EFFECT OF ZINC AND SULPHUR ON GROWTH AND YIELD OF POTATO

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EFFECT OF ZINC AND SULPHUR ON GROWTH AND YIELD OF POTATO

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CERTIFICATE

This is to certify that the thesis entitled ***'EFFECT OF ZINC AND SULPHUR ON GROWTH AND YIELD OF POTATO'*** *submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of* ***MASTER OF SCIENCE (MS)*** *in* ***SOIL SCIENCE****, embodies the result of a piece of bona fide research work carried out by* ***SHAILA PARVIN****, Registration number:* ***18-09186,*** *under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

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

Dated:
Place: Dhaka, Bangladesh

Prof. Mst. Afrose Jahan
Department of Soil Science
Supervisor

Dedicated to My Beloved Parents

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The Author

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ABSTRACT

The experiment was conducted at the research field of Sher-e-Bangla Agricultural University, Dhaka to study the effect of zinc and sulphur on growth and yield of potato during November, 2019 to February, 2020. The experiment consisted of two factors. Factor A: Three levels of zinc fertilizer *viz*., Zn_0= 0 kg ha^{-1}, Zn_1= 2 kg ha^{-1} and Zn_2= 4 kg ha^{-1} and Factor B: Three levels of sulphur *viz.*, S_0= 0 kg ha^{-1}, S_1= 15 kg ha^{-1} and S_2= 25 kg ha^{-1}. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Plant height, leaves number plant^{-1}, numbers of stem hill^{-1}, number of tubers hill^{-1}, average tuber weight, tuber yield per plot, tuber yield per hectare and grading of tuber on the basis of diameter were compared for different treatments. Results indicated that zinc and sulphur had significant influence on most of the growth parameters, yield and yield components of potato. The maximum tuber yield per hectare (24.72 t) was recorded from the treatment Zn_2 whereas minimum tuber yield per hectare (23.24 t) was recorded from the treatment Zn_0. On the other hand, maximum tuber yield per hectare (24.61 t) was recorded from the treatment S_1 whereas minimum tuber yield per hectare (23.46 t) was recorded from the treatment S_0. In case of interaction effect of zinc and sulphur result observed that maximum number of tuber hill^{-1} (10.53), maximum average tuber weight (70.29 g), yield per plot of tuber (10.09 kg), tuber yield per hectare of potato (25.24 t) and 46.15% of maximum tuber grade in respect of 28-45 mm diameter were found from the treatment combination of Zn_2S_1 whereas minimum number of tuber hill^{-1} (7.40), average tuber weight (55.28 g), tuber yield per plot (8.98 kg), tuber yield per hectare (22.46 t) and 38.11% of minimum tuber grade in respect of 28-45 mm diameter were recorded from the treatment combination of Zn_0S_0. So, the combination of zinc fertilization, Zn_2 (4 kg ha^{-1}) along with sulphur fertilization, S_1 (15 kg ha^{-1}) provided better performance for all growth related parameters and yield with better grade of potato (BARI Alu-8).

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LIST OF ACRONYMS

Acronym		Full meanings
AEZ	=	Agro-Ecological Zone
%	=	Percent
^0C	=	Degree Celsius
BARI	=	Bangladesh Agricultural Research Institute
cm	=	Centimeter
CV%	=	Percentage of coefficient of variance
cv.	=	Cultivar
DAP	=	Days after planting
et al.	=	And others
g	=	Gram
ha^{-1}	=	Per hectare
kg	=	Kilogram
LSD	=	Least Significant Difference
MOP	=	Muriate of Potash
N	=	Nitrogen
No.	=	Number
NPK	=	Nitrogen, Phosphorus and Potassium
SAU	=	Sher-e-Bangla Agricultural University
SRDI	=	Soil Resources and Development Institute
t	=	Ton
TSP	=	Triple Super Phosphate
viz.	=	Videlicet (namely)
Wt.	=	Weight

CHAPTER I

INTRODUCTION

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INTRODUCTION

Potato (*Solanum tuberosum* L.) is a very popular and important tuber crop grown all over the world belonging to the Solanaceae family. It originated in the central Andean region of South America (Keeps, 1979). It is the fourth largest crop in the world after wheat, rice and maize. Bangladesh is the seventh largest producer of potatoes in the world (FAOSTAT, 2019). It not only adds energy, but also significant amounts of high-quality protein and essential vitamins, minerals and trace elements to the diet (Horton, 1987). It is a rich source of vitamins, especially vitamin C & B and also minerals. Tubers contain 70-80% water, 20.6% carbohydrate, 2.1% protein, 0.3% fat, 1.1% crude fibre and 0.9% ash (Banerjee *et al.*, 2016).

It ranks second in Bangladesh after rice in terms of production. In Bangladesh, the total area under potato cultivation, national average yield and total production are 0.47 M hectares, 20.41 t ha^{-1} and 9.74 M metric tons, respectively (BBS, 2019). Total production is increasing over time, as consumption in Bangladesh is also increasing rapidly (MOA, 2013). It is considered a vegetable crop and accounts for as much as 55% of total vegetable production in Bangladesh (BBS, 2013). The yield is very low in comparison to that of the other leading potato growing countries of the world, for instance, 50.30 t ha^{-1} in USA, 42.48 t ha^{-1} in Denmark and 36.47 t ha^{-1} in UK (FAO, 2019).

Potato has acquired considerable importance in the rural economy of Bangladesh. It is not just a cash crop, it is also a food crop alternative to rice and wheat. Bangladesh has a great agro-ecological potential to grow potatoes. The area and production of potatoes in Bangladesh has increased over the last decades, but yields per unit area remain more or less static. The reasons for such a low yield of potatoes in Bangladesh are the unbalanced application of the source, the use of low-quality seed and the use of sub-optimal production practices. Available reports indicate that the production of potatoes in Bangladesh can be increased by improving cultural practices, including the optimization of manure and source, planting time, spacing and use of optimal seed sizes, which influence the yield of potatoes (Divis and Barta, 2001). According to

Grewal *et al.* (1992) potato yield could be increased by almost 50% only by improved nutrient management.

Zinc is considered as the most important micronutrient for potato, and low recovery of applied Zn is the main limitation in enhancing the yield of potato crop (Singh *et al.*, 2014). Zinc is very important crop nutrient that plays a vital role in growth and development of potato by enhancing the synthesis of growth hormone and chlorophyll (Ali *et al*., 2008; Graham *et al*., 2000). Zinc is involved in the synthesis of growth promoting hormones and the reproductive process of many plants (Ram *et al.*, 2014). Zinc plays an important role as a metal component of enzymes (alcohol dehydrogenase, superoxide dismutase, carbonic anhydrase and RNA polymerase) or as a functional, structural or regulator cofactor of a large number of enzymes (Ali *et al.*, 2013). Depending upon the duration of variety, potato crop is highly sensitive to Zn application. Further, Zn has been found to increase ascorbic acid content, but reduces the tyrosine and total phenol content in tubers which are the important criteria for processing Industries (Mondal *et al.*, 2015). Authors hypothesized that potato responds well with applied Zn fertilizer and Zn plays an important role for physiology, productivity and post-harvest quality of potato.

Sulphur is one of sixteen critical nutrient elements and fourth main nutrient after NPK, obligatory by plants for appropriate development and yield as it is recognized to take part in several reactions in all living cells (Sud and Sharma, 2002). Its application is less expensive but can give higher profits than other nutrients (Tandon and Messick, 2007). Sulphur plays an essential role in chlorophyll formation and therefore helps to give plants their green colour. It is the key component of balanced nutrition required to potato. Intensive cropping and use of high-grade fertilizers have resulted in depletion of sulphur in soils. Various workers have reported the need of application of sulphur fertilizers along with its beneficial effects on yield and quality (Chettri *et al.*, 2002, Jaga and Sharma, 2013 and Choudhary *et al*., 2013). Sulphur lacking plants had deprived use of nitrogen, phosphorus and potash and a major decrease of catalase activities at all age (Nasreen *et al*., 2003). Intensive cropping and usage of high-grade fertilizers have produced the reduction of sulphur in soils. Decline in tuber dry matter yield and concentrations of dry matter, starch and vital amino acids mainly cystine and leucine were detected with sulphur shortage (Petitte and Ormrod, 1988 and

Eppendorfer and Eggum, 1994). Sulphur has a straight influence on soil properties as it may decrease soil pH which expands the obtainability of microelements such as Fe, Zn, Mn and Cu in addition to crop yield and its associated characteristics (Tantawy *et al*., 2009). Moreover, it is essential for good vegetative growth and bulb development in plant and it has a strong influence on potato flower and pungency through involvement in the volatile S-compounds (Forney *et al*., 2010).

It is evident that uses of zinc and sulphur are very important variables in potato production. The aim of this work was to evaluate the effect of zinc and sulphur on growth and yield of potato which have an effect on potato production in Bangladesh with the following objectives:

i. To observe the effect of different doses of zinc and sulphur on growth and yield of potato
ii. To study the combined effect of zinc and sulphur for maximum growth and yield of potato

CHAPTER II

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

Yield and yield contributing characters of potato are considerably depended on manipulation of different nutrients for obtaining higher production. Among the mentioned different nutrients, zinc and sulphur are more responsible for the growth and yield of potato. The available relevant reviews related to zinc and sulphur in the recent past have been presented and discussed:

Sarker *et al.* (2018) Different crops have variations in their responses to applied micronutrients in soil. A study was conducted on floodplain soil of Bangladesh to explore the response of potato to application of micronutrients in soil. The experimental site was located at farmers' field in Chandina upazila under Cumilla district of Bangladesh covering the soils of Old Meghna Estuarine Floodplain (AEZ 19) during 2011-12. Randomized complete block design with 3 replications of each treatment was used in the experiment, where seven treatments including a control were tested. Additive element trial technique was followed while designing the treatments taking six micronutrients i. e. Zn, B, Cu, Mn, Fe and Mo at the rate of 3, 2, 2, 3, 5 and 1 kg ha^{-1}, respectively. Macronutrients, such as N, P, K and S were applied at recommended rates to all plots. The highest tuber yield (28.7 t ha^{-1}) was produced by the combined application of Zn and B. Only Zn application was sufficient to obtain the highest content of protein as well as content of almost all the nutrients in potato tuber. Antagonistic relation between Zn and P in soil-plant system was recorded in the study. Zinc and boron application influenced different growth and yield parameters of potato while the other four added micronutrients did not have any significant effect but combined application of Zn, B, Cu, Mn, Fe and Mo had beneficial role for better plant growth and production. Proper management of zinc and boron fertilizers including optimization of application rates of those nutrients can help to uphold the yield and quality of potato in floodplain soil.

Foliar application of micro-element solution (B, Cu, Mn, Zn and Mo) on potato leaves increased the uptake of N, P, K; chlorophyll content and photosynthesis in leaves, promoted the tuber expansion and increase potato yield. Micronutrients like zinc and manganese also influences the protein and sugar content in potato tubers (Singh and Kathayat 2018)

Ahmed *et al.* (2011) conducted an experiment and observed that foliar application of yeast at the concentration of 5 g/l. combined with application of zinc at the concentration of 300 ppm gave the highest values of vegetative growth characters, improved tubers quality and increased the productivity of potato plants and marketable tubers percentage.

Kelling and Speth (2001) reported that utilization of elements like Zn and Mn together from resource sulfate Zn and Mn increased efficiency and quality of potato crop. The alternative approach is the application of these nutrients to plant leaves and stems through foliar fertilization.

Eugenia (2008) shows that, potato emergence depends on 1) Soil Moisture. Sprouts grow faster in soils that are close to field capacity than in drier soils. 2) Soil Temperature. Sprout development and elongation occur more rapidly at 17-19°C than at 10-15°C. 3) Seed Warming. Seed tubers warmed (10-15°C) prior to planting will emerge more rapidly and uniformly. The warming period needs to be controlled carefully so that the seed has sprouts just emerging (white points). Longer sprouts are tender and susceptible to mechanical damage. 4) Physiological Age of Seed, temperature is the main factor that determines the physiological age of a seed tuber. The physiological age of a potato tuber is determined not from harvest but from tuber initiation. Seed grown during a season with stressful weather conditions, will be physiologically older at harvest than tubers from a more favorable growing season. It is possible to determine the physiological age of a seed lot by taking a representative sample of tubers from cold storage and warming them to 15-17°C in the dark. The length of time required for sprout emergence (white point stage) will provide an estimate of the amount of time and warming that will be required in storage for that particular variety and seed lot. If the seed is physiological old the sprouts are weak and form branches. This results in weak plants that will mature before maximum yield. This results in a lot of small sized tubers 5) Diseases. Developing sprouts are susceptible to Rhizoctonia canker and soft rot. Rhizoctonia can be reduced by applying Quadris in-furrow.

Khan *et al.* (2019) carried out a field trial to evaluate the impact of Potassium (K) and Zinc (Zn) on quantitative and qualitative attributes of potato (*Solanum tuberosum* L.) at Agricultural Research Institute Mingora Swat, during winter 2014. The experiment was laid out in randomized complete block design using three replications. Four K levels (00, 90, 120 and 150 kg ha^{-1}) and three levels of Zn (00, 05 and 10 kg ha^{-1}) were used. The various parameters studied during experiment were tuber yield (ton ha^{-1}), total soluble solids (TTS), specific gravity and starch content. Potassium and zinc application at various levels were significant for all parameters. Potassium applied at the rate of 120 kg ha^{-1} increased tuber yield (27.9 ton ha^{-1}), TSS (5.099 °Brix), specific gravity (1.083) and starch content (14.83 %). Yield parameter was recorded maximum with 150 kg K ha^{-1}. Application of Zn at 10 kg ha^{-1} maximized tuber yield (26.9 ton ha^{-1}), TSS (4.879 °Brix), specific gravity (1.081) and starch content (14.83%). Most of the parameters were not significantly different from that of 5 kg Zn ha^{-1}. None of the studied parameters was significantly affected by K and Zn interaction. On the basis of the current research, 120 kg K ha^{-1} and 5 kg Zn ha^{-1} gave maximum yield of potato and thus the mentioned rates of these nutrients are suggested for general cultivation of potato in Swat valley.

Mohamadi (2000) found that application of Zn along with Mn foliar application caused increase in efficiency and quality of potato crop.

Singh *et al.* (2018) conducted an experiment to study the response of potato cv. Kufri Pukhraj to foliar application of zinc during November-February cropping season of year 2017-2018. The experiment was conducted with eight different treatments namely; T_1 - control, T_2- zinc @ 5 ppm, T_3 - zinc @ 10 ppm, T_4 - zinc @ 15 ppm, T_5 - zinc @ 20 ppm, T_6 - zinc @ 25 ppm, T_7 - zinc @ 30 ppm and T_8 - zinc @ 35 ppm, following Randomized Block Design with three replications. The observations recorded during the research, showed that foliar application of T_7 - zinc @ 30 ppm had significant effect on growth, yield and quality characters of potato. The range of plant height (22.87 cm and 31.91 cm) and number of leaves (132.45 and 199.03) were recorded maximum in T_7 - zinc @ 30 ppm, at 45 and 75 days after sowing respectively. Tuber yield (18.89 t ha^{-1}), carbohydrate (19.52 g/100g) and TSS (7.55%) were also recoded maximum in T_7 - zinc @ 30 ppm. Based upon the present investigation, it can be concluded that for commercial cultivation of potato cv. Kufri

Pukhraj foliar application of Zn @ 30 ppm is very effective for getting the higher tuber yield with best quality tubers.

Singh *et al.* (2017) conducted an experiment to study the effect of different levels of potassium and zinc on growth, yield and economics of sweet potato. The experiment was laid out on clay and loam soil by adopting randomized block design with factorial technique (FRBD). The sixteen treatments consisted of combination of four levels of potassium (0, 80, 100 and 120 kg/ha through muriate of potash and four levels of foliar zinc (control i.e. water spray, 10, 20 and 30ppm) through zinc sulphate. The individual application of potassium 120 kg K_2O/ha significantly increased the number of tubers per plant (4.60), average weight of tuber (275.31 g), length of tuber (16.77 cm), diameter of tuber (5.69 cm), tuber yield per plot (9.71 kg), tuber yield per hectare (49.04 t) respectively as compared to control. With the foliar application of zinc (30 ppm) significant increase in number of tubers per plant (4.18), average weight of tuber (234.73 g), length of tuber (18.12 cm), diameter of tuber (5.16 cm), tuber yield per plot (8.33 kg) and tuber yield per hectare (42.05 t) was recorded as compared to control. The treatment combination (120 kg K_2O + 30 ppm Zn) recorded the maximum yield parameters i.e. chlorophyll content (37.00 mg/100 g), average weight of tuber (302.17 g), length of tuber (19.82 cm), diameter of tuber (5.97 cm), maximum tuber yield per plot (11.02 kg), tuber yield per hectare (55.67 t) and benefit-cost ratio (B: C ratio) of 4.22:1.While, the treatment (120 kg K_2O + 30 ppm Zn) had the maximum number of tuber (4.86), minimum number of tuber was recorded in control. From the experiment, it appeared that application of potassium and zinc can be used to improve yield and higher net monetary returns of sweet potato.

Dhakal and Shrestha (2019) conducted an experiment to evaluate the effect of foliar application of zinc on potato (*Solanum tuberosum* L.) in Bhaktapur, Nepal with the objective to increase the yield of potato through foliar application of zinc during mid-January to April 2018. The experiment was laid out in Randomized Complete Block Design (RCBD) with 3 replications and 7 treatments. The treatments employed were control (water spray), single spray with 60 ppm Zn-EDTA, single spray with 120 ppm Zn-EDTA, single spray with 180 ppm Zn-EDTA, double spray with 60 ppm Zn-EDTA, double spray with 120 ppm Zn-EDTA and double spray with 180 ppm Zn-EDTA at 45 DAP and 65 DAP. The growth parameters including plant height, stem diameter and plant canopy were recorded at 45 DAE and 60 DAE whereas yield parameters including number of tubers per plant, individual tuber weight and tuber yield were measured at harvest. Results revealed that the growth and yield contributing characters of potato were significantly affected by foliar application of zinc. It was observed that all the concentrations of zinc increased the plant height compared to control. Minimum plant height of 27.53 cm was recorded with control and maximum height of 43.20 cm was recorded with two foliar spray with 180 ppm Zn-EDTA solution. The results obtained with 180 ppm was found significantly superior to its lower doses and control for increasing stem diameter and plant canopy too. The highest stem diameter (9.66 mm) and the maximum plant canopy (48.67 cm) was recorded with double pray of 180 ppm Zn-EDTA whereas the lowest stem diameter (7 mm) and the lowest canopy (31.90 cm) was recorded with control. Tuber yield was also found as the highest (23.29 mt/ha) with two foliar spray of 180 ppm Zn-EDTA solution. The tuber yield of potato was found quite strongly correlated with individual tuber weight (R^2 = 0.6876). The results suggested that foliar applications of Zn-EDTA@180 ppm at 45 DAP and 65 DAP is suitable in potato production with respect to better growth and yield in Sudal, Bhaktapur.

Adekiya *et al.* (2018) conducted an experiment in 2015 and 2016 cropping seasons to determine the impact of various levels of $ZnSO_4$ fertilizer on soil chemical properties, foliage and storage root yields and proximate qualities of sweet potato (*Ipomoea batatas* L.). The experiment consisted of 5 levels (0, 5, 10, 15 and 20 kg ha^{-1}) of $ZnSO_4$ fertilizer. These were arranged in a randomized complete block design and replicated three times. $ZnSO_4$ increased (with the exception of P) soil chemical properties compared with the control. N, K, Ca, Mg and Zn were increased up to the 20 kg ha^{-1} $ZnSO_4$ level in both years. $ZnSO_4$ reduced P concentrations in soil as the level increased. For sweet potato performance, 5 kg ha^{-1} $ZnSO_4$ fertilizer had the highest values of foliage yield (vine length and vine weight) and storage root yield. Using the mean of the two years and compared with the control, $ZnSO_4$ fertilizer at 5 kg ha^{-1} increased storage root yield of sweet potato by 17.4%. On fitting the mean storage root yield data of the two years with a cubic equation, the optimum rate of Zn for sweet potato was found to be 3.9 kg ha^{-1} to achieve the maximum sweet potato yield. In this study, relative to the control, $ZnSO_4$ fertilizer increased moisture and decreased the fibre contents of sweet potato. There were no consistent patterns of variation between the 5, 10, 15 and 20 kg ha^{-1} $ZnSO_4$ treatments for proximate qualities except that the highest values of fat, protein, carbohydrate and ash was at 5 kg ha^{-1} $ZnSO_4$.

A field experiment was carried out by Sarker *et al.* (1996) at the Gangachra Series of Mithapukur, Rangpur to assess the effect of fertilizers alone and in combination with cow dung on the growth and yield of potato. They found that the highest tuber yields of 29.97 and 28.72 t/ha were produced by the combined effect of 150kg N + 60kg P + 120kg K + 20 kg S + 40 kg Zn + 2 kg B + 15 kg Mg/ha + 5 t/ha of cow dung respectively.

Mousavi *et al.* (2018) carried out a study to investigate the effect of compost and manure with phosphorus and zinc on potato yield (*Solanum tuberosum* L.). The experiment was conducted in the Kerman agricultural and natural resources research centre (Iran) by using a factorial design in randomized complete block in two independent experiments with three replications. In the first experiments compost with phosphorus and zinc were used, and in second experiment animal manure with phosphorus and zinc were used. The three levels of compost (0, 10 and 20 ton ha^{-1}) and same level of animal manure were used as main. Four levels of phosphorus (0, 75, 150 and 225 kg ha^{-1}) and two levels of zinc (0 and 50 kg ha^{-1}) used as the sub factors. Results showed that the main factors of compost and animal manure application had no significant effect on any of the all evaluated traits in the experiments. Effect of zinc on number of small tubers was significant in the first experiment. The highest number of large tubers were found in 20 ton ha^{-1} compost + 225 kg ha^{-1} phosphorus + 50 kg ha^{-1} zinc in first experiment and 20 ton ha^{-1} animal manure + 75 kg ha^{-1} phosphorus + no zinc in second experiment. Tubers dry matter was significantly affected by the interaction effect of zinc and phosphorus, the maximum dry matter being obtained with the application of 225 kg ha^{-1} phosphorus +50 kg ha^{-1} zinc.

Sati *et al.* (2017) conducted an experiment to investigate the response of zinc sulphate application on quality of potato tubers, field experiments were carried out during winter seasons of 2014-15 and 2015-16 at Vegetable Research Centre, G. B. Pant University of Agriculture & Technology, Pantnagar, Udham Singh Nagar, Uttarakhand. The lay-out of experimental field was laid in randomized block design with 10 treatments with three replications. The results indicated that dry matter (22.57, 22.27 and 22.42%), starch (18.56, 19.11 and 18.83%) and protein (8.20, 8.45

and 8.33%) were maximum under treatment T_9 (zinc sulphate @ 12.5 kg/ha at the time of planting and 12.5 kg/ha at the time of earthing-up), whereas available zinc content of potato tubers (52.27, 55.60 and 53.93 ppm) was higher under treatment T_7 (zinc sulphate @ 25 kg/ha at the time of planting) during both the years and pooled analysis over the years, respectively. Results also indicated that specific gravity of potato tuber did not vary significantly with the treatments during both the years and pooled analysis over the years. Based on present investigation, it can be concluded that basal and/or split application of zinc sulphate at 25 kg/ha improved potato tuber quality under present agro-climatic conditions.

Tarafder *et al.* (2008) conducted an experiment at the Bangladesh Institute of Nuclear Agriculture (BINA) sub-staion, Tajhat, Rangpur, using potato-Boro-T. aman rice cropping pattern with an objective to evaluate the direct and residual effects of sulphur and zinc on the growth, yield and nutrient uptake by the crops. The surface soil was sandy loam texture, pH 6.3, organic matter 1.24%, available sulphur 6.62 ppm and available zinc 0.45 ppm. The experiment comprised of eight treatments for potato $S_{15}Zn_2$ (T_2, T_4 and T_8), S_8Zn_1 (T_5 and T_6) and S_0Zn_0 (T_1, T_3 and T_7), for boro rice $S_{20}Zn_4$ (T_3, T_5, T_6 and T_7) and S_0Zn_0 (T_1, T_3, T_4 and T_6). The experiment was laid out in a randomized complete block design with three replications. Average tuber yield of potato (var. cardinal) varied from 28.29 to 32.86 t ha^{-1} with the highest yield in $S_{15}Zn_2$ treatment (100% recommended dose) and the lowest was in the S_0Zn_0 treatment (control).

Singh *et al.* (2014) conducted a field experiment at Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G) during rabi 2010-11 and 2011-12.The experiment was laid out in split–split plot design with three replications. The treatments consisted of three irrigation schedule i.e. drip irrigation (125 % of OPE), drip irrigation (100 %of OPE) and control (furrow irrigation) as a main plot and four weed management i.e. weedy check, hand weeding (at 25 and 45 DAP) metribuzin (500 g a.i. ha^{-1} PE) and chlorimuron + quizalofop (6 + 50 g a.i ha^{-1}) at 20 DAP as sub plot and four integrated nutrient management i.e. 100 % RDF, 100 % RDF + Micro nutrient (Zinc sulphate 25 kg ha^{-1}), 75 % N inorganic fertilizer + 25 % N poultry manure + PSB + Azatobactor and 50 % N inorganic fertilizer + 50 % N poultry manure + PSB + Azatobactor as sub sub plot. Kufri Chipsona- 2 variety was used for experiment, the spacing of crop is 60 cm×20 cm. Application of 75% N inorganic fertilizer + 25 % N organic (Poultry manure) + PSB + Azotobactor was found non-significant to weed control while produced significantly highest yield attributes and total tuber yield.

Muthanna *et al.* (2017) carried out an experiment to study the effect of boron and sulphur application on plant morphology and yield of potato during the month of October in 2015-16 and 2016-17. The experiment was laid out in randomized block design with three replications and thirteen treatments. Out of thirteen treatments one control, one recommended dose of fertilizers (N/P/K: 150/80/120 kg ha^{-1}) and eleven treatment combinations along with recommended dose of fertilizers (RDF) including 3 doses of boron (1 kg, 2 kg and 3 kg); 2 doses of sulphur (30 kg and 40 kg) and their combinations (1 kg boron + 30 kg sulphur, 2 kg boron + 30 kg sulphur, 3 kg boron + 30 kg sulphur, 1 kg boron + 40 kg sulphur, 2 kg boron + 40 kg sulphur and 3 kg boron + 40 kg sulphur) were applied. The study indicated that plant morphology and yield of potato plant were significantly influenced by boron and sulphur application. The maximum plant height and yield of marketable tubers (17.99 t ha^{-1} and 27.00 t ha^{-1}) were recorded in the plants treated with RDF + 2 kg B + 40 kg S during both year of investigation. RDF + 2 kg B + 40 kg S was also found statistically at par with the maximum values under characters viz., number of sprouts per tuber, stem diameter and number of marketable tubers/hill.

Fantow *et al.* (2019) conducted a field experiment from 2016-2018 with 9 combination of nitrogen, phosphorous and sulfur fertilizers arranged in randomized complete block design with three replications to assess response of potato to these rates. The application 110-19.74-50.8 kg ha^{-1} $N_2/S_2/P_2O_5$ fertilizer delayed days to flowering and maturity by 8 and 11 days at Darark and 10 and 14 days at Dabat. However, it increased plant height and number of stems per plant, which may positively contribute to increased photosynthetic area. The application of these fertilizers advanced marketable tuber yield by 153% and the total tuber yield by 86.6% relative to unfertilized plants. Furthermore, the partial budget analysis data showed that the highest net benefit and marginal rate of return (4453.6%) was obtained from 110-19.74-50.8 kg ha^{-1}. Therefore, the current study results is indicative that potato can grow well and provide better yield at Dabat, Dabark and similar agro ecology by using 110-19.74-50.8 kg ha^{-1} $N_2/S_2/P_2O_5$, respectively.

Moussa *et al.* (2018) led to defects in processed potato products. Obtaining the highest possible potato productivity per unit of the cultivated area, as well as the high quality of the processed products, is the focus of this research. Four levels of sulphur fertilizer (zero, 100, 200 and 300 kg S/feddan = 4200 m^2) and two levels of nitrogen fertilizer (100 and 200 kg N/feddan) were applied to the growing potato plants. Seven pre-treatments were utilized on sliced potatoes before frying (without soaking; soaking in salt and acetic acid for 30 and for 60 min, respectively; soaking in salt and rosemary powder for 30 and for 60 min, respectively and soaking in salt, acetic acid and rosemary powder for 30 and for 60 min, respectively). Most of the studied vegetative growth characters and potato tuber yield (ton/Fed.) were improved by increasing sulfur fertilization levels from zero up to 300 kg/Fed. and/or increasing nitrogen fertilization levels from 100 kg up to 200 / Fed. during the two seasons. The best results for the vegetative growth traits and total tuber yield/Fed could be achieved from the application of 300 kg S/Fed. + 200 kg N/Fed. Levels of acrylamide in potato processed were significantly increased by increasing nitrogen fertilizer treatments from 100 up to 200 kg N/Fed. and / or increasing sulphur treatments from 100 kg up to 300 kg S/Fed. Soaking the potato slices before frying for 60 min. in a solution composed of salt + acetic acid + rosemary reduced the proportion of acrylamide formed in potato chips during the frying.

Moinuddin and Shahid (2004) carried out an experiment to investigate the effect of nitrogen and sulphur. Potato cv. Kufri Jyoti was fertilized with 0, 60, 120 or 180 kg N ha^{-1} and 0, 20 or 40 kg S ha^{-1}. Tuber yield was increased by application of S and increased with increasing N rate. Interaction between N and S was not found significant. They noticed that combined application of N and S had a positive effect on tuber quality.

Roy *et al.* (2014) conducted an experiment at the research field of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during the period from November 2010 to March 2011 to investigate the effect of potassium and sulfur on morpho-physiological characters, yield attributes and yield of potato. The experiment comprised of four different doses of potassium (0, 117, 130, 43 kg ha^{-1}) along with sulfur (0, 24, 29 and 34 kg ha^{-1}). The experiment was laid out in a split plot design with three replications. The growth parameters such as plant height, stems $hill^{-1}$, leaves $hill^{-1}$, TDM m^{-2} and total dry mass (TDM) $plant^{-1}$, yield attributes such as tubers hill^{-1} and single tuber weight and tuber yield and marketable yield were significantly influenced by potassium and sulfur. Results revealed that, number of leaves hill^{-1}, stems hill^{-1}, plant dry matter content, tuber dry matter content, tubers m^{-2}, tuber yield, marketable yield significantly increased with increasing potassium levels, whereas, plant height decreased with increasing potassium level. On the other hand plant dry matter content, tuber dry matter content, stems hill^{-1}, tubers m^{-2}, tuber yield, marketable yield increased significantly with increasing sulfur level. While plant height, number of leaves hill^{-1} and tubers m^{-2} decreased with increasing sulfur level. Combined effect of potassium and sulfur revealed that the highest number of tubers m^{-2} was achieved by 130 kg potassium with 34 kg sulfur ha^{-1}. But 130 kg potassium with 29 kg sulfur ha^{-1} produced more 45-55 mm sized tuber than 130 kg potassium with 34 kg sulfur ha^{-1}. Application of 130 kg potassium with 34 kg sulfur ha^{-1} produced more <28 mm sized tuber than that of 130 kg potassium with 34 kg sulfur ha^{-1}. Finally 130 kg potassium with 29 kg sulfur ha^{-1} produced numerically highest yield but statistically similar with 130 kg potassium with 34 kg sulfur ha^{-1}.

Singh *et al.* (2016) carried out an experiment to study the effect of four levels of nitrogen (0, 90, 180, 270 kg ha^{-1}) and three levels of sulphur (0, 25, 50 kg ha^{-1}) application on growth and yield attributes of potation a split plot design with three replication. The treatments were replicated thrice in split plot design. The study revealed that application of N 180 kg ha^{-1} + S 50 kg ha^{-1} significantly enhanced morphological and quality attributes such as plant emergence, number of shoots, periodic plant height, dry matter accumulation, leaf area index, percent reducing sugar and tuber dry matter, there by proving the role of sulphur and nitrogen in high tuber yield in potato ‘Kufri-chipsona-3’. Among all treatments, highest total and process able yield was exhibited by treatment T_9 i.e N 180 kg ha^{-1} + S 50 kg ha^{-1} expressing the role of S in N uptake and use efficiency. Benefit cost (B: C) ratio was 2.25 which also indicates maximum profitability obtained with this combination.

Kushwah *et al.* (2015) carried out an experiment to evaluate the four potato cultivars (Kufri Chipsona-1, Kufri Chipsona-2, Kufri Jyoti, Kufri Pushkar) under five sulphur (0, 15, 30, 45, and 60 kg ha^{-1}) levels. Twenty treatment combinations were replicated thrice in factorial randomized block design. Significant variations were observed in different varieties of potato for growth parameters, yield attributes, and tuber yield.

Maximum number of sprouts was recorded in Kufri Pushkar followed by Kufri Chipsona-1 and lowest in Kufri Jyoti. Kufri Chipsona-2 produced tallest plants and higher number of leaves per plant. Fresh weight of shoot per plant number of tuber per plant (8.33), average tuber weight (167.3g) and total tuber yield (41.90 t ha^{-1}) was recorded maximum with Kufri Pushkar. There was an increase in these parameters with increasing dose of sulphur upto 45 kg ha^{-1}. Further increase in sulphur dose either reduced the values or showed non-significant improvement. The highest number of sprout per tuber (7.5), plant height (41.7, 47.9, 59.2 cm), number of leaves per plant (29.6, 52.0, 76.5), fresh weight of shoot per plant (50.3, 64.2, 76.5 g), tuber per plant (8.58), tuber weight (166.56 g) as well as total tuber yield (37.74 t ha^{-1}) were recorded with 45 kg S ha^{-1}. Highest net return (0.188 ha^{-1}) as well as B: C ratio (3.02) was recorded with Kufri Pushkar. Among the sulphur levels, maximum net return (0.165 ha^{-1}) and B: C ratio (2.57) was obtained with 45 kg S ha^{-1}.

From the above literature, it is evident that effects of zinc and sulphur have a significant influence on yield and yield components of potato. The literature suggests that suitable doses of zinc and sulphur increase the tuber yield of potato. Reduction in tuber yield is mainly attributed by the reduced amount of zinc and sulphur.

CHAPTER III

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

This chapter presents a brief description about experimental period, site, climatic condition, crop or planting materials, treatments, experimental design and layout, crop growing procedure, intercultural operations, data collection and statistical analysis. The details of experimental materials and methods are described below:

3.1 Experimental site

The experiment was carried out at the research field of Sher-e-Bangla Agricultural University, Dhaka, during the period from 5 November 2019 to 7 February 2020. Geographically the experimental area is located at $23^{0}41'$ N latitude and $90^{0}22'$ E longitudes at the elevation of 8.6 m above the sea level. The experimental field was medium high land belonging to the Madhupur Tract. The soil was silty loam. Fertility status of soil in experimental site has been shown in the Appendix I.

3.2 Climate and weather

The experimental field was under subtropical climates characterized by heavy rainfall during the month of April to September and scanty rainfall during October to March. The monthly means of daily maximum, minimum and average temperature, relative humidity, total rainfall and sunshine hours received at the experimental site during the period from October 2019 to February 2020 have been presented in Appendix II.

3.3 Soil characteristics

The experimental site belongs to the general soil type, Shallow Red Brown Terrace Soils under Tejgaon Series. Top soils were silty clay loam in texture, olive-gray with common fine to medium distinct dark yellowish brown mottles. Soil pH was 5.6 and had organic matter 0.78%. The experimental area was flat having available irrigation and drainage system. The experimental site was a medium high land. It 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

The variety BARI Alu-8 (Cardinal) was used as the planting material for the present study and was collected from the Tuber Research Centre, Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur.

3.5 Land preparation

The land of the experimental site was first opened in the last week of October with power tiller. Later on, the land was ploughed and cross-ploughed four times followed by laddering to obtain the desirable tilth. The corners of the land were spaded and weeds and stubbles were removed from the field. The land was finally prepared on 2nd November 2019 three days before planting the seed. In order to avoid water logging due to rainfall during the study period, drainage channels were made around the land. The soil was treated with Furadan 5G @10 kg ha^{-1} when the plot was finally ploughed to protect the young seedlings from the attack of cut worm.

3.6 Experimental design and lay out

The two-factor experiment was laid out in a Randomized Complete Block Design (RCBD) with 3 replications. The size of the unit plot was 2.0 m × 2.0 m. Block to block and plot to plot distances were 1 m and 0.5. Treatments were randomly distributed within the blocks. The plots were raised up to 10 cm.

3.7 Treatments of the experiment

The experiment comprised of two factors

Factor A: Zinc (Zn) Fertilizer -3 levels

Zn_0= 0 kg ha^{-1}

Zn_1= 2 kg ha^{-1}

Zn_2= 4 kg ha^{-1}

Factor B: Sulphur (S) Fertilizer -3 levels

S_0= 0 kg ha^{-1}

S_1= 15 kg ha^{-1}

S_2= 25 kg ha^{-1}

Nine treatment combinations were as: Zn_0S_0, Zn_0S_1, Zn_0S_2, Zn_1S_0, Zn_1S_1, Zn_1S_2, Zn_2S_0, Zn_2S_1 and Zn_2S_2.

3.8 Manure and fertilizer application

Urea, Triple superphosphate (TSP), Muriate of potash (MOP), Zinc oxide, Gypsum and Boric acid were used as sources of nitrogen, phosphorus, potassium, zinc, sulphur and boron, respectively. The applied doses of fertilizers were 115, 30, 125, 1.5 and 8000 kg ha^{-1} for nitrogen, phosphorus, potassium, boron and cowdung, respectively. Cowdung was applied 10 days before final land preparation. Total amount of TSP, MOP, boric acid and half of urea was applied at basal doses during final land preparation. Different doses of zinc oxide and gypsum fertilizer were applied for sulphur and zinc as per treatment advised. The remaining 50% urea was side dressed in two equal splits at 25 and 45 days after planting (DAP) during first and second earthing up.

3.9 Seed preparation and sowing

The seedling tubers were taken out of the cold store about three weeks before planting. The tubers were kept under diffuse light conditions to have healthy and good sprouts. Planting was done on November 5, 2019. The well sprouted seed tubers were planted at a depth of 5-7 cm in furrow made 60 cm apart. Hill to hill distance was 20 cm. After planting, the seed tubers were covered with soil.

3.10 Intercultural operations

3.10.1 Weeding

Weeding was necessary to keep the plant free from weeds. First weeding was done two weeks after emergence 30 November, 2019. Another weeding was done before 2^{nd} top dressing of urea on 20 November, 2019.

3.10.2 Earthing up

Earthing up was done twice during growing period. The first earthing up was done at 25 DAP on 30 November, 2019 and second earthing up was done after 15 days of first earthing up on 15 December, 2019.

3.10.3 Irrigation

Three irrigations were provided throughout the growing period in controlled way. The first irrigation was given at 25 DAP on 30 November, 2019. Subsequently, another two irrigations were given at 45 and 60 DAP.

3.10.4 Plant protection

Furadan 5G @ 10 kg ha^{-1} was applied in soil at the time of final land reparation on 25 October, 2019 to control cut worm. Dithane M-45 was sprayed in 2 installments at an interval of 15 days from 45 DAP as preventive measure against late blight disease.

3.11 Harvesting

The crop was harvested to study growth and development rate from 30 DAP to 75 DAP at 15 days interval and the final harvest was taken at 85 DAP. The harvested plants were tagged separately plot wise. Five sample plants were randomly selected from each plot and tagged for recording necessary data and then the all plots was harvested with the help of spade. The maturity of plant was indicated by the plants showing 80 to 90% of leaf senescence and the top started drying. Haulm cutting was done before 7 days of harvesting. The yield of tuber was taken plot wise and converted into tons ha^{-1}. Care was taken to avoid injury in potatoes during harvesting.

3.12 Data collection

The following parameters were recorded and their mean values were calculated from the sample plants.

i. Days to 1st emergence and days to final emergence

After planting the potato tuber keenly observed the emergence twice in a day (morning and afternoon) until final emergence.

ii. Plant height

Plant height was taken to be the length between the base of the plant to the tip at 30, 45, 60 and 75 DAP. The height of each plant of each plot was measured in cm with the help of a meter scale and mean was calculated.

iii. Number of leaves plant^{-1}

Number of leaves plant^{-1} was counted at an interval of 15 days starting from 30 DAP till 75 DAP. Leaves number plant^{-1} were recorded by counting all leaves from each plant of each plot and mean was calculated.

iv. Number of stems hill^{-1}

Number of stems hill^{-1} was counted at an interval of 15 days starting from 30 DAP till 75 DAP. Stem numbers hill^{-1} was recorded by counting all stem from each plot.

v. Number of tubers hill^{-1}

The number of tubers hill^{-1} was determined from the average of 5 hills selected from each unit plot.

vi. Average tuber weight

Five hills were randomly selected from each plot. The total tuber was enumerated and weighted from five hills by using an electronic balance. It was recorded by dividing total fresh weight of tubers by the total number of fresh tubers per plot.

vii. Tuber yield plot^{-1}

Tubers of each plot were collected separately from which yield of tuber was recorded in kilogram.

viii. Tuber yield

The weight of tuber hill^{-1} was calculated from 10 plants from each unit plot at harvest. All the tubers weight per plot was recorded and the tuber weight was finally converted into tons ha^{-1}.

ix. Grade of tubers on the basis of diameter

The grading of tubers was done in the following manner: > 55 mm in diameter, 45-55 mm in diameter, 28-45 mm in diameter and < 28 mm in diameter.

3.13 Statistical analysis

The collected data were analyzed statistically following the analysis of variance (ANOVA) technique and the means were separated by Least Significant Difference (LSD) using the statistical computer package program, MSTAT-C at 5% level of significant (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

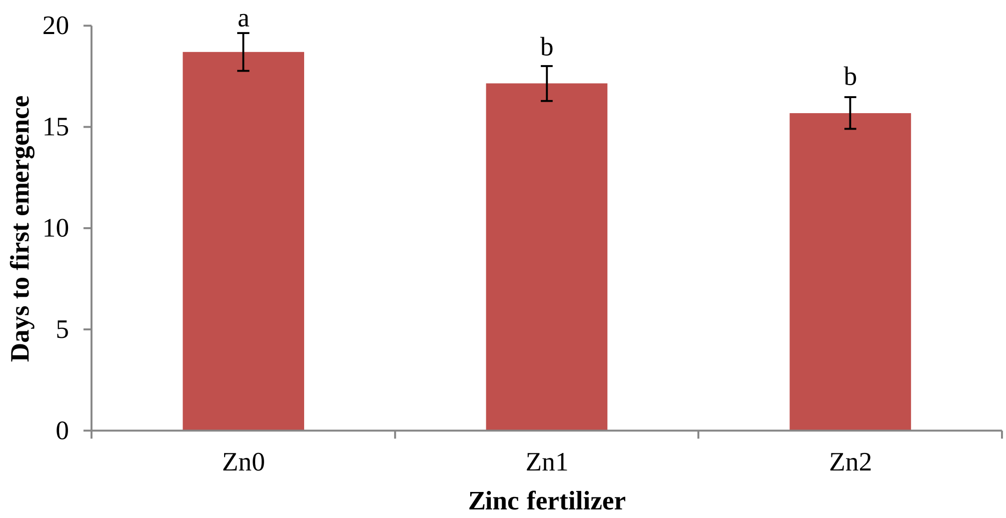
CHAPTER IV

RESULTS AND DISCUSSION

The experiment was conducted to study the effect of zinc and sulphur levels on yield of potato. Data on different plant characters, yield components and yield were recorded. The analyses of variance (ANOVA) of the data on different parameters are presented in Appendix V to X. The results have been presented with the help of graphs and table, and possible interpretations given under the following headings.

4.1 Days to 1st emergence

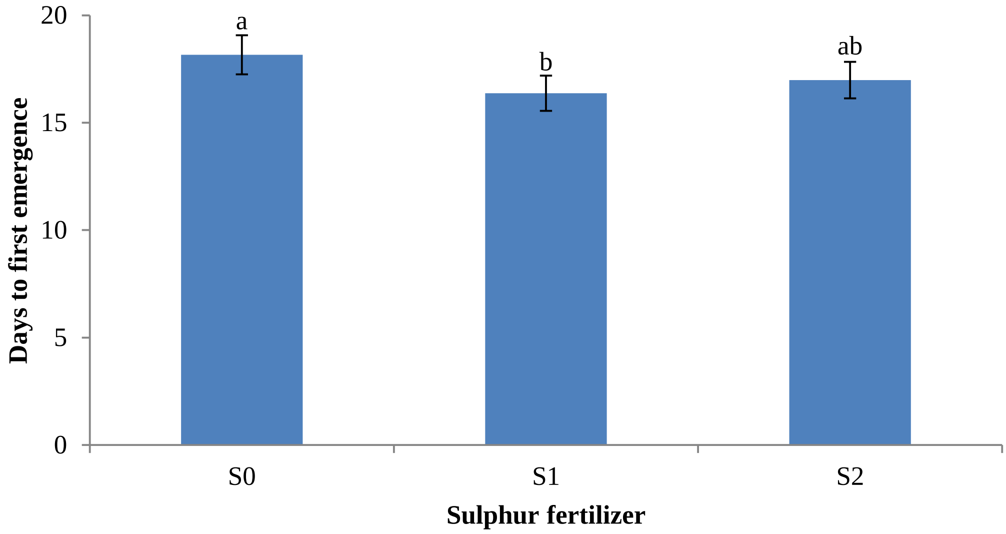
The time required for 1st emergence of the crop was significantly influenced by different levels of zinc application. Results of the experiment indicated that minimum days (15.68) required for 1st emergence of potato plant was noted in Zn_2 treatment which was statistically identical to Zn_1 treatment where maximum days (18.70) required for 1st emergence of potato plant was recorded in Zn_0 treatment (Figure 1). Emergence depends on soil moisture, soil temperature, seed temperature, disease and physiological age of seed. Roots are being developed 10-15 days after emergence. This trend was supported by the trends of Eugenia (2008).



Zn_0= 0 kg ha^{-1}, Zn_1= 2 kg ha^{-1} and Zn_2= 4 kg ha^{-1}

Figure 1. Effect of zinc on days to first emergence of potato plant

In case of the effect of different levels of sulphur on 1st emergence of potato plant the minimum days (16.37) required was recorded in S_1 treatment which was statistically similar with S_2 treatment where maximum days (18.16) required for 1st emergence of potato plant was noted in S_0 treatment (Figure 2). Emergence depends on soil moisture, soil temperature, seed temperature, disease and physiological age of seed. Roots are being developed 10-15 days after emergence. This trend was supported by the trends of Eugenia (2008).



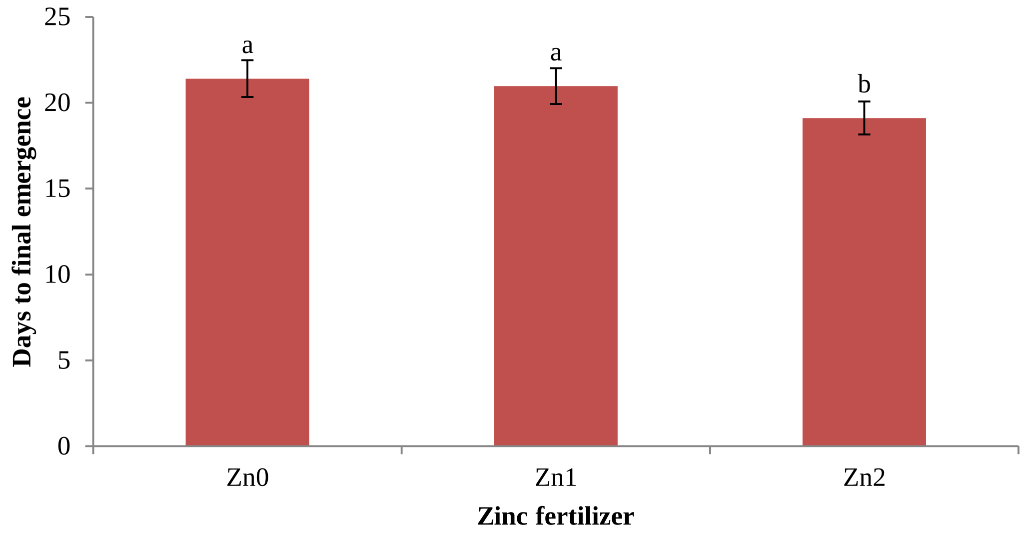
S_0= 0 kg ha^{-1}, S_1= 15 kg ha^{-1} and S_2= 25 kg ha^{-1}

Figure 2. Effect of sulphur on days to first emergence of potato plant

Interaction effect of zinc and sulphur were significantly influenced by days to 1st emergence of potato tubers (Table 1). The minimum duration for 1st emergence (14.17 days) was recorded from the combination of Zn_2S_1 which was statistically similar with Zn_2S_2 whereas, the maximum duration (19.47 days) was recorded from the combination of Zn_0S_0 which was statistically similar with the combination of Zn_0S_2, Zn_0S_1, Zn_1S_0 and Zn_2S_0.

4.2 Days to final emergence

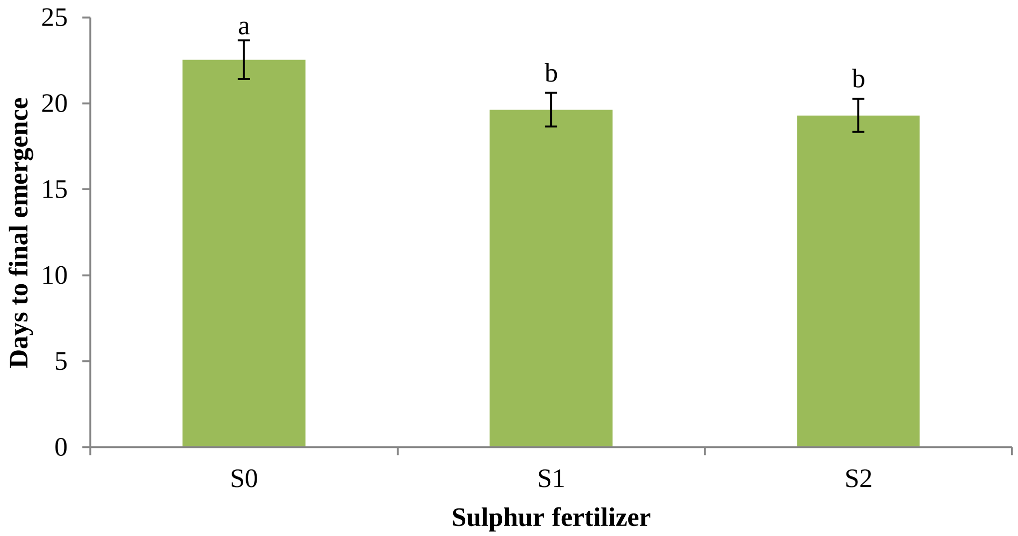
The time required for final emergence of the crop was significantly influenced by different levels of zinc application. Results of the experiment indicated that minimum days (19.11) required for final emergence of potato plant was noted in Zn_2 treatment where maximum days (21.40) required for final emergence of potato plant was recorded in Zn_0 treatment which was statistically identical to Zn_1 treatment (Figure 3). Emergence depends on soil moisture, soil temperature, seed temperature, disease and physiological age of seed. Roots are being developed 10-15 days after emergence. This trend was supported by the trends of Eugenia (2008).



Zn_0= 0 kg ha^{-1}, Zn_1= 2 kg ha^{-1} and Zn_2= 4 kg ha^{-1}

Figure 3. Effect of zinc on days to final emergence of potato plant

In case of the effect of different levels of sulphur on final emergence of potato plant the minimum days (19.30) required was recorded in S_1 treatment which was statistically identical to S_2 treatment where maximum days (22.54) required for final emergence of potato plant was noted in S_0 treatment (Figure 4). Emergence depends on soil moisture, soil temperature, seed temperature, disease and physiological age of seed. Roots are being developed 10-15 days after emergence. This trend was supported by the trends of Eugenia (2008).



S_0= 0 kg ha^{-1}, S_1= 15 kg ha^{-1} and S_2= 25 kg ha^{-1}

Figure 4. Effect of sulphur on days to final emergence of potato plant

Interaction effect of zinc and sulphur were significantly influenced by days to final emergence of potato tubers (Table 1). The minimum duration for final emergence (17.55 days) was recorded from the combination of Zn_2S_1 which was statistically similar with Zn_2S_2, Zn_0S_2 and Zn_1S_2 whereas the maximum duration (23.56 days) was recorded from the combination of Zn_0S_0 which was statistically similar with the combination of Zn_0S_2, Zn_0S_1, Zn_1S_0 and Zn_2S_0.

Table 1. Interaction effect of zinc and sulphur on days to first and final emergence of potato

Treatment combinations	Days to first emergence	Days to final emergence
Zn_0S_0	19.47 a	23.56 a
Zn_0S_1	18.11 a-c	20.86 ab
Zn_0S_2	18.51 ab	19.77 b-d
Zn_1S_0	17.89 a-c	22.29 ab
Zn_1S_1	16.84 bc	20.50 a-d
Zn_1S_2	16.70 bc	20.13 b-d
Zn_2S_0	17.13 a-c	21.78 ab
Zn_2S_1	14.17 d	17.55 d
Zn_2S_2	15.76 cd	18.00 cd
$LSD_{0.05}$	**2.52**	**3.21**
CV%	**8.48**	**9.06**

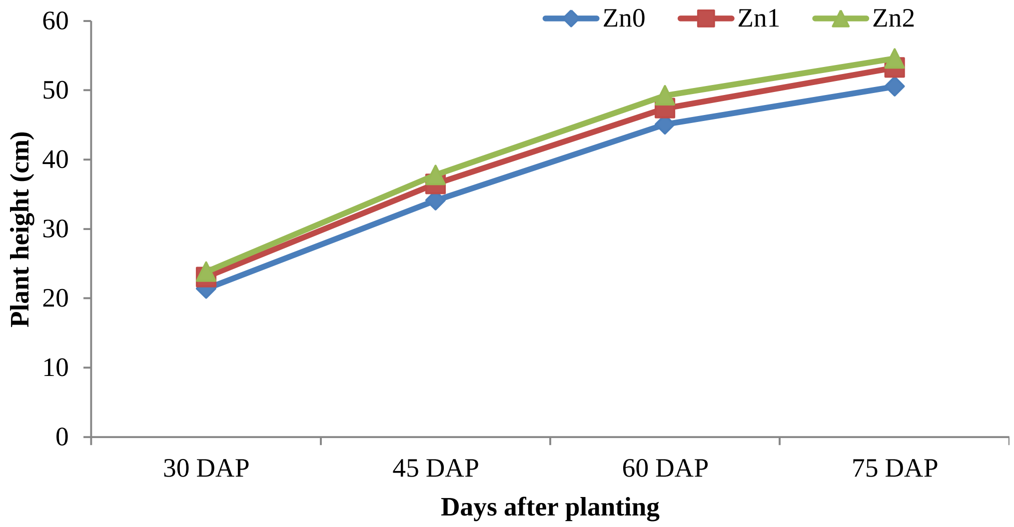
Zn_0= 0 kg ha^{-1}, Zn_1= 2 kg ha^{-1} and Zn_2= 4 kg ha^{-1}

S_0= 0 kg ha^{-1}, S_1= 15 kg ha^{-1} and S_2= 25 kg ha^{-1}

In a column mean values having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of significance

4.3 Plant height

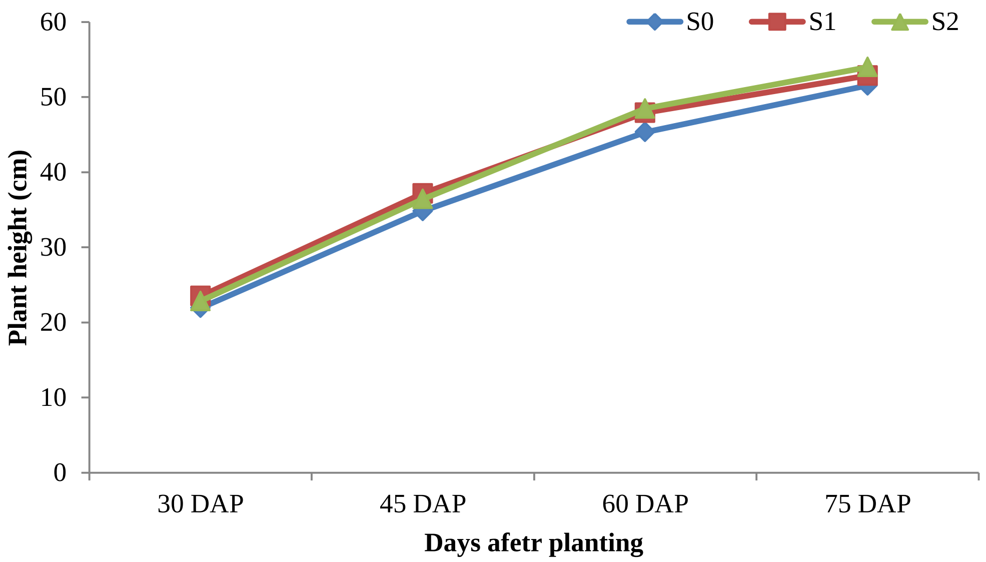
Plant height at different growth stages was significantly influenced by zinc in the study (Figure 5). It was observed that the highest plant height (23.82, 37.79, 49.24 and 54.58 cm at 30, 45, 60 and 75 DAP, respectively) was obtained from the treatment Zn_2 where the lowest plant height (21.37, 34.12, 45.07 and 50.53 cm at 30, 45, 60 and 75 DAP, respectively) was found from the treatment Zn_0. The findings of the study are also coinciding with the findings of Singh *et al.* (2018), Dhakal and Shrestha (2019) who reported that zinc application increases the plant height of tuber.



Zn_0= 0 kg ha^{-1}, Zn_1= 2 kg ha^{-1} and Zn_2= 4 kg ha^{-1}

Figure 5. Effect of zinc on plant height of potato at different days after planting

There was marked variation was observed on plant height at different growth stages which was significantly influenced by sulphur application. It was observed that the highest plant height (23.49, 37.17, 48.46 and 53.98 cm at 30, 45, 60 and 75 DAP, respectively) was obtained from the treatment S_1 where the lowest plant height (21.92, 34.82, 45.34 and 51.53 cm at 30, 45, 60 and 75 DAP, respectively) was found from the treatment S_0 (Figure 6). The results of the experiment was coincide with the findings of Muthanna *et al.* (2017), Fantow *et al.* (2019), Roy *et al.* (2014) who reported that plant height was significantly influenced by sulphur application.



S_0= 0 kg ha^{-1}, S_1= 15 kg ha^{-1} and S_2= 25 kg ha^{-1}

Figure 6. Effect of sulphur on plant height of potato at different days after planting

Significant variation on plant height of potato at different growth stages was observed in the study. Interaction effect of zinc and sulphur application showed significant differences (Table 2). Results observed that the highest plant height (24.84, 39.16, 51.28 and 56.11 cm at 30, 45, 60 and 75 DAP, respectively) was found from the treatment combination of Zn_2S_1 which were statistically similar with Zn_2S_2, Zn_1S_1 and Zn_1S_2 at 45 DAP, Zn_2S_2 at 60 and 75 DAP. The lowest plant height (20.36, 32.74, 43.25 and 49.13 cm at 30, 45, 60 and 75 DAP, respectively) was obtained from the treatment combination of Zn_0S_0 which was statistically at par with Zn_0S_2.

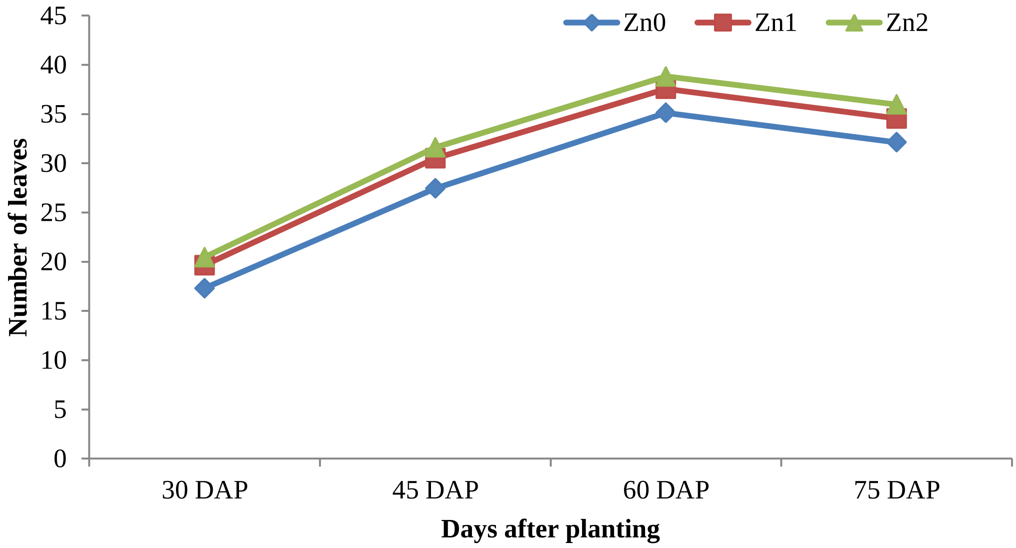
Table 2. Interaction effect of zinc and sulphur on plant height of potato at different days after planting

Treatment combinations	Plant height (cm) at			
	30 DAP	**45 DAP**	**60 DAP**	**75 DAP**
Zn_0S_0	20.36 f	32.74 e	43.25 f	49.13 f
Zn_0S_1	22.07 de	35.03 c-e	45.19 e	51.80 de
Zn_0S_2	21.68 e	34.60 de	46.77 de	50.66 ef
Zn_1S_0	22.50 c-e	35.52 b-d	46.00 de	52.78 cd
Zn_1S_1	23.56 b	37.33 a-c	48.90 bc	54.04 bc
Zn_1S_2	23.10 bc	36.61 a-d	47.29 cd	53.00 b-d
Zn_2S_0	22.91 b-d	36.19 b-d	46.77 de	52.67 c-e
Zn_2S_1	24.84 a	39.16 a	51.28 a	56.11 a
Zn_2S_2	23.70 b	38.02 ab	49.65 ab	54.95 ab
$LSD_{0.05}$	**0.86**	**2.59**	**1.87**	**2.06**
CV%	**2.20**	**4.15**	**2.30**	**2.26**

Zn_0= 0 kg ha^{-1}, Zn_1= 2 kg ha^{-1} and Zn_2= 4 kg ha^{-1}
S_0= 0 kg ha^{-1}, S_1= 15 kg ha^{-1} and S_2= 25 kg ha^{-1}
In a column mean values having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of significance

4.4 Number of leaves plant^{-1}

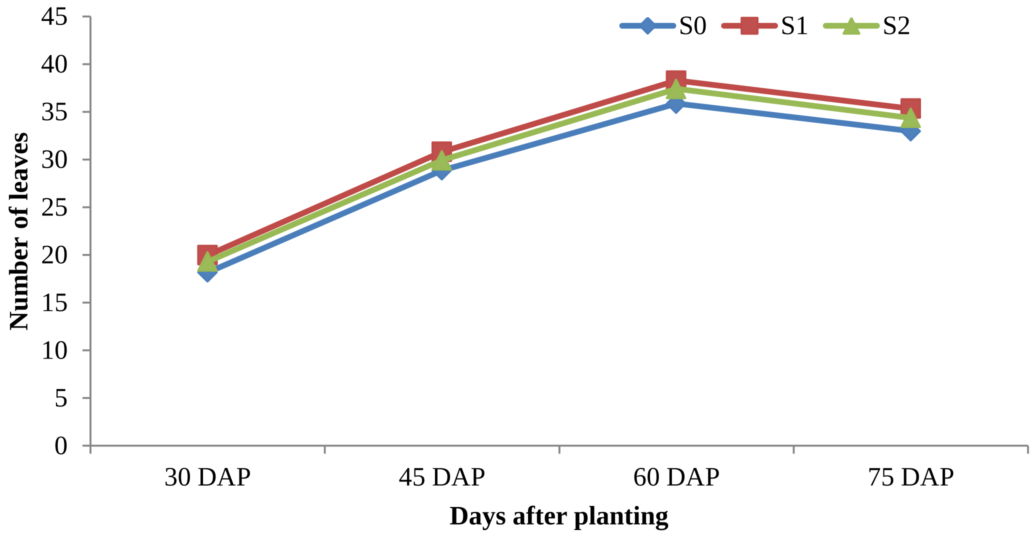
Different rates of zinc exhibited significant variation on number of leaves plant^{-1} in the study (Figure 7). It was observed that maximum number of leaves plant^{-1} (20.47, 31.62, 38.83 and 35.97 at 30, 45, 60 and 75 DAP, respectively) was obtained from the treatment Zn_2 where minimum number of leaves plant^{-1} (17.32, 27.45, 35.13 and 32.14 at 30, 45, 60 and 75 DAP, respectively) was found from the treatment Zn_0. The findings was also coinciding with the findings with Singh and Kathayat (2018), Kelling and Speth (2001) and Singh *et al.* (2018) who reported that zinc fertilizer increases the growth and yield of potato when applied as foliar application.



Zn_0= 0 kg ha^{-1}, Zn_1= 2 kg ha^{-1} and Zn_2= 4 kg ha^{-1}

Figure 7. Effect of zinc on number of leaves plant^{-1} of potato at different days after planting

Marked variation was observed on number of leaves at different growth stages which were significantly influenced by sulphur application (Figure 8). It was observed that maximum number of leaves plant^{-1} (19.98, 30.80, 38.27 and 35.33 at 30, 45, 60 and 75 DAP, respectively) was obtained from the treatment S_1 where minimum number of leaves plant^{-1} (18.15, 28.86, 35.86 and 32.98 at 30, 45, 60 and 75 DAP, respectively) was found from the treatment S_0. The results of our study was similar with the findings of Roy *et al.* (2014) who reported that Results revealed that, number of leaves hill^{-1}, stems hill^{-1}, plant dry matter content, tuber dry matter content, tubers number m^{-2}, tuber yield, marketable yield significantly increased with increasing potassium levels, whereas, plant height decreased with increasing potassium level. On the other hand plant dry matter content, tuber dry matter content, stems hill^{-1}, tubers m^{-2}, tuber yield, marketable yield increased significantly with increasing sulfur level. While plant height, number of leaves hill^{-1} and tubers m^{-2} decreased with increasing sulfur level. Combined effect of potassium and sulfur revealed that the highest number of tubers m^{-2} was achieved by 130 kg potassium with 34 kg sulfur ha^{-1}.



S_0= 0 kg ha^{-1}, S_1= 15 kg ha^{-1} and S_2= 25 kg ha^{-1}

Figure 8. Effect of sulphur on number of leaves per plant of potato at different days after planting

Significant variation on number of leaves $plant^{-1}$ of potato at different growth stages was observed in the study. Interaction effect of zinc and sulphur application showed significant differences (Table 3). Results observed that maximum number of leaves $plant^{-1}$ (21.50, 32.95, 40.33 and 37.62 at 30, 45, 60 and 75 DAP, respectively) was found from the treatment combination of Zn_2S_1 which were statistically similar with Zn_2S_2, Zn_1S_1 and Zn_1S_2 at 30, 45 and 60 DAP and Zn_2S_2 at 75 DAP, respectively. On the other hand, minimum number of leaves $plant^{-1}$ (16.37, 26.90, 34.55 and 31.33 at 30, 45, 60 and 75 DAP, respectively) was obtained from the treatment combination of Zn_0S_0 which was statistically at par with Zn_0S_2.

Table 3. Interaction effect of zinc and sulphur on leaves number plant^{-1} of potato at different days after planting

Treatment combinations	Leaves number plant^{-1} at			
	30 DAP	**45 DAP**	**60 DAP**	**75 DAP**
Zn_0S_0	16.37 e	26.90 e	34.55 e	31.33 f
Zn_0S_1	18.10 c-e	28.36 de	35.84 de	32.93 d-f
Zn_0S_2	17.50 de	27.09 e	35.00 e	32.15 ef
Zn_1S_0	18.86 b-d	29.56 cd	36.09 c-e	33.51 c-e
Zn_1S_1	20.33 ab	31.09 a-c	38.65 a-c	35.44 bc
Zn_1S_2	19.75 a-c	30.88 a-c	38.00 a-d	34.76 b-d
Zn_2S_0	19.21 b-d	30.13 b-d	36.95 b-e	34.11 c-e
Zn_2S_1	21.50 a	32.95 a	40.33 a	37.62 a
Zn_2S_2	20.69 ab	31.77 ab	39.21 ab	36.19 ab
$LSD_{0.05}$	**2.11**	**2.09**	**2.67**	**2.02**
CV%	**6.40**	**4.06**	**4.16**	**3.42**

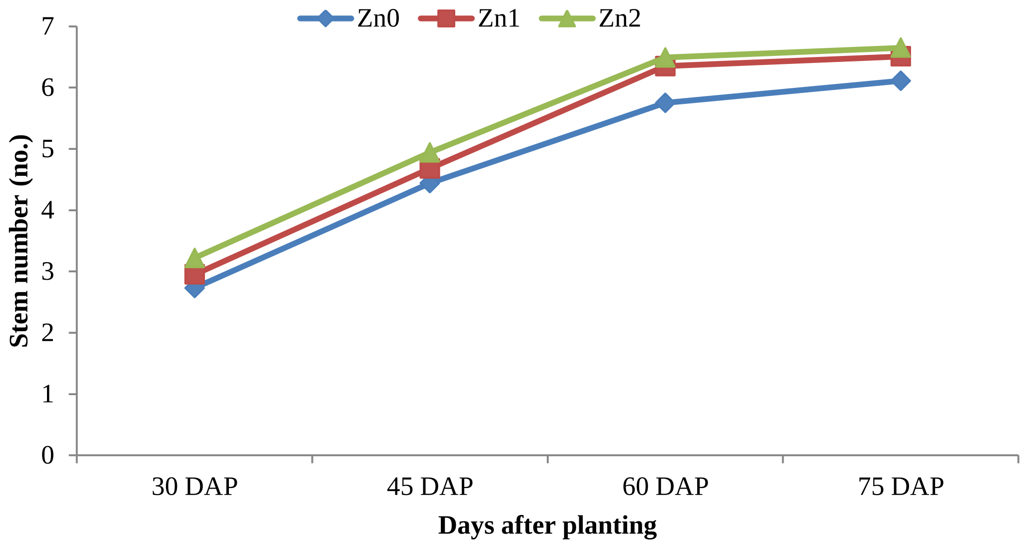
Zn_0= 0 kg ha^{-1}, Zn_1= 2 kg ha^{-1} and Zn_2= 4 kg ha^{-1}

S_0= 0 kg ha^{-1}, S_1= 15 kg ha^{-1} and S_2= 25 kg ha^{-1}

In a column mean values having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of significance

4.5 Number of stem hill^{-1}

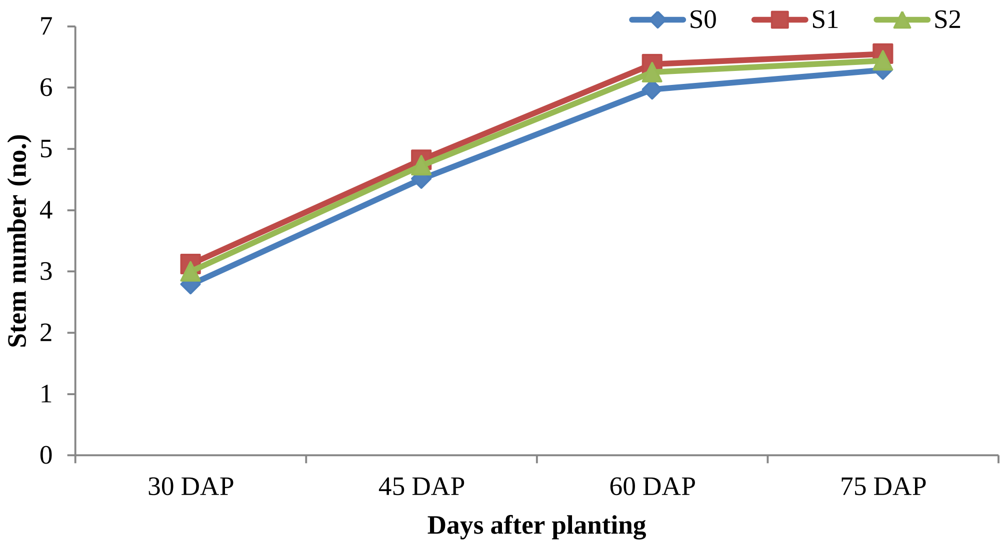
Different rates of zinc exhibited significant variation on number of stem hill^{-1} in the study (Figure 9). It was observed that maximum number of stem hill^{-1} (3.22, 4.94, 6.49 and 6.65 at 30, 45, 60 and 75 DAP, respectively) was obtained from the treatment Zn_2 where minimum number of stem hill^{-1} (2.73, 4.44, 5.75 and 6.11 at 30, 45, 60 and 75 DAP, respectively) was found from the treatment Zn_0. The results of the study was also coincide with the findings of Kelling and Speth (2001) and Dhakal and Shrestha (2019) who reported foliar applications of Zn-EDTA@180 ppm at 45 DAP and 65 DAP is suitable in potato production with respect to better growth and yield.



Zn_0= 0 kg ha^{-1}, Zn_1= 2 kg ha^{-1} and Zn_2= 4 kg ha^{-1}

Figure 9. Effect of zinc on stem number hill^{-1} of potato at different days after planting

There was marked variation was observed on number of stem hill^{-1} at different growth stages which was significantly influenced by sulphur application (Figure 10). It was observed that maximum number of stem hill^{-1} (3.12, 4.82, 6.38 and 6.54 at 30, 45, 60 and 75 DAP, respectively) was obtained from the treatment S_1 where minimum number of stem hill^{-1} (2.78, 4.51, 5.97 and 6.27 at 30, 45, 60 and 75 DAP, respectively) was found from the treatment S_0. The findings of the study was similar with the findings of Fantow *et al.* (2019) who reported that application 110-19.74-50.8 kg ha^{-1} $N_2/S_2/P_2O_5$ fertilizer delayed days to flowering and maturity by 8 and 11 days at Darark and 10 and 14 days at Dabat. However, it increased plant height and number of stems per plant, which may positively contribute to increased photosynthetic area. The application of these fertilizers advanced marketable tuber yield by 153% and the total tuber yield by 86.6% relative to unfertilized plants.



S_0= 0 kg ha^{-1}, S_1= 15 kg ha^{-1} and S_2= 25 kg ha^{-1}

Figure 10. Effect of sulphur on stem number hill^{-1} of potato at different days after planting

Significant variation on number of stem hill^{-1} of potato at different growth stages was observed in the study. Interaction effect of zinc and sulphur application showed significant differences (Table 4). Results observed that maximum number of stem hill^{-1} (3.53, 5.16, 6.66 and 6.82 at 30, 45, 60 and 75 DAP, respectively) was found from the treatment combination of Zn_2S_1 which were statistically similar with Zn_2S_2 at 30 DAP; Zn_2S_2 and Zn_1S_1 45 DAP; Zn_2S_2, Zn_1S_1, Zn_1S_2, Zn_2S_0 and Zn_1S_0 at 60 DAP and Zn_2S_2, Zn_1S_1 and Zn_1S_2 at 75 DAP, respectively. On the other hand, minimum number of stem hill^{-1} (2.70, 4.40, 5.48 and 6.02 at 30, 45, 60 and 75 DAP, respectively) was obtained from the treatment combination of Zn_0S_0 which was statistically at par with Zn_0S_2.

Table 4. Interaction effect of zinc and sulphur on stem number hill^{-1} of potato at different days after planting

Treatment combinations	Stem number at			
	30 DAP	**45 DAP**	**60 DAP**	**75 DAP**
Zn_0S_0	2.70 c	4.40 c	5.48 d	6.02 d
Zn_0S_1	2.77 c	4.49 c	5.99 b-d	6.21 b-d
Zn_0S_2	2.73 c	4.43 c	5.79 cd	6.11 cd
Zn_1S_0	2.80 c	4.54 c	6.18 a-c	6.39 a-d
Zn_1S_1	3.07 bc	4.81 a-c	6.49 ab	6.61 ab
Zn_1S_2	2.99 bc	4.68 bc	6.38 a-c	6.53 a-c
Zn_2S_0	2.86 bc	4.60 bc	6.24 a-c	6.45 a-d
Zn_2S_1	3.53 a	5.16 a	6.66 a	6.82 a
Zn_2S_2	3.28 ab	5.07 ab	6.57 ab	6.69 a
$LSD_{0.05}$	**0.46**	**0.48**	**0.66**	**0.45**
CV%	**8.87**	**5.86**	**6.17**	**4.00**

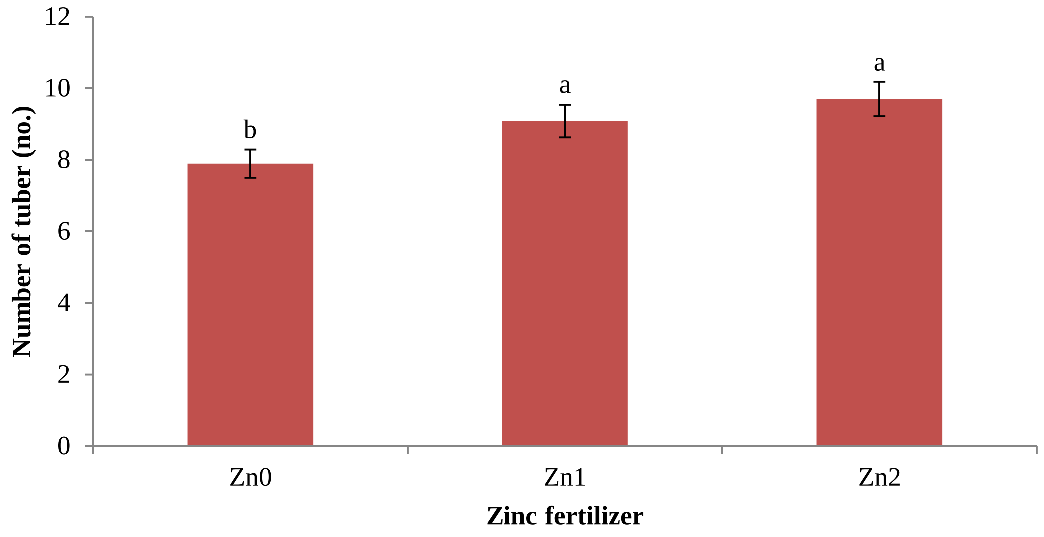
Zn_0= 0 kg ha^{-1}, Zn_1= 2 kg ha^{-1} and Zn_2= 4 kg ha^{-1}

S_0= 0 kg ha^{-1}, S_1= 15 kg ha^{-1} and S_2= 25 kg ha^{-1}

In a column mean values having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of significance

4.6 Number of tuber hill^{-1}

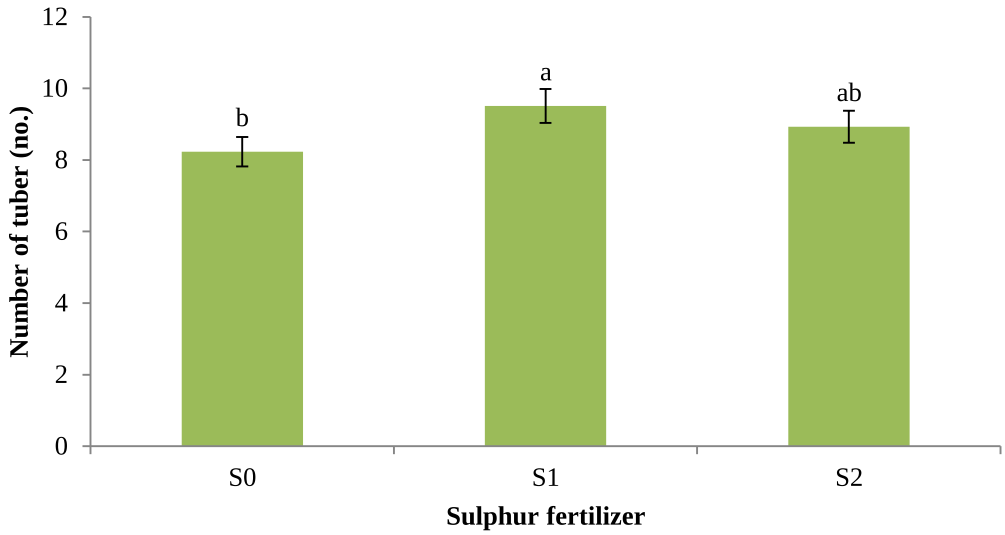
Different rates of zinc exhibited significant variation on number of tuber hill^{-1} in the study (Figure 11). It was observed that maximum number of tuber hill^{-1} (9.70) was obtained from the treatment Zn_2 which was statistically identical to Zn_1 treatment where minimum number of tuber hill^{-1} (7.89) was found from the treatment Zn_0. The results of the study was also coincide with the findings of Singh *et al.* (2017) who reported that with the foliar application of zinc (30 ppm) significant increase in number of tubers per plant, average weight of tuber, length of tuber, diameter of tuber, tuber yield per plot and tuber yield per hectare was recorded as compared to control.



Zn_0= 0 kg ha^{-1}, Zn_1= 2 kg ha^{-1} and Zn_2= 4 kg ha^{-1}

Figure 11. Effect of zinc on number of tuber hill^{-1} of potato

Marked variation was observed on number of tuber hill^{-1} which was significantly influenced by sulphur application (Figure 12). It was observed that maximum number of tuber hill^{-1} (9.51) was obtained from the treatment S_1 which was statistically similar with S_2 treatment where minimum number of tuber hill^{-1} (8.23) was found from the treatment S_0. Similar trends was also found by Roy *et al.* (2014) who reported that plant dry matter content, tuber dry matter content, stems hill^{-1}, number of tubers m^{-2}, tuber yield, marketable yield increased significantly with increasing sulfur level. While plant height, number of leaves hill^{-1} and tubers m^{-2} decreased with increasing sulfur level. Combined effect of potassium and sulfur revealed that the highest number of tubers m^{-2} was achieved by 130 kg potassium with 34 kg sulfur per hectare.



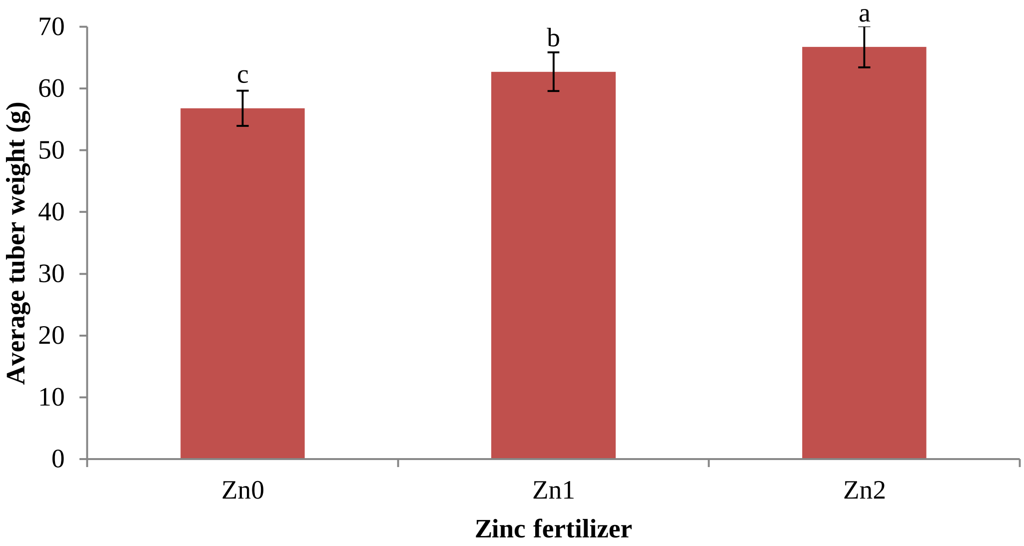
S_0= 0 kg ha^{-1}, S_1= 15 kg ha^{-1} and S_2= 25 kg ha^{-1}

Figure 12. Effect of sulphur on number of tuber hill^{-1} of potato

Significant variation on number of tuber hill^{-1} of potato was observed due to different levels of fertilizer application in the study. Interaction effect of zinc and sulphur application showed significant differences (Table 5). Results observed that maximum number of tuber hill^{-1} (10.53) was found from the treatment combination of Zn_2S_1 which were statistically similar with Zn_2S_2 and Zn_1S_1. On the other hand, minimum number of tuber hill^{-1} (7.40) was obtained from the treatment combination of Zn_0S_0 which was statistically at par with Zn_0S_2, Zn_0S_2, Zn_0S_1 and Zn_1S_0.

4.7 Average tuber weight

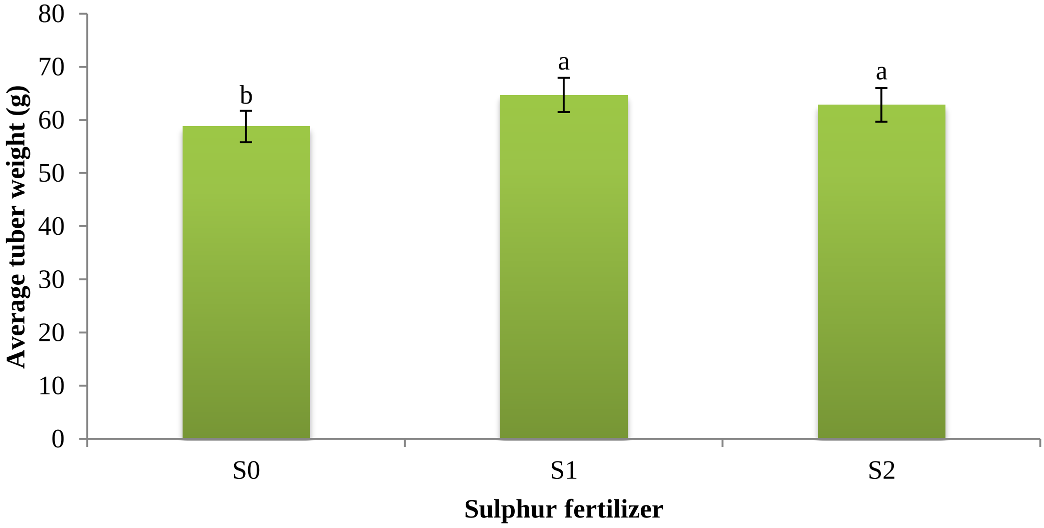
Different rates of zinc exhibited significant variation on average tuber weight in the study (Figure 13). It was observed that maximum average tuber weight (66.76 g) was obtained from the treatment Zn_2 where minimum average tuber weight (56.81 g) was found from the treatment Zn_0. The findings of the experiment was also coincide with the findings of Singh *et al.* (2017) who reported that with the foliar application of zinc (30 ppm) significant increase in number of tubers per plant, average weight of tuber, length of tuber, diameter of tuber, tuber yield per plot and tuber yield per hectare was recorded as compared to control.



Zn_0= 0 kg ha^{-1}, Zn_1= 2 kg ha^{-1} and Zn_2= 4 kg ha^{-1}

Figure 13. Effect of zinc on average tuber weight of potato

Significant variation was observed on average tuber weight of potato influenced by sulphur application (Figure 14). It was observed that maximum average tuber weight (64.69 g) was obtained from the treatment S_1 which was statistically identical to S_2 treatment where minimum average tuber weight (58.78 g) was found from the treatment S_0. Similar results was also found by Roy *et al.* (2014) who reported that plant dry matter content, average tuber weight, tuber dry matter content, stems hill^{-1}, tubers m^{-2}, tuber yield, marketable yield increased significantly with increasing sulfur level.



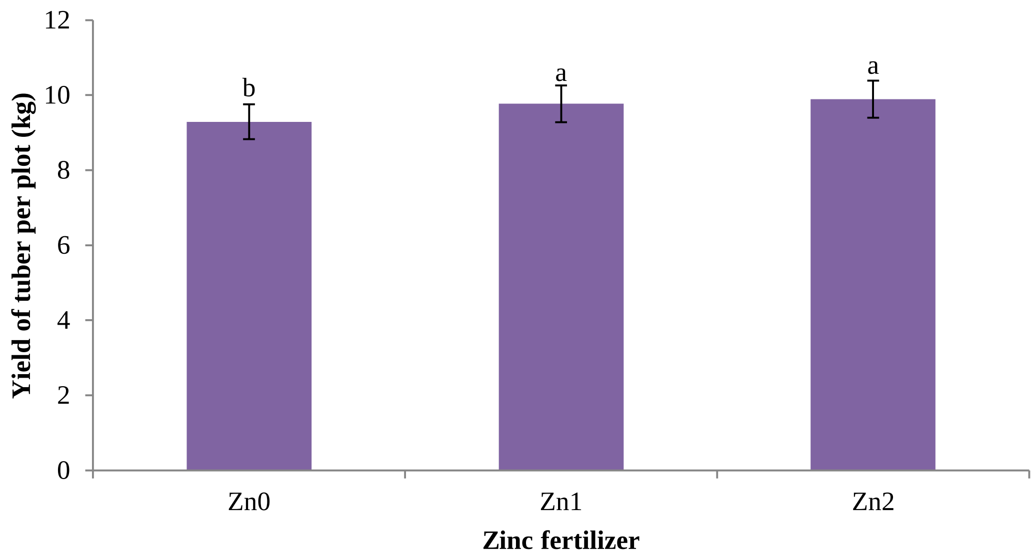
S_0= 0 kg ha^{-1}, S_1= 15 kg ha^{-1} and S_2= 25 kg ha^{-1}

Figure 14. Effect of sulphur on average tuber weight of potato

Significant variation on average tuber weight of potato was observed due to different levels of fertilizer application in the study. Interaction effect of zinc and sulphur application showed significant differences (Table 5). Results observed that maximum average tuber weight (70.29 g) was found from the treatment combination of Zn_2S_1 which were statistically similar with Zn_2S_2 and Zn_1S_1. On the other hand, minimum average tuber weight (55.28) was obtained from the treatment combination of Zn_0S_0 which was statistically at par with Zn_0S_2.

4.8 Yield per plot of tuber

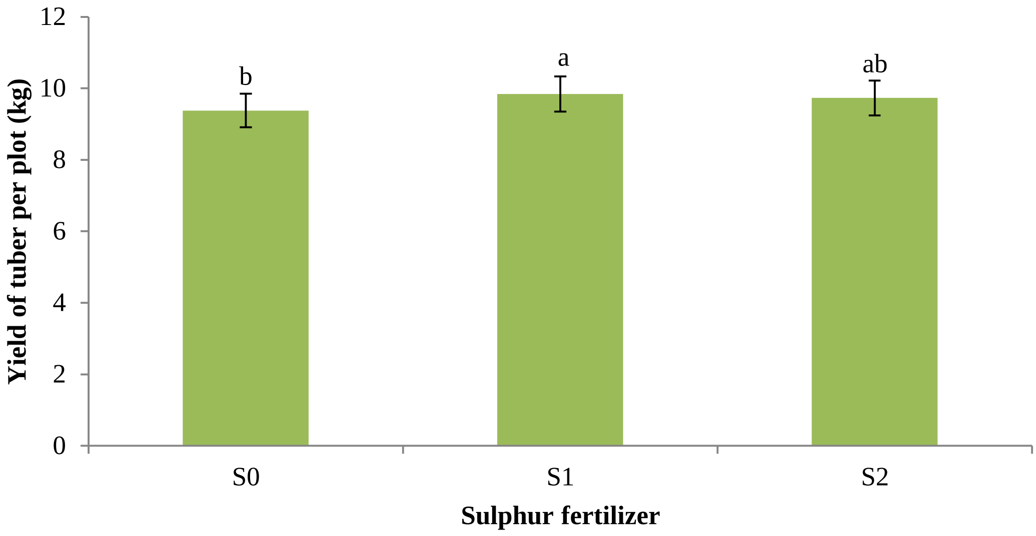
Different rates of zinc exhibited significant variation on yield per plot of tuber in the study (Figure 15). It was observed that the highest yield per plot (9.89 kg) was obtained from the treatment Zn_2 which was statistically identical to Zn_1 treatment where the lowest yield per plot (9.29 kg) was found from the treatment Zn_0. The findings of the experiment was also coincide with the findings of Singh *et al.* (2017) who reported that with the foliar application of zinc (30 ppm) significant increase in number of tubers per plant, average weight of tuber, length of tuber, diameter of tuber, tuber yield per plot and tuber yield per hectare was recorded as compared to control.



Zn_0= 0 kg ha^{-1}, Zn_1= 2 kg ha^{-1} and Zn_2= 4 kg ha^{-1}

Figure 15. Effect of zinc on tuber yield per plot of potato

Significant variation was observed on yield per plot of tuber which was statistically influenced by sulphur application (Figure 16). It was observed that maximum yield per plot tuber (9.84 kg) was obtained from the treatment S_1 which was statistically similar with S_2 (9.73 kg) treatment whereas minimum yield per plot tuber (9.38 kg) was found from the treatment S_0. The findings of the experiment was also as par with the findings of Roy *et al.* (2014) who reported that plant dry matter content, tuber dry matter content, stems hill^{-1}, tubers m^{-2}, tuber yield, marketable yield increased significantly with increasing sulfur level. While plant height, number of leaves hill^{-1} and tubers m^{-2} decreased with increasing sulfur level.



S_0= 0 kg ha^{-1}, S_1= 15 kg ha^{-1} and S_2= 25 kg ha^{-1}

Figure 16. Effect of sulphur on tuber yield per plot of potato

Significant variation on yield per plot of potato was observed due to different levels of fertilizer application in the study. Interaction effect of zinc and sulphur application showed significant differences (Table 5). Result observed that maximum yield per plot of tuber (10.09 kg) was found from the treatment combination of Zn_2S_1 which were statistically similar with Zn_2S_2, Zn_1S_1, Zn_1S_2, and Zn_2S_0. On the other hand, minimum yield per plot (8.98 kg) was obtained from the treatment combination of Zn_0S_0 which was statistically at par with Zn_0S_2.

4.9 Yield per hectare of tuber

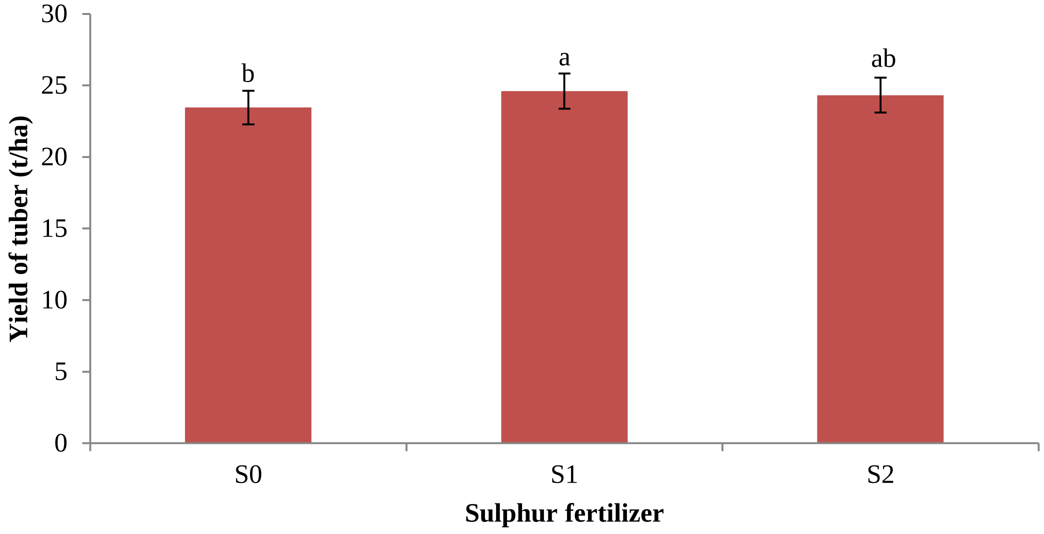
Different rates of zinc exhibited significant variation on yield per hectare of tuber in the study (Figure 17). It was observed that the highest yield per hectare (24.72 t) was obtained from the treatment Zn_2 which was statistically identical to Zn_1 (24.43 t) treatment whereas the lowest yield per hectare (23.24 t) was found from the treatment

Zn_0. The findings of our study was also coinciding with the findings of Sarker *et al.* (2018) who reported that the highest tuber yield was produced by the combined application of Zn and B. Only Zn application was sufficient to obtain the highest content of protein as well as content of almost all the nutrients in potato tuber. Antagonistic relation between Zn and P in soil-plant system was recorded in the study. Zinc and boron application influenced different growth and yield parameters of potato while the other four added micronutrients did not have any significant effect but combined application of Zn, B, Cu, Mn, Fe and Mo had beneficial role for better plant growth and production.

Zn_0= 0 kg ha^{-1}, Zn_1= 2 kg ha^{-1} and Zn_2= 4 kg ha^{-1}

Figure 17. Effect of zinc on tuber yield per hectare of potato

There was marked variation was observed on yield per hectare of potato which was significantly influenced by sulphur application (Figure 18). It was observed that maximum yield per hectare of potato (24.61 t) was obtained from the treatment S_1 which was statistically similar with S_2 (24.32 t) treatment whereas minimum yield per hectare of potato (23.46 t) was found from the treatment S_0. The results of the study was also similar with the findings of Tarafder *et al.* (2008) who reported that average tuber yield of potato (var. cardinal) varied from 28.29 to 32.86 t ha^{-1} with the highest yield in $S_{15}Zn_2$ treatment (100% recommended dose) and the lowest was in the S_0Zn_0 treatment (control). The findings of the experiment were also similar with the findings of Kushwah *et al.* (2015) who reported that applying 45 kg S ha^{-1} gave the highest performance of tuber yield of potato.



S_0= 0 kg ha^{-1}, S_1= 15 kg ha^{-1} and S_2= 25 kg ha^{-1}

Figure 18. Effect of sulphur on tuber yield per hectare of potato

Significant variation on yield per hectare of potato was observed due to different levels of fertilizer application in the study. Interaction effect of zinc and sulphur application showed significant differences (Table 4). Results observed that maximum yield per hectare of potato (25.24 t) were found from the treatment combination of Zn_2S_1 which were statistically similar with Zn_2S_2, Zn_1S_1 and Zn_1S_2. On the other hand, minimum yield per hectare of potato (22.46 t) was obtained from the treatment combination of Zn_0S_0 which was statistically at par with Zn_0S_2.

Table 5. Interaction effect of zinc and sulphur on yield contributing characters and yield of potato

Treatment combinations	Number of tuber hill^{-1}	Average tuber weight	Yield of tuber per plot (kg)	Yield (t ha^{-1})
Zn_0S_0	7.40 d	55.28 f	8.98 c	22.46 c
Zn_0S_1	8.40 b-d	58.32 d-f	9.49 a-c	23.73 a-c
Zn_0S_2	7.87 cd	56.84 ef	9.40 bc	23.51 bc
Zn_1S_0	8.53 b-d	59.54 d-f	9.55 a-c	23.87 a-c
Zn_1S_1	9.58 a-c	65.44 a-c	9.94 ab	24.86 ab
Zn_1S_2	9.13 a-d	63.17 b-d	9.83 ab	24.58 ab
Zn_2S_0	8.77 a-d	61.51 c-e	9.62 ab	24.06 a-c
Zn_2S_1	10.53 a	70.29 a	10.09 a	25.24 a
Zn_2S_2	9.80 ab	68.50 ab	9.95 ab	24.87 ab
$LSD_{0.05}$	**1.81**	**5.42**	**0.60**	**1.72**
CV%	**11.79**	**5.05**	**3.65**	**4.11**

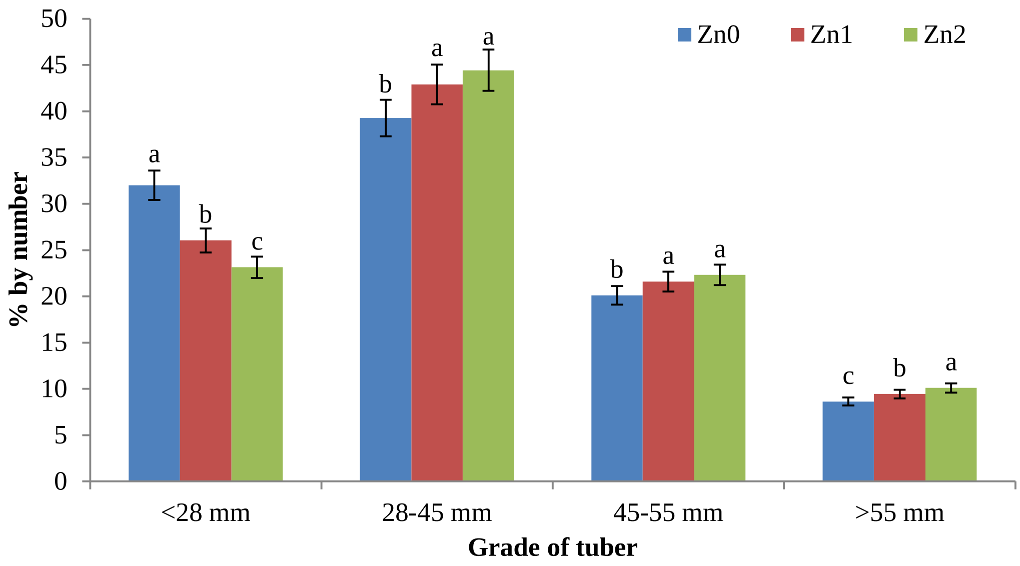
Zn_0= 0 kg ha^{-1}, Zn_1= 2 kg ha^{-1} and Zn_2= 4 kg ha^{-1}

S_0= 0 kg ha^{-1}, S_1= 15 kg ha^{-1} and S_2= 25 kg ha^{-1}

In a column mean values having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of significance

4.10 Grading of tuber on the basis of diameter (% by number)

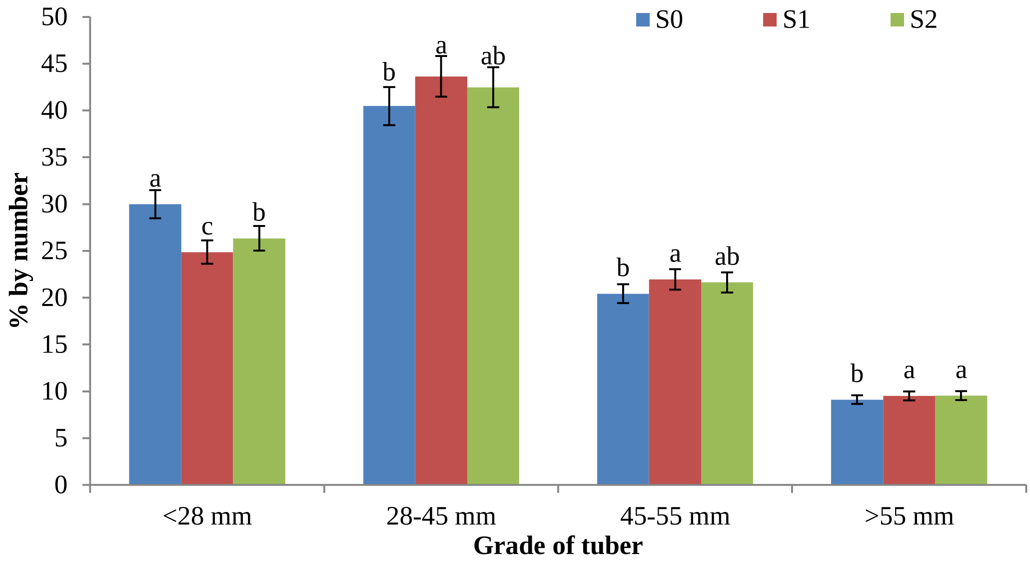
There was significant variation in grading of tuber on the basis of diameter was observed due to different levels of zinc application in diameter but numerical maximum diameter required (Figure 19). In case of <28 mm, the maximum percentage of tuber on the basis of diameter (32.01) was recorded on Zn_0 treatment where minimum percentage of tuber on the basis of diameter (23.14) was recorded on Zn_2 treatment. In case of 28-45 mm, the maximum percentage of tuber on the basis of diameter (44.43) was recorded on Zn_2 treatment which was statistically identical to Zn_1 treatment whereas minimum percentage of tuber on the basis of diameter (39.26) was recorded on Zn_0 treatment. Results indicated that in case of 45-55 mm, the maximum percentage of tuber on the basis of diameter (22.32) was recorded on Zn_2 treatment which was statistically identical to Zn_1 treatment where minimum percentage of tuber on the basis of diameter (20.10) was recorded on Zn_0 treatment. In case of above 55 mm, the maximum percentage of tuber on the basis of diameter (10.10) was recorded on Zn_2 treatment where minimum percentage of tuber on the basis of diameter (8.63) was recorded on Zn_0 treatment.



Zn_0= 0 kg ha^{-1}, Zn_1= 2 kg ha^{-1} and Zn_2= 4 kg ha^{-1}

Figure 19. Effect of zinc on grading of tuber on the basis of diameter of potato

Significant variation was found in grading of tuber on the basis of diameter due to different levels of sulphur fertilizer application (Figure 20). In case of <28 mm, the maximum percentage of tuber on the basis of diameter (29.99) was recorded on S_0 treatment where minimum percentage of tuber on the basis of diameter (24.87) was recorded on S_1 treatment. In case of 28-45 mm, the maximum percentage of tuber on the basis of diameter (43.64) was recorded on S_1 treatment which was statistically similar with S_2 treatment whereas minimum percentage of tuber on the basis of diameter (40.48) was recorded on S_0 treatment. Results indicated that in case of 45-55 mm, the maximum percentage of tuber on the basis of diameter (21.96) was recorded on S_1 treatment which was statistically similar with S_2 treatment whereas minimum percentage of tuber on the basis of diameter (20.43) was recorded on S_0 treatment. In case of above 55 mm, the maximum percentage of tuber on the basis of diameter (9.54) was recorded on S_2 treatment which was statistically identical to S_1 treatment whereas minimum percentage of tuber on the basis of diameter (9.11) was recorded on S_0 treatment.



S_0= 0 kg ha^{-1}, S_1= 15 kg ha^{-1} and S_2= 25 kg ha^{-1}

Figure 20. Effect of sulphur on grading of tuber on the basis of diameter of potato

Statistically significant variation in grading of tuber on the basis of diameter was observed due to interaction of zinc and sulphur fertilizers (Table 6). In case of <28 mm, the maximum percentage of tuber (34.53) was recorded on Zn_0S_0 treatment combination which was statistically dissimilar with the other treatment combinations under the present study where minimum percentage of tube (20.28) was recorded on Zn_2S_1 treatment combination which was statistically similar with Zn_2S_2. In case of 28-45 mm, the maximum percentage of tuber (46.15) was recorded on Zn_2S_1 treatment combination which were statistically similar with Zn_2S_2, Zn_1S_1 and Zn_1S_2. On the other hand, minimum percentage of tuber (38.11) was recorded on Zn_0S_0 treatment combination which were statistically similar with Zn_0S_2, Zn_0S_1 and Zn_1S_0. Results indicated that in case of 45-55 mm, the maximum percentage of tuber (23.11) was recorded on Zn_2S_1 treatment combination which were statistically similar with Zn_2S_2, Zn_1S_1, Zn_1S_2 and Zn_2S_0 where minimum percentage of tube (19.10) was recorded on Zn_0S_0 treatment combination which were statistically similar with Zn_0S_2, Zn_0S_1 and Zn_1S_0. In case of above 55 mm, the maximum percentage of tuber (10.46) was recorded on Zn_2S_1 treatment combination which was statistically dissimilar with the other treatment under the study where minimum percentage of tuber (8.26) was recorded on Zn_0S_0 treatment combination which was statistically similar with Zn_0S_1 treatment combination.

Table 6. Interaction effect of zinc and sulphur on grading of tuber on the basis of diameter (% by number) of potato

Treatment combinations	**Grading of tuber on the basis of diameter (% by number)**			
	<28 mm	**28-45 mm**	**45-55 mm**	**>55 mm**
Zn_0S_0	34.53 a	38.11 e	19.10 d	8.26 g
Zn_0S_1	30.00 bc	40.57 c-e	20.72 b-d	8.71 fg
Zn_0S_2	31.50 b	39.10 de	20.47 cd	8.91 ef
Zn_1S_0	28.66 cd	41.19 b-e	20.95 b-d	9.21 de
Zn_1S_1	24.33 fg	44.20 a-c	22.05 a-c	9.42 cd
Zn_1S_2	25.18 ef	43.33 a-d	21.79 a-c	9.70 bc
Zn_2S_0	26.79 de	42.13 a-e	21.23 a-c	9.85 bc
Zn_2S_1	20.28 h	46.15 a	23.11 a	10.46 a
Zn_2S_2	22.35 gh	45.02 ab	22.63 ab	10.00 b
$LSD_{0.05}$	**2.22**	**4.23**	**2.11**	**0.45**
CV%	**4.75**	**5.80**	**5.71**	**2.77**

Zn_0= 0 kg ha^{-1}, Zn_1= 2 kg ha^{-1} and Zn_2= 4 kg ha^{-1}

S_0= 0 kg ha^{-1}, S_1= 15 kg ha^{-1} and S_2= 25 kg ha^{-1}

In a column mean values having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of significance

CHAPTER V

SUMMARY AND CONCLUSION

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SUMMARY

The field experiment was conducted at the central farm of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka-1207 during the period from November 2019 to February 2020 to find out the growth and yield of potato as influenced by zinc and sulphur fertilization. The experiment consisted of two factors Factor A: Different levels of zinc such as Zn_0: 0 kg ha^{-1}, Zn_1: 2 kg ha^{-1} and Zn_2: 4 kg ha^{-1}; Factor B: Different levels of sulphur such as S_0: 0 kg ha^{-1}, S_1: 15 kg ha^{-1} and S_2: 25 kg ha^{-1}. Data on different growth and yield contributing characters were recorded.

The two factors experiment was laid out in a Randomized Complete Block Design (RCBD) containing nine treatments with 3 replications. The unit plot size was 2.0 m × 2.0 m. There were nine numbers of treatments and total numbers of plots were twenty seven. Data were collected based on the following parameters- Days to 1st emergence, days to final emergence, plant height, number of leaves $plant^{-1}$, number of stem $hill^{-1}$ and number of tuber $hill^{-1}$, average tuber weight, yield of tuber $plot^{-1}$, tuber yield and grade of tuber. The collected data were analyzed statistically following the analysis of variance (ANOVA) technique and the means were separated by Least Significant Difference (LSD) using the statistical computer package program, MSTAT-C at 5% level of significant.

Most of the parameters were significantly influenced by different levels of zinc and sulphur fertilization that were revealed the result of the experiment.

Different levels of zinc fertilizer showed significant effects on days to 1st emergence. Results of the experiment indicated that minimum days (15.68) required for 1st emergence of potato plant was noted in Zn_2 treatment where maximum days (18.70) required for 1st emergence of potato plant was recorded in Zn_0 treatment. In case of final emergence, minimum days (19.11) required for final emergence of potato plant was noted in Zn_2 treatment where maximum days (21.40) required for 1st emergence of potato plant was recorded in Zn_0 treatment. Different levels of zinc significantly influenced on plant height, number of leaves $plant^{-1}$, number of stem $hill^{-1}$, number of tubers $hill^{-1}$, average tuber weight, yield per plot, tuber yield and grading of tuber.

The maximum plant height (23.82, 37.79, 49.24 and 54.58 cm at 30, 45, 60 and 75 DAP, respectively), number of leaves plant^{-1} (20.47, 31.62, 38.83 and 35.97 at 30, 45, 60 and 75 DAP, respectively), number of stem hill^{-1} (3.22, 4.94, 6.49 and 6.65 at 30, 45, 60 and 75 DAP, respectively), number of tuber hill^{-1} (9.70), average tuber weight (66.76 g), yield per plot (9.89 kg), yield per hectare (24.72 t) and 44.43% maximum tuber grade in respect of 28-45 mm diameter were recorded from the treatment Zn_2. On the other hand, the minimum plant height 21.37, 34.12, 45.07 and 50.53 cm at 30, 45, 60 and 75 DAP, respectively), number of leaves plant^{-1} (17.32, 27.45, 35.13 and 32.14 at 30, 45, 60 and 75 DAP, respectively), number of stem hill^{-1} (2.73, 4.44, 5.75 and 6.11 at 30, 45, 60 and 75 DAP, respectively), number of tuber hill^{-1} (7.89), average tuber weight (56.81 g), yield per plot (9.29 kg), yield per hectare (23.24 t) and 39.26% of minimum tuber grade in respect of 28-45 mm diameter were recorded from the treatment Zn_0.

Different levels of sulphur fertilizer showed significant effects on days to 1st emergence. Results of the experiment indicated that minimum days (16.37) required was recorded in S_1 treatment where maximum days (18.16) required for 1st emergence of potato plant was noted in S_0 treatment. In case of final emergence, minimum days (19.30) required was recorded in S_1 treatment where maximum days (22.54) required for final emergence of potato plant was noted in S_0 treatment. Different levels of sulphur significantly influenced on plant height, number of leaves plant^{-1}, number of stem hill^{-1}, number of tuber hill^{-1}, average tuber weight, yield per plot, tuber yield and grading of tuber. The maximum plant height (23.49, 37.17, 48.46 and 53.98 cm at 30, 45, 60 and 75 DAP, respectively), number of leaves plant^{-1} (19.98, 30.80, 38.27 and 35.33 at 30, 45, 60 and 75 DAP, respectively), number of stem hill^{-1} (3.12, 4.82, 6.38 and 6.54 at 30, 45, 60 and 75 DAP, respectively), number of tuber hill^{-1} (9.51), average tuber weight (64.69 g), yield per plot (9.84 kg), yield per hectare (24.61 t) and 43.64% maximum tuber grade in respect of 28-45 mm diameter were recorded from the treatment S_1. On the other hand, the minimum plant height (21.92, 34.82, 45.34 and 51.53 cm at 30, 45, 60 and 75 DAP, respectively), number of leaves plant^{-1} (18.15, 28.86, 35.86 and 32.98 at 30, 45, 60 and 75 DAP, respectively), number of stem hill^{-1} (2.78, 4.51, 5.97 and 6.27 at 30, 45, 60 and 75 DAP, respectively), number of tuber hill^{-1} (8.23), average tuber weight (58.78 g), yield per plot (9.38 kg), yield per hectare (23.46 t) and 40.48% of minimum tuber grade in respect of 28-45 mm diameter were recorded from the treatment S_0.

Interaction effect of zinc and sulphur fertilizer showed significant effects on days to 1st emergence. Results of the experiment indicated that minimum days (14.17) required was recorded in Zn_2S_1 treatment combination which was statistically similar with Zn_2S_2 where maximum days (19.47) required for 1st emergence of potato plant was noted in Zn_0S_0 treatment combination which was statistically similar with the combination of Zn_0S_2, Zn_0S_1, Zn_1S_0 and Zn_2S_0. In case of final emergence, minimum duration for final emergence (17.55 days) was recorded from the combination of Zn_2S_1 which was statistically similar with Zn_2S_2 whereas, the maximum duration (23.56 days) was recorded from the combination of Zn_0S_0 which was statistically similar with the combination of Zn_0S_2, Zn_0S_1, Zn_1S_0 and Zn_2S_0.

Interaction effect of zinc and sulphur fertilizer significantly influenced on plant height, number of leaves plant^{-1}, number of stem hill^{-1}, number of tubers hill^{-1}, average tuber weight, yield per plot, tuber yield and grading of tuber. The maximum plant height (24.84, 39.16, 51.28 and 56.11 cm at 30, 45, 60 and 75 DAP, respectively) was found from the treatment combination of Zn_2S_1 which were statistically similar with Zn_2S_2, Zn_1S_1 and Zn_1S_2 at 45 DAP, Zn_2S_2 at 60 and 75 DAP. The lowest plant height (20.36, 32.74, 43.25 and 49.13 cm at 30, 45, 60 and 75 DAP, respectively) was obtained from the treatment combination of Zn_0S_0 which was statistically at par with Zn_0S_2. The maximum number of leaves plant^{-1} (21.50, 32.95, 40.33 and 37.62 at 30, 45, 60 and 75 DAP, respectively) was found from the treatment combination of Zn_2S_1 which were statistically similar with Zn_2S_2, Zn_1S_1 and Zn_1S_2 at 30, 45 and 60 DAP and Zn_2S_2 at 75 DAP, respectively. On the other hand, minimum number of leaves plant^{-1} (16.37, 26.90, 34.55 and 31.33 at 30, 45, 60 and 75 DAP, respectively) was obtained from the treatment combination of Zn_0S_0 which was statistically at par with Zn_0S_2. Maximum number of stem hill^{-1} (3.53, 5.16, 6.66 and 6.82 at 30, 45, 60 and 75 DAP, respectively) was found from the treatment combination of Zn_2S_1 which were statistically similar with Zn_2S_2 at 30 DAP; Zn_2S_2 and Zn_1S_1 45 DAP; Zn_2S_2, Zn_1S_1, Zn_1S_2, Zn_2S_0 and Zn_1S_0 at 60 DAP and Zn_2S_2, Zn_1S_1 and Zn_1S_2 at 75 DAP, respectively. On the other hand, minimum number of stem hill^{-1} (2.70, 4.40, 5.48 and 6.02 at 30, 45, 60 and 75 DAP, respectively) was obtained from the treatment combination of Zn_0S_0 which was statistically at par with

Zn_0S_2. Results observed that maximum number of tuber $hill^{-1}$ (10.53) was found from the treatment combination of Zn_2S_1 which were statistically similar with Zn_2S_2 and Zn_1S_1. On the other hand, minimum number of tuber $hill^{-1}$ (7.40) was obtained from the treatment combination of Zn_0S_0 which was statistically at par with Zn_0S_2, Zn_0S_2, Zn_0S_1 and Zn_1S_0. The maximum average tuber weight (70.29 g) was found from the treatment combination of Zn_2S_1 which were statistically similar with Zn_2S_2 and Zn_1S_1. On the other hand, minimum average tuber weight (55.28 g) was obtained from the treatment combination of Zn_0S_0 which was statistically at par with Zn_0S_2. The maximum yield per plot of tuber (10.09 kg) was found from the treatment combination of Zn_2S_1 which were statistically similar with Zn_2S_2, Zn_1S_1, Zn_1S_2 and Zn_2S_0. On the other hand, minimum yield per plot (8.98 kg) was obtained from the treatment combination of Zn_0S_0 which was statistically at par with Zn_0S_2. Results observed that maximum yield per hectare of potato (25.24 t) were found from the treatment combination of Zn_2S_1 which were statistically similar with Zn_2S_2, Zn_1S_1 and Zn_1S_2. On the other hand, minimum yield per hectare of potato (22.46 t) was obtained from the treatment combination of Zn_0S_0 which was statistically at par with Zn_0S_2. In case of 28-45 mm, the maximum percentage of tuber (46.15) was recorded on Zn_2S_1 treatment combinations which were statistically similar with Zn_2S_2, Zn_1S_1 and Zn_1S_2. On the other hand, minimum percentage of tuber (38.11) was recorded on Zn_0S_0 treatment combinations which were statistically similar with Zn_0S_2, Zn_0S_1 and Zn_1S_0.

CONCLUSION

This study showed that zinc and sulphur had a positive effect growth and yield of potato. The combination of zinc fertilization, Zn_2 (4 kg ha^{-1}) along with sulphur fertilization, S_1 (15 kg ha^{-1}) provided better performance for all growth related parameters and yield with better grade of potato. Therefore, it can be concluded that BARI Alu-8 (Cardinal) grown in Bangladesh by applying Zn_2S_1 treatment combination (4 kg Zn ha^{-1} + 15 kg S ha^{-1}) for producing higher yield with better grade of potato.

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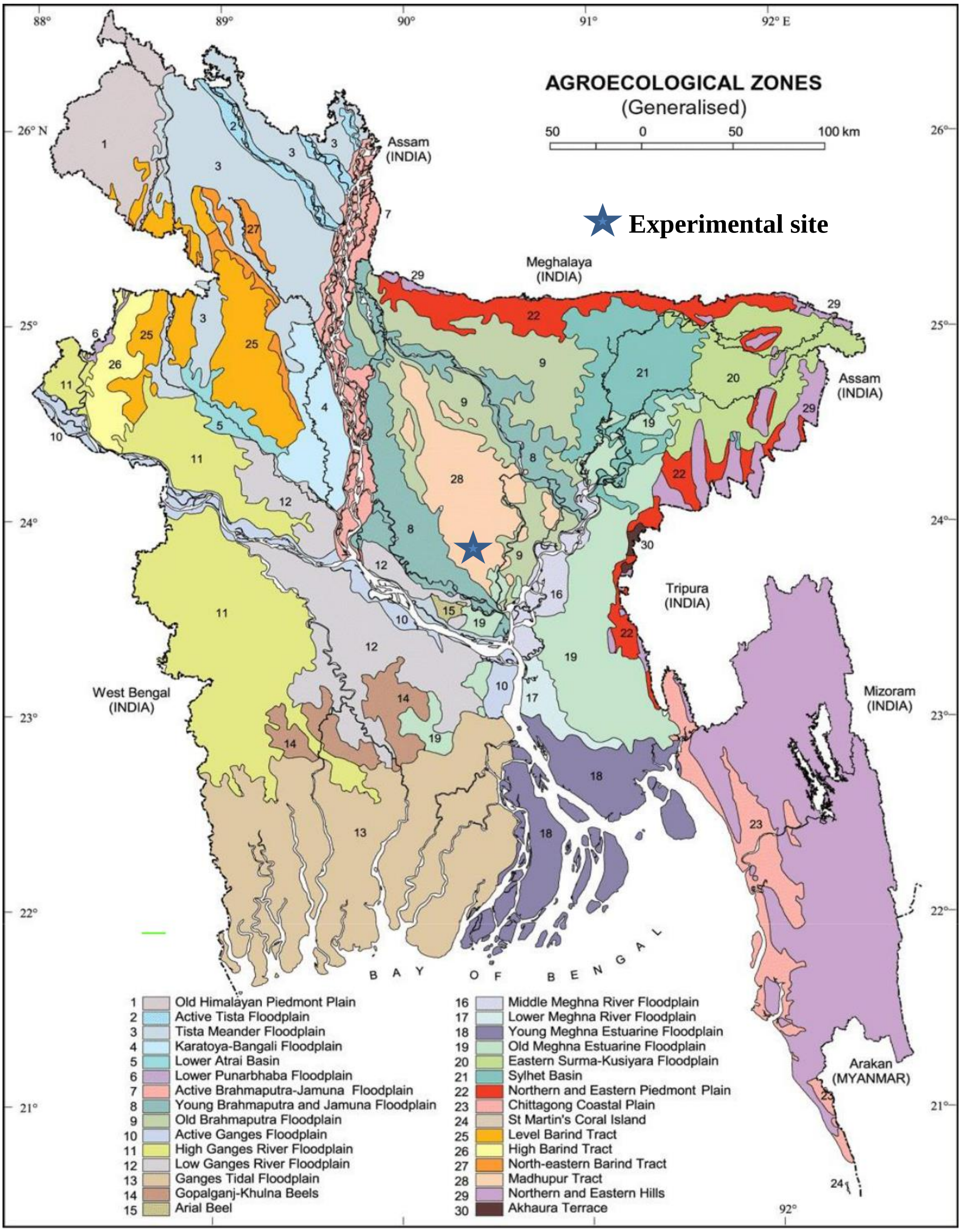
APPENDICES

APPENDICES

Appendix I. Agro-Ecological Zone of Bangladesh showing the experimental location



Appendix II. Monthly records of air temperature, relative humidity and rainfall during the period from November 2019 to February, 2020

Month and year	RH (%)	Air temperature (C)			Rainfall
		Max.	*Min.*	*Mean*	(mm)
November, 2019	56.25	28.70	8.62	18.66	14.5
December, 2019	51.75	26.50	9.25	17.87	12.0
January, 2020	46.20	23.70	11.55	17.62	0.0
February, 2020	37.95	22.85	14.15	18.50	0.0

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

Appendix III. Characteristics of experimental soil analyzed at Soil Resources Development Institute (SRDI), Farmgate, Dhaka

A. Morphological characteristics of the experimental field

Morphological features	**Characteristics**
Location	Sher-e-Bangla Agricultural University, Dhaka
AEZ	Modhupur Tract (28)
General Soil Type	Shallow red brown terrace soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained
Cropping pattern	Not Applicable

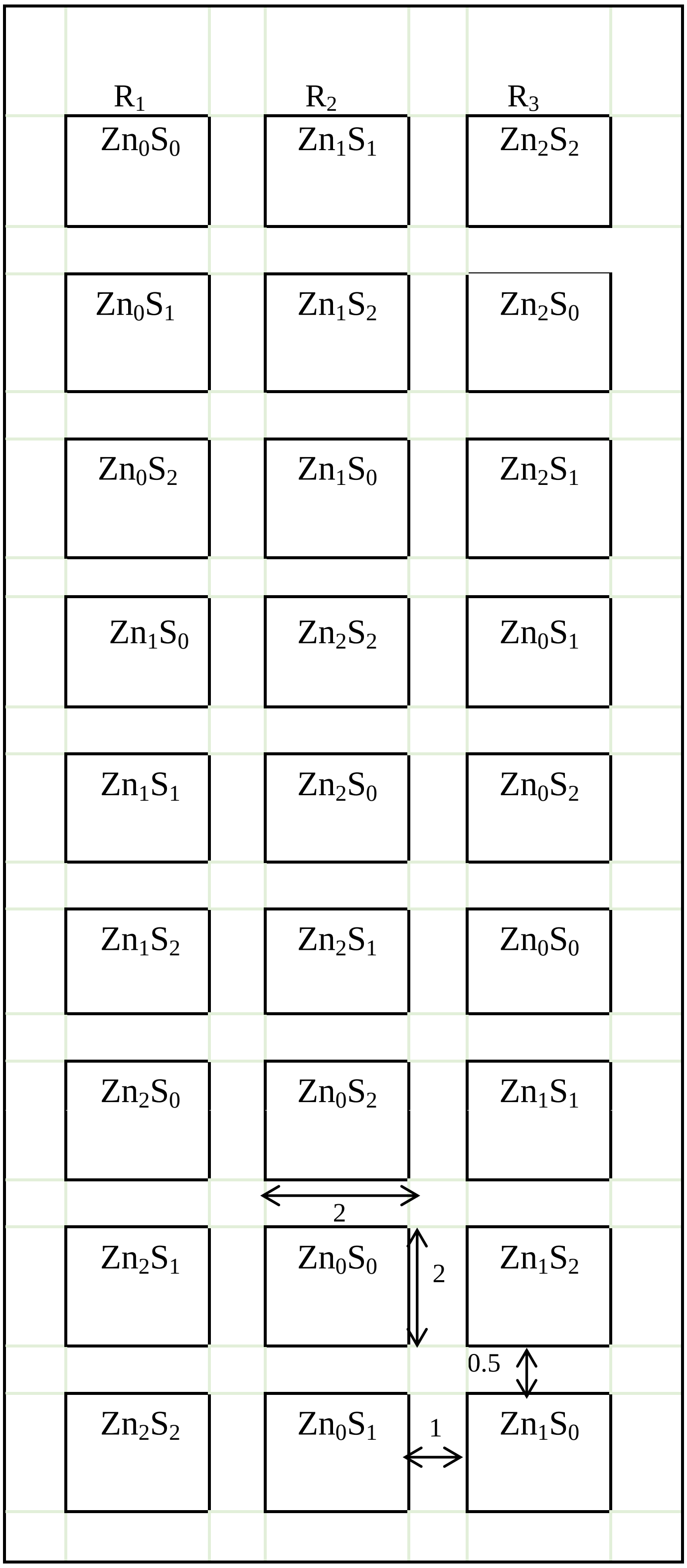
Source: Soil Resource Development Institute (SRDI)

B. Physical and chemical properties of the initial soil

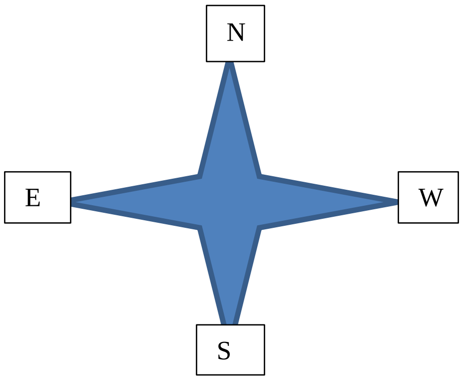
Characteristics	**Value**
Partical size analysis % Sand	27
%Silt	43
% Clay	30
Textural class	Silty Clay Loam
pH	5.6
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total N (%)	0.03
Available P (ppm)	20
Exchangeable K (me/100 g soil)	0.1
Available S (ppm)	45

Source: Soil Resource Development Institute (SRDI)

Appendix IV: Layout of the experimental field



Legends



Factor A: Zinc (Zn) Fertilizer -3 levels

Zn_0= 0 kg ha^{-1}

Zn_1= 2 kg ha^{-1}

Zn_2= 4 kg ha^{-1}

Factor B: Sulphur (S) Fertilizer -3 levels

S_0= 0 kg ha^{-1}

S_1= 15 kg ha^{-1}

S_2= 25 kg ha^{-1}

Length of plot: 2 m, **Width of plot:** 2 m

Replication to replication distance: 1 m

Plot to plot distance: 0.5 m,

Unit plot size: 2 m × 2 m (4 m^2)

Appendix V. Mean square values of days to first emergence and days to final emergence of potato plant growing under the experiment

Sources of variation	Degrees of freedom	Mean square of	
		Days to first emergence	Days to final emergence
Replication	2	26.438	28.444
Factor A	2	13.771*	13.320*
Factor B	2	30.205**	28.622**
A×B	4	0.508*	1.497*
Error	16	2.618	3.444

* significant at 5% level of significance

** significant at 1% level of significance

Appendix VI. Mean square values of plant height at different days after planting in potato growing under the experiment

Sources of variation	Degrees of freedom	Mean square of plant height at			
		30 DAP	45 DAP	60 DAP	75 DAP
Replication	2	49.000	169.000	165.659	209.484
Factor A	2	14.104**	31.093**	39.220**	38.400**
Factor B	2	5.566**	13.013*	24.899**	13.619**
A×B	4	0.258*	0.329*	3.207*	1.157*
Error	16	0.250	2.250	1.178	1.429

* significant at 5% level of significance

** significant at 1% level of significance

Appendix VII. Mean square values of number of leaves plant^{-1} at different days after planting in potato growing during experimentation

Sources of variation	Degrees of freedom	Mean square of number of leaves plant^{-1}			
		30 DAP	45 DAP	60 DAP	75 DAP
Replication	2	99.967	128.554	71.234	214.916
Factor A	2	23.913**	41.852**	31.883**	33.930**
Factor B	2	7.735*	8.450*	13.405*	12.523**
A×B	4	0.141*	0.754*	1.043*	0.805*
Error	16	1.499	1.467	2.387	1.368

* significant at 5% level of significance

** significant at 1% level of significance

Appendix VIII. Mean square values of number of stem hill^{-1} at different days after planting in potato growing during experimentation

Sources of variation	Degrees of freedom	Mean square of number of stem hill^{-1}			
		30 DAP	45 DAP	60 DAP	75 DAP
Replication	2	0.967	1.747	1.646	2.387
Factor A	2	0.542**	0.568**	1.377**	0.701**
Factor B	2	0.261*	0.222*	0.400*	0.155*
A×B	4	0.072*	0.055*	0.009*	0.007*
Error	16	0.069	0.075	0.146	0.066

* significant at 5% level of significance

** significant at 1% level of significance

Appendix IX. Mean square values of yield components and yield of potato growing during experimentation

Sources of variation	Degrees of freedom	Mean square of			
		Number of tuber hill^{-1}	Average tuber weight	Yield per plot tuber	Yield
Replication	2	1.894	209.274	7.258	118.139
Factor A	2	7.631**	225.500**	0.903**	5.605*
Factor B	2	3.654*	82.214**	0.509*	3.215*
A×B	4	0.147*	7.924*	0.005*	0.029*
Error	16	1.099	9.824	0.124	0.983

* significant at 5% level of significance

** significant at 1% level of significance

Appendix X. Mean square values of grading of tuber of potato plant growing under the experiment

Sources of variation	Degrees of freedom	Mean square of grading of tuber			
		<28	28-45	45-55	>55
Replication	2	128.778	400.000	178.111	1.460
Factor A	2	183.939**	63.588**	11.604**	4.932**
Factor B	2	62.613**	23.057*	5.862*	0.542**
A×B	4	1.172*	0.816*	0.137*	0.136*
Error	16	1.653	6.000	1.486	0.068

* significant at 5% level of significance

** significant at 1% level of significance

SOME PICTORIAL VIEW OF THE RESEARCH WORK

Plate 1: General view of experimental field during land preparation

Plate 2: General view of experimental field during seed sowing

Plate 3: General view of the experimental plot during emergence of plant

Plate 4: General view of the experiment plot during weeding

Plate 5: General view of the experimental field during earthing up

Plate 6: General view of the experimental field

Plate 7: General view of the experimental field with treatments

Plate 8: General view of the experiment field during harvesting of potato

Plate 9: General view of the experiment during weighing of tuber

Plate 10: Packaging and storing of potato tuber