t ha^{-1}), stover yield (5.56 t ha^{-1}) and harvest index (43.21%) were achieved from the treatment of Zn_1 (1.3 kg Zn ha^{-1}) but the lowest plant height (77.86 cm), number of tillers $plant^{-1}$ (3.21), dry weight $plant^{-1}$ (31.41 g), spike length (7.01 cm), number of grain $spike^{-1}$ (25.38), 1000 grain weight (44.94 g), grain yield (3.77 t ha^{-1}), stover yield (5.15 t ha^{-1}) and harvest index (42.26%) were obtained from the control treatment, Zn_0 (0 kg Zn ha^{-1}).

Combination of sulphur and zinc had great influence on different growth and yield parameters. Results exposed that the highest plant height (88.85 cm) was obtained with S_3Zn_1 and highest 1000 grain weight (48.42 g) was obtained with S_3Zn_2 but the highest number of tillers $plant^{-1}$ (4.05), highest dry weight $plant^{-1}$ (34.89 g a), highest spike length (12.40 cm), highest number of grain $spike^{-1}$ (38.25), highest grain yield (4.46 t ha^{-1}), highest stover yield (5.80 t ha^{-1}) and harvest index (43.47%) were obtained from S_2Zn_1. The lowest plant height (73.71 cm), lowest number of tillers $plant^{-1}$ (3.00), dry weight $plant^{-1}$ (30.11 g), spike length (6.43 cm), number of grain $spike^{-1}$ (23.03), 1000 grain weight (44.13 g), grain yield (3.27 t ha^{-1}), stover yield (4.80 t ha^{-1}) and harvest index (40.52%) were found from S_0Zn_0.

The overall results of the present study demonstrated that wheat may be grown successfully for obtaining maximum yield with the application of S_2 (15 kg S ha^{-1}) as foliar application and Zn_1 (1.3 kg Zn ha^{-1}) treatment as soil application. However, before making conclusion concerning the appropriate dose of S and Zn, the study needs further investigation in other Agro Ecological Zones (AEZs) of Bangladesh for country-wide recommendation which will be useful.

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APPENDICES

Appendix l: Experimental site showing in the map under the present study

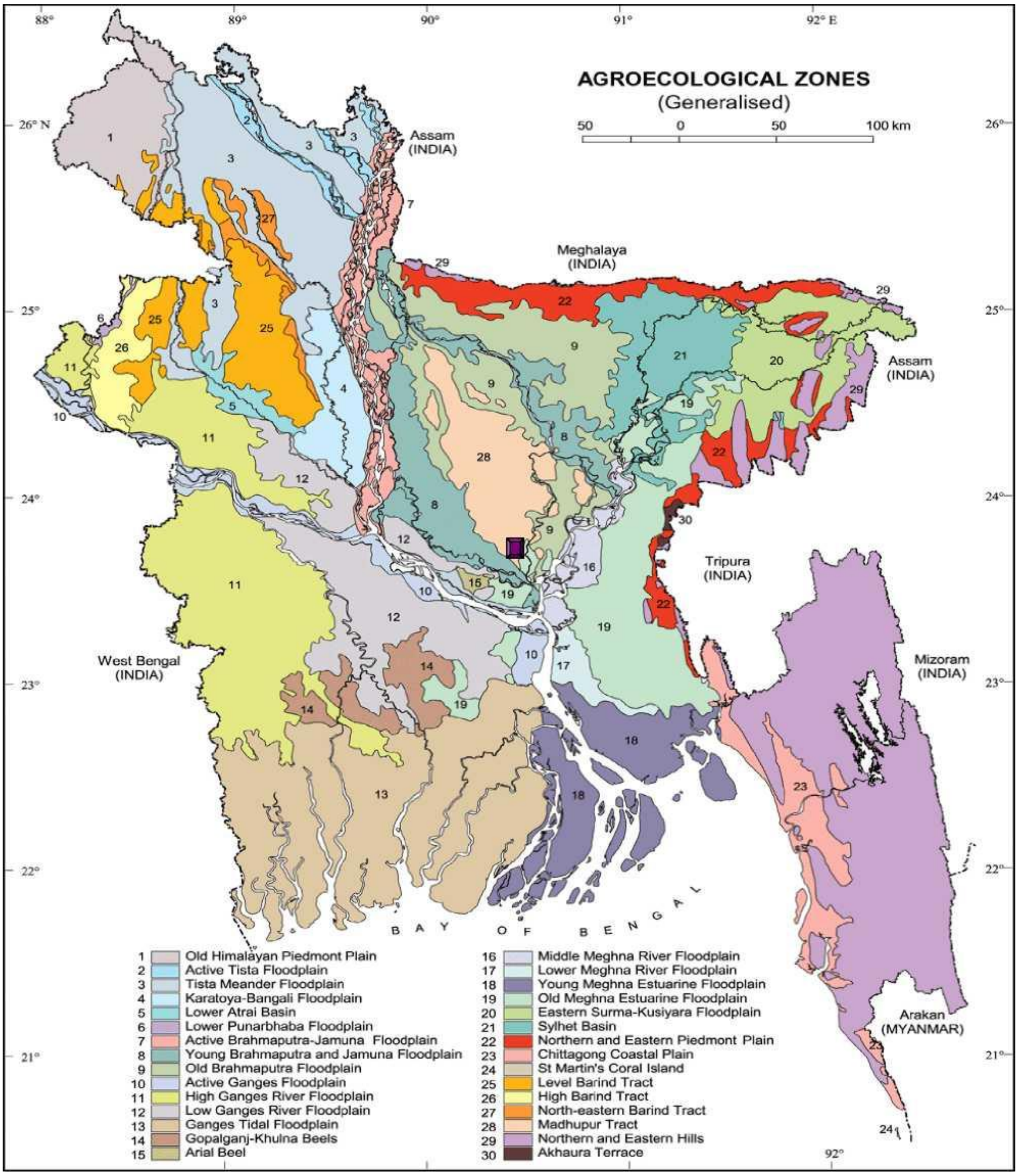


Fig. 13. Map of Bangladesh remarked with study area

Appendix II. Monthly records of air temperature, relative humidity, rainfall and sunshine during the period from December 2015 to March 2016

Year	Month	Air temperature (°C)			Relative humidity (%)	Rainfall (mm)	Sunshine (Hours)
		Max.	Min.	Avg.			
2015	December	24.32	15.4	19.86	70.76	0	192.6
2016	January	22.67	13.17	17.92	70.05	8.52	161.6
2016	February	26.56	17.49	22.03	72.25	20.60	219.9
2016	March	30.60	22.76	26.68	80.64	24.40	224.6

Source: Bangladesh Meteorological Department (Climate division), Agargaon, Dhaka-1207.

Appendix III. The mechanical and chemical characteristics of soil of the experimental site as observed prior to experimentation

Particle size constitution:

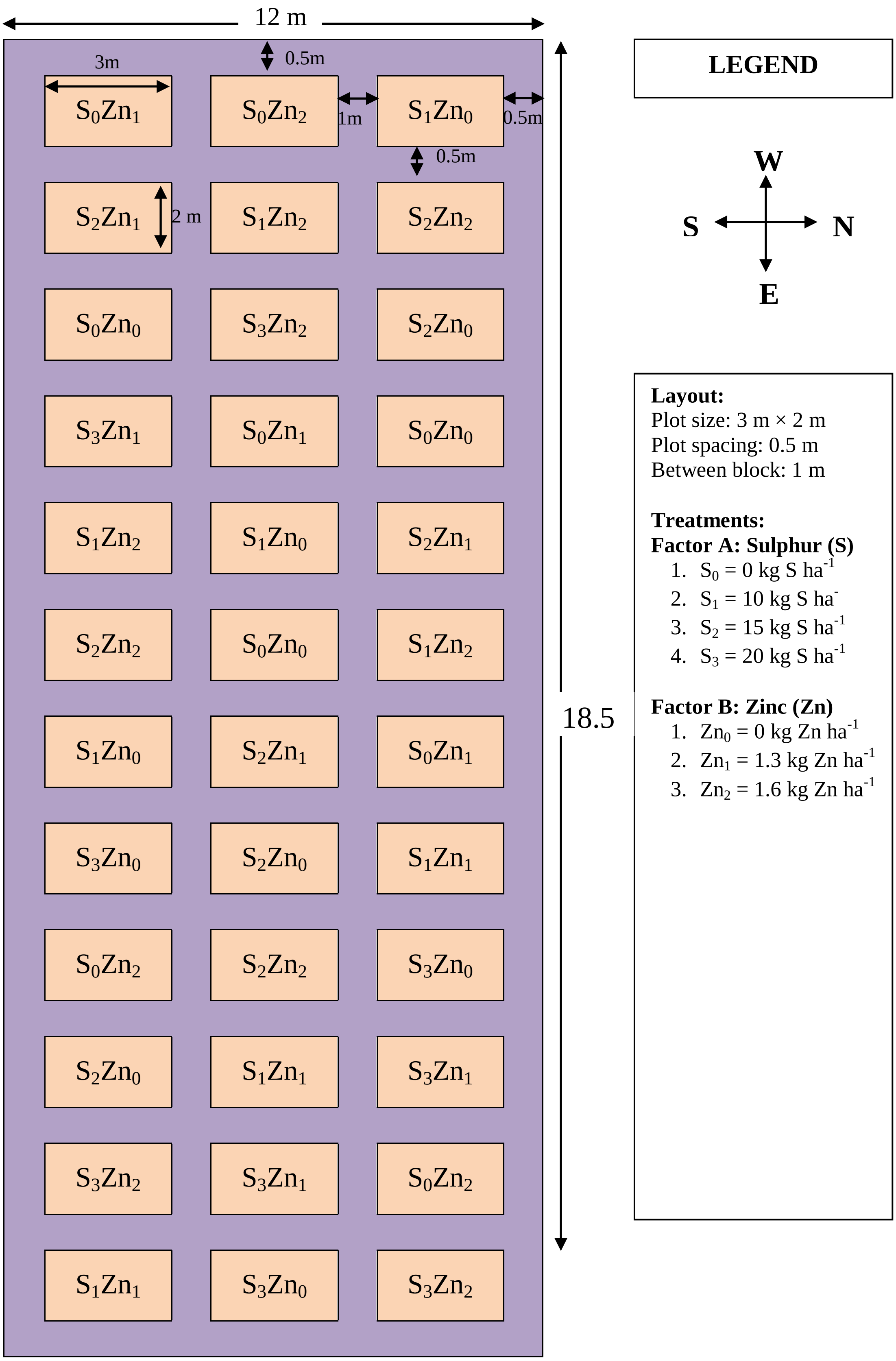
Sand : 40 %
Silt : 40 %
Clay : 20 %
Texture : Loamy

Chemical composition:

Constituents : 0-15 cm depth
P^H : 5.45-5.61
Total N (%) : 0.07
Available P (µ gm/gm) : 18.49
Exchangeable K (µ gm/gm) : 0.07
Available S (µ gm/gm) : 20.82
Available Fe (µ gm/gm) : 229
Available Zn (µ gm/gm) : 4.48
Available Mg (µ gm/gm) : 0.825
Available Na (µ gm/gm) : 0.32
Available B (µ gm/gm) : 0.94
Organic matter (%) : 0.83

Source: Soil Resources Development Institute (SRDI), Farmgate, Dhaka.

Appendix IV. Layout of the experiment field



Layout:
Plot size: 3 m × 2 m
Plot spacing: 0.5 m
Between block: 1 m

Treatments:
Factor A: Sulphur (S)
1. $S_0 = 0$ kg S ha^{-1}
2. $S_1 = 10$ kg S ha^{-}
3. $S_2 = 15$ kg S ha^{-1}
4. $S_3 = 20$ kg S ha^{-1}

Factor B: Zinc (Zn)
1. $Zn_0 = 0$ kg Zn ha^{-1}
2. $Zn_1 = 1.3$ kg Zn ha^{-1}
3. $Zn_2 = 1.6$ kg Zn ha^{-1}

Fig. 14. Layout of the experimental plot

Appendix V. Significant effect on plant height of wheat (BARI Gom-29) as influenced by S and Zn donated on growth and yield

Source of variation	Degrees of freedom	Mean square of plant height			
		30 DAS	50 DAS	70 DAS	At harvest
Replication	2	0.620	1.891	2.944	2.133
Factor A	3	8.710*	14.70**	19.300*	16.684*
Factor B	2	9.142*	18.591*	16.088**	12.547*
AB	6	3.260**	5.043*	4.151*	5.613*
Error	22	0.317	2.241	3.261	2.332

Appendix VI. Significant effect on number of tillers plant^{-1} of wheat (BARI Gom-29) as influenced by S and Zn donated on growth and yield

Source of variation	Degrees of freedom	Mean square of number of tillers plant^{-1}			
		30 DAS	50 DAS	70 DAS	At harvest
Replication	2	0.261	1.012	1.053	2.144
Factor A	3	4.808**	8.148**	14.331*	19.261*
Factor B	2	2.125*	9.612*	17.115*	12.265*
AB	6	1.114*	4.84*	7.034**	8.336**
Error	22	0.447	1.722	1.973	2.713

Appendix VII. Significant effect on dry weight plant^{-1} (BARI Gom-29) as influenced by S and Zn donated on growth and yield

Source of variation	Degrees of freedom	Mean square of dry weight plant^{-1}			
		30 DAS	50 DAS	70 DAS	At harvest
Replication	2	0.001	0.223	0.435	0.378
Factor A	3	1.013**	5.311**	6.014*	8.669*
Factor B	2	0.229*	3.164*	8.532*	6.128*
AB	6	0.078**	1.113*	2.346*	4.385*
Error	22	0.044	0.417	1.044	1.736

Appendix VIII. Significant effect on yield contributing parameters of wheat (BARI Gom-29) as influenced by S and Zn donated on growth and yield

Source of variation	Degrees of freedom	Mean square of yield contributing parameters		
		Spike length (cm)	Number of grain spike^{-1}	1000 see weight (g)
Replication	2	1.211	2.119	2.755
Factor A	3	6.758*	14.622**	16.531*
Factor B	2	4.882*	8.403*	10.532**
AB	6	1.931*	4.552*	7.824*
Error	22	1.017	2.317	2.171

Appendix IX. Significant effect on yield parameters of wheat (BARI Gom-29) as influenced by S and Zn donated on growth and yield

Source of variation	Degrees of freedom	Mean square of yield parameters		
		Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	Harvest index (%)
Replication	2	0.265	0.867	1.332
Factor A	3	8.344*	10.724*	15.425**
Factor B	2	6.261*	7.553*	10.627*
AB	6	3.322*	3.719*	6.515**
Error	22	0.315	1.326	2.118

Appendix X. Significant effect on nutrient status in post harvest soils as influenced by S and Zn donated on growth and yield

Source of variation	Degrees of freedom	Mean square of yield parameters		
		% Organic matter	Available S (µ gm/gm)	Available Zn (µg g^{-1})
Replication	2	0.005	0.017	0.044
Factor A	3	NS	6.529**	NS
Factor B	2	NS	NS	NS
AB	6	1.302*	4.019*	2.517**
Error	22	0.015	1.322	0.144