EFFECT OF SULPHUR AND ZINC FERTILIZATION FOR BIOFORTIFICATION IN SOYBEAN (*Glycine max* L. Merrill) UNDER NAGALAND CONDITION

Thesis

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by

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Affectionately

dedicated to my beloved

Late Grandpa

and

JILS family

DECLARATION

I, Watisenla Imsong, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form the basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis had not been submitted by me for any research degree in any other university/institute.

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CERTIFICATE – I

This is to certify that the thesis entitled **"Effect of sulphur and zinc fertilization for biofortification in soybean (*Glycine max* L. Merrill) under Nagaland condition"** submitted to Nagaland University in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy (Agriculture) in Agronomy is the record of research work carried out by Ms. Watisenla Imsong Registration No. 829/2019 under my personal supervision and guidance.

The results of the investigation reported in the thesis have not been submitted for any other degree or diploma. The assistance of all kinds received by the student has been duly acknowledged.

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VIVA VOCE ON THESIS OF DOCTOR OF PHILOSOPHY IN AGRONOMY

This is to certify that the thesis entitled **"Effect of sulphur and zinc fertilization for biofortification in soybean (*Glycine max* L. Merrill) under Nagaland condition"** submitted by Watisenla Imsong Admission No. 216/16 Registration No.829/2019 to the NAGALAND UNIVERSITY in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy in Agronomy has been examined by the Advisory Board and External examiner on ………………...........

The performance of the student has been found **Satisfactory/Unsatisfactory.**

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ABSTRACT

A field experiment was conducted at the Experimental Research Farm of School and Agricultural Sciences (SAS), Nagaland University, during the *kharif* season of 2017 and 2018 to study the **'Effect of sulphur and zinc fertilization for biofortification in soybean (*Glycine max* L. Merrill) under Nagaland condition"**. The experiment was laid out in a Factorial Randomized Block Design (RBD) with 15 treatments combinations *viz* three levels of sulphur @ 0 kg ha^{-1}, 20 kg ha^{-1}, 40 kg ha^{-1}, five levels of zinc @ 0 kg ha^{-1}, 5 kg ha^{-1}, 10 kg ha^{-1}, 15 kg ha^{-1}, and 20 kg ha^{-1} replicated thrice. The results obtained showed that the plant growth and yield attributes were significantly influenced by the application of 20 kg S ha^{-1} and showed higher plant height, number of leaves and branches, shoot dry weight, leaf area index (LAI), crop growth rate (CGR) and number of nodules which was found to be quite comparable with the treatment of 40 kg S ha^{-1}. The zinc fertilization of 20 kg Zn ha^{-1} showed greater response by the plant and showed increased plant height, number of leaves, branches; shoot dry weight, LAI and number of nodules at par with 15 kg Zn ha^{-1}. A higher number of pods (40.48 and 40.89), seed yield of (1.07 t ha^{-1} and 1.10 t ha^{-1}) and stover yield (1.97 t ha^{-1} and 2.02 t ha^{-1}) were observed in 20 kg S ha^{-1} and 20 kg Zn ha^{-1} fertilization respectively as compared to the other levels of treatments. The effect on quality of soybean such as oil and protein content along with the nutrient N, P, K, S and Zn uptake in seed, stover and soil were also observed to show a significant increase with the application of 20 kg S ha^{-1}. The zinc level of 20 kg ha^{-1} showed higher content and uptake of nutrients as compared to the other zinc levels. In terms of the economics of the treatments, $S_{20}Zn_{20}$ gave the highest B: C ratio followed by $S_{20}Zn_{15}$ for both the years.

Key words: Soybean, Biofortification, Sulphur, Zinc, B:C ratio, Economics.

CHAPTER I

INTRODUCTION

CHAPTER-I

INTRODUCTION

Soybean is one of the most valuable food crops today in the global oilseed cultivation scenario due to its unique characteristics, high productivity, and profitability, adaptability to varied agro-climatic conditions and vital contribution to maintaining soil fertility. It contributes about 25% of the world′s vegetable oil production and about two-thirds of the global protein concentrates. It is grouped as an oilseed rather than a pulse and is known as legumes, vegetables, or even fuel sources based on their usage.

It contains essential amino acids, carbohydrates, unsaturated fatty acids, vitamins, and minerals and is composed of 40 per cent protein and 20 per cent oil. Its protein is rich in the valuable amino acid lycine (5%), generally deficient in most cereals, and is a complete protein comparable with meats, eggs and milk products. Some of the valuable products made from soybean include tofu, soy milk, flour, curds, soy oil, protein powders, and textured vegetable protein. It is also widely used as a livestock feed.

Some of the soybean-producing nations dominating global production are the United States, Brazil, and Argentina, accounting for 80% of the world's soybean supply. In India, its production is mainly confined to Madhya Pradesh, Maharashtra, Rajasthan, Karnataka, Telangana, Andhra Pradesh, Uttar Pradesh, and Chhattisgarh and on a small acreage in Himachal Pradesh, Punjab, and Delhi. Soybean has become an important oilseed crop in the country within a short period covering 113.98 lakh ha land area under its cultivation during *kharif* 2019-20. Its success story is evident from the productivity front where growth have tripled from 426 kg ha^{-1} to 1361 kg ha^{-1} from the 1970s to 2010. The crop has also been fetching more than Rs.74000 million annually from the export of de-oiled cake, a by-product of oil extraction plants.

With increasing demand for vegetable oil projected to be 16.44 kg year^{-1} and 19.16 kg year^{-1} for the years 2020 and 2050 respectively, the country will require nearly 25.26 and 35.90 million tons of edible oil to meet these demands. These can be possible if there is a greater emphasis on the nutrient requirement of the plants for increasing the productivity of the crops (Strategic Plan, 2011-2016). In India, where more than 40% of the population suffers from energy protein malnutrition, soybean will serve as an excellent source of high-quality protein. Its inclusion in the diet will aid in providing overall health security to the Indian masses.

Lately, a new approach termed "biofortification" has garnered attention globally (Graham *et al*., 2001) to address the growing dietary micronutrient deficiency and to combat food security (Burchi *et al*., 2011). It is defined as "the process of increasing the bio available concentrations of essential elements in edible portions of crop plants through genetic selection or agronomic intervention" (White & Broadley, 2005) and is considered as one of the most cost effective approach in addressing these micronutrient malnutrition (Qaim *et al*., 2007).

Nutrient deficiencies in crops particularly in soybean are a limiting factor in obtaining increased crop yield. Therefore, it becomes imperative that these deficiencies are addressed to and biofortification is one such approach to meet these deficiencies. The role of micronutrients is profound in playing a vital role in the quality and quantity of soybean crop and the supplementation of different sulphur treatments are known to have a notable effect on the micronutrient accumulation on seeds. Deficiencies of these nutrients will drastically reduce their growth and yield. Among these nutrients, sulphur and zinc are now studied and emphasized on how they influence the plant.

Sulphur represents the ninth and least abundant essential macronutrient in plants. Pulses are particularly responsive to sulphur containing fertilizers in places where sulphur deficiency is reported in soil. The application of elemental sulphur and sulphates increases the nitrogen percentage as well as the yield on such deficient soils. It is required to fix nitrogen from the soil and plays a significant role in seed development. It is also a major nutrient for the photosynthesis process and the synthesis of tertiary structures of proteins, chlorophyll, and oil content in oilseeds.

However, lately its deficiencies in crops have been reported in many areas especially in soils of coarse texture, low organic matter, and good drainage (Waddoups, 2011). The increased use of sulphur free fertilizers, little or no addition of sulphur fertilizers, removal of sulphur from the soil and intensive cropping systems (Scherer, 2001) have potentially led to sulphur deficiencies in the soil.

Recently, a widespread deficiency of sulphur in the soil of crop fields has occurred in many parts of India (Jamal *et al*., 2005). Areas of sulphur deficiency are becoming widespread globally (Irwin *et al*., 2002; Scherer, 2001). Therefore, understanding the role of sulphur in pulses growth becomes pertinent as the deficiency of the sulphur-containing amino acids cysteine, cystine, and methionine may limit the nutritional value of food and feed (Sexton *et al*., 1998).

Micronutrients such as zinc are essential element used by plants in small quantities and are a pivotal component of many enzymes’ requisite for plant hormone balance and auxin activity. The crop uptake of these micronutrients is very less about one pound per acre. Despite this low requirement, critical plant functions are finite if it’s deficient, causing stunted growth, reduced internodes length, and young leaves that appear smaller than usual. In such scenarios, the use of expensive and high-requirement crop inputs such as nitrogen and water may be dissipated.

In India, soil zinc deficiency is estimated to be 50% (Sharma, 2008). Deficiencies were found to be even more severe (60%) in the acidic soils of

Northeastern India, especially Assam (35.7% of the total survey area), followed by Sikkim (15.7%), Nagaland (14.4%), and Tripura (13.6%). In Nagaland, the district of Dimapur recorded the most zinc deficient district (25.6% of TSA) (Bandyopadhyay *et al*., 2018). These deficiencies in the soil may be attributed to the various climatic and soil factors such as increase in rainfall, leaching, an increase of Fe and Al oxides in the soil, slower rate of decomposition of organic matters and a high critical level of nutrient availability.

Such findings have significant implications for crop production and productivity, necessitating a thorough understanding and study of the importance of these nutrients. Currently, minimal research on the effects of sulphur and particularly zinc on soybean concerning Nagaland have been conducted. Taking into account all these, an effort were made to study the **"Effect of sulphur and zinc fertilization for biofortification in soybean (*Glycine max* L. Merrill) under Nagaland condition"** with the following objectives:

- To find out the suitable dose of sulphur and zinc for soybean
- To assess the effect of sulphur and zinc biofortification on the quality of soybean.
- To assess the effect of sulphur and zinc on soil chemical properties
- To find out the economics of the treatments understudy.

CHAPTER II

REVIEW OF LITERATURE

CHAPTER-II
REVIEW OF LITERATURE

In this chapter, an attempt has been made to review various experimental findings carried out by different research workers covering important aspects such as the effects of sulphur and zinc fertilization on growth, yield, quality, nutrient content and uptake in soybean and nutrient concentration in soil.

2.1 Effect of sulphur on soybean

2.1.1 Effect of sulphur on growth and yield of soybean

Mohanti *et al.* (2000) evaluated the effects of different levels of S (0, 10, 20 and 30 kg ha^{-1}) and B (0 and 0.002% at pre-flowering or pre-podding) on soybean. S at 30 kg ha^{-1} recorded the highest values for these parameters. B and its interaction with S had no significant effect. Net realization per investment was highest with S at 20 kg ha^{-1} (1.18), followed by S at 30 kg ha^{-1} (1.09).

Awlad *et al*. (2003) reported that among the S treatments, S_{30} gave the highest number of nodules $plant^{-1}$ mostly at the later stages of growth although the effect was not significant. Zinc did not show any significant influence on the nodulation of soybean. The dry matter yield, sulphur and zinc contents were significantly increased with increasing levels of S and Zn up to 30 kg S ha^{-1} and 20 kg Zn ha^{-1} in most growth stages and then decreased with higher levels of S.

Gupta and Abraham (2003) experimented to study the performance of soybean to rhizobium inoculation and different levels of sulphur. The result showed that the dry matter accumulation, number of pods $plant^{-1}$, grain yield and stover yield increased significantly due to the application of rhizobium inoculation coupled with 30 kg S ha^{-1}. The interaction between rhizobium and sulphur was found significant with respect to pods plant^{-1}, grain yield, stover yield and oil content. The treatment rhizobium inoculation + 30 kg S ha^{-1} gave the maximum B: C ratio.

Jamal *et al*. (2005) conducted a field experiment to assess the growth characteristics, seed and oil yield of two cultivars of soybean cv. PK- 416 (V_1) and cv. PK-1024 (V_2) about sulphur and nitrogen nutrition. Six combinations (T_1-T_6) of two levels of sulphur (0 kg ha^{-1} and 40 kg ha^{-1}) and two levels of nitrogen (23.5 kg ha^{-1} and 43.5 kg ha^{-1}) were applied to the two soybean cultivars as nutrients. Results indicated a significant effect of sulphur and nitrogen when applied together, on the growth characteristics, yield components, and seed and oil yield. Maximum response was observed with treatment T_6 (having 40 kg S ha^{-1} and 43.5 kg N ha^{-1}). Positive responses of S and N interaction on leaf area index, leaf area duration, crop growth rate and biomass production were also observed.

Biswas *et al*. (2006) in an experiment conducted indicated that different levels of sulphur and molybdenum had a significant effect on nodulation and protein content of soybean. The application of 12 kg S ha^{-1} and 2 kg Mo ha^{-1} produced a maximum number of effective nodules plant^{-1} at all the growth stages. Application of different levels of sulphur had a significant effect on plant N, K, S, Ca, Mg, Zn and B content. The interaction results obtained from the study indicated that the 12 kg S ha^{-1} + 2 kg Mo ha^{-1} combinations were very responsive to all nutrients studied at all growth stages.

Vyas *et al*. (2008) studied the effect of sulphur and boron levels on physiological parameters, productivity, soil fertility and economics of soybean under rainfed conditions. Progressive increase in sulphur and boron levels increased crop growth rate, total chlorophyll content, pods per plant and seed yield. But the significant response of sulphur application was obtained up to 20 kg ha^{-1} and it gave GCR (10.94 $g^{-1}m^{-2}day^{-1}$), total chlorophyll content (2.55 $mg^{-1}g^{-1}$ fresh weight), number of pods $plant^{-1}$ (24.19), harvest index (42.91%), and seed yield (2059 kg ha^{-1}), being 33.74, 13.33, 9.35, 4.92 and 12.14 per cent higher, and respectively over the control. The uptake of sulphur in seed (6.82 kg ha^{-1}) and straw (4.8 kg ha^{-1}) was significantly higher up to 10 kg S ha^{-1}. A significant higher value of oil was obtained at 10 kg S ha^{-1} and 0.5 kg B ha^{-1} whereas, the protein was significantly higher at 30 kg S ha^{-1} and 2.0 kg B ha^{-1}. The interaction effect between sulphur and boron in all the parameters was not significant

Dixit *et al.* (2009) conducted an experiment with selected technology module: INMS i.e. (RDF=20:60:30+20 kg S ha^{-1}) which was recommended by AICRP, 2007 on various farmers' fields in the Ujjain district under On-Farm Testing programme of KVK to assess the sulphur requirement in soybean. It was observed that the yield of soybean increased by 37% with the application of 20 kg sulphur ha^{-1}, giving an overall net profit of Rs 10,150 over the farmer's practice.

Farhad *et al*. (2010) conducted a field experiment at the Sher-e-Bangla Agricultural University Farm, Dhaka 2009 to study the role of potassium and sulphur on the growth, yield and oil content of soybean (*Glycine max* var. BARI Soybean-5). The experiment included four levels of potassium viz. 0, 20, 40 and 70 kg K ha^{-1} and four levels of sulphur viz. 0, 10, 20 and 40 kg S ha^{-1}. Sulphur fertilizer had a significant effect on the growth and yield attributes of soybean. Application of sulphur @ 20 kg ha^{-1} produced the highest plant height, seed yield, 1000-seed weight and straw yield. Potassium in combination with sulphur showed a significant effect on the growth and yield attributes of soybean. The combined application of potassium @ 40 kg ha^{-1} and sulphur @ 20 kg ha^{-1} resulted in the highest seed yield, plant height, 1000-seed weight, stover yield, and protein and oil contents of soybean.

Hussain *et al.* (2011) carried out a field experiment using soybean (*Glycine max*) to investigate the effect of inoculation in combination with different sulphur rates (0, 15 & 30 kg S ha^{-1}) on soybean growth, nitrogen fixation and soil nitrogen balance. Results showed that the combined application of inoculation and sulphur (30 kg ha^{-1}) resulted in a significant increase in seed yield and yield attribute relative to control. Soybean plant height, the number of pods per plant, straw yield, seed yield and dry matter yield increased up to 14, 56, 25, 20 and 26% as compared to control, respectively.

Trivedi *et al*. (2011) in a study conducted to investigate the effect of iron and sulphur application on the growth and yield of soybean reported a positive effect of iron and sulphur application on different investigated parameters *viz*. shoot height, root length, number of leaves $plant^{-1}$, chlorophyll content, leaf nitrogen content, number of pods $plant^{-1}$, length of pods, growth analysis parameters, 100 seed weight and seed protein content.

Devi *et al*. (2012) conducted a three-year experiment to study the effect of sulphur and boron fertilization on yield, quality, and nutrient uptake by soybean under upland conditions. The study revealed that yield attributing characteristics like the number of branches $plant^{-1}$, pods $plant^{-1}$ and 100 seed weight and yield were increased with the application of sulphur and boron as compared to control. The overall result revealed that application of 30 kg sulphur ha^{-1} and 1.5 kg boron ha^{-1} were found to be the optimum levels of sulphur and boron for obtaining maximum yield attributes, yield, oil and protein content, total uptake of sulphur and boron, the net return, cost and benefit ratio of soybean under the upland condition as compared to other levels of sulphur and boron respectively.

Akter *et al.* (2013) conducted a field experiment at Sher-e-Bangla Agricultural University Farm, Dhaka, Bangladesh from December 2008 to April 2009 to evaluate the effect of P (viz. 0, 15, 30, 50 kg P_2O_5 ha^{-1}) and S (viz. 0, 10, 20, 40 kg S ha^{-1}) and their interaction on the growth and yield of soybean (*Glycine* max L.). The numbers of pods $plant^{-1}$, the number of seeds $plant^{-1}$, thousand seed weight, grain yield, and biological yield increased significantly up to 30 kg P ha^{-1}. However, in the case of S, the positive response was observed only up to 20 kg S ha^{-1}. The combined application of phosphorus @ 30 kg P ha^{-1} and sulphur @ 20 kg S ha^{-1} gave rise to the highest number of pods $plant^{-1}$ (30.07), number of seeds $plant^{-1}$ (84.94), thousand seed weight (94.61 g), and in turn produced highest grain yield (2.29 t ha^{-1}).

Bhattacharjee *et al*. (2013) carried out a field experiment on an acid alfisol (pH 4.5), with 12 treatments consisting of three levels of P (30, 60 and 90 kg P_2O_5 ha^{-1}), two levels of S (15 and 30 kg S ha^{-1}) and two levels of Co (1 and 2 kg Co ha^{-1}) application in factorial combination. The growth and yield parameters of soybean responded positively to higher doses of P, S and Co applications, with the response to P fertilization being the best.

Chauhan *et al*. (2013) in a field experiment conducted during 2009-10 and 2010-11 to study the effect of potassium, sulphur and zinc on the number of nodules, seed yield and oil content in soybean (*Glycine max*. L) variety JS-95-60 observed that during both the years, number of nodules, seed yield and oil content, were highly significant at $K_{20}S_{20}Zn_5$ combination dose among all other combination doses. Due to the application of K_{20} kg ha^{-1}, S_{20} kg ha^{-1} and Zn_5 kg ha^{-1} in combination dose, the number of nodules increased significantly as compared to control by 91%, seed yield increased by 43.2% and 32.7% oil percentage increased by 1.3% and 1.1% in both the years respectively. It was also observed that when doses of potash and sulphur were increased from 20 kg ha^{-1} to 40 kg ha^{-1} each, nodule number, seed yield and oil content all decreased.

Yadav *et al.* (2013) conducted a field experiment during the summer season at the Instructional Farm, Department of Agronomy, College of Agriculture, Junagadh Agricultural University, Junagadh to study the effect of phosphorus and sulphur on the growth and yield of summer soybean. The result of the experiment revealed that an application of phosphorus @ 60 kg ha^{-1} recorded significantly higher plant height (49.56 cm), branch $plant^{-1}$ (5.83), plant spread (36.78 cm), pods $plant^{-1}$ (58.78), seed/pod (3.04), test weight (149.22 g), seed yield (2675 kg ha^{-1}), and stover yield (2980 kg ha^{-1}) over control. Similarly, sulphur levels also recorded a significant effect in increasing all these growth and yield attributes.

Hosmath *et al*. (2014) in a field experiment carried out on sulphur nutrition in soybean found that the soybean seed yield was significantly increased with the application of sulphur @ 20 kg ha^{-1} (2534 kg ha^{-1}) compared to sulphur levels; 30 kg ha^{-1} (2494 kg ha^{-1}), 40 kg ha^{-1} (2376 kg ha^{-1}) and 10 kg ha^{-1} (2226 kg ha^{-1}). The oil content, net return and benefit-cost ratio followed a similar trend.

Ram *et al*. (2014) in a 3-year field experiment conducted recorded the highest grain yield, protein, oil content, and gross and net returns of soybean with 40 kg S ha^{-1}, which were statistically at par with 30 kg S ha^{-1} but significantly higher than other levels of sulphur. The productivity in 40 kg S ha^{-1} was enhanced by 61.9% over the absolute control.

Konyak *et al*. (2016) reported that the application of different levels of S and Co significantly increased the plant height, number of leaves and number of nodules in comparison to control. The combined application of S and Co also significantly enhanced the number of pods plant^{-1}, seed and stover yields, and protein and oil content of soybean.

Parakhia *et al.* (2016) carried out a pot experiment using factorial CRD with four replications to investigate the effect of varieties and sulphur levels on dry matter, yield and yield attributes and quality of soybean (*Glycine max* L.). Significantly higher values of nodules per plant (4.63), pods per plant (23.52) and seed yield (6.78) were recorded under application of sulphur @15 mg kg^{-1}, which was at par with S_3 (10 mg kg^{-1}) for nodules per plant and seed yield.

Gill and Sharma (2017) in a study conducted reported that sulphur supplementation increased zinc and iron content in mature soybean seeds, however, copper and manganese were found to be least effective. Sulphur supplementation with gypsum @ 20 kg ha^{-1} increased plant height and pods per plant.

Kumar *et al*. (2017) carried out a field experiment at KVK, Srinagar during two consecutive *kharif* seasons of 2010 and 2011 to study the effect of phosphorus and sulphur on yield and quality of soybean (*Glycine max* L. Merill) under eutrochrepts. Study showed that both seed and stover yield of soybean increased significantly due to individual as well as combined application of phosphorus and sulphur. Application of increasing levels of both phosphorus and sulphur resulted in a significant increase in macro and micronutrient content of soybean seed.

Longkumer *et al*. (2017) in a field experiment conducted found that the application of S and B; either alone or in combination, significantly increased the growth, yield, and quality of soybean. When applied alone, S resulted in the best yield at S_{40}, which was 21.2% higher than the yield at control, while B produced a maximum yield at $B_{1.5}$ (8.23% higher than control). 57.4% yield improvement over control was recorded with the combined application of S_{40}

and $B_{1.5}$, which shows their synergistic effect on crop performance. Similarly, with concurrent application of S_{40} and $B_{1.5}$, a 28% increase in protein and a 33% increase in oil content of soybean were recorded relative to control. In general, S_{40} + $B_{1.5}$ also resulted in the highest nutrient nitrogen, phosphorus, potassium sulphur, and boron (NPKSB) uptake by soybean.

Mall *et al*. (2017) in a pot experiment conducted reported that significant grain yield and highest yield were obtained with the application of 40 ppm S and 7.5 ppm Zn resulting in improvement in yield and quantity traits of soybean grain.

Ravi *et al*. (2017) in a study carried out to assess the sulphur and boron nutrient dynamics in soil and their effect on seed yield of soybean under a rainfed situation in northern Karnataka reported that the application of a recommended dose of fertilizer + 12 kg $ZnSO_4$ ha^{-1} + 30 kg Sulphur ha^{-1} + 1.0 kg Boron ha^{-1} recorded significantly higher seed yield (22.7 q ha^{-1}) which was at par with the application of a recommended dose of fertilizer + 12 kg $ZnSO_4$ ha^{-1} + 30 kg Sulphur ha^{-1} +1.5 kg Boron ha^{-1} (21.5 q ha^{-1}) compared to other treatments. Further, significantly higher uptake of nitrogen (163.0 kg ha^{-1}), phosphorus (18.5 kg ha^{-1}), potassium (74.61 kg ha^{-1}), sulphur (22.16 kg ha^{-1}) and boron (0.14 kg ha^{-1}) were recorded in the treatment with the application of recommended dose of fertilizer + 12 kg $ZnSO_4$ ha^{-1} + 30 kg Sulphur ha^{-1} + 1.0 kg Boron ha^{-1} which was at par with the application of recommended dose of fertilizer + 12 kg $ZnSO_4$ ha^{-1} + 30 kg Sulphur ha^{-1} + 1.5 kg Boron ha^{-1} (160.5, 16.48. 73.19, 20.12 and 0.12 kg ha^{-1} respectively. Application of recommended dose of fertilizer (40:80:25 kg NPK ha^{-1}) + 12 kg ZnSO4 ha^{-1} + 30 kg sulphur ha^{-1} + 1.0 kg Boron ha^{-1} also increased the seed yield of soybean and uptake of nutrients.

Singh *et al*. (2018) carried out a field experiment to study the response of soybean to levels and sources of sulphur under mid-hill conditions in Himachal Pradesh. The result revealed that growth, yield attributes, and seed and straw yield of soybean increased with the application of S up to 40 kg ha^{-1}. The higher dose of sulphur could not significantly influence growth, yield attributes and seed and straw yield of soybean. The response per kg S was 14.5 kg of soybean grain. Among the sources of sulphur, gypsum gave better response in terms of growth, yield attributes and seed and straw yield of soybean over the other sources. Gross returns, net returns and B: C ratios were significantly higher at 40 kg S ha^{-1}. Gypsum gave the highest gross returns, net returns and B: C ratio.

Gallani *et al*. (2019) carried out an On-farm trial (OFTs) for consecutive two years 2011-12 and 2012-13 to assess the optimum sulphur levels of soybean concerning growth, yield attributing characters, productivity, protein content and economics involved under Malwa plateau conditions of Central India. Treatment RDF+ 40 Kg S ha^{-1} was found to be the optimum level of sulphur as this treatment recorded significantly higher soybean root nodulation, yield and yield attributing characters, oil and protein content over 0 and 20 kg sulphur ha^{-1}. This treatment also expressed its superiority over the rest of the treatments in the case of the B: C ratio and net return.

Sahebagouda *et al*. (2019) in a study conducted revealed that application of 100 % RDF + poultry manure at 6 t ha^{-1} + sulphur at 40 kg ha^{-1} through gypsum recorded significantly higher growth and yield parameters like plant height, number of leaves per plant, number of branches, dry matter content, test weight and yield parameters like number of pods $plant^{-1}$, pod yield $plant^{-1}$, pod yield, seed yield and haulm yield.

2.1.2 Effect of sulphur on quality of soybean

Chauhan *et al.* (2013) conducted a field experiment in vertisols (black cotton soil) during 2009-10 and 2010-11, to study the effect of potassium, sulphur and zinc on the number of nodules, seed yield and oil content in soybean (*Glycine max* L.) variety JS-95-60 at Ujjain, M.P. It was observed that during both the years, number of nodules, seed yield and oil content, were highly significant at K_{20}, S_{20}, Zn_5 combination dose among all other combination doses. Application of K_{20} kg ha^{-1}, S 20 kg ha^{-1} and Zn 5 kg ha^{-1} in combination dose, number of nodules resulted in a significant increase by 91% compared to control, seed yield increased by 43.2% and 32.7% oil percentage increased by 1.3% and 1.1% in both the years respectively.

Choudhary *et al.* (2014) carried out a pot experiment using factorial CRBD with four replications to investigate S and Zn application effects on soybean (*Glycine max* L.) yield, yield attributing traits and quality parameters. The highest protein (38.64%) and oil (21.54%) content were observed due to the application of 60 ppm S, while 5 ppm Zn gave the highest protein (38.42%) and oil (20.90%) content of soybean grain.

Sharma *et al.* (2014) conducted a pot experiment where soybean plants were grown under different treatments viz. control, recommended dose of nitrogen as urea @ 31.25 kg N ha^{-1}, sulphur as gypsum @ 20 kg S ha^{-1} or in combination. Nutrient uptake and protein content in soybean seeds increased in all the treatments as compared to control whereas N alone or combined with S significantly increased seed yield.

Mamatha *et al.* (2018) conducted a field experiment to study the effect of different levels of nitrogen and sulphur on the yield and quality of soybean with four levels of nitrogen (0, 40, 80, 120 kg N ha^{-1}) and four levels of sulphur (0, 20, 30 and 40 kg ha^{-1}). The highest mean grain yield of 1997 and 1874 kg ha^{-1} was recorded with the application of 120 kg N ha^{-1} and 40 kg S

ha^{-1}, respectively. The oil content and protein content also progressively increased with increasing levels of nitrogen and sulphur. The highest oil and protein content of 18.65 and 40.3 per cent were observed with the application of 120 kg N ha^{-1}. Application of 40 kg S ha^{-1} recorded higher oil and protein contents of 18.38 and 38.74 per cent, respectively.

2.1.3 Effect of sulphur on nutrient content, uptake in soybean and nutrient concentration in soil

Vaiyapuri *et al.* (2008) studied the effect of sulphur and boron fertilization on yield, uptake of sulphur, boron and protein content of soybean. The results of the experiment revealed that sulphur and boron uptake of grains showed a significant variation due to the application of different levels of sulphur and boron. The highest S and B uptake, yield and protein content were found with the application of sulphur @ 30 kg ha^{-1} and boron @ 1.0 kg ha^{-1}.

Dhanashree *et al.* (2011) conducted a field experiment to study the effect of sulphur and zinc on nutrient uptake and yield of soybean var. JS 335 crop on vertisol during year *kharif* 2009. The different doses of sulphur were applied singly with a recommended dose of fertilizer and along with a constant dose of zinc also. Results indicated that with the application of 30 kg S ha^{-1} and 2.5 kg Zn ha^{-1} with a fertilizer dose of 30:75:0 kg NPK ha^{-1}, total uptake of nutrients and micronutrients was recorded significantly highest after harvest of the crop.

Dhage *et al.* (2014) conducted a field experiment to study the effect of phosphorus and sulphur levels on soybean during 2009-10 and 2010-11 at Research Farm Department of Soil Science and Agricultural Chemistry, MKV, Parbhani (MS) on Vertisol. The treatment consisted of four levels of phosphorus (P_0, P_{30}, P_{60} and P_{90} kg P_2O_5 ha^{-1}) and four levels of sulphur (S_0, S_{20}, S_{40} and S_{60} kg ha^{-1}) applied through DAP and elemental sulphur, respectively. Results indicated that uptake of phosphorus and sulphur increased with an increase in the rate of application of P and S individually as well as in various combinations. Available P in soil increased with increasing levels of phosphorus. Similarly available S in the soil increased with increasing levels of sulphur.

2.2 Effect of zinc on soybean

2.2.1 Effect of zinc on growth and yield of soybean

Gupta *et al.* (1984) conducted a screen house in pots on sandy loam soil deficient in Zn. Salinity was induced by adding 44, 88 and 132 me/l of chloride and sulphate salts to the saturation extract. To these treatments, 0, 5 and 10 ppm Zn was added as $ZnSO_4.7H_2O$ or Zn-EDTA. The results indicated that the yield of soybean shoot was lowest at the highest salinity level and highest at the lowest level. Shoot yield improved markedly with Zn application. Both sources of Zn were equally effective in augmenting crop yields.

Khamparia (1996) reported that pod per plant, grain, straw and biological yield, and grain: straw ratio, harvest index of soybean increased with P and Zn application in a vertisol. The highest grain yield (3.01 t ha^{-1}) was recorded with the application of 50 kg P_2O_5 and 6 kg Zn ha^{-1}.

Shripurkar *et al.* (2006) revealed that the use of micronutrients in soybean is one of the ways to boost productivity. The yield attributing characters and yield are directly related to productivity. They observed the application of recommended dose (30 N, 60 P_2O_5, 0 K_2O kg ha^{-1}) + Zn @ 10 kg ha^{-1} + 10 t FYM ha^{-1} significantly increase the number of pods 14.50 at 60 DAS, 24.40 at 90 DAS, several nodules (33) and dry weight of nodules (508.80 mg), grain weight (6.70 g), test weight (13.60 g), grain yield (2081 kg ha^{-1}) and stover yield (1370 kg ha^{-1}).

Madani *et al.* (2007) reported the application of 40 kg ha^{-1} zinc sulphate at flowering and during grain formation of soybean significantly improved quantitative parameters of soybean yield.

Tomar and Sharma (2007) reported that the application of FYM, S and Zn along with recommended fertilizer has increased the yield of soybean by 1465 kg ha^{-1}. Application of 20 kg Zn ha^{-1} with a recommended dose of fertilizer increased yield by 36 per cent, over untreated plots.

Kanase *et al.* (2008) conducted a field experiment during *kharif*, 2001- 02 to study the response of soybean to the application of Zn (in an Inceptisol). The result revealed that the application of Zn @ 7.5 kg ha^{-1} through zinc sulphate recorded the highest grain yield (3958 kg ha^{-1}) and was on par with 5 and 10 kg ha^{-1} (3955 kg ha^{-1}).

Jadhav *et al.* (2009) reported that the recommended dose of NPK + basal application of $ZnSO_4$ @ 20 kg ha^{-1} recorded positive response for test weight over control. The second application of zinc sulphate @ 20 kg ha^{-1} was found to significantly increase seed germination, dry weight and vigour index in soybean over control.

Ghasemian *et al.* (2010) experimented to study the effect of Fe, Zn and Mn on the yield of soybean. Treatment included Fe (0, 25 and 50 kg ha^{-1}), Zn (0, 25 and 40 kg ha^{-1}) and Mn (0 and 40 kg ha^{-1}). They showed that 40 kg ha^{-1} Zn and Mn led to the highest seed yield (3397 and 3367 kg ha^{-1}) and biological yield (7447 and 7387 kg ha^{-1}) respectively. In general, the highest numbers of grain and seed weight per plant, and pod number of soybean plants were also obtained at 40 kg ha^{-1} of Zn and Mn.

Heidarian *et al*. (2011) conducted a field experiment wherein results showed a significant effect of Zn+Fe treatment on grain yield, the number of pods per plant ($p < 0.05$) and 1000 grain weight ($p < 0.01$). The time of foliar application on several pods per plant ($p < 0.05$) and 1000 grain weight ($p < 0.01$) was also significant. In general, the highest yield was produced by the Zn+Fe combination treatment. There was a significant and positive correlation between grain yield and its components.

Kobraee *et al.* (2011) conducted a pot experiment to study the relationship between chlorophyll concentrations, nodulation and quality and quantity traits in soybean and micronutrients at the research field of the Islamic Azad University of Kermanshah province, Iran in 2010. The experiment consisted of 27 treatments which included 3 rates of Zn (0, 4 and 8 mg Zn kg^{-1} as zinc sulphate), three rates of Fe (0, 4 and 8 mg Fe kg^{-1} as $FeSO_4$), and 3 rates of Mn (0, 15 and 30 mg Mn kg^{-1} as $MnSO_4.4H_2O$) at 48 days after sowing and before harvesting. The maximum number of nodules per plant was obtained from 4, 8 and 30 mg Zn, Fe and Mn per kg soil respectively. Maximum plant height and total dry weight were obtained in $Zn_4Fe_8Mn_{30}$ with 46.8 (cm), 3.37 (g) and 31.9 respectively.

Mostafavi (2012) revealed that the Zn+Fe combined treatment produced a maximum seed yield of 1575 kg ha^{-1}. Zn treatment and Fe 10 treatment yield were 7.42 kg ha^{-1} and 8.33 kg ha^{-1} higher than the control treatment in soybean.

Thenua *et al*. (2014) conducted a field experiment during the *kharif* season of 2009 and 2010 at the Agronomical Research Farm of Amar Singh College Lakhaoti, Bulandshahr with five levels of sulphur (0, 10, 20, 30 and 40 kg S ha^{-1}) and four levels of zinc (0, 10, 20 and 30 kg Z ha^{-1}) to study the sulphur and zinc requirement of soybean and its effect on yield and their availability status in the soil. The study found that the highest yield of soybean was recorded under 40 kg S ha^{-1}. It was closely followed by 30 kg S ha^{-1} and application of zinc @ 30 kg ha^{-1} recorded higher yield as compared to its lower levels.

Sharifi (2016) conducted factorial experiments using a randomized complete block design with three replications. Experimental factors included nano zinc oxide in four levels: without nano zinc oxide (Zn_0) as control, application of 0.3 (Zn_1), 0.6 (Zn_2) and 0.9 (Zn_3) g L^{-1}, and five biofertilizers levels: no biofertilizer (B0), seed inoculation by *Bradyrhizobium japonicum* (B1), B. *japonicum* + Azosprillum *lipoferum* strain of (B2), B. *japonicum* + *Pseudomonas putida* strain 186 (B_3) and B. *japonicum* + A. *lipoferum* strain of + P. *putida* strain 186 (B_4). The results showed that the maximum number of nodules per plant (16.55) and grain yield (1875 kg ha^{-1}) was recorded at the application of biofertilizer and nano zinc oxide as Zn_3B_4. The highest dry weight of nodules per plant and the number of pods and grains per plant were obtained in the application of nano zinc oxide as Zn_3 and biofertilizers as B_4.

Meena *et al.* (2017) in an experiment reported that application of 100% RDP i.e. 30: 75: 30 NPK kg ha^{-1} with 5 kg zinc ha^{-1} recorded higher soybean yield and quality and improved soil fertility status after harvest of soybean. High levels of available phosphorus in soil or a high dose of phosphorus application may induce zinc deficiency in the soil characterized by a low concentration of available zinc.

Raghuwanshi *et al.* (2017) in a field experiment reported that each and alternate year Zn application significantly increased the plant height, pods $plant^{-1}$, seeds pod^{-1}, test weight, grain and straw yield, oil and protein content, Zn uptake by seed and straw.

Singh *et al.* (2017) experimented to study the influences of sulphur and zinc levels on the growth, yield and quality of soybean. The study showed that application of sulphur and zinc increased all the growth and yield attributes of soybean but significant increases up to 40 kg S ha^{-1} and 30 kg Zn ha^{-1} were observed in plant height, the number of branches $plant^{-1}$ at all stages, seed yield and protein content in the seed of soybean. The zinc level also had a significant influence on the number of pods plant^{-1}, the number of grains pod^{-1}, pod length, pod weight plant^{-1}, test weight, and grain weight plant^{-1}. Application up to 40 kg S ha^{-1} and 30 kg Zn ha^{-1} increased the uptake of sulphur and zinc significantly more than control.

Ganesh *et al*. (2018) investigated to study the various concentrations (0, 5, 10, 25, 50, 100, 200 and 300 mg l^{-1}) of copper and zinc in germination studies of soybean. The different concentrations of copper and zinc were used for germination studies. The seedlings were allowed to grow for up to seven days. The study showed increased morphological traits at 5 mg L^{-1} concentration and these parameters were gradually decreased with the increase of copper and zinc concentrations.

Oliveira *et al*. (2019) conducted a greenhouse study to investigate the effect of Zn fertilization on soybean grain cultivars intended for human consumption. The study showed that zinc fertilization increased the protein content in soybean grain, plant height, and the number of grains per plant.

Rohini *et al*. (2020) conducted a pot culture experiment to assess the effect of zinc on the uptake of micronutrients on soybean in swell shrink soil. The experiment was laid out completely randomised design (CRD) with five treatments and two replications. The treatments comprised varied levels of soil application of zinc at 0.0, 1.5, 3.0, 4.5 and 6.0 kg ha^{-1} in different soil samples. The results of the pot culture study revealed that application of zinc @ 4.5 kg ha^{-1} had significantly influenced and improved the dry matter yield and uptake of zinc, iron, manganese and copper by soybean.

Ankomah (2021) carried out a research study to identify possible interactions of P and Zn and determine the effect on soybean nutrient status, yield, and agronomic efficiency. Phosphorus fertilization did not affect the P concentration of leaves but increased the P concentration of the seeds. Zinc application did not affect the Zn concentration of soybean leaves and seeds.

Neither P nor Zn affected soybean yield components and yield. Phosphorus and zinc agronomic efficiency did not improve with P and Zn application, respectively.

2.2.2 Effect of zinc on quality of soybean

Sonune *et al.* (2001) have reported that the highest protein (37.25%) and oil (20.42%) contents of soybean (CV PKV-1) were observed with the application of 3 kg Zn ha^{-1} as zinc oxide. They also observed the highest protein (37.35%) and oil (21.29%) contents of soybean grain with 40 kg S ha^{-1} as gypsum.

Zada *et al.* (2001) studied the effect of Fe (0, 7 and 14 kg ha^{-1}) and Zn (0, 5 and 10 kg ha^{-1}) alone and in combination on grain yield and quality of inoculated soybean cv. Bragg in a slit clay loam soil. Application of Fe and Zn increased grain yield by an increase in protein synthesis, N metabolism, and recovery in the grain and shoots. The soil exhibited a significant improvement due to Fe and Zn application.

Bairagi *et al.* (2007) conducted a field experiment in Maharashtra during *kharif* of 2004 to study the effect of zinc and phosphorus on the yield and oil and protein content of soybean (cv. JS-335). The treatment consisted of 3 levels of Zn (0, 10 and 20 kg ha^{-1}) and 4 levels of P (0, 50, 75 and 100 kg ha^{-1}). The application of Zn @ 10 kg ha^{-1} significantly increased the oil and protein content of soybean.

Nandanwar *et al.* (2007) revealed that the application of 5 kg Zn as zinc sulphate along with RDF @ 30:75 kg N: P increases the protein (38.72%) and oil content (18.18 %) of soybean in vertisol.

Kakad *et al.* (2008) conducted a field experiment at STRU farm Dr PDKV, Akola during the *kharif* to study the effect of zinc and phosphorus on yield, oil and protein content of soybean. The experiment was conducted in FRBD with twelve treatments of three levels of zinc (0, 10 and 20 kg Zn ha^{-1}) and four levels of phosphorus (0, 50, 75 and 100 kg P_2O_5) on the yield and quality of soybean. The sources of zinc and phosphorus were zinc oxide and diammonium phosphate respectively. Application of zinc @ 10 kg ha^{-1} recorded a significant increase in oil and protein per cent.

Yasari and Vahedi (2012) reported that with the treatment of adding Mn (30 kg ha^{-1}) and Zn (40 kg ha^{-1}) to the soil the oil per cent observed were 23.5 and 22.73% respectively which were higher than that of control (22.23%). Similarly, in the treatment of adding Mn (30 kg ha^{-1}) and Zn (40 kg ha^{-1}) to the soil the protein per cent observed were 35.67 and 35.45% respectively which were higher than that of the control (35.09%). In terms of yield, the addition of Zn (40 kg ha^{-1}) into the soil increased the oil yield (321.85 kg ha^{-1}) which was higher than that of control (249.64 kg ha^{-1}) and protein yield (501.97 kg ha^{-1}) which was also higher than that of control (397.06 kg ha^{-1}).

Sale and Nazirkar (2013) in a study reported that micronutrient application had a significant effect on grain and straw yield, nutrient uptake, and oil and protein content of soybean. The maximum grain and straw yield, as well as nutrient uptake, were received in treatment receiving a foliar application of Fe and Zn. The maximum oil and protein percentage was obtained with the foliar application of Fe and Zn along with seed fortification of Mo. Overall, data concluded that micronutrients had a positive effect on nutrient uptake with qualitative and quantitative traits of soybean in the conditions of the studied area.

2.2.3 Effect of zinc on nutrient uptake in soybean and nutrient concentration in soil

Jahiruddin *et al.* (2001) experimented with the addition of Zn and B with a basal application of N, P and K in maize-soybean cropping sequence and found that the dry matter yield of the crops did not respond to B or Zn addition to soil. However, the concentration of B and Zn in plant tissues greatly increased. The extractable B, Zn, N and Mn concentrations in the rhizosphere increased. The increased concentration of B and Zn in the rhizosphere was found to be related to a decrease in soil pH.

Wasmatkar *et al*. (2002) conducted a field experiment during *kharif* of 1998 at Akola, Maharashtra, India to investigate the effect of different levels of sulphur (S) and zinc (Zn) on the quality and nutrient uptake of soybean. S and Zn had a significant effect on the uptake of N, P, K, S and Zn at harvest. The highest uptake of N (124.02 and 128.25 kg ha^{-1}) was recorded with S at 15 kg ha^{-1} and Zn at 5 kg ha^{-1} respectively. The highest uptake of P (14.71 and 14.31 kg ha^{-1}), K (59.15 and 58.35 kg ha^{-1}), S (12.03 and 10.75 kg ha^{-1}) and Zn (108.23 and 101.43 kg ha^{-1}) was recorded with S at 30 kg ha^{-1} and Zn at 5 kg ha^{-1} respectively.

Kanase *et al.* (2008) conducted a field experiment during *kharif*, 2001- 02 to study the response of soybean to the application of Zn (in an Inceptisol). The result revealed that the application of Zn @ 7.5 kg ha^{-1} through zinc sulphate indicated that the application of Zn increased the uptake of the NPK and micronutrient at harvest and zinc sulphate was superior to zinc oxide.

Pable and Patil (2011) conducted a field experiment to study the effect of sulphur and zinc on nutrient uptake and yield of soybean var. JS 335 crop. Results indicated that application of 30 kg S ha^{-1} and 2.5 kg Zn ha^{-1} with a fertilizer dose of 30:75:0 kg NPK ha^{-1} recorded higher grain yield and straw yield. Total uptake of nutrients and micronutrients was recorded significantly highest in the same treatment after harvesting of the crop.

Rathod *et al.* (2017) conducted a field experiment to study the effect of lime, zinc and boron on soybean yield and uptake of nutrients. The results of the experiment showed significantly increased the grain and straw yield of soybean due to the application of 1 L.R + Zn + B through the soil and foliar spray along with RDF. The uptake of N, P, K, Ca, Mg and S by soybean was also significantly increased by this treatment.

Jat *et al*. (2021) conducted a field experiment to study the influence of soil-applied zinc on the yield and quality of soybean (*Glycine max* L.) under typic haplustepts soil of sub-humid southern plain and Aravalli hills region of Rajasthan. The treatments consisted of five levels of zinc viz., zero (control), 3 kg Zn ha^{-1}, 4 kg Zn ha^{-1}, 5 kg Zn ha^{-1} and 6 kg Zn ha^{-1} with four replications. Results revealed that significantly maximum seed, haulm and biological yield, and oil and protein content were recorded with the application of zinc 6 kg ha^{-1} along with the recommended dose of fertilizer (NPK) during the years 2016 & 2017 and on a pooled basis. However, the increase was observed significant up to 5 kg Zn ha^{-1} during both the years as well as on pooled basis but found statistically at par with 6 kg Zn ha^{-1}. The application of a recommended dose of fertilizer along with the combined application of Zn @ 5 kg ha^{-1} offered the best combination in realizing the maximum yield and quality content of soybean.

CHAPTER III

MATERIALS AND METHODS

CHAPTER-III
MATERIALS AND METHODS

The present research entitled "Effect of sulphur and zinc fertilization for biofortification in soybean (*Glycine max* L. Merrill) under Nagaland condition" was conducted at the experimental research farm of School and Agricultural Sciences (SAS), Nagaland University campus, Medziphema during the *kharif* season of 2017 and 2018. The details of materials used and the research methodology followed during the investigation for recording various observations and analysis are described below.

3.1 General information

3.1.1 Site of the experiment

The research farm was located in the foothill of Nagaland at an altitude of 310 meters above mean sea level with the geographical location at 25° 45' 43" N latitude and 95° 53' 04" E longitude. Previously, rice crop was cultivated in the selected field from 2015 to 2016.

3.1.2 Climatic conditions

The experimental farm lies in a humid subtropical zone with an average rainfall ranging from 2000-2500 mm. The maximum rainfall is received from May-October, while the remaining period from November to March remains comparatively dry. The mean temperature ranges from 21°C to 32°C during summer and rarely goes below 8°C during winter. The detailed meteorological data are presented monthly, starting from July to October during the period of research 2017 and 2018 in Table 3.1 and illustrated in Fig 3.1.

Table 3.1: Meteorological data during the experimental period (July-October, 2017 and July-October, 2018)

Month /Year	Temperature (^{0}C)				Relative Humidity (%)				Sunshine hours		Rainfall (mm)	
	Minimum		Maximum		Minimum		Maximum					
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
July	24.4	24.9	31.3	33.2	76.00	71.71	93.75	91.65	3.1	3.1	112.7	43.4
August	24.7	24.8	32.1	33.6	71.75	71.39	93.25	94.23	4.0	3.8	109.2	72.2
September	24.5	23.9	31.6	33.4	74.00	66.70	95.20	93.60	4.2	5.3	60.1	30.4
October	22.4	21.7	30.9	32.2	74.25	66.71	95.00	95.68	5.5	6.0	24.9	14.6

Source: Agro Meteorological Observatory, ICAR Nagaland Centre, Jharnapani.

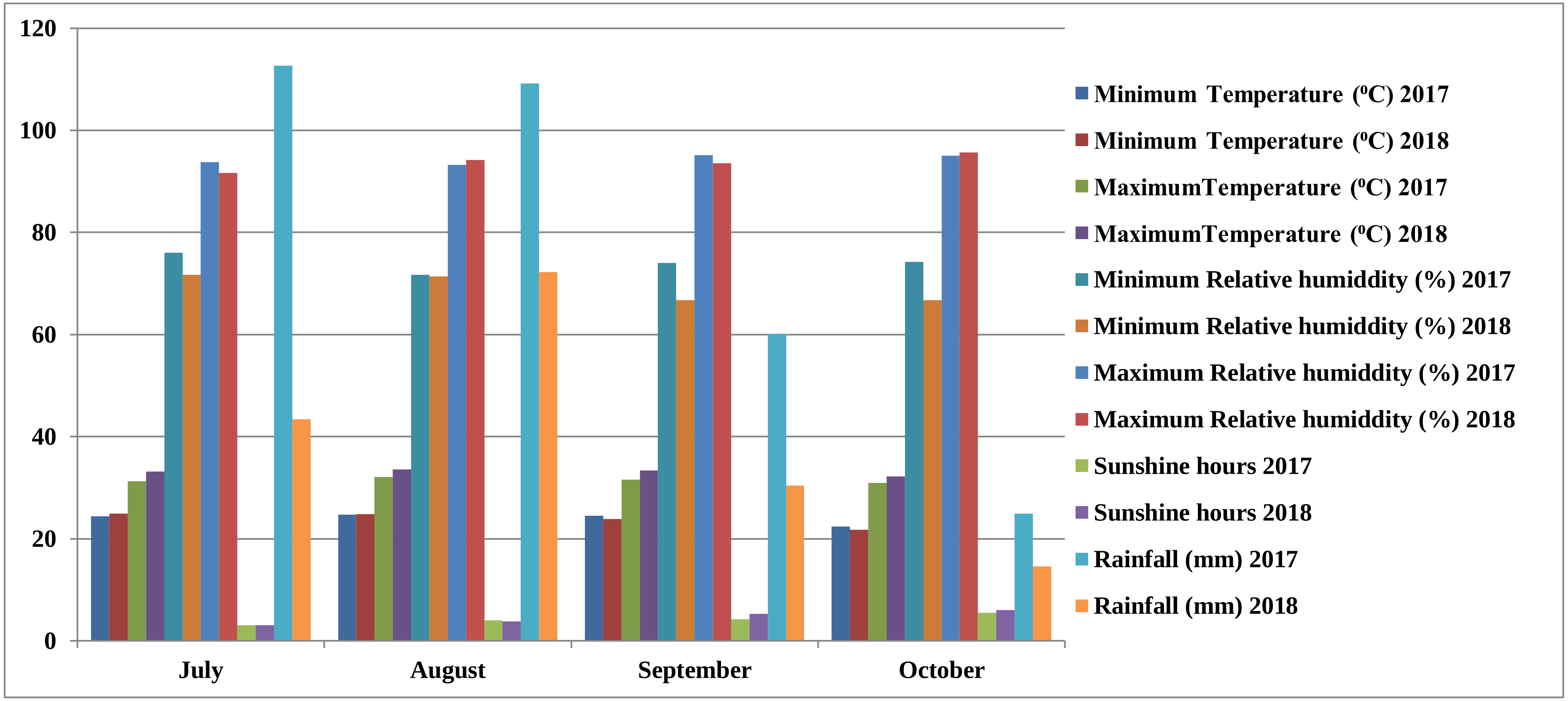


Fig 3.1: Meteorological data during the experimental period (July-October 2017 and July-October, 2018).

3.1.3 Soil condition

The soil sample was drawn from the experimental site randomly from different locations with a soil auger at 0-60 cm depth before the establishment of the experiment. The soil samples were air-dried and crushed with a wooden pestle and mortar and sieved through a 2 mm sieve and used for the analysis of various soil parameters by following standard procedures. The soil was found to be well-drained and sandy loam in texture. The results obtained are shown in Table 3.2.

Table 3.2: Initial soil fertility status of the experiment field

Particulars	Method employed	2017	2018	Inference
		Content	Content	
pH (1:2 soil water suspension)	Digital pH meter (Single electrode meter)	4.9	4.75	Acidic
Soil organic carbon (%)	Walkley and Black method (Walkley and Black, 1934)	1.46	1.48	High
Available N (kg ha^{-1})	Kjeldahl Flask method (Subbiah and Asija, 1956)	340.86	335.21	Medium
Available P_2O_5 (kg ha^{-1})	Bray's No 1 method (Bray and Kurtz Method, (1945)	18.25	19.60	Low
Available K_2O (kg ha^{-1})	Flame photometer (Hanway and Heidal, 1952)	226.82	230.56	Medium
Available sulphur (kg ha^{-1})	Turbidimetric determination (Chesnin and Yein, 1951)	15.3	18.18	Medium
DTPA extractable-Zn (mg kg^{-1})	DTPA extractable-Zn (Lindsay and Norvell, 1978).	0.48	0.5	Low

3.2 Details of the experiment

3.2.1 Test crop

JS 97-52 is a widely adaptable, high yielding and multiple resistant varieties. The yielding potential of this variety is 25-30 q ha^{-1}. It possesses excellent germinability, field emergence and longevity during storage. Its maturity period is 98-102 days, categorized as medium duration. It has been found resistant to Yellow Mosaic Virus, root rot, bacterial pustules, charcoal rot, Cercospora leaf spot and target leaf spot and rated as resistant high yielding based on reaction to disease complex and against insect pests based on tolerance shown against stem-fly, girdle beetle and defoliators.

3.2.2 Experimental design

The field experiment was laid out in Factorial RBD design and replicated thrice with fifteen treatments. The layout of the experimental field is given in Fig 3.2.

3.2.3 Details of the experimental field

1)	Crop	: Soybean
2)	Variety	: JS 97-52
3)	Experimental Design	: Factorial RBD
4)	Number of replications	: 3
5)	Number of treatments	: 15
6)	Total number of experimental plots	: 45
7)	Spacing	: 40 cm x 10 cm
8)	Net plot size	: 4 m x 3 m
9)	Total length and width of the field	: 38 m and 16 m
10)	Total area of the experimental field	: 608 m^2

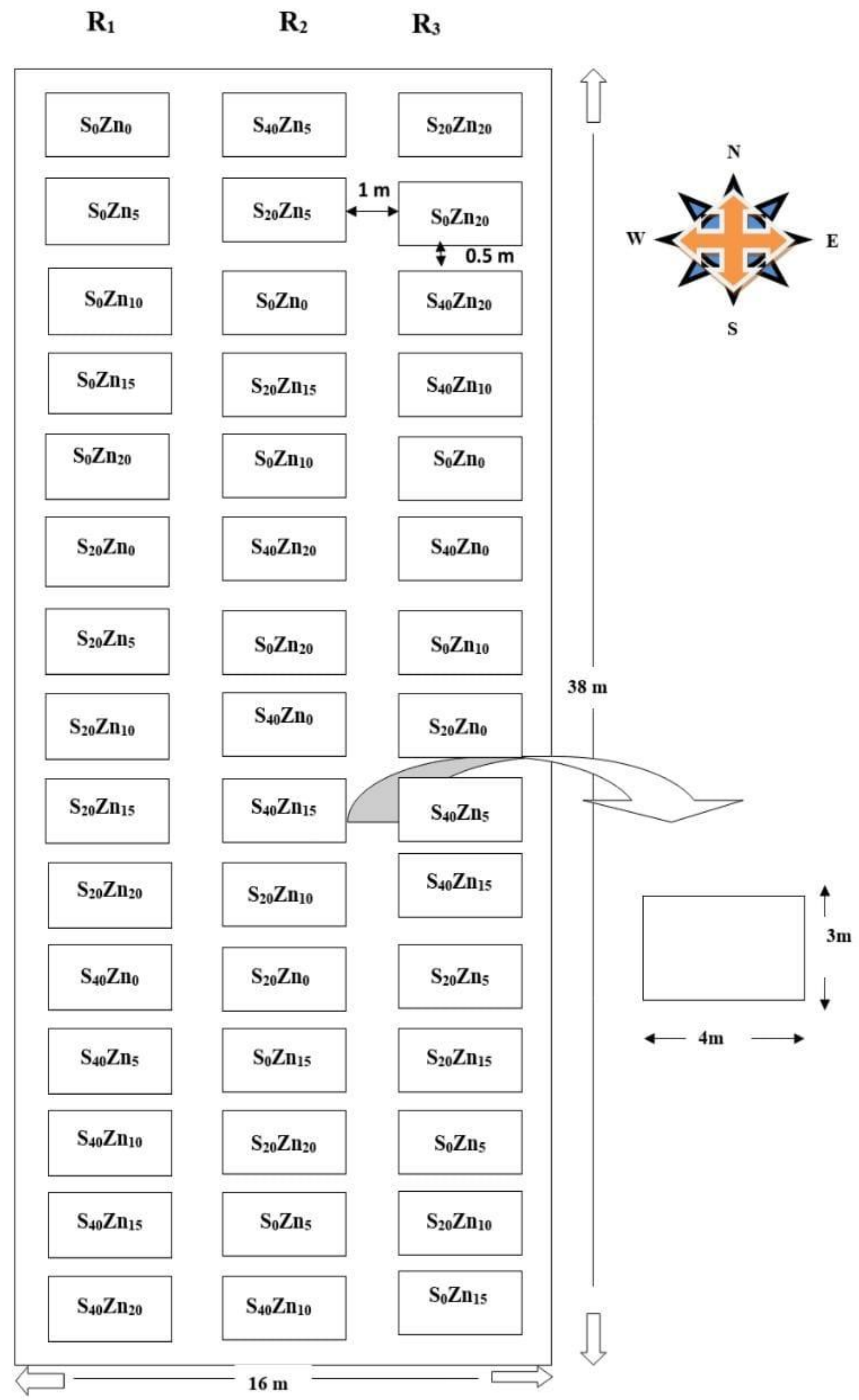


Fig 3.2: Layout of the experimental field in Factorial Randomized Block Design (RBD)

3.2.4 Treatment details

Factor 1: Three levels of sulphur

S_0 : 0 kg S ha^{-1}

S_{20} : 20 kg S ha^{-1}

S_{40} : 40 kg S ha^{-1}

Factor 2: Five levels of zinc

Zn_0 : 0 kg Zn ha^{-1}

Zn_5 : 5 kg Zn ha^{-1}

Zn_{10} : 10 kg Zn ha^{-1}

Zn_{15} : 15 kg Zn ha^{-1}

Zn_{20} : 20 kg Zn ha^{-1}

The experiment was carried out with the following treatment combinations.

$T_1 = S_0Zn_0$

$T_2 = S_0Zn_5$

$T_3 = S_0Zn_{10}$

$T_4 = S_0Zn_{15}$

$T_5 = S_0Zn_{20}$

$T_6 = S_{20}Zn_0$

$T_7 = S_{20}Zn_5$

$T_8 = S_{20}Zn_{10}$

$T_9 = S_{20}Zn_{15}$

$T_{10} = S_{20}Zn_{20}$

$T_{11} = S_{40}Zn_0$

$T_{12} = S_{40}Zn_5$

$T_{13} = S_{40}Zn_{10}$

$T_{14} = S_{40}Zn_{15}$

$T_{15} = S_{40}Zn_{20}$

Fertilizer sources	Content	Method of application
DAP	18% N, & 46% P_2O_5	Basal
MOP	60% K_2O	Basal
Elemental Sulphur	90% sulphur	Basal
Zinc oxide	70% zinc	Basal

3.3 Agronomic practices

3.3.1 Selection and preparation of field

A well-drained and fertile plot was selected for carrying out the research work in the experimental farm of the Agronomy Department. Land preparation was carried out by ploughing it well by a tractor-drawn plough one month before the sowing time. Later, the hardpans and clods were broken down with the help of a tractor-drawn rotavator to make it into a fine seedbed. The land was then levelled to make the layout.

3.3.2 Manures and fertilizers application

Well decomposed farmyard manure and recommended dose of nitrogen, phosphorus and potassium at 20:60:40 kg ha^{-1} through DAP (18% N and 46% P_2O_5) and MOP (60% K_2O), respectively were applied to each plot as basal dose and mixed with the soil. Sulphur was applied through elemental sulphur powder (90%) at 0, 20, 40 kg ha^{-1} and zinc through zinc oxide (70% Zn) at 0, 5, 10, 15 and 20 kg ha^{-1}.

3.3.3 Seed rate and sowing

Healthy seeds @ 60 kg ha^{-1} were sown on July 8, 2017, and July 11, 2018, respectively. The seeds were first treated with fungicide Bavistin @ 2g/L of water and *Rhizobium japonicum* @ 20 g kg^{-1} seed and dried in shade for an hour before sowing. The seeds were then sown at a depth of 1.5 cm - 2 cm maintaining row to row distance of 40 cm and plant to plant distance of 10 cm. The spacing was maintained by thinning out the plants after 15 DAS.

3.3.4 Irrigation

Irrigation was provided after sowing to obtain proper moisture of the soil for germination and establishment of the crops. Thereafter, irrigation was given as and when required depending on rainfall.

3.3.5 Intercultural operations

The various operations after sowing included thinning and gap-filling at 15 DAS. This was done to maintain the optimum and uniform plant population. Hand weeding was done on the emergence of weeds at regular intervals to control the weeds. For controlling the insect pests, hand picking of the insects was done to monitor them.

3.3.6 Harvesting and threshing

Harvesting was done manually from the net plot area once the seed became hard and the leaves turned yellow in colour. Two to three pickings were done and the stover was left to be sun-dried for some days. The pods were dried, threshed and cleaned manually. Threshing was done manually by beating with a wooden stick. Stover and seed yield were recorded separately with the help of a weighing balance for each treatment plot-wise.

3.4 Experimental observations recorded

3.4.1 Meteorological observations

Meteorological observations on temperature (minimum and maximum in ^{0}C), relative humidity (minimum and maximum in %), sunshine hours and rainfall (mm) were recorded for the research period of 2017 and 2018.

3.4.2 Growth attributes

Five healthy plants were selected randomly from each plot excluding the border row plants and tagged to determine the various growths attributes of the plants. The readings were recorded at 25 DAS, 50 DAS and 75 DAS.

3.4.2.1 Plant height (cm)

The plant height on different days after sowing was recorded by taking the readings of five healthy tagged plants. The height was taken from the ground level to the tip of the main stem of the plant and measured in cm. The observations were taken at 25 DAS, 50 DAS and 75 DAS. The average plant height was then calculated for each treatment.

3.4.2.2 Number of leaves per plant

The number of leaves was recorded from the five tagged plants of each plot and the observation was taken at 25 DAS, 50 DAS and 75 DAS. The average leaves were then calculated for each treatment.

3.4.2.3 Number of branches per plant

The number of branches was observed and recorded from the five tagged plants at 25 DAS, 50 DAS and 75 DAS. The average number of branches was calculated for each treatment.

3.4.2.4 Shoot dry weight (g plant^{-1})

Plant samples for dry matter studies were collected at 25 DAS, 50 DAS and 75 DAS. At each sampling, three plants were uprooted randomly, and the plant shoots were kept in the oven for about 75-80°C till they reached a constant weight. After drying, the shoot samples were taken out, and weight and the average value were obtained from each treatment and expressed in g plant^{-1}.

3.4.2.5 Leaf Area Index (LAI)

For the leaf area index, three healthy plants excluding the border row were randomly selected and taken at 25 DAS, 50 DAS and 75 DAS. From the measured values of leaf area, LAI was computed considering the area occupied by each plant according to the following formula as suggested by Watson (1947).

The LAI was worked out by using the formula:

$$\text{LAI} = \frac{\text{Total leaf area of the plant}}{\text{Ground area}}$$

3.4.2.6 Crop Growth Rate (CGR) (g m^{-2} day^{-1})

The dry weight gained by a unit area of crop in a unit time was calculated by the following formula (Watson, 1952). .The Crop Growth Rate (CGR) was calculated at 25-50 DAS and 50-75 DAS.

$$\text{CGR (g m}^{-2}\text{ day}^{-1}\text{)} = \frac{\text{W2} - \text{w1}}{t2 - t1} \text{ x } \frac{1}{\text{P}}$$

W_1 and W_2 are the dry weight of the plants on two successive sampling times of t_1 and t_2 respectively and P is the unit land area occupied by the plant (m^2).

3.4.2.7 Relative Growth Rate (RGR) (g g^{-1}day^{-1})

The Relative Growth Rate (RGR) is expressed as g of dry matter produced by a g of existing dry matter in a day and was calculated from the obtained crop growth rate values (Blackman, 1919).

$$\text{RGR} = \frac{logeW2 - logeW1}{t2 - t1}$$

Where,

W_1 and W_2 are the plant dry weight (g) at time t_1 and t_2 respectively.

3.4.2.8 Net Assimilation Rate (NAR) (g m^{-2} of leaf area day^{-1})

The increase in dry weight of plant per unit leaf area per unit time was calculated at 25-50 DAS and 50-75 DAS by the following formula (Gregory, 1917).

$$NAR=\frac{(W2-W1)(logeL2-logeL1)}{(t2-t1)(L2-L1)}$$

Where,

L_1 and W_1 are the leaf area and dry weight of plants at time t_1, and L_2 and W_2 are the leaf area and dry weight of plants at time t_2.

3.4.2.9 Number of nodules per plant

The number of nodules was taken by taking the readings of three random uprooted plants dug with the help of a shovel at 25, 50, and 75 DAS. The roots were then gently washed and separated from the plant. The nodules were counted and recorded an average value of each treatment was calculated.

3.4.3 Yield attributes

3.4.3.1 Number of pods per plant

At harvest, the pods were collected from the tagged plants separately from each plot and the average was recorded.

3.4.3.2 Length of pods (cm)

The length of the pods was taken by randomly selecting ten pods from each of the collected tagged plants and measured in cm. The average was then recorded.

3.4.3.3 Number of seeds per pod

The seeds were taken from the ten randomly selected pods and counted. This was done for all the treatments and the average was recorded.

3.4.3.4 Test weight (g)

From each treatment, one thousand seeds were counted and then weighed. The averages of weight were calculated and expressed in grams.

3. 4.3.5 Seed yield (t ha^{-1})

The pods were harvested from each treatment and dried, threshed and cleaned separately. These were weighed and then expressed in terms of t ha^{-1}.

3.4.3.6 Stover yield (t ha^{-1})

The harvested produce from each net plot was sundried for some days and the stover was tied in bundles separately. The stover yield of the plot was calculated after subtraction of seed yield from bundle weight. Bundle weight was recorded with the help of spring balance and converted into t ha^{-1}.

3.4.3.7 Harvest index (%)

The harvest index was calculated by using the formula.

$$HI = \frac{Economic\ yield}{Biological\ yield} \times 100$$

Where

Economic yield = Grain yield

Biological yield = Grain yield + Stover yield.

3.4.4 Quality of soybean

3.4.4.1 Determination of oil content in grain

The oil content was determined by the Soxhlet extraction method (AOAC, 1960). In this method, the seeds were crushed to powder and a 2 g sample was taken. This sample was placed in a thimble pre-weighed oil flask which was attached to the Soxhlet assembly. Oil extraction was done by using petroleum ether (A.R.Grade 60^0C - 80^0C) for eight hours. After extraction, the excess solvent was removed by heating the flask at 800^0C in an oven for 2 hours. The flask was cooled in desiccators and weighed for oil content.

3.4.4.2 Estimation of crude protein content in grain

The nitrogen content value of grain was multiplied by 6.25 to get the crude protein content, which also includes non-protein nitrogen. The crude protein content (%) of soybean grain was worked out by the following formula (A.O.A.C. 1965)

Crude protein (%) = N content (%) x 6.25 (as a constant factor).

3.4.5 Plant sample for NPKS and Zn uptake

3.4.5.1 Collection and preparation of plant samples

The plant samples from each plot were collected randomly at the harvest stage. The plant material i.e., the seeds and the stover were dried under the sun followed by oven drying at around 60-65°C. It was then powdered with a grinder and kept in labelled polythene bags for chemical analysis of N, P, K, S and Zn.

3.4.5.2 Digestion of plant samples

Powdered plant samples were pre-digested separately in HNO_3. The pre-digested samples were digested with di acid (HNO_3: $HClO_4$) mixture at a 10:4 ratio till a clear solution was observed, cooled and diluted in HCl. The content was made up to known volume by using double distilled water. A known quantity of liquid was used for further analysis of N, P, K, S and Zn.

3.4.5.3 Nitrogen content (%)

Nitrogen content in digested grain and plant samples were determined by using the Micro-kjeldahl method (Jackson, 1973).

3.4. 5.4 Phosphorus content (%)

Phosphorus content of digested grain and plant samples was estimated by the development of the Vanadomolybdo-phosphoric acid yellow colour method using a double beam spectrophotometer at the wavelength (Jackson, 1973).

3.4.5.5 Potassium content (%)

The aliquots after wet digestion for P estimation were distilled to the desired level and were analyzed for K, by a direct reading using a Flame Photometer (Jackson, 1973).

3.4.5.6 Sulphur content (%)

Sulphur by turbidimetric method (Chesnin and Yien, 1950).

3.4.5.7 Zinc content (mg kg^{-1})

The Zn content in the plant was analyzed by atomic absorption spectrophotometer (Lindsay and Norvell, 1978).

3.4. 5.8 Nutrient uptake (kg ha^{-1})

Macro (N, P, and K), secondary nutrient (S) & micronutrient (Zn) uptake in seed & stover yields were computed by multiplying their respective nutrient contents with yields using the following formula:

Nutrient uptake (kg ha^{-1}) in seed = Concentration (%) x seed yield (kg ha^{-1}) /100

Nutrient uptake (kg ha^{-1}) in stover = Concentration (%) x straw yield (kg ha^{-1})/100

3.4.6 Nutrient status of the soil at harvest

Soil samples from the field before and after the harvest of soybean were taken to assess the change in nutrient status *viz.* pH, organic carbon and available nitrogen, phosphorus, potassium, sulphur and zinc. The soil samples collected from 0-60 cm depth were dried under shade, ground with a wooden pestle and mortar, passed through a 2 mm sieve and were used for analysis.

3.4.6.1 Soil pH

Soil pH was determined by glass electrode pH meter, taking 1:2.5 soil water suspension after stirring it for 30 minutes and measured by a pH meter as described by Jackson (1973).

3.4.6.2 Organic carbon (%)

Soil organic carbon was determined by using Walkley and Black's method (1934) and the data was calculated in terms of kg $ha^{-1.}$

3.4.6.3 Available Nitrogen (kg ha^{-1})

The available soil Nitrogen (N) was determined by Alkaline Potassium Permanganate Method as suggested by Subbiah and Asija (1956) and the data was calculated in terms of kg $ha^{-1.}$

3.4.6.4 Available Phosphorus (kg ha^{-1})

The available soil Phosphorus (P_2O_5) was determined by Bray's No 1 method (Bray and Kurtz, 1945). The results were expressed in kg ha^{-1}.

3.4.6.5 Available Potassium (kg ha^{-1})

Available K was determined by the Flame-photometer method (Hanway and Heidal, 1952) and the result obtained was expressed in kg ha$^{-1.}$

3.4.6.6 Available sulphur (kg ha^{-1})

Available sulphur in soil was determined by the turbidimetric method (Chesnin andYein, 1951).

3.4.6.7 DTPA extractable zinc (g ha^{-1})

The DTPA (Diethylene Triamine Penta Acetic acid pH 7.3), extractable Zn, was extracted by 0.005 M DTPA, 0.01 M $CaCl_2$ and 0.1 M triethanolamine (TEA) and determined on atomic absorption spectrophotometer (Lindsay and Norvell, 1978).

3.5 Statistical analysis

The data recorded on various parameters during the investigation were statistically analyzed duly following the analysis of variance technique for factorial randomized block design. The statistical significance was tested with the F test at a 0.05 level of probability and wherever the F value was found significant, the critical difference (CD) was worked out to test the significance.

CHAPTER IV

RESULTS AND DISCUSSION

CHAPTER-IV

RESULTS AND DISCUSSION

A field experiment entitled "Effect of sulphur and zinc fertilization for biofortification in soybean (*Glycine max* L. Merrill) under Nagaland condition" was undertaken to elicit information on growth parameters, yield attributes, quality, content and uptake of nutrients, soil nutrient status and economics of the experiment conducted during *kharif* of 2017 and 2018. The results of the investigation are presented in this chapter.

The results have been critically examined and statistically analyzed and presented here along with tables and graphs. The findings obtained through the experiment is also discussed and relevant references have been cited based on experiments carried out by different researchers to draw valid conclusions for scientific and practical utility.

4.1 Effect of sulphur and zinc fertilization for biofortification on growth parameters and yield attributes of soybean

4.1.1 Plant height (cm)

The perusal data on plant height of soybean at different stages of growth as influenced by different levels of sulphur and zinc was analyzed statistically, presented and depicted in Table 4.1 and Fig 4.1 and their interaction effects in Table 4.2 and Fig 4.2 at 25, 50 and 75 DAS.

4.1.1.1 Effect of sulphur levels

Based on the data presented, the plant height did not differ significantly at 25 DAS for both the experiment years of 2017 and 2018. However, at 50 and 75 DAS, the different levels of sulphur had a significant effect on the plant height with the highest plant height recorded with the application of 20 kg S ha^{-1} (39.01 cm and 39.52cm, 44.94 cm and 46.74 cm) and the lowest was found with 0 kg S ha^{-1} (31.29 cm and 31.79 cm, 35.37 cm and 38.75 cm). The application of 20 kg S ha^{-1} and 40 kg S ha^{-1} (37.40 cm and 39.14 cm) were found to be statistically at par with each other but significantly higher than that of control. The pooled data also complied with the above data and showed significant variation with the treatment 20 kg S ha^{-1} (39.27 cm and 45.84 cm) recording the highest plant height at 50 and 75 DAS while control plot recorded the lowest (31.54 cm and 37.06 cm).

Apropos to the findings, sulphur is an important nutrient required by the crops for protein structure, vitamins and other structural components for improving plant growth and yield (Marshner, 2005; Kopriva *et al*. 2002). The increase in plant height may therefore be due to the favorable effects of sulphur on N-metabolism and consequently on the vegetative growth of soybean plant (Akter *et al*. 2013). Another plausible explanation could be sulphur's role in stimulating cell division, photosynthetic process and chlorophyll formation, promotion of root nodules in legumes, increasing sulphur availability during growth stage and development of plant resulting in increased plant height, number of branches per plant and plant spread (Yadav *et al*. 2013).

A similar conclusion to the findings was reached by Farhad *et al*. (2010) who reported that the highest plant height, seed yield, 1000-seed weight and straw yield were produced by the application of sulphur @ 20 kg ha^{-1}.(Sharma *et al*. 2014; Gill & Sharma, 2017) also reported highest plant height with sulphur supplementation of gypsum @ 20 kg ha^{-1}.

4.1.1.2 Effect of zinc levels

The increasing levels of Zn were found to have a significant effect on the plant height at all stages of growth except at 25 DAS. The highest plant height was observed in 20 kg Zn ha^{-1} (38.93 cm and 40.06 cm, 45.05 cm and

46.55 cm) and the lowest was noted in the control (32.34 cm and 32.71 cm, 37.64 cm and 40.06 cm) at 50 and 75 DAS for both the years. There was a compelling difference with the application of the different levels of zinc i.e. 5, 10, 15 and 20 kg Zn ha^{-1} over the control at 50 and 75 DAS. The difference between 15 and 20 kg Zn ha^{-1} was however found to be non-significant. The pooled data also showed similar trend showing no significant influence at 25 DAS but recording significant variation at 50 and 75 DAS with the application of 20 kg Zn ha^{-1} (39.50 cm and 45.80 cm) recording the highest plant height while control recorded the lowest (32.52 cm and 38.85 cm).

Zinc application in each and alternate year was found to significantly increase the plant growth and yield parameters such as height, pods $plant^{-1}$, seeds pod^{-1}, test weight, grain and straw yield (Raghuwanshi *et al*. 2017). Its addition to the soil resulted in increased photosynthesis and chlorophyll formation leading to increase in meristem activity and internodes length ultimately enhancing the plant height (Maurya *et al.* 2010). Singh *et al*. (2017) reported that the application of zinc increased all the growth and yield attributes of soybean but significant increase up to 30 kg Zn ha^{-1} were observed in plant height, the number of branches $plant^{-1}$ at all stages, seed yield soybean.

4.1.1.3 Interaction effect of sulphur and zinc

The interaction effect of sulphur and zinc on the plant height was found to be non-significant.

4.1.2 Number of leaves per plant

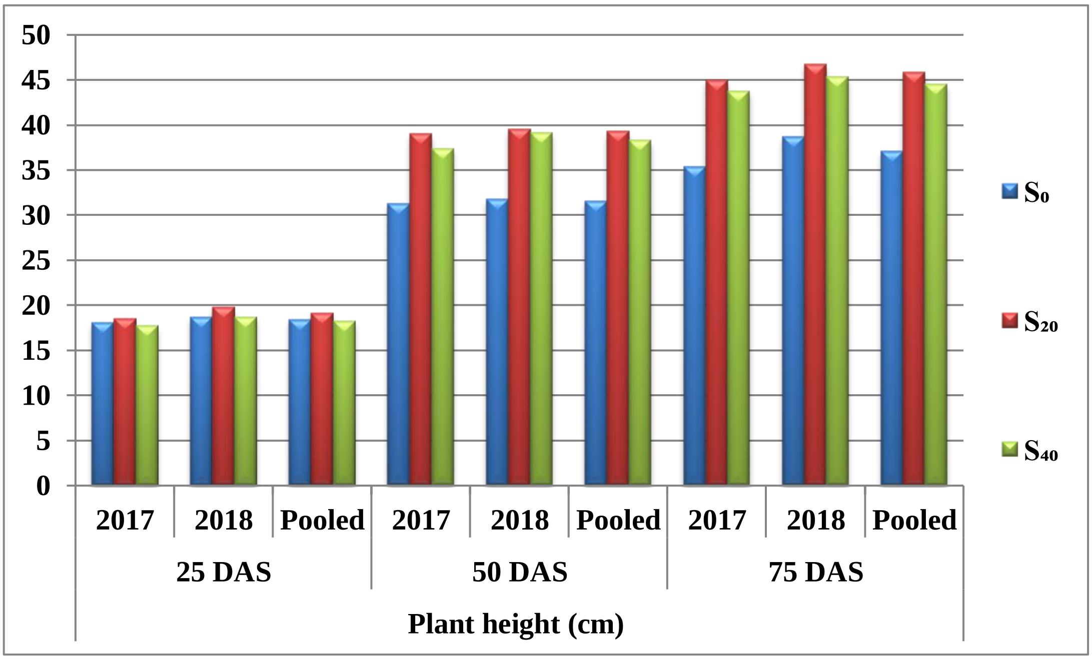
The perusal data on number of leaves per plant of soybean at different stages of growth as influenced by different levels of sulphur and zinc was analyzed statistically, presented and depicted in Table 4.3 and Fig 4.3 and their interaction effects in Table 4.4 and Fig 4.4 at 25, 50 and 75 DAS.

Table 4.1: Effect of sulphur and zinc fertilization for biofortification on plant height of soybean at different growth stages

Treatments	Plant height (cm)								
	25 DAS			50 DAS			75 DAS		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
S_0	18.11	18.70	18.41	31.29	31.79	31.54	35.37	38.75	37.06
S_{20}	18.51	19.75	19.13	39.01	39.52	39.27	44.94	46.74	45.84
S_{40}	17.71	18.69	18.20	37.40	39.14	38.27	43.78	45.32	44.55
SEm ±	0.45	0.47	0.29	0.63	0.61	0.35	0.54	0.60	0.36
CD (P=0.05)	NS	NS	NS	1.81	1.78	1.01	1.58	1.75	1.06
Zn_0	18.22	18.95	18.59	32.34	32.71	32.52	37.64	40.06	38.85
Zn_5	17.51	18.35	17.93	34.78	35.02	34.90	39.81	42.45	41.13
Zn_{10}	17.43	19.79	18.61	35.98	37.56	36.77	40.61	43.80	42.21
Zn_{15}	18.53	18.90	18.71	37.49	38.72	38.11	43.71	45.17	44.44
Zn_{20}	18.86	19.25	19.05	38.93	40.06	39.50	45.05	46.55	45.80
SEm ±	0.58	0.61	0.38	0.81	0.79	0.45	0.70	0.78	0.47
CD (P=0.05)	NS	NS	NS	2.34	2.30	1.30	2.03	2.26	1.36

Table 4.2: Interaction effects of sulphur and zinc fertilization for biofortification on plant height of soybean at different growth stages

Treatments	Plant height (cm)								
	25 DAS			50 DAS			75 DAS		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
S_0Zn_0	17.63	17.37	17.50	24.73	24.10	24.42	29.10	32.63	30.87
S_0Zn_5	18.57	17.92	18.24	30.30	28.97	29.63	33.92	37.10	35.51
S_0Zn_{10}	18.07	20.67	19.37	31.90	34.18	33.04	34.54	39.83	37.19
S_0Zn_{15}	17.77	19.02	18.39	34.30	35.00	34.65	38.13	41.31	39.72
S_0Zn_{20}	18.53	18.53	18.53	35.23	36.69	35.96	41.15	42.87	42.01
$S_{20}Zn_0$	18.13	20.70	19.42	36.60	37.03	36.82	42.07	44.50	43.28
$S_{20}Zn_5$	16.40	17.93	17.17	37.27	38.07	37.67	43.23	45.41	44.32
$S_{20}Zn_{10}$	17.37	19.07	18.22	38.63	39.47	39.05	44.07	46.30	45.18
$S_{20}Zn_{15}$	19.77	20.10	19.93	40.17	41.00	40.58	47.33	48.03	47.68
$S_{20}Zn_{20}$	20.90	20.95	20.93	42.40	42.03	42.22	48.00	49.48	48.74
$S_{40}Zn_0$	18.90	18.79	18.85	35.68	37.00	36.34	41.76	43.06	42.41
$S_{40}Zn_5$	17.57	19.20	18.38	36.77	38.03	37.40	42.27	44.83	43.55
$S_{40}Zn_{10}$	16.87	19.63	18.25	37.40	39.02	38.21	43.23	45.28	44.26
$S_{40}Zn_{15}$	18.07	17.57	17.82	38.00	40.17	39.08	45.66	46.16	45.91
$S_{40}Zn_{20}$	17.13	18.25	17.69	39.17	41.47	40.32	46.00	47.30	46.65
SEm ±	1.00	1.06	0.66	1.40	1.37	0.78	1.22	1.35	0.82
CD (P=0.05)	NS	NS	1.90	NS	NS	2.25	NS	NS	2.36



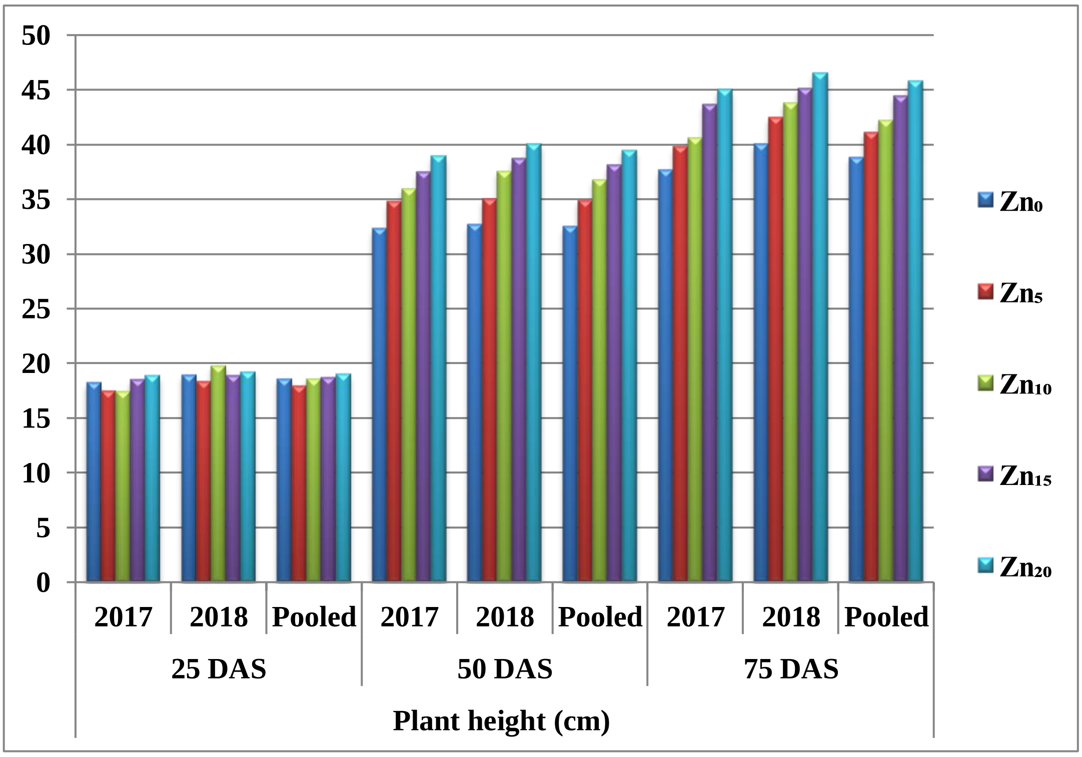


Fig 4.1: Effect of sulphur and zinc fertilization for biofortification on plant height of soybean at different growth stages.

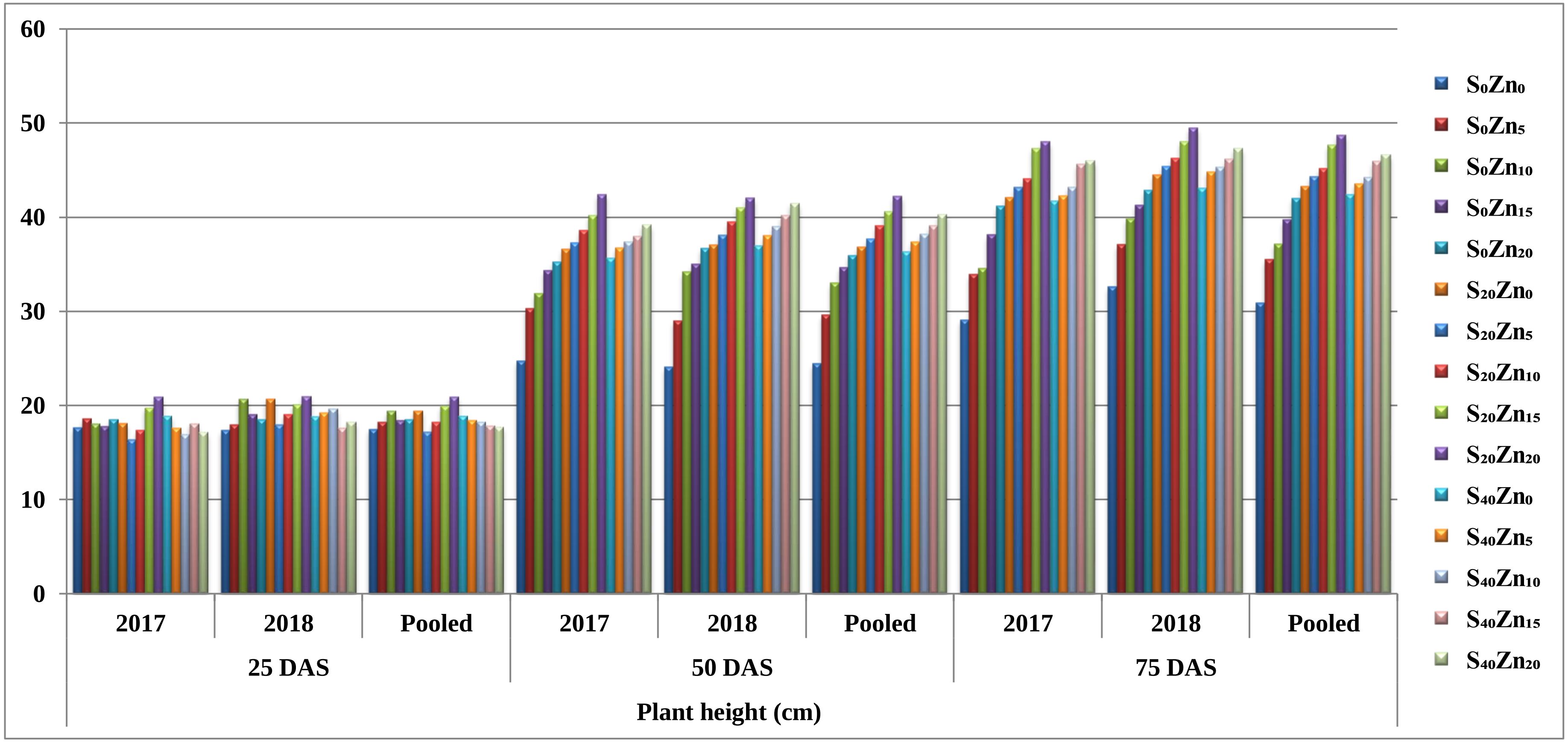


Fig 4.2: Interaction effects of sulphur and zinc fertilization for biofortification on plant height of soybean at different growth stages.

4.1.2.1 Effect of sulphur level

Application of sulphur was shown to have a notable effect on the number of leaves at all the growth stages except 25 DAS. A significant higher number of leaves per plant were observed in the treatment of 20 kg S ha^{-1} (17.45 and 20.46, 23.53 and 27.53) at 50 and 75 DAS for both the years of experiment 2017 and 2018 respectively. It was statiscally at par with 40 kg S ha^{-1} (16.90 and 20.11, 22.08 and 26.99). Similar trend was also shown in the pooled data with 20 kg ha^{-1} recording the highest number of leaves per plant (18.95 and 25.53) while control recorded the lowest (13.46 and18.92) at 50 and 75 DAS.

An increase in sulphur supply has been reported to increase tissue differentiation from somatic to reproductive, meristematic activity and development resulting in increase in number and size of leaves. As sink lies in leaves, greater translocation of photosynthates occur from leaves to the site, i.e. seed when supply of sulphur is optimum (Mengel and Kirkby, 1987). Sulphur is also known to play a vital role in formation of chlorophyll resulting in higher photosynthesis leading to increase in plant height, number of leaves and number of branches. The findings are consistent with the researches carried out by (Trivedi *et al*. 2011; Sahebagouda *et al*. 2019) showing positive effect of sulphur application on growth parameters such as number of leaves $plant^{-1}$.

4.1.2.2 Effect of zinc levels

The number of leaves per plant increased with increasing levels of zinc up to 20 kg Zn ha^{-1} at all the stages of growth except 25 DAS during the year 2017 and 2018. The application of 5, 10, 15 and 20 kg Zn ha^{-1} showed a remarkable increase in the number of leaves at 50 and 75 DAS though the Zn levels were found to be at par amongst them. The highest number of leaves was recorded at 20 kg Zn ha^{-1} (17.57 and 20.63, 23.67 and 27.58) which was significantly higher as compared to control (14.32 and 14.89, 18.22 and 21.78) at 50 and75 DAS. The pooled data for both the years was also found to be highest at 20 kg Zn ha^{-1} (19.10 and 25.62) followed by 15 kg Zn ha^{-1} (18.93 and 24.22) while control recorded the lowest number of leaves (14.61 and 20) at 50 and 75 DAS respectively.

The above results are in tandem with the work of Sonkar *et al.* (2012) who reported the increase of number of leaves of soybean with increasing levels of Zn. The increase in number of plant leaves could be ascribed to zinc's role in synthesis of tryptophan, nitrogen metabolism and production of growth hormones such as indole acetic acid.

4.1.2.3 Interaction effect of sulphur and zinc

The interaction effect between sulphur and zinc on number of leaves plant per plant did not show any significant difference at all the growth stages

4.1.3 Number of branches per plant

The effect of sulphur and zinc on number of branches at 25, 50 and 75 DAS is shown in Table 4.5 and Fig 4.5 and their interaction effects in Table 4.6 and Fig 4.6.

4.1.3.1 Effect of sulphur level

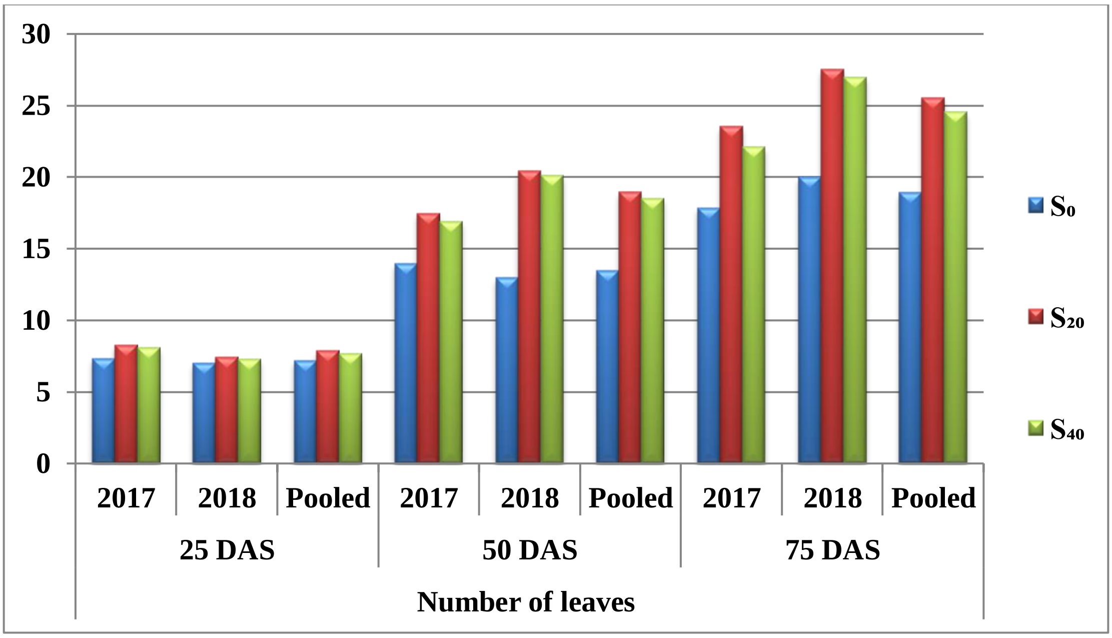
The number of branches at 25 DAS was significantly increased with the application of 20 kg S ha^{-1} (2.05) during 2017. However, no significant increase could be seen during the year 2018 at 25 DAS. The pooled value showed the highest number of branches in the treatment of 20 kg S ha^{-1} (2.09). At 50 DAS, not much variation could be seen as the treatments of 20 kg S ha^{-1} (3.79 and 2.84) and 40 kg S ha^{-1} (3.71 and 2.55) were at par with each other while control recorded the lowest number of branches (2.88 and 2.33) for both the years. The pooled data also showed similar trend with 20 kg S ha^{-1} (3.31) recording a higher number of branches as compared to the other treatments.

Table 4.3: Effect of sulphur and zinc fertilization for biofortification on number of leaves of soybean at different growth stages

Treatments	Number of leaves per plant								
	25 DAS			50 DAS			75 DAS		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
S_0	7.35	7.03	7.19	13.96	12.96	13.46	17.85	19.98	18.92
S_{20}	8.28	7.43	7.86	17.45	20.46	18.95	23.53	27.53	25.53
S_{40}	8.08	7.29	7.69	16.90	20.11	18.51	22.08	26.99	24.54
SEm ±	0.33	0.24	0.22	0.49	0.48	0.34	0.57	0.50	0.44
CD (P=0.05)	NS	NS	NS	1.43	1.38	0.98	1.64	1.44	1.27
Zn_0	7.78	7.00	7.39	14.32	14.89	14.61	18.22	21.78	20.00
Zn_5	7.51	7.18	7.34	15.84	16.73	16.29	20.36	23.27	21.81
Zn_{10}	8.22	6.98	7.60	16.18	18.04	17.11	21.37	25.26	23.31
Zn_{15}	8.18	7.53	7.86	16.60	18.93	17.77	22.16	26.29	24.22
Zn_{20}	7.83	7.56	7.69	17.57	20.63	19.10	23.67	27.58	25.62
SEm ±	0.43	0.32	0.29	0.64	0.61	0.43	0.73	0.64	0.57
CD (P=0.05)	NS	NS	NS	1.85	1.78	1.26	2.12	1.86	1.64

Table 4.4: Interaction effects of sulphur and zinc fertilization for biofortification on number of leaves of soybean at different growth stages

Treatments	Number of leaves per plant								
	25 DAS			50 DAS			75 DAS		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
S_0Zn_0	7.07	6.07	6.57	10.80	8.40	9.60	12.83	15.87	14.35
S_0Zn_5	7.53	7.87	7.70	13.73	12.53	13.13	17.20	17.80	17.50
S_0Zn_{10}	7.33	6.80	7.07	14.27	13.20	13.74	18.23	21.10	19.67
S_0Zn_{15}	7.47	6.93	7.20	14.93	14.27	14.60	19.20	22.03	20.62
S_0Zn_{20}	7.33	7.47	7.40	16.07	16.40	16.23	21.80	23.10	22.45
$S_{20}Zn_0$	8.47	7.27	7.87	16.27	18.20	17.23	21.97	25.17	23.57
$S_{20}Zn_5$	7.67	6.60	7.13	17.27	19.00	18.13	22.67	26.03	24.35
$S_{20}Zn_{10}$	8.20	7.00	7.60	17.40	20.84	19.12	23.73	27.53	25.63
$S_{20}Zn_{15}$	8.40	8.00	8.20	17.68	21.33	19.51	24.07	28.43	26.25
$S_{20}Zn_{20}$	8.69	8.27	8.48	18.63	22.90	20.77	25.21	30.47	27.84
$S_{40}Zn_0$	7.80	7.67	7.73	15.90	18.07	16.98	19.87	24.30	22.08
$S_{40}Zn_5$	7.33	7.07	7.20	16.53	18.67	17.60	21.20	25.97	23.58
$S_{40}Zn_{10}$	9.13	7.13	8.13	16.87	20.07	18.47	22.13	27.13	24.63
$S_{40}Zn_{15}$	8.67	7.67	8.17	17.20	21.19	19.20	23.20	28.40	25.80
$S_{40}Zn_{20}$	7.47	6.93	7.20	18.00	22.58	20.29	24.00	29.16	26.58
SEm ±	0.74	0.55	0.50	1.10	1.06	0.75	1.27	1.11	0.98
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS



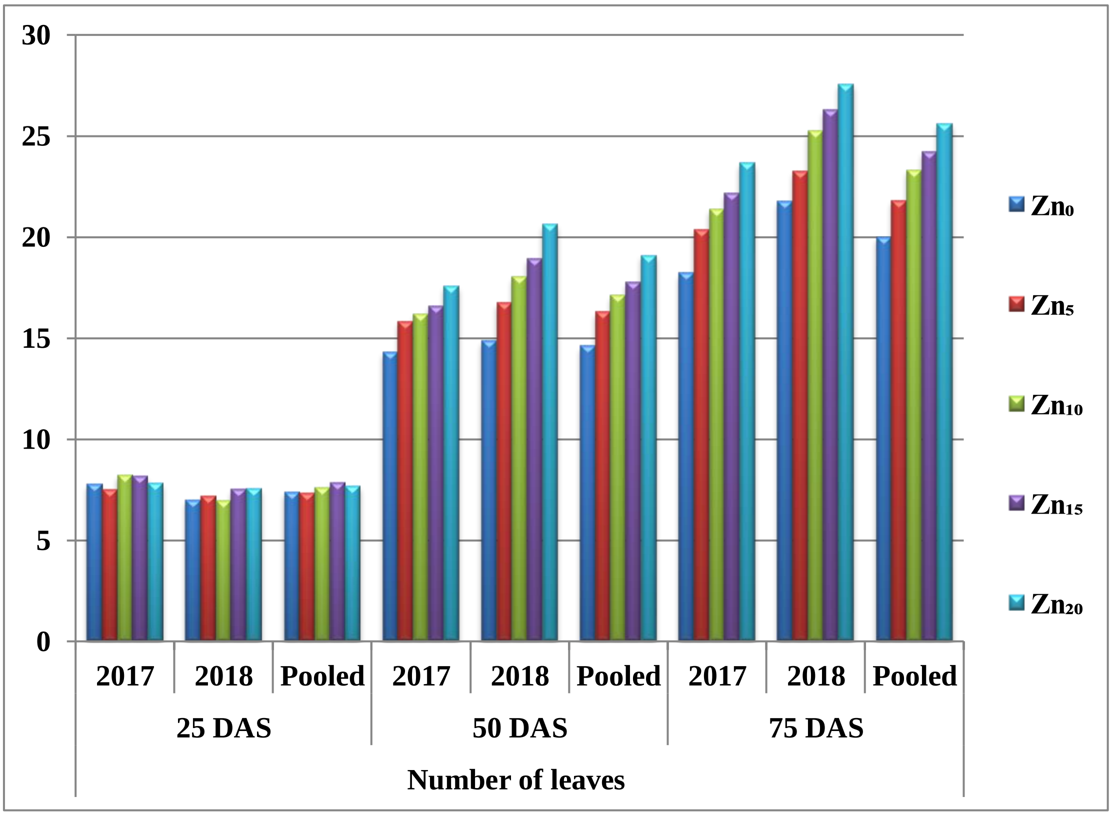


Table 4.3: Effect of sulphur and zinc fertilization for biofortification on number of leaves of soybean at different growth stages

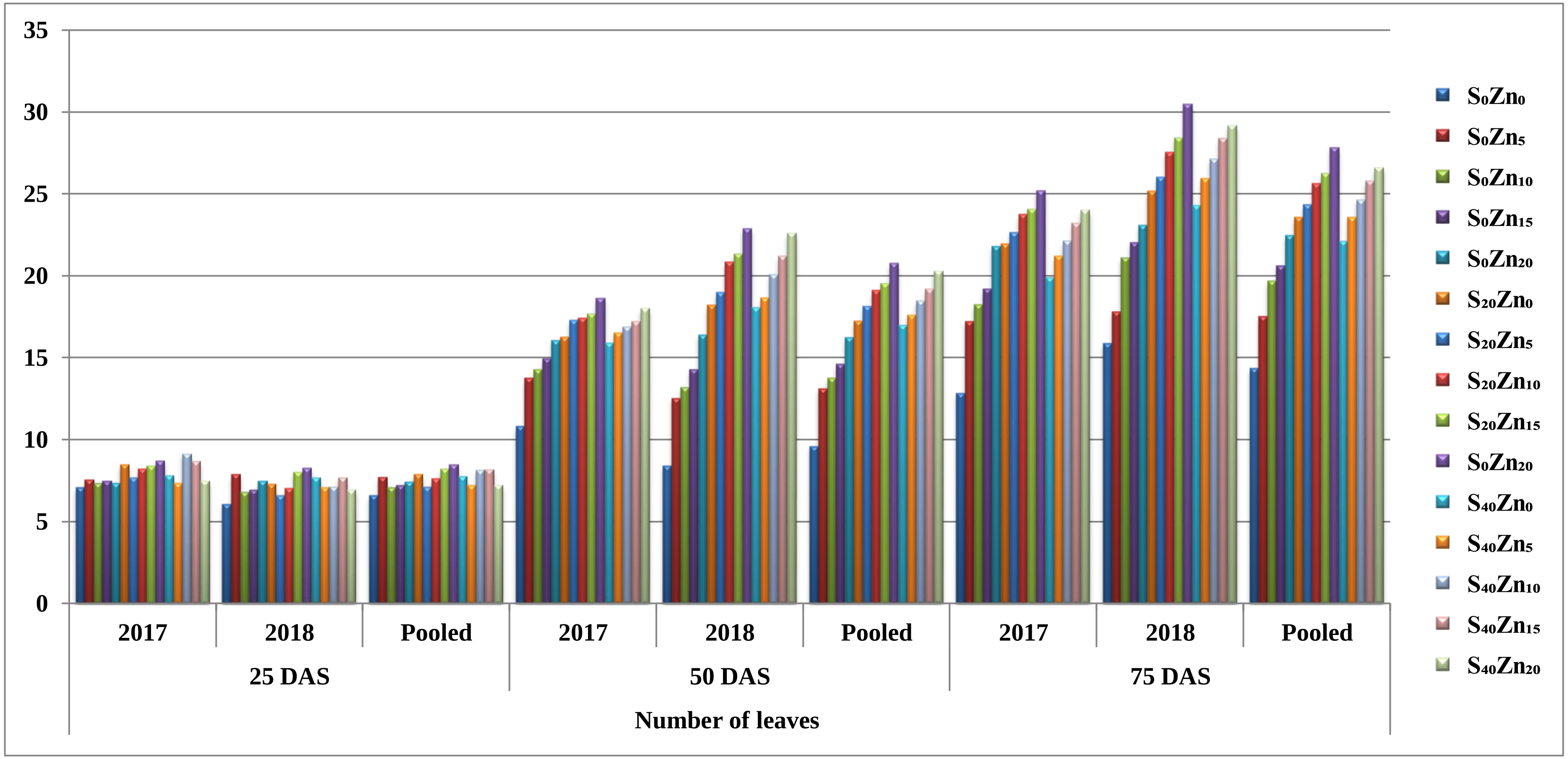


Fig 4.4: Interaction effects of sulphur and zinc fertilization for biofortification on number of leaves of soybean at different growth stages.

A measurable increase at 75 DAS could be seen with the application of 20 kg S ha^{-1} in the number of branches (4.15, 4.25 and 4.20) for both the years and pooled.

This result ties well with previous studies of Akter *et* al. (2013) wherein sulphur fertilizer application of 20 kg S ha^{-1} resulted in the highest number of primary branches plant^{-1} while the lowest number of primary branches plant^{-1} was recorded in no sulphur fertilizer application. The function of sulphur in stimulating cell division, chlorophyll formation and photosynthetic process may have aided in increasing in the growth and development of the plant resulting in increased number of branches (Yadav *et al*. 2013). The findings were also in close conformity with Mohanti *et al*. (2004) who reported similar observations with 30 kg S ha^{-1} application.

4.1.3.2 Effect of zinc levels

The data presented showed that no significant variation could be established at 25 DAS. However, the number of branches per plant increased with the increasing levels of Zn at 50 and 75 DAS over control. Treatment 20 kg Zn ha^{-1} (3.80 and 2.89, 4.15 and 4.22) recorded the highest number of branches while the lower Zn levels were almost at par with each other, and control (3.01 and 2.14, 3.51 and 3.76) recorded the lowest number of branches for both the years. Pooled data revealed 20 kg Zn ha^{-1} (3.34 and 4.19) recording a significant increase in the number of branches followed by 15 kg Zn ha^{-1} (3.16 and 4.13) while the lowest was recorded by control (2.58 and 3.63).

The findings were in line with the previous studies conducted by Sarker *et al*. (2002) who reported an increase in the number of branches with the application of zinc and boron in soybean. (Singh & Bansal, 2000; Singh *et al*. 2017) also reported that application of sulphur and zinc had significant influence up to 30 kg Zn ha^{-1} in the crop height and the number of branches plant^{-1}.

4.1.3.3 Interaction effect of sulphur and zinc

The interactions between sulphur and zinc levels were found to be non-significant at 25 DAS for both the years. At 50 and 75 DAS, a significant effect was reported with the treatment combinations of $S_{20}Zn_{20}$ with pooled data showing the highest number of branches (3.70 and 4.34) followed by $S_{15}Zn_{15}$ (3.30 and 4.23).

4.1.4 Shoot dry weight (g plant^{-1})

The data pertaining to shoot dry weight (g plant^{-1}) as influenced by different levels of sulphur and zinc is presented in Table 4.7 and Fig 4.7 and their interaction effects in Table 4.8 and Fig 4.8 at 25, 50 and 75 DAS.

4.1.4.1 Effect of sulphur level

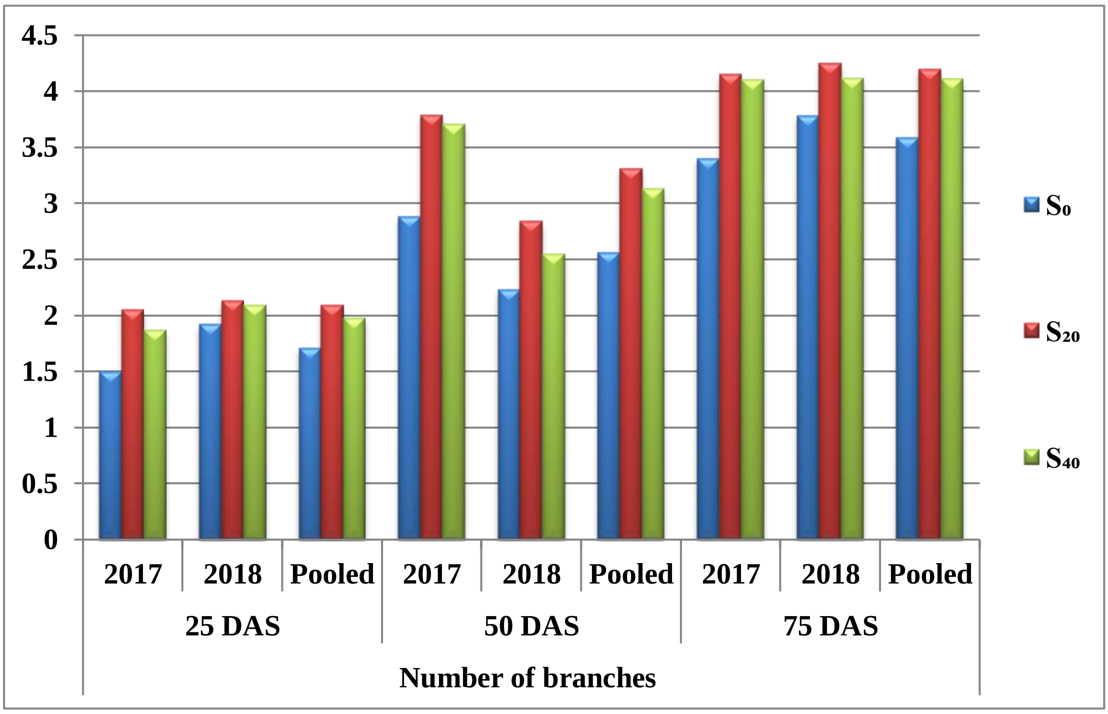
The results presented in the Table 4.7 revealed that sulphur levels recorded significant differences in shoot dry weight at all stages. During the year 2017, 20 kg S ha^{-1} (1.25 g plant^{-1}) treatment showed remarkable increase in the shoot dry weight in comparison to control (0.80 g plant^{-1}) which recorded the lowest shoot dry weight at 25 DAS. For the year 2018, no variation was observed, and it was non-significant. The pooled data complied with the data of the year 2017 and showed significant influence on the shoot dry weight. The highest being recorded in 20 kg S ha^{-1} treatment (1.35 g plant^{-1}) and the lowest in control (1.02 g plant^{-1}). At 50 and 75 DAS, shoot dry weight was found to be highest in the sulphur level of 20 kg S ha^{-1} (10.60 g plant^{-1} and 10.69 g plant^{-1}) which was at par with 40 kg S ha^{-1} (10.18 g plant^{-1} and 10.08 g plant^{-1}) during both the years. The pooled data also showed similar trend with 20 kg S ha^{-1} (10.65 g plant^{-1} and 25.81 g plant^{-1}) recording the highest dry weight while control recorded the lowest (6.40 g plant^{-1} and 17.61 g plant^{-1}).

Table 4.5: Effect of sulphur and zinc fertilization for biofortification on number of branches of soybean at different growth stages

Treatments	Number of branches								
	25 DAS			50 DAS			75 DAS		
	2017	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
S_0	1.50	1.92	1.71	2.88	2.23	2.56	3.40	3.78	3.59
S_{20}	2.05	2.13	2.09	3.79	2.84	3.31	4.15	4.25	4.20
S_{40}	1.87	2.09	1.98	3.71	2.55	3.13	4.10	4.12	4.11
SEm ±	0.14	0.13	0.09	0.07	0.08	0.05	0.05	0.05	0.03
CD (P=0.05)	0.42	NS	0.27	0.21	0.23	0.15	0.15	0.16	0.09
Zn_0	1.79	1.88	1.83	3.01	2.14	2.58	3.51	3.76	3.63
Zn_5	1.51	1.87	1.69	3.29	2.47	2.88	3.77	3.98	3.87
Zn_{10}	1.91	1.84	1.88	3.53	2.54	3.04	3.90	4.13	4.02
Zn_{15}	1.87	2.31	2.09	3.67	2.66	3.16	4.09	4.17	4.13
Zn_{20}	1.97	2.32	2.14	3.80	2.89	3.34	4.15	4.22	4.19
SEm ±	0.19	0.17	0.12	0.09	0.10	0.07	0.07	0.07	0.04
CD (P=0.05)	NS	NS	NS	0.27	0.30	0.19	0.20	0.21	0.12

Table 4.6: Interaction effects of sulphur and zinc fertilization for biofortification on number of branches of soybean at different growth stages

Treatments	Number of branches								
	25 DAS			50 DAS			75 DAS		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
S_0Zn_0	1.27	1.23	1.25	1.77	1.33	1.55	2.43	3.13	2.78
S_0Zn_5	1.50	2.13	1.82	2.53	2.27	2.40	3.13	3.67	3.40
S_0Zn_{10}	1.47	1.80	1.63	3.20	2.37	2.78	3.47	4.00	3.73
S_0Zn_{15}	1.50	1.97	1.73	3.43	2.57	3.00	3.97	4.03	4.00
S_0Zn_{20}	1.77	2.47	2.12	3.47	2.63	3.05	4.00	4.07	4.03
$S_{20}Zn_0$	2.30	2.27	2.28	3.66	2.66	3.16	4.07	4.13	4.10
$S_{20}Zn_5$	1.70	1.67	1.68	3.70	2.67	3.18	4.10	4.17	4.13
$S_{20}Zn_{10}$	1.73	1.73	1.73	3.73	2.70	3.22	4.13	4.27	4.20
$S_{20}Zn_{15}$	2.20	2.47	2.33	3.80	2.80	3.30	4.17	4.30	4.23
$S_{20}Zn_{20}$	2.33	2.50	2.42	4.03	3.37	3.70	4.28	4.40	4.34
$S_{40}Zn_0$	1.80	2.13	1.97	3.60	2.43	3.02	4.03	4.00	4.02
$S_{40}Zn_5$	1.33	1.80	1.57	3.63	2.47	3.05	4.07	4.10	4.08
$S_{40}Zn_{10}$	2.53	2.00	2.27	3.67	2.57	3.12	4.10	4.13	4.12
$S_{40}Zn_{15}$	1.90	2.50	2.20	3.77	2.60	3.18	4.13	4.17	4.15
$S_{40}Zn_{20}$	1.80	2.00	1.90	3.90	2.67	3.28	4.17	4.20	4.18
SEm ±	0.32	0.30	0.21	0.16	0.18	0.11	0.12	0.12	0.07
CD (P=0.05)	NS	NS	NS	0.47	NS	0.33	0.34	NS	0.21



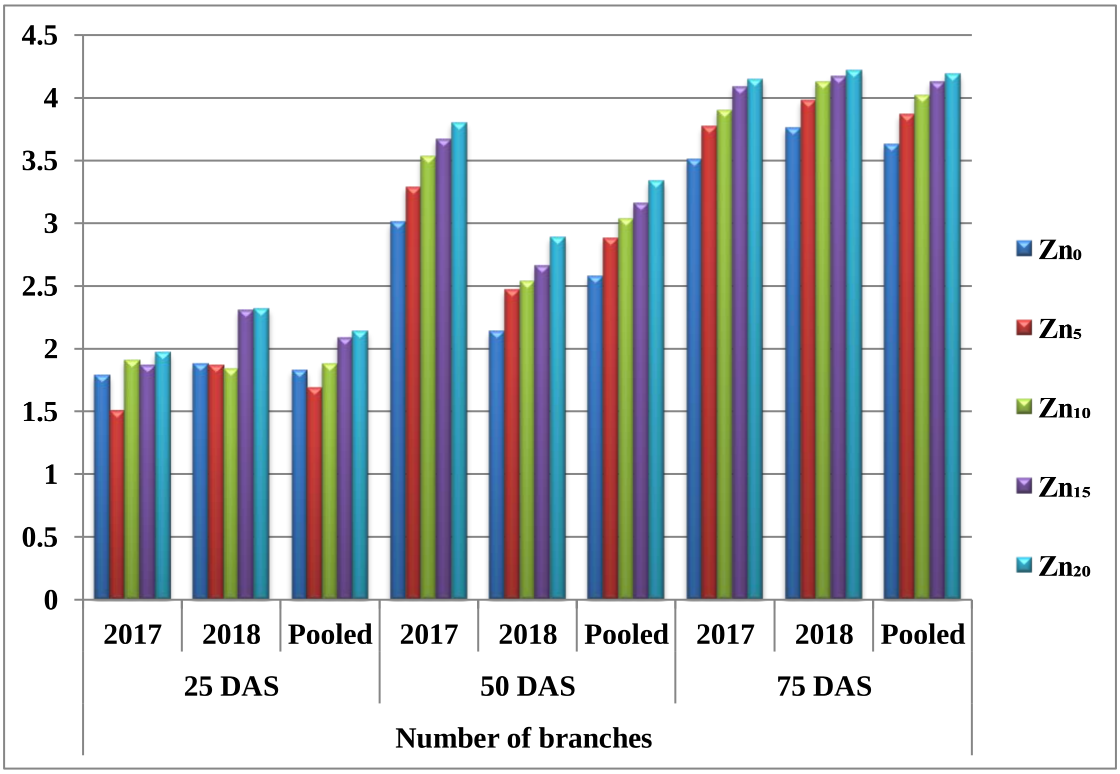


Fig 4.5: Effect of sulphur and zinc fertilization for biofortification on number of branches of soybean at different growth stages.

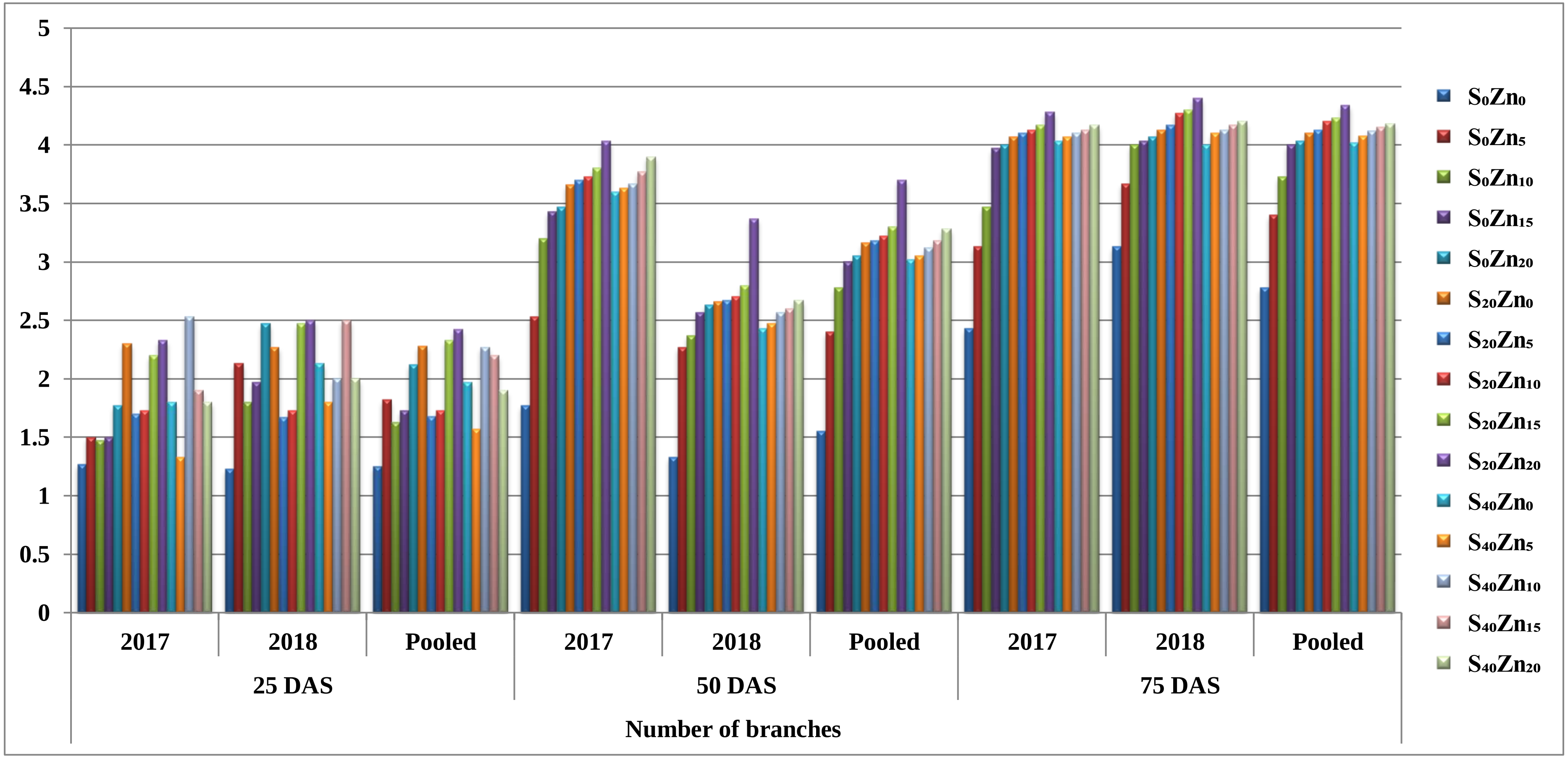


Fig 4.6: Interaction effects of sulphur and zinc fertilization for biofortification on soybean number of branches at different growth stages.

The higher shoot dry matter could possibly be due to the increase crop growth and development resulting from better absorption of sulphur nutrient from the soil leading to an increase in the plant height, number of leaves and branches. (Singh and Singh, 1995; Sahebagouda *et al*. 2019) also shared similar observations with the above findings. The dry matter accumulation was found to be increased significantly due to the application of rhizobium inoculation coupled with 30 kg S ha^{-1} (Gupta and Abraham, 2003).

4.1.4.2 Effect of zinc levels

The appraisal from the data showed no significant effect on the shoot dry weight by the zinc treatments at 25 DAS for both the years. However, it was observed that the different levels of zinc increased the shoot dry matter per plant with the increasing levels of Zn over control at 50 and 75 DAS during both the years. The highest shoot dry weight of (10.81 g plant^{-1} and 11.11 g plant^{-1}, 23.77 g plant^{-1} and 26.89 g plant^{-1}) were noted with 20 kg Zn ha^{-1} and the lowest shoot dry weight (6.51 g plant^{-1} and 7.08 g plant^{-1} and 17.76 g plant^{-1} and 21.38 g plant^{-1}) was found with 0 kg Zn ha^{-1}. The pooled data also showed significant variation with 20 kg Zn ha^{-1} (10.96 g plant^{-1} and 25.33 g plant^{-1}) recording the highest shoot dry weight followed by 15 kg Zn ha^{-1} (9.84 g plant^{-1} and 24.26 g plant^{-1}) with control recorded the lowest shoot dry weight (6.80g plant^{-1} and 19.57 g plant^{-1}).

These findings are in accordance with the findings of (Awlad *et al*. 2003; Thenua *et al*. 2014) who reported an increase in dry matter up to the highest Zn dose applied at 20 kg ha^{-1} at all the stages of the crop. A similar conclusion was also reached by Jadhav *et al.* (2009) who reported that the application of zinc sulphate @ 20 kg ha^{-1} was found to significantly increase seed germination, dry weight and vigour index in soybean over control. Among the micronutrients, available zinc and iron were found to be positively and significantly correlated with dry matter production in both below average and above average yield categories. (Chandra Sheker *et al*. 2017).

4.1.4.3 Interaction effect of sulphur and zinc

No significant variations could be established in either of the years.

4.1.5 Leaf Area Index (LAI)

The Leaf Area Index (LAI) at 25, 50 and 75 DAS as influenced by different levels of sulphur and zinc is presented in Table 4.9 and Fig 4.9 and their interaction effects in Table 4.10 and Fig 4.10.

4.1.5.1 Effect of sulphur level

The data regarding the leaf area index showed that the application of 40 kg S ha^{-1} had a significant influence on the leaf area index (0.42) during 2017. However, no significant increase could be seen during the year 2018 at 25 DAS. The highest leaf area index was also seen in the treatment of 40 kg S ha^{-1} (0.41) in the pooled data while the lowest was recorded in the control plot (0.34). At 50 DAS, the treatments of 20 kg S ha^{-1} (0.90 and 0.83) and 40 kg S ha^{-1} (0.89 and 0.81) did not show much variation and were at par with each other while the lowest LAI was seen in control (0.56 and 0.56) for both the years. The pooled data also showed similar trend with 20 kg S ha^{-1} (0.86) recording a higher LAI as compared to the other treatment. At 75 DAS, the highest LAI could be seen with the application of 20 kg S ha^{-1} (1.14, 1.25 and 1.20) for both the years and pooled followed by 40 kg S ha^{-1} (1.08, 1.20 and 1.14).

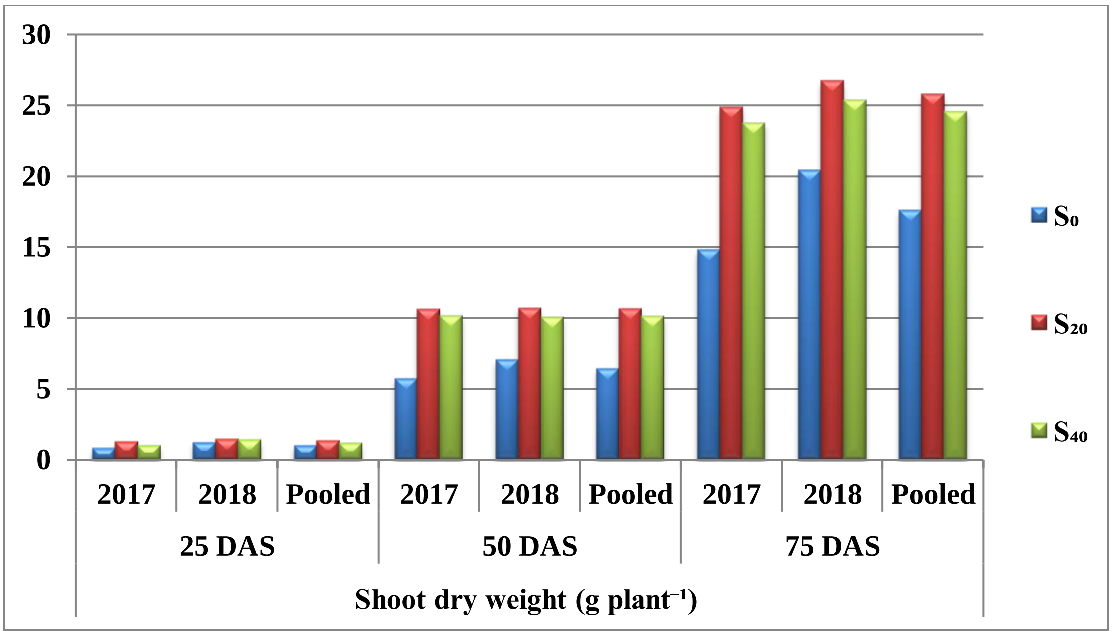
The results were in close conformity with the work carried out by Singh and Bansal, (2000) who reported an increase in Leaf Area Index, branches $plant^{-1}$ and nodules $plant^{-1}$ significantly with increase in S level up to 30 kg ha^{-1}. A positive response of S and N interaction on leaf area index, leaf area

Table 4.7: Effect of sulphur and zinc fertilization for biofortification on shoot dry weight of soybean at different growth stages

Treatments	Shoot dry weight (g plant^{-1})								
	25 DAS			50 DAS			75 DAS		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
S_0	0.80	1.24	1.02	5.76	7.03	6.40	14.81	20.42	17.61
S_{20}	1.25	1.44	1.35	10.60	10.69	10.65	24.90	26.72	25.81
S_{40}	1.01	1.39	1.20	10.18	10.08	10.13	23.78	25.38	24.58
SEm ±	0.08	0.06	0.06	0.46	0.42	0.36	0.45	0.26	0.22
CD (P=0.05)	0.24	NS	0.16	1.34	1.22	1.04	1.31	0.76	0.64
Zn_0	0.93	1.27	1.10	6.51	7.08	6.80	17.76	21.38	19.57
Zn_5	0.96	1.32	1.14	8.29	8.84	8.57	19.50	22.90	21.20
Zn_{10}	0.98	1.37	1.18	8.87	9.35	9.11	21.92	24.06	22.99
Zn_{15}	1.03	1.40	1.22	9.74	9.94	9.84	22.87	25.64	24.26
Zn_{20}	1.21	1.43	1.32	10.81	11.11	10.96	23.77	26.89	25.33
SEm ±	0.11	0.08	0.07	0.60	0.55	0.46	0.58	0.34	0.29
CD (P=0.05)	NS	NS	NS	1.73	1.58	1.34	1.69	0.98	0.83

Table 4.8: Interaction effects of sulphur and zinc fertilization for biofortification on shoot dry weight of soybean at different growth stages

Treatments	Shoot dry weight (g plant^{-1})								
	25 DAS			50 DAS			75 DAS		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
S_0Zn_0	0.73	1.13	0.93	1.16	2.72	1.94	10.64	17.93	14.29
S_0Zn_5	0.75	1.23	0.99	5.87	7.52	6.70	13.91	19.39	16.65
S_0Zn_{10}	0.79	1.25	1.02	5.95	7.61	6.79	15.84	20.03	17.94
S_0Zn_{15}	0.80	1.29	1.05	6.72	8.29	7.51	16.62	21.81	19.22
S_0Zn_{20}	0.93	1.30	1.12	9.09	9.00	9.05	17.03	22.93	19.98
$S_{20}Zn_0$	1.09	1.35	1.22	9.25	9.47	9.36	22.08	23.16	22.63
$S_{20}Zn_5$	1.14	1.42	1.28	9.75	9.54	9.65	23.40	25.17	24.29
$S_{20}Zn_{10}$	1.15	1.44	1.30	10.46	10.40	10.43	25.55	26.20	25.88
$S_{20}Zn_{15}$	1.24	1.46	1.35	11.52	10.85	11.18	26.21	28.69	27.46
$S_{20}Zn_{20}$	1.63	1.53	1.58	12.03	13.18	12.61	27.25	30.37	28.81
$S_{40}Zn_0$	0.96	1.34	1.15	9.11	9.06	9.09	20.57	23.03	21.80
$S_{40}Zn_5$	0.98	1.31	1.15	9.27	9.47	9.37	21.18	24.13	22.66
$S_{40}Zn_{10}$	1.00	1.41	1.21	10.20	10.04	10.12	24.36	25.96	25.16
$S_{40}Zn_{15}$	1.04	1.44	1.24	10.99	10.67	10.84	25.78	26.42	26.10
$S_{40}Zn_{20}$	1.07	1.45	1.26	11.31	11.14	11.22	27.02	27.37	27.20
SEm ±	0.19	0.14	0.13	1.03	0.94	0.80	1.01	0.59	0.50
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS



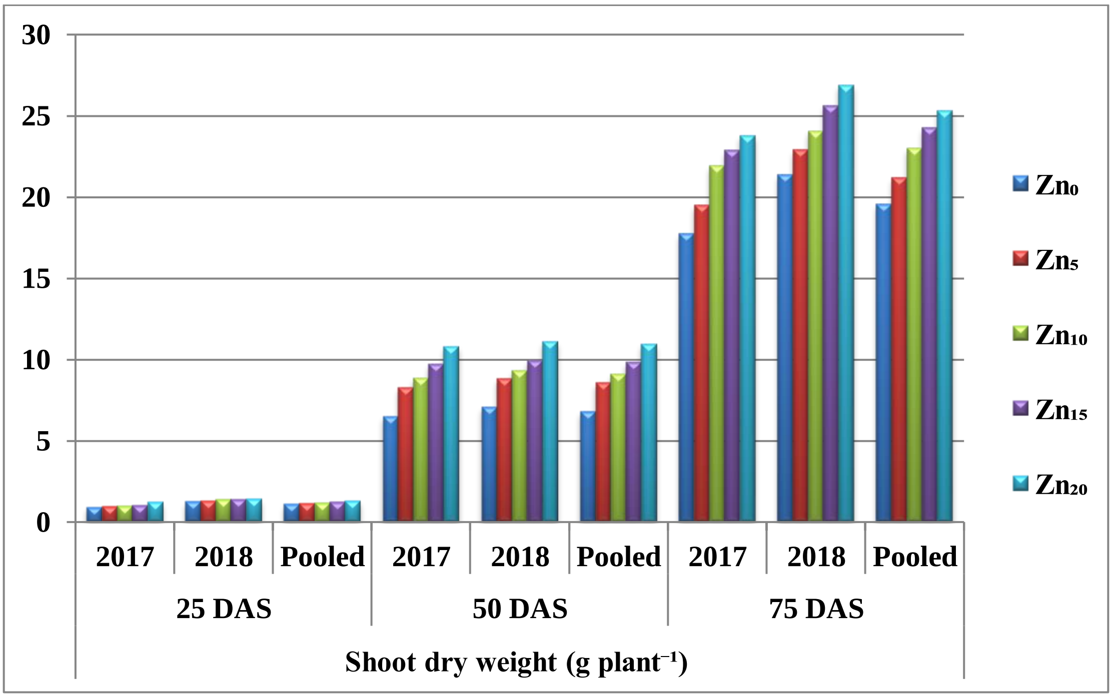


Fig 4.7: Effect of sulphur and zinc fertilization for biofortification on shoot dry weight of soybean at different growth stages.

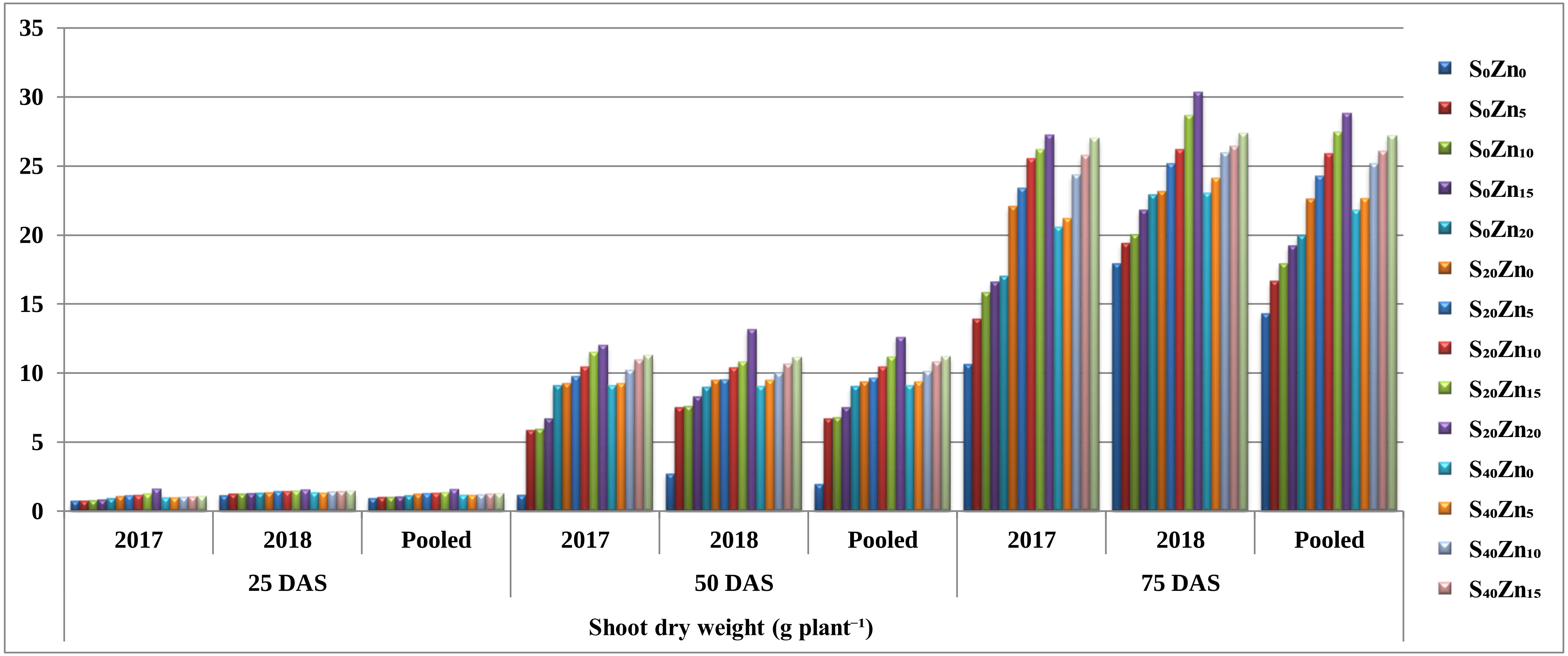


Fig 4.8: Interaction effects of sulphur and zinc fertilization for biofortification on shoot dry weight of soybean at different growth stages.

duration, and crop growth rate and biomass production were also observed by Jamal *et al*. (2005). Application of S @ 30 kg ha^{-1} was observed to have a significantly higher LAI over the remaining S levels, whereas CGR continued to rise to 40 kg S ha^{-1} (Chaurasia and Chaurasia, 2010).

4.1.5.2 Effect of zinc levels

The different levels of zinc did not show any significant effect on the leaf area index at 25 DAS for either of the years. However, at 50 DAS, there was an increase in the LAI of the crop with increasing levels of zinc (5, 10, 15 and 20 kg Zn ha^{-1}). The application of 20 and 15 kg Zn ha^{-1} were found to be significantly superior to 10 and 5 kg Zn ha^{-1} but the difference between the two Zn levels was found non-significant for both the years. The treatment of 20 kg Zn ha^{-1} (1.16, 1.25 and 1.21) showed a higher LAI at 75 DAS for both the years and pooled followed by 15 kg Zn ha^{-1} (1.11, 1.21 and 1.16) while the lowest was recorded in 0 kg Zn ha^{-1} (0.80, 0.86 and 0.8).

4.1.5.3 Interaction effect of sulphur and zinc

The interaction effect of sulphur and zinc was found to be non-significant for either of the years.

4.1.6 Crop Growth Rate (CGR) (g m^{-2} day^{-1})

The data pertaining to the Crop Growth Rate (CGR) is presented in Table 4.11 and Fig 4.11 and their interaction effects in Table 4.12 and Fig 4.12 at 25-50 DAS and 50-75 DAS.

4.1.6.1 Effect of sulphur level

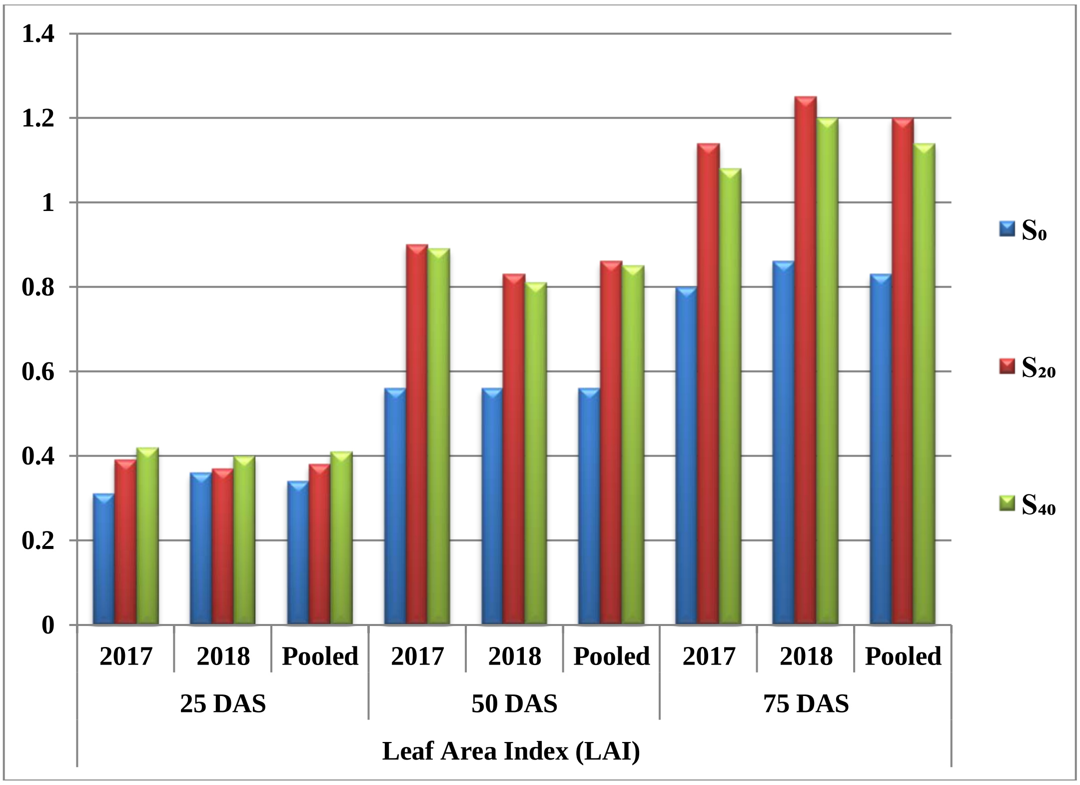
The data on sulphur levels showed significant influence on the Crop Growth Rate (g m^{-2} day^{-1}) at all the growth stages. Among the different treatments, a significant increase in the Crop Growth Rate was recorded with

Table 4.9: Effect of sulphur and zinc fertilization for biofortification on Leaf Area Index (LAI) of soybean at different growth stages

Treatments	Leaf Area Index (LAI)								
	25 DAS			50 DAS			75 DAS		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
S_0	0.31	0.36	0.34	0.56	0.56	0.56	0.80	0.86	0.83
S_{20}	0.39	0.37	0.38	0.90	0.83	0.86	1.14	1.25	1.20
S_{40}	0.42	0.40	0.41	0.89	0.81	0.85	1.08	1.20	1.14
SEm ±	0.03	0.03	0.02	0.03	0.02	0.02	0.02	0.04	0.02
CD (P=0.05)	0.09	NS	0.06	0.10	0.06	0.06	0.06	0.11	0.07
Zn_0	0.30	0.39	0.35	0.63	0.58	0.61	0.82	0.91	0.87
Zn_5	0.38	0.36	0.37	0.77	0.72	0.75	0.92	1.06	0.99
Zn_{10}	0.39	0.38	0.39	0.78	0.75	0.77	1.02	1.09	1.06
Zn_{15}	0.38	0.37	0.38	0.82	0.78	0.80	1.11	1.21	1.16
Zn_{20}	0.42	0.40	0.41	0.91	0.83	0.87	1.16	1.25	1.21
SEm ±	0.04	0.04	0.03	0.05	0.03	0.03	0.03	0.05	0.03
CD (P=0.05)	NS	NS	NS	0.13	0.07	0.07	0.08	0.15	0.09

Table 4.10: Interaction effects of sulphur and zinc fertilization for biofortification on Leaf Area Index (LAI) of soybean at different growth stages

Treatments	Leaf Area Index (LAI)								
	25 DAS			50 DAS			75 DAS		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
S_0Zn_0	0.13	0.34	0.24	0.20	0.25	0.23	0.59	0.50	0.55
S_0Zn_5	0.36	0.47	0.42	0.56	0.57	0.57	0.81	0.86	0.83
S_0Zn_{10}	0.36	0.39	0.38	0.57	0.59	0.58	0.85	0.87	0.86
S_0Zn_{15}	0.32	0.33	0.33	0.62	0.64	0.63	0.87	1.02	0.95
S_0Zn_{20}	0.35	0.29	0.32	0.83	0.75	0.79	0.88	1.07	0.97
$S_{20}Zn_0$	0.35	0.38	0.37	0.86	0.75	0.81	0.96	1.12	1.04
$S_{20}Zn_5$	0.36	0.17	0.27	0.87	0.82	0.85	0.98	1.21	1.10
$S_{20}Zn_{10}$	0.36	0.37	0.37	0.89	0.83	0.86	1.18	1.25	1.22
$S_{20}Zn_{15}$	0.32	0.43	0.38	0.92	0.85	0.89	1.27	1.33	1.30
$S_{20}Zn_{20}$	0.54	0.51	0.53	0.95	0.87	0.91	1.32	1.36	1.34
$S_{40}Zn_0$	0.41	0.46	0.43	0.84	0.75	0.80	0.92	1.11	1.01
$S_{40}Zn_5$	0.43	0.44	0.44	0.86	0.78	0.82	0.96	1.13	1.05
$S_{40}Zn_{10}$	0.44	0.37	0.41	0.88	0.83	0.86	1.04	1.17	1.11
$S_{40}Zn_{15}$	0.49	0.34	0.42	0.91	0.84	0.88	1.19	1.27	1.23
$S_{40}Zn_{20}$	0.35	0.39	0.37	0.94	0.86	0.90	1.28	1.31	1.30
SEm ± CD (P=0.05)	0.07 NS	0.08 NS	0.04 0.13	0.08 NS	0.04 NS	0.04 0.13	0.05 NS	0.09 NS	0.05 NS



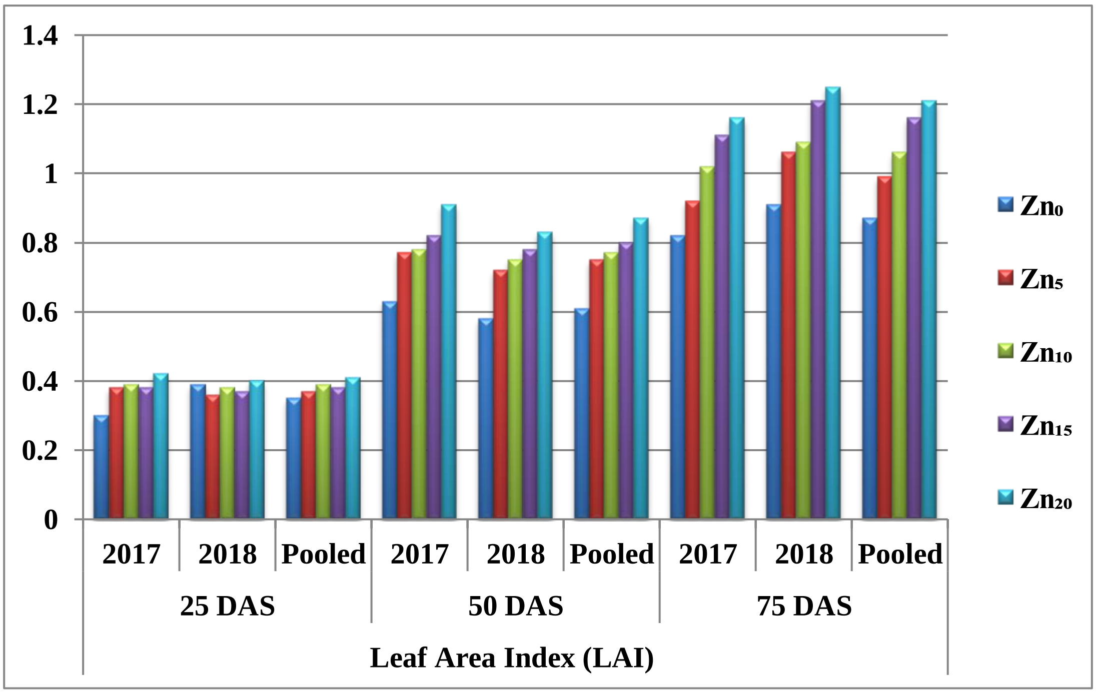


Fig 4.9: Effect of sulphur and zinc fertilization for biofortification on Leaf Area Index (LAI) of soybean at different growth stages.

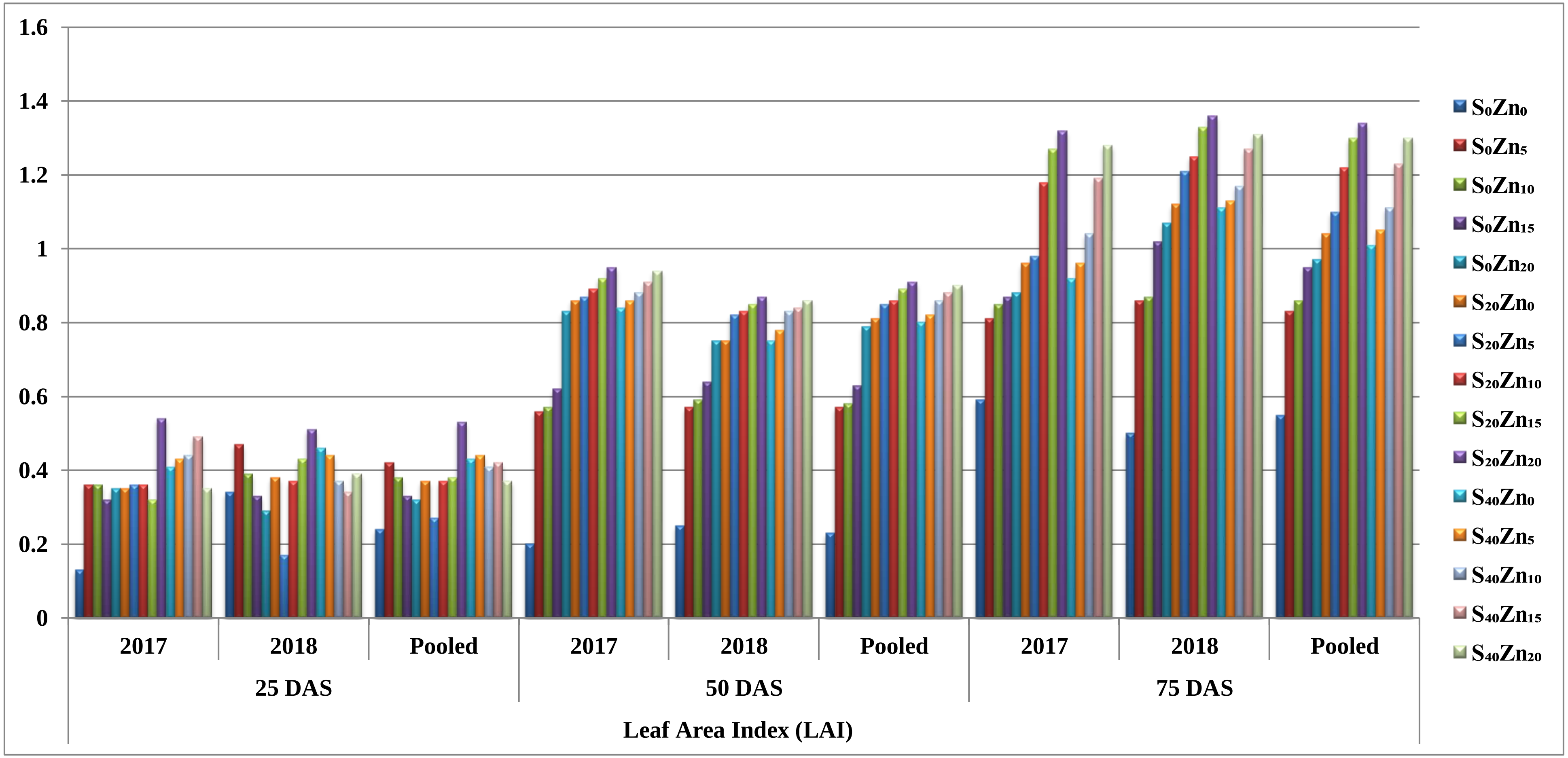


Fig 4.10: Interaction effects of sulphur and zinc fertilization for biofortification on Leaf Area Index (LAI) of soybean at different growth stages.

the application of sulphur at 20 kg S ha^{-1} (9.35 g m^{-2} day^{-1} and 9.25 g m^{-2} day^{-1}, 14.30 g m^{-2} day^{-1} and 16.03 g m^{-2} day^{-1}) at 25-50 and 50-75 DAS over control (4.96 g m^{-2} day^{-1} and 5.79 g m^{-2} day^{-1}, 9.06 g m^{-2} day^{-1} and 13.39 g m^{-2} day^{-1}). However, it was statistically at par with 40 kg S ha^{-1} (9.17 g m^{-2} day^{-1} and 8.69 g m^{-2} day^{-1}, 13.61 g m^{-2} day^{-1} and 15.31 g m^{-2} day^{-1}) during both the years. The pooled data also complied with both the years and recorded the highest CGR at 20 kg S ha^{-1} (9.30 g m^{-2} day^{-1} and 15.17 g m^{-2} day^{-1}) and the lowest at control (5.38 g m^{-2} day^{-1} and 11.22 g m^{-2} day^{-1}) at 25-50 and 50-75 DAS respectively.

With increasing sulphur doses, a positive correlation between the different growth indices was observed and the leaf area index, leaf area duration, crop-growth rate and biomass production were reported to increase Jamal *et al*. (2005). The above findings are also directly in line with previous findings of Vyas *et al*. (2008) who reported significant response of crop growth rate, total chlorophyll content, pods per plant and seed yield with sulphur application up to 20 kg S ha^{-1}.

4.1.6.2 Effect of zinc levels

The Crop Growth Rate showed a notable increase with the application of different levels of zinc at 25-50 DAS. However, it failed to exert significant influence on the Crop Growth Rate at 50-75 DAS. The perusal data revealed that the control treatment recorded the lowest CGR (5.58 g m^{-2} day^{-1} and 5.81 g m^{-2} day^{-1}) while 20 kg Zn ha^{-1} (9.60 g m^{-2} day^{-1} and 9.68 g m^{-2} day^{-1}) recorded the highest CGR and was statistically at par amongst them. The same inferences were also observed in the pooled data showing the highest and the lowest CGR in the treatments of 20 kg Zn ha^{-1} and control at 25-50 DAS while no significant variation was observed at 50-75 DAS for both the years.

Zinc application invariably increased the dry matter production of soybean (Sarkar and Aery, 1990). The CGR and NAR were higher due to foliar spray of 0.1 % $ZnSO_4$ (Selim, 1992). The findings were in partial conformity with that of Saxena and Chandel, (1997) who reported that the plant height, seed weight, CGR, RGR, LAI, DMP, yield attributes and yield of soybean were increased due to zinc application @ 5 kg ha^{-1}.

4.1.6.3 Interaction effect of sulphur and zinc

The interaction effect of sulphur and zinc on Crop Growth Rate was found to be non-significant.

4.1.7 Relative Growth Rate (RGR) (g $g^{-1}$$day^{-1}$)

The Relative Growth Rate (RGR) at 25, 50 and 75 DAS is presented in Table 4.13 and Fig 4.13 and their interaction effects in Table 4.14 and Fig 4.14 at 25-50 DAS and 50-75 DAS.

4.1.7.1 Effect of sulphur level

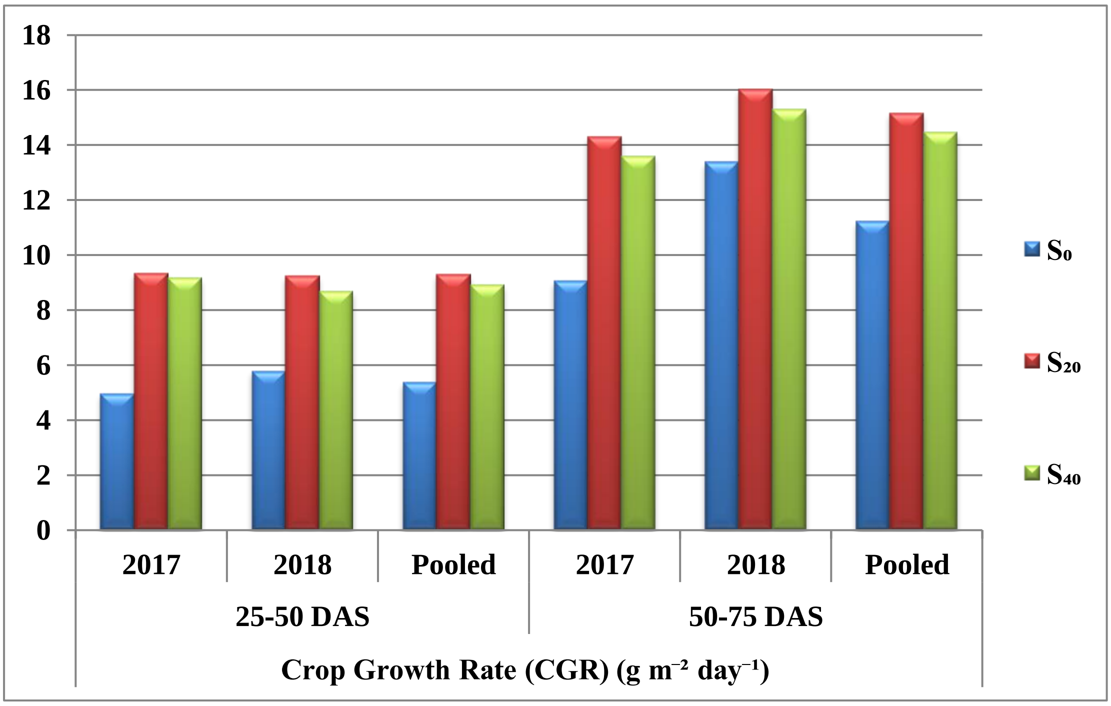
The data on sulphur levels showed significant variations in Relative Growth Rate (RGR) due to application of different levels of sulphur at all the growth stages. Among the different treatments, a significant increase in the RGR was recorded with the application of sulphur at 40 kg S ha^{-1} (0.0933 g g^{-1} day^{-1} and 0.0793 g g^{-1} day^{-1}) which was at par with 20 kg S ha^{-1} (0.0859 g g^{-1} day^{-1} and 0.0793 g g^{-1} day^{-1}) at 25-50 DAS. The control plot (0.0729 g g^{-1} day^{-1} and 0.0671 g $g^{-1}$$day^{-1}$) recorded lower RGR as compared to the higher levels of sulphur. At 50-75 DAS, however control (0.0455 g g^{-1} day^{-1} and 0.0458 g g^{-1} day^{-1}) recorded the highest RGR as compared to sulphur supplementation at 20 kg S ha^{-1} (0.0347 g g^{-1} day^{-1} and 0.0377 g g^{-1} day^{-1}) and 40 kg S ha^{-1} (0.0341 g g^{-1} day^{-1} and 0.0370 g g^{-1} day^{-1}). The pooled data of both the years recorded the highest RGR at 40 kg S ha^{-1} (0.0867 g g^{-1} day^{-1}) and the lowest at control (0.0701 g g^{-1} day^{-1}) at 25-50 while at 50-75 DAS, control (0.0459 g g^{-1} day^{-1}) recorded the highest RGR while 40 kg S ha^{-1} (0.0359 g g^{-1} day^{-1}) recorded the lowest.

Table 4.11: Effect of sulphur and zinc fertilization for biofortification on Crop Growth Rate (CGR) of soybean at different growth stages

Treatments	Crop Growth Rate (CGR) (g m^{-2} day^{-1})					
	25-50 DAS			50-75 DAS		
	2017	2018	Pooled	2017	2018	Pooled
S_0	4.96	5.79	5.38	9.06	13.39	11.22
S_{20}	9.35	9.25	9.30	14.30	16.03	15.17
S_{40}	9.17	8.69	8.93	13.61	15.31	14.46
SEm ±	0.48	0.41	0.36	0.75	0.61	0.50
CD (P=0.05)	1.39	1.20	1.06	2.16	1.78	1.44
Zn_0	5.58	5.81	5.70	11.27	14.30	12.78
Zn_5	7.34	7.52	7.43	11.20	14.05	12.63
Zn_{10}	7.89	7.99	7.94	13.05	14.71	13.88
Zn_{15}	8.72	8.54	8.63	13.13	15.71	14.42
Zn_{20}	9.60	9.68	9.64	12.96	15.78	14.37
SEm ±	0.62	0.53	0.47	0.96	0.79	0.64
CD (P=0.05)	1.80	1.55	1.36	NS	NS	NS

Table 4.12: Interaction effects of sulphur and zinc fertilization for biofortification on Crop Growth Rate (CGR) of soybean at different growth stages

Treatments	Crop Growth Rate (CGR) ($g\ m^{-2}\ day^{-1}$)					
	25-50 DAS			50-75 DAS		
	2017	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
S_0Zn_0	0.43	1.59	1.01	9.53	15.22	12.35
S_0Zn_5	5.12	6.29	5.71	8.04	11.87	9.96
S_0Zn_{10}	5.16	6.37	5.77	9.89	12.42	11.15
S_0Zn_{15}	5.92	7.00	6.46	9.90	13.52	11.71
S_0Zn_{20}	8.16	7.70	7.94	7.93	13.93	10.94
$S_{20}Zn_0$	8.16	8.12	8.14	12.83	13.69	13.26
$S_{20}Zn_5$	8.61	8.12	8.37	13.65	15.62	14.64
$S_{20}Zn_{10}$	9.30	8.96	9.13	15.10	15.79	15.45
$S_{20}Zn_{15}$	10.28	9.39	9.84	14.70	17.84	16.27
$S_{20}Zn_{20}$	10.40	11.65	11.02	15.22	17.19	16.21
$S_{40}Zn_0$	8.16	7.72	7.94	11.45	13.98	12.72
$S_{40}Zn_5$	8.29	8.16	8.23	11.91	14.66	13.29
$S_{40}Zn_{10}$	9.19	8.63	8.92	14.17	15.92	15.04
$S_{40}Zn_{15}$	9.95	9.23	9.59	14.78	15.75	15.27
$S_{40}Zn_{20}$	10.24	9.69	9.97	15.71	16.23	15.97
SEm ±	1.07	0.93	0.82	1.67	1.37	1.11
CD (P=0.05)	NS	NS	NS	NS	NS	NS



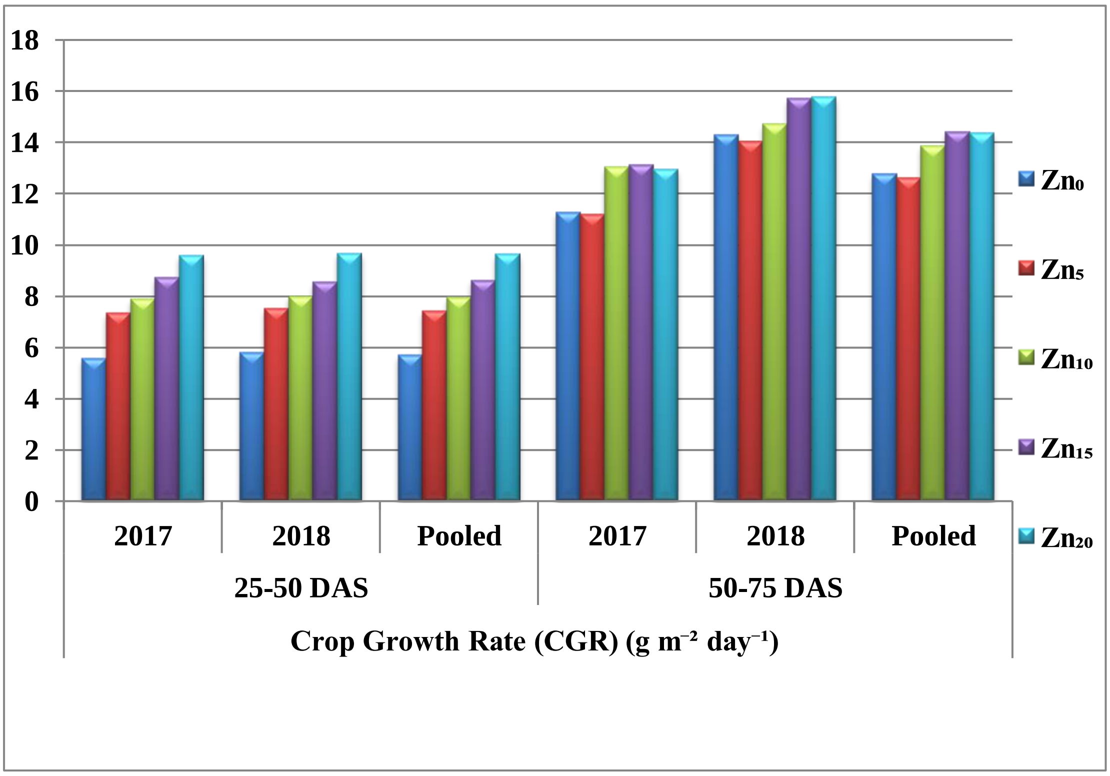


Fig 4.11: Effect of sulphur and zinc fertilization for biofortification on Crop Growth Rate (CGR) of soybean at different growth stages.

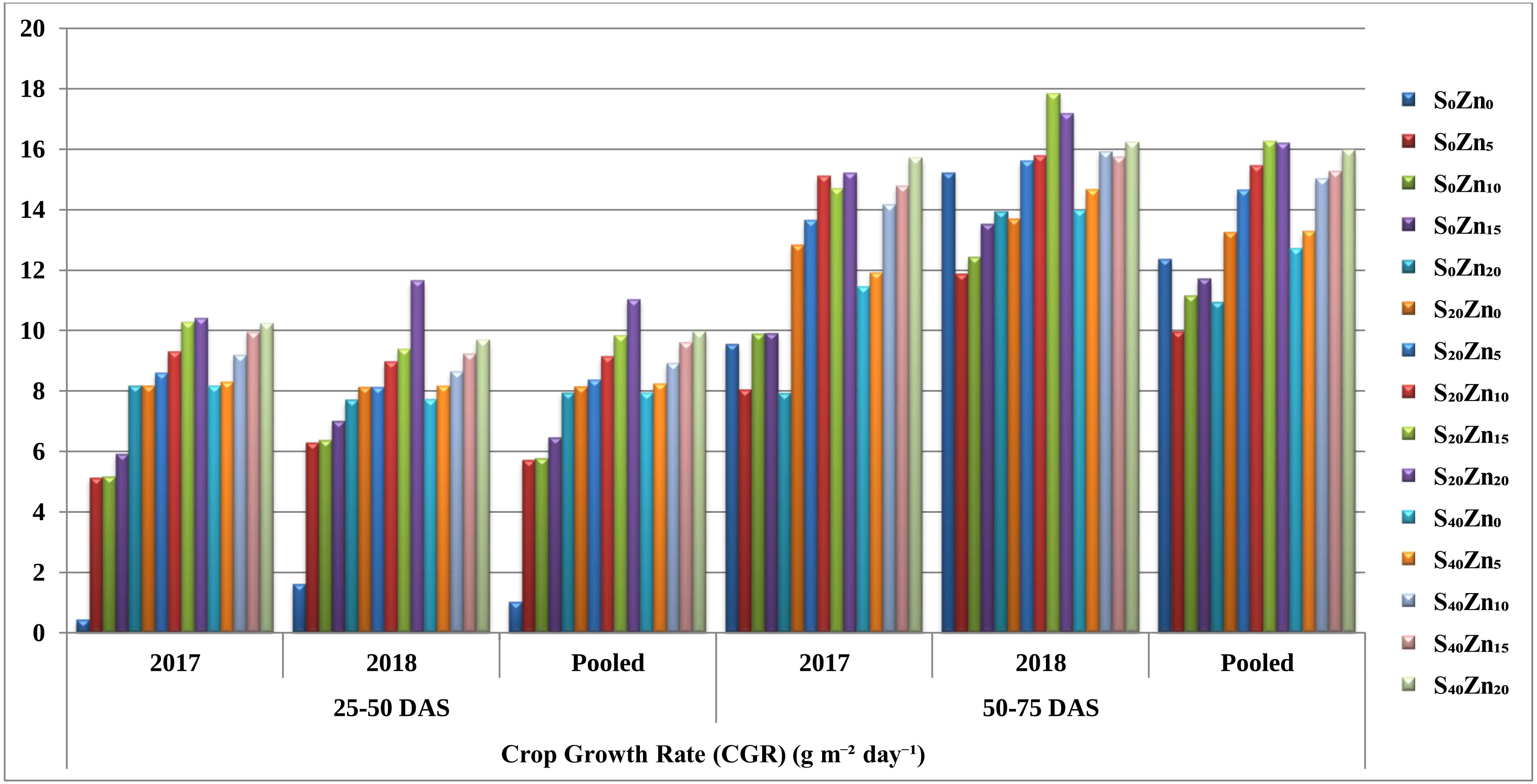


Fig 4.12: Interaction effects of sulphur and zinc fertilization for biofortification on Crop Growth Rate (CGR) of soybean at different growth stages.

4.1.7.2 Effect of zinc levels

The application of different levels of zinc in the first year did not show any significant influence on the Relative Growth Rate (RGR) at 25-50 DAS. However, in the subsequent year, 20 kg Zn ha^{-1} (0.0814 g g^{-1} day^{-1}) was reported to have a notable effect at par with the other levels of zinc (5, 10 and 15 kg Zn ha^{-1}) on the RGR. The pooled data shared similar observation recording a higher RGR with 20 kg Zn ha^{-1} (0.0852 g g^{-1} day^{-1}). At 50-75 DAS, however, control plot (0.0520, 0.0499 and 0.512 g g^{-1} day^{-1}) was reported to show higher RGR followed by 10 kg Zn ha^{-1} (0.0369, 0.0390 and 0.0382 g g^{-1} day^{-1}) for both the years and pooled.

The findings were in partial conformity with that of Saxena and Chandel, (1997) who reported that the RGR, LAI, DMP, yield attributes and yield of soybean were increased due to zinc application @ 5 kg ha^{-1}.

4.1.7.3 Interaction effect of sulphur and zinc

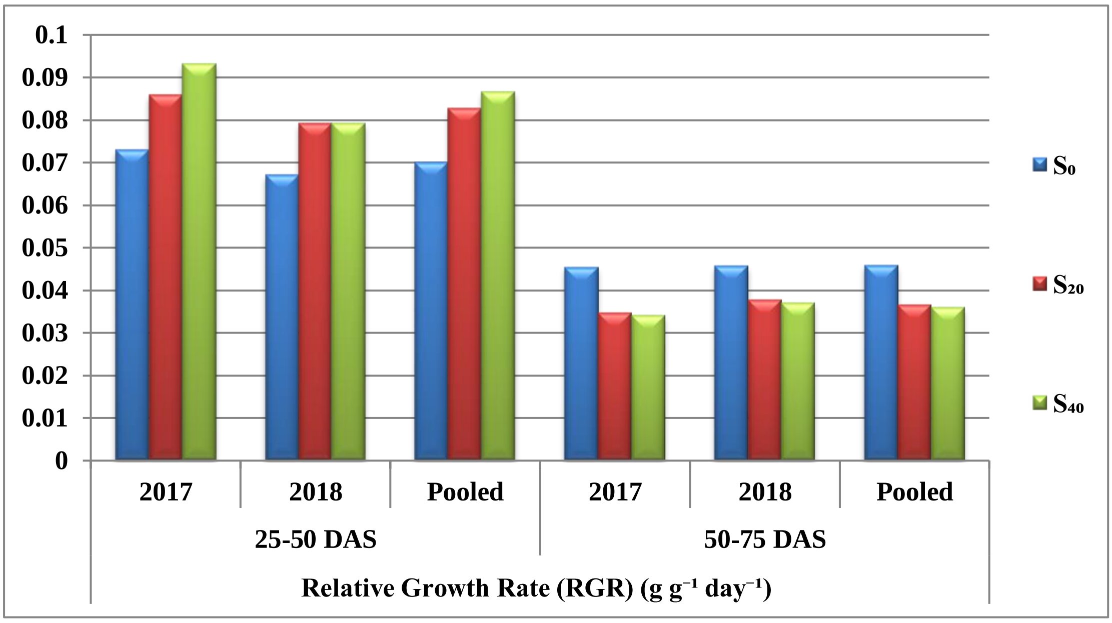
The interaction effect between sulphur and zinc had a significant influence with the combination treatment of $S_{40}Zn_{15}$ (0.0953 g g^{-1} day^{-1}) recording a higher RGR during the first year of experiment while $S_{20}Zn_{20}$ (0.0853 g g^{-1} day^{-1}) was observed to show the highest RGR in the subsequent year at 25-50 DAS. The pooled data reported increase in the RGR with the interaction of $S_{40}Zn_{20}$ (0.0883 g $g^{-1}day^{-1}$) and $S_{40}Zn_{15}$ (0.0883 g $g^{-1}day^{-1}$) while the lowest was reported by control (0.0317 g $g^{-1}day^{-1}$). At 50-75 DAS, the result obtained showed the highest RGR in the control plot (0.0887, 0.0760 and 0.0827 g $g^{-1}day^{-1}$) for both the years and pooled.

Table 4.13: Effect of sulphur and zinc fertilization for biofortification on Relative Growth Rate (RGR) of soybean at different growth stages

Treatments	Relative Growth Rate (RGR) ($g\ g^{-1}\ day^{-1}$)					
	25-50 DAS			50-75 DAS		
	2017	2018	Pooled	2017	2018	Pooled
S_0	0.0729	0.0671	0.0701	0.0455	0.0458	0.0459
S_{20}	0.0859	0.0793	0.0827	0.0347	0.0377	0.0365
S_{40}	0.0933	0.0793	0.0867	0.0341	0.0370	0.0359
SEm ±	0.0044	0.0022	0.0026	0.0027	0.0019	0.0017
CD (P=0.05)	0.0126	0.0065	0.0075	0.0077	0.0056	0.0049
Zn_0	0.0681	0.0633	0.0660	0.0520	0.0499	0.0512
Zn_5	0.0870	0.0762	0.0817	0.0341	0.0381	0.0364
Zn_{10}	0.0884	0.0762	0.0826	0.0369	0.0390	0.0382
Zn_{15}	0.0880	0.0789	0.0838	0.0362	0.0380	0.0373
Zn_{20}	0.0887	0.0814	0.0852	0.0313	0.0359	0.0338
SEm ±	0.0056	0.0029	0.0033	0.0034	0.0025	0.0022
CD (P=0.05)	NS	0.0083	0.0097	0.0099	0.0073	0.0063

Table 4.14: Interaction effects of sulphur and zinc fertilization for biofortification on Relative Growth Rate (RGR) of soybean at different growth stages

Treatments	Relative Growth Rate (RGR) ($g\ g^{-1}\ day^{-1}$)					
	25-50 DAS			50-75 DAS		
	2017	2018	Pooled	2017	2018	Pooled
S_0Zn_0	0.0270	0.0357	0.0317	0.0887	0.0760	0.0827
S_0Zn_5	0.0827	0.0730	0.0780	0.0337	0.0380	0.0363
S_0Zn_{10}	0.0830	0.0743	0.0787	0.0393	0.0387	0.0393
S_0Zn_{15}	0.0793	0.0750	0.0773	0.0413	0.0387	0.0400
S_0Zn_{20}	0.0927	0.0773	0.0850	0.0243	0.0377	0.0310
$S_{20}Zn_0$	0.0863	0.0777	0.0820	0.0347	0.0363	0.0357
$S_{20}Zn_5$	0.0870	0.0763	0.0817	0.0353	0.0390	0.0373
$S_{20}Zn_{10}$	0.0877	0.0757	0.0820	0.0363	0.0403	0.0387
$S_{20}Zn_{15}$	0.0893	0.0813	0.0857	0.0330	0.0390	0.0363
$S_{20}Zn_{20}$	0.0790	0.0853	0.0823	0.0343	0.0340	0.0343
$S_{40}Zn_0$	0.0910	0.0767	0.0843	0.0327	0.0373	0.0353
$S_{40}Zn_5$	0.0913	0.0793	0.0853	0.0333	0.0373	0.0357
$S_{40}Zn_{10}$	0.0947	0.0787	0.0870	0.0350	0.0380	0.0367
$S_{40}Zn_{15}$	0.0953	0.0803	0.0883	0.0343	0.0363	0.0357
$S_{40}Zn_{20}$	0.0943	0.0817	0.0883	0.0353	0.0360	0.0360
SEm ±	0.0098	0.0050	0.0058	0.0059	0.0044	0.0038
CD (P=0.05)	0.0283	0.0145	0.0167	0.0172	0.0126	0.0110



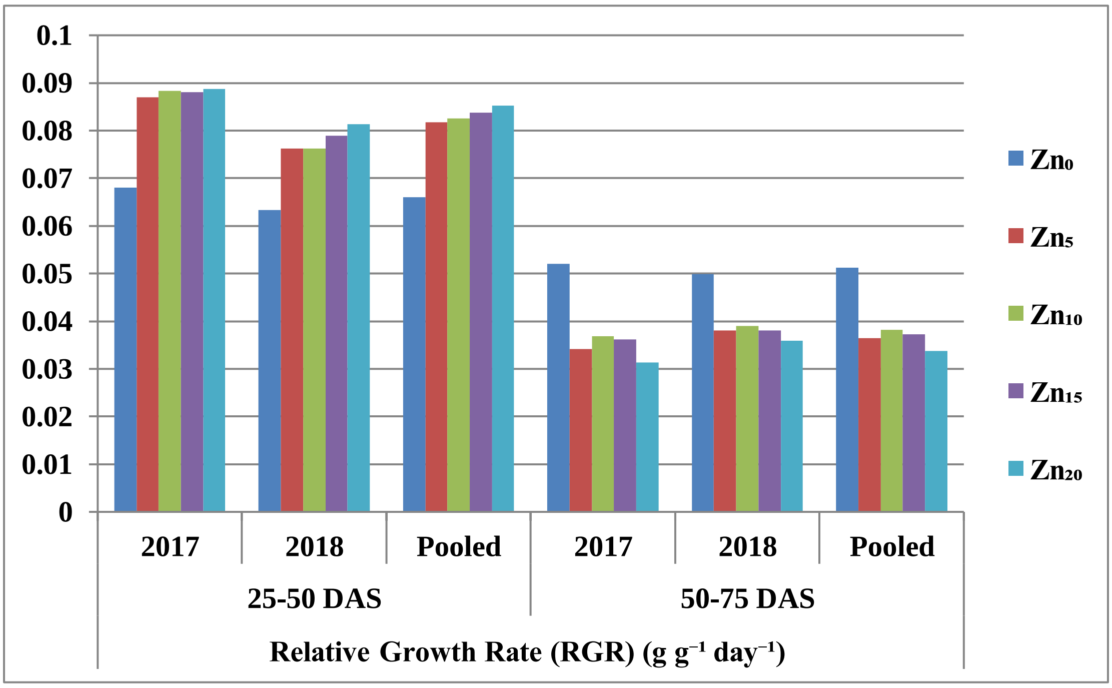


Fig 4.13: Effect of sulphur and zinc fertilization for biofortification on Relative Growth Rate (RGR) of soybean at different growth stages.

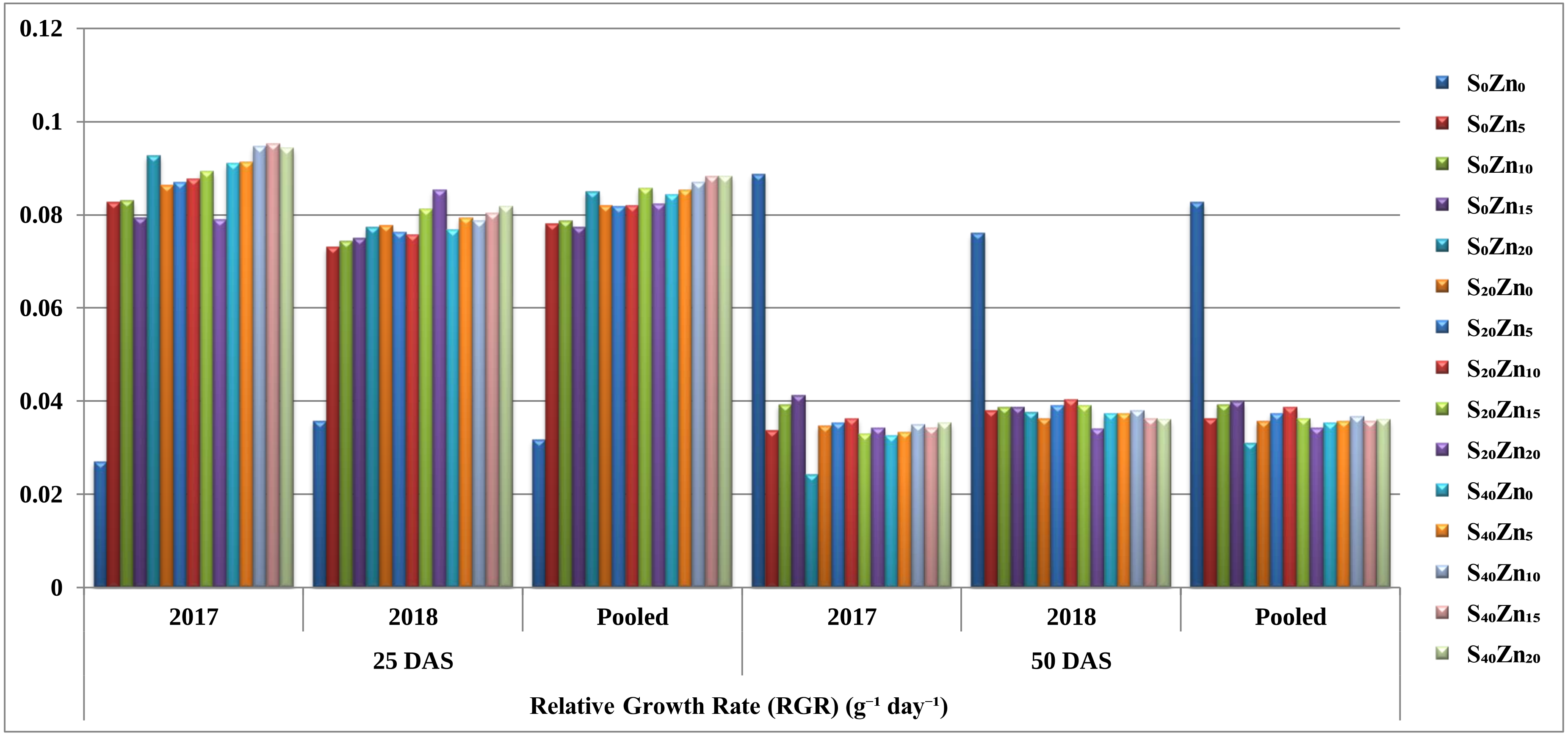


Fig 4.14: Interaction effects of sulphur and zinc fertilization for biofortification on Relative Growth Rate (RGR) of soybean at different growth stages.

4.1.8 Net Assimilation Rate (NAR) (g m^{-2} of leaf area day^{-1})

The observation recorded on Net Assimilation Rate (NAR) as influenced by sulphur and zinc treatment is presented in Table 4.15 and their interaction effects in Table 4.16 at 25-50 DAS and 50-75 DAS.

4.1.8.1 Effect of sulphur level

The data presented a significant result in the year 2017 and pooled data at 25-50 DAS with the treatment 20 kg S ha^{-1} (0.0225 and 0.0193 g m^{-2} of leaf area day^{-1}) recording the highest NAR while the control recorded the lowest (0.0053 and 0.0060 g m^{-2} of leaf area day^{-1}). However, there was no significant influence at 50-75 DAS for both years.

4.1.8.2 Effect of zinc levels

No significant variation could be established at the zinc levels.

4.1.8.3 Interaction effect of sulphur and zinc

The interaction effect of sulphur and zinc was found to be non-significant for either of the years.

4.1.9 Number of nodules per plant

The data on number of nodules per plant as affected by sulphur and zinc treatment is presented in Table 4.17 and Fig 4.17 and their interaction effects in Table 4.18 and Fig 4.18 at 25, 50 and 75 DAS.

4.1.9.1 Effect of sulphur level

Based on the experimental data, the number of nodules showed significant differences with the application of 20 kg S ha^{-1} (15.33 and 26.13, 38.40 and 71.47, 81.93and 65.47) recording the maximum number of nodules

Table 4.15: Effect of sulphur and zinc fertilization for biofortification on Net Assimilation Rate (NAR) of soybean at different growth stages

Treatments	Net Assimilation Rate (NAR) (g m^{-2} of leaf area day^{-1})					
	25-50 DAS			50-75 DAS		
	2017	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
S_0	0.0053	0.0067	0.0060	0.0068	0.0099	0.0084
S_{20}	0.0221	0.0195	0.0208	0.0082	0.0148	0.0115
S_{40}	0.0225	0.0161	0.0193	0.0055	0.0120	0.0088
SEm ±	0.0038	0.0035	0.0022	0.0029	0.0020	0.0018
CD (P=0.05)	0.0110	NS	0.0063	NS	NS	NS
Zn_0	0.0133	0.0064	0.0098	0.0085	0.0114	0.0100
Zn_5	0.0130	0.0213	0.0172	0.0017	0.0100	0.0059
Zn_{10}	0.0151	0.0113	0.0132	0.0049	0.0101	0.0075
Zn_{15}	0.0181	0.0141	0.0161	0.0076	0.0149	0.0113
Zn_{20}	0.0237	0.0173	0.0205	0.0116	0.0148	0.0132
SEm ±	0.0049	0.0045	0.0028	0.0038	0.0025	0.0023
CD (P=0.05)	NS	NS	NS	NS	NS	NS

Table 4.16: Interaction effects of sulphur and zinc fertilization for biofortification on Net Assimilation Rate (NAR) of soybean at different growth stages

Treatments	Net Assimilation Rate (NAR) (g m^{-2} of leaf area day^{-1})					
	25-50 DAS			50-75 DAS		
	2017	2018	Pooled	2017	2018	Pooled
S_0Zn_0	0.0001	0.0006	0.0003	0.0201	0.0141	0.0171
S_0Zn_5	0.0028	0.0052	0.0040	0.0035	0.0066	0.0051
S_0Zn_{10}	0.0023	0.0026	0.0025	0.0055	0.0067	0.0061
S_0Zn_{15}	0.0046	0.0067	0.0057	0.0047	0.0119	0.0083
S_0Zn_{20}	0.0167	0.0182	0.0175	0.0002	0.0105	0.0054
$S_{20}Zn_0$	0.0182	0.0109	0.0145	0.0008	0.0104	0.0056
$S_{20}Zn_5$	0.0192	0.0482	0.0337	0.0009	0.0131	0.0070
$S_{20}Zn_{10}$	0.0217	0.0136	0.0176	0.0060	0.0139	0.0100
$S_{20}Zn_{15}$	0.0316	0.0130	0.0223	0.0082	0.0189	0.0136
$S_{20}Zn_{20}$	0.0197	0.0117	0.0157	0.0253	0.0177	0.0215
$S_{40}Zn_0$	0.0216	0.0077	0.0146	0.0047	0.0098	0.0073
$S_{40}Zn_5$	0.0171	0.0106	0.0138	0.0007	0.0103	0.0055
$S_{40}Zn_{10}$	0.0214	0.0177	0.0195	0.0031	0.0097	0.0064
$S_{40}Zn_{15}$	0.0180	0.0226	0.0203	0.0100	0.0140	0.0120
$S_{40}Zn_{20}$	0.0347	0.0219	0.0283	0.0093	0.0162	0.0127
SEm ±	0.0085	0.0078	0.0048	0.0066	0.0044	0.0041
CD (P=0.05)	NS	NS	NS	NS	NS	NS

however, it was at par with 40 kg S ha^{-1} (14.87 and 25.13, 37.07 and 60.87, 76.93 and 64) at all the crop stages during both the years. Both the treatments had a relatively higher significant effect over control. Similar result was also observed in the pooled value wherein S application gave the highest number of nodules (20.73, 54.93 and 73.70) while control recorded the lowest (12.30, 29.10 and 47.33).

In sulphur deficient soil, the application of sulphur improved nitrogenase activity, nitrogen fixation, plant dry matter and quality of soybean grain (Morshed *et al*. 2009) resulting in an increase in the number of nodules. Chauhan *et al*. 2013 reported increased in number of nodules by 91% significantly due to the application of K_{20} kg ha^{-1}, S_{20} kg ha^{-1} and Zn_5 kg ha^{-1} in combination dose. The findings were also in partial conformity with the works concluded by Awlad *et al*. (2003) and Ganeshmurthy and Reddy, (2000) who reported the maximum root nodules per plant up to the application of 30 kg S ha^{-1}.

4.1.9.2 Effect of zinc levels

The effect of different levels of zinc showed a remarkable effect on the number of nodules. In either of the years, 20 kg Zn ha^{-1} (15.56 and 26, 39.11 and 67.89, 81.22 and 67.22) recorded a higher number of nodules at all the crop growth stages at 25, 50 and 75 DAS respectively although it was at par with 15 kg Zn ha^{-1} while control (10.78 and 16.22, 26.89 and 40, 58.67 and 46.22) recorded the lowest number of nodules. The pooled value for both the years also complied with the same and recorded the maximum number of nodules at 20 kg Zn ha^{-1} (20.78, 53.50 and 74.22) and the lowest in control (13.50, 33.44 and 52.44).

Apropos to the above findings, as zinc is known to be involved in nitrogen fixation through nodule formations (Balusamy *et al*. 1996), the supplementation of zinc have been reported to increase the nodulation efficiency and nodulation activity (Zhang *et al*. 1996). Previous works carried out by Thenua *et al*. (2014) reported significantly increase in the number of nodules per plant and nodule dry weight per plant by the zinc levels. The level of zinc 30 kg ha^{-1} increased the number of nodule and nodule dry weight per plant and found to be at par with 20 kg Zn ha^{-1}. Awlad *et al*. (2003) also reported maximum number of main nodules per plant obtained at 20 kg Zn ha^{-1}

4.1.9.3 Interaction effect of sulphur and zinc

No significant observation was seen due to the interaction effect of sulphur and zinc on number of nodules.

4.1.10 Number of pods per plant

The effect of sulphur and zinc on number of pods per plant at harvest is shown in Table 4.19 and Fig 4.19 and their interaction effects in Table 4.20 and Fig 4.20.

4.1.10.1 Effect of sulphur level

Based on the data presented, it was observed that the application of 20 kg S ha^{-1} had a notable effect as compared to the control and was at par with the treatment 40 kg S ha^{-1}. It gave the highest number of pods for both the years 2017 and 2018 (34.12 and 46.83) while control recorded the lowest (20.98 and 27.77). The pooled data also showed similar result with S_{20} recording the highest number of pods (40.48) while the lowest was seen in the control plot (24.37).

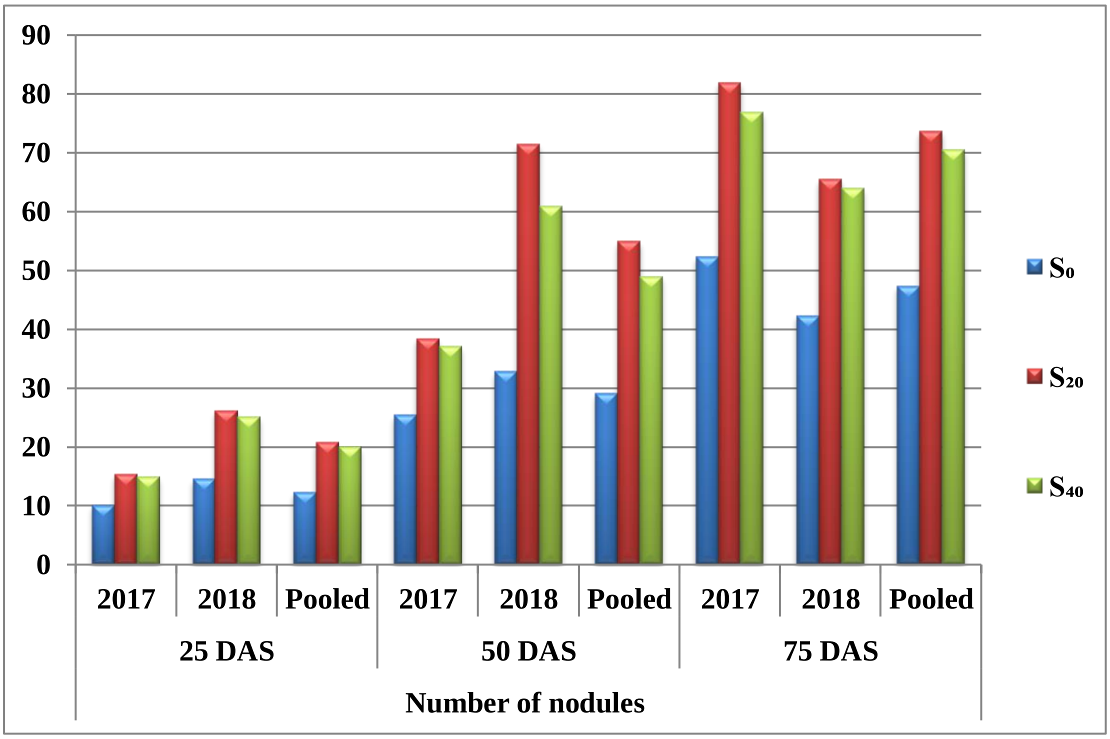
The increase in the number of pods could be attributed to sulphur supplementation and availability in the vegetative and reproductive growth of the plant aiding in its chlorophyll formation, photosynthetic process, and activation of enzymes and grain formation (Yadav *et al*. 2013). The combined application of phosphorus @ 30 kg P ha^{-1} and sulphur @ 20 kg S ha^{-1} gave rise

Table 4.17: Effect of sulphur and zinc fertilization for biofortification on number of nodules of soybean at different growth stages

Treatments	Number of nodules								
	25 DAS			50 DAS			75 DAS		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
S_0	10.07	14.53	12.30	25.40	32.80	29.10	52.33	42.33	47.33
S_{20}	15.33	26.13	20.73	38.40	71.47	54.93	81.93	65.47	73.70
S_{40}	14.87	25.13	20.00	37.07	60.87	48.97	76.93	64.00	70.47
SEm ±	0.54	0.80	0.56	1.25	3.30	1.74	2.22	2.27	1.73
CD (P=0.05)	1.56	2.32	1.63	3.61	9.55	5.04	6.44	6.57	5.02
Zn_0	10.78	16.22	13.50	26.89	40.00	33.44	58.67	46.22	52.44
Zn_5	12.89	20.56	16.72	32.22	53.22	42.72	67.22	55.11	61.17
Zn_{10}	13.44	22.56	18.00	33.56	55.56	44.56	69.89	57.22	63.56
Zn_{15}	14.44	24.33	19.39	36.33	58.56	47.44	75.00	60.56	67.78
Zn_{20}	15.56	26.00	20.78	39.11	67.89	53.50	81.22	67.22	74.22
SEm ±	0.70	1.03	0.73	1.61	4.26	2.24	2.87	2.93	2.24
CD (P=0.05)	2.02	2.99	2.10	4.66	12.33	6.50	8.32	8.49	6.48

Table 4.18: Interaction effects of sulphur and zinc fertilization for biofortification on number of nodules of soybean at different growth stages

Treatments	Number of nodules								
	25 DAS			50 DAS			75 DAS		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
S_0Zn_0	5.33	5.00	5.17	13.00	11.00	12.00	35.00	18.33	26.67
S_0Zn_5	9.67	13.67	11.67	26.00	31.67	28.83	49.00	41.00	45.00
S_0Zn_{10}	10.00	15.67	12.83	26.67	33.00	29.83	50.33	43.67	47.00
S_0Zn_{15}	12.00	18.33	15.17	30.00	35.00	32.50	58.67	50.00	54.33
S_0Zn_{20}	13.33	20.00	16.67	31.33	53.33	42.33	68.67	58.67	63.67
$S_{20}Zn_0$	13.67	22.67	18.17	34.33	54.67	44.50	71.67	60.33	66.00
$S_{20}Zn_5$	14.67	24.67	19.67	36.00	69.67	52.83	78.33	63.00	70.67
$S_{20}Zn_{10}$	15.33	26.33	20.83	37.33	72.67	55.00	83.33	64.33	73.83
$S_{20}Zn_{15}$	16.00	27.67	21.83	40.33	76.00	58.17	85.33	66.00	75.67
$S_{20}Zn_{20}$	17.00	29.33	23.17	44.00	84.33	64.17	91.00	73.67	82.33
$S_{40}Zn_0$	13.33	21.00	17.17	33.33	54.33	43.83	69.33	60.00	64.67
$S_{40}Zn_5$	14.33	23.33	18.83	34.67	58.33	46.50	74.33	61.33	67.83
$S_{40}Zn_{10}$	15.00	25.67	20.33	36.67	61.00	48.83	76.00	63.67	69.83
$S_{40}Zn_{15}$	15.33	27.00	21.17	38.67	64.67	51.67	81.00	65.67	73.33
$S_{40}Zn_{20}$	16.33	28.67	22.50	42.00	66.00	54.00	84.00	69.33	76.67
SEm ± CD (P=0.05)	1.21 NS	1.79 NS	1.26 NS	2.79 NS	7.37 NS	3.89 NS	4.97 NS	5.07 NS	3.87 NS



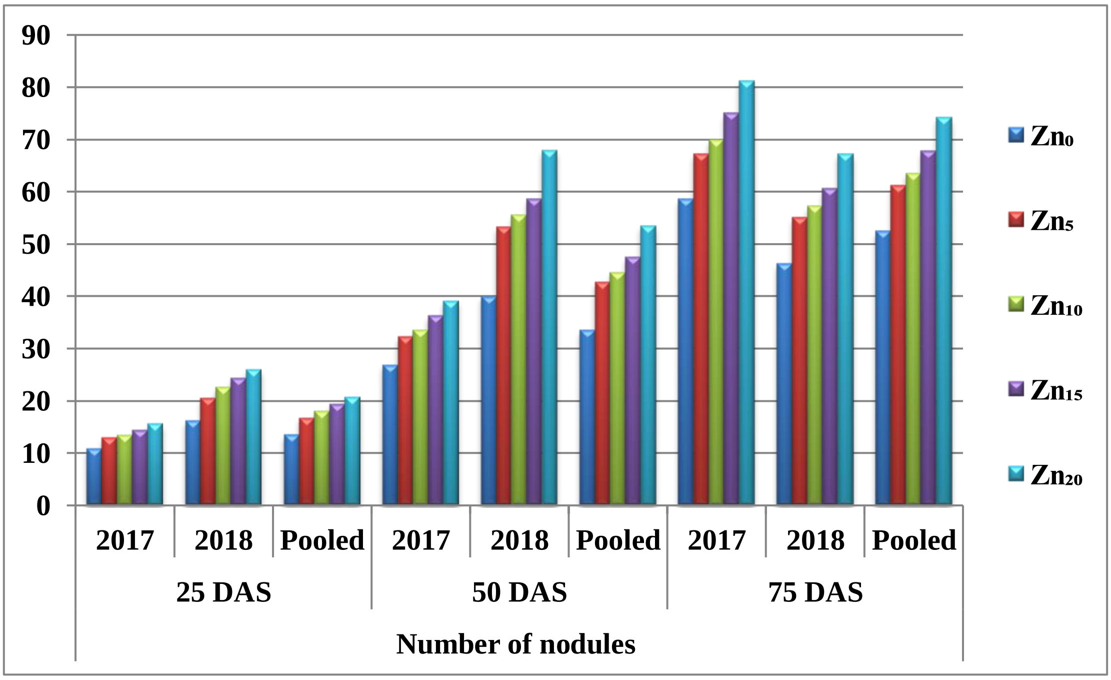


Fig 4.17: Effect of sulphur and zinc fertilization for biofortification on number of nodules of soybean at different growth stages.

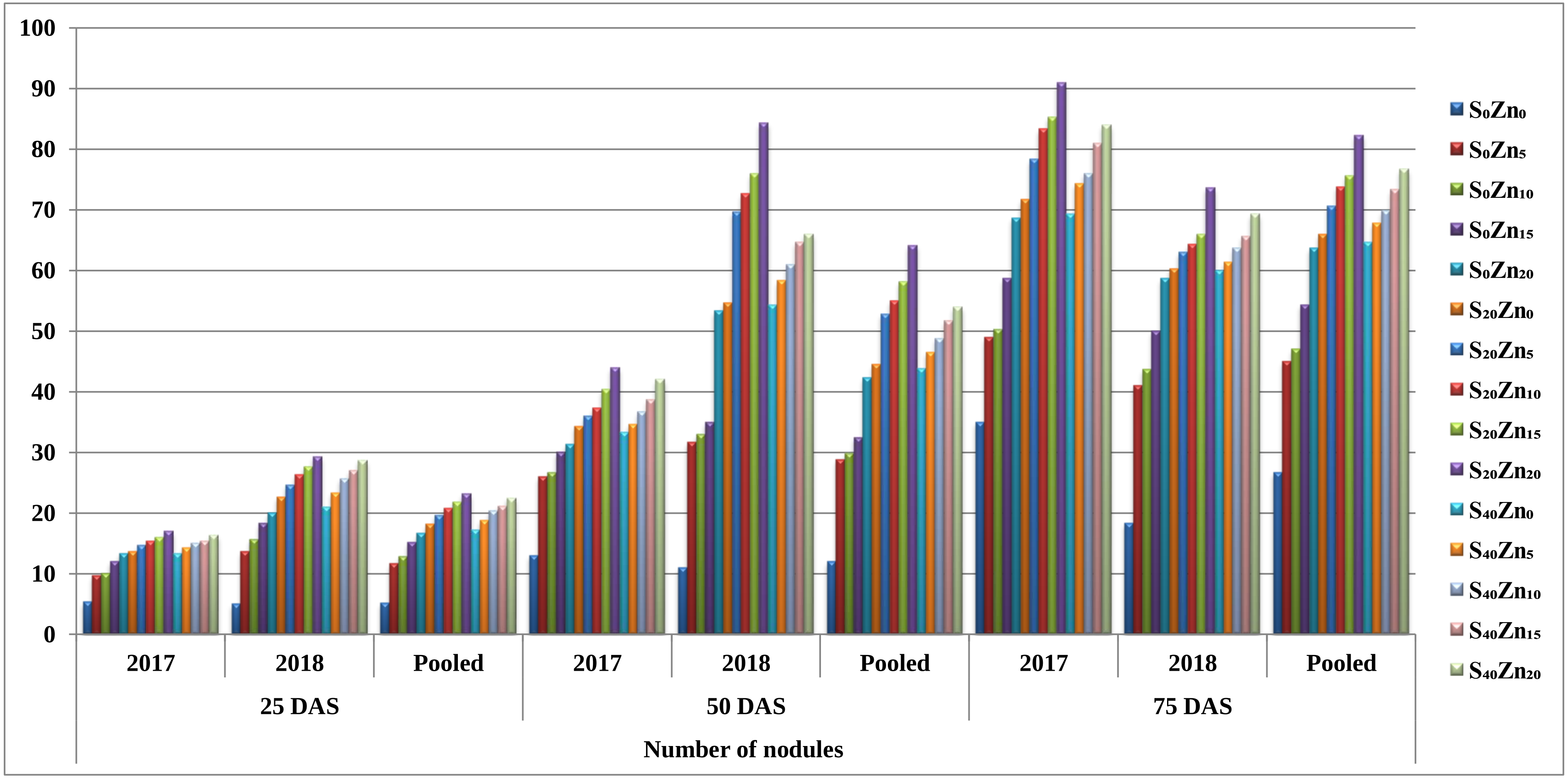


Fig 4.18: Interaction effects of sulphur and zinc fertilization for biofortification on number of nodules of soybean at different growth stage.

to the highest number of pods plant^{-1}, number of seeds plant^{-1}, thousand seed weight, and in turn produced highest grain yield (Akter *et al*. 2013). Treatment with gypsum @ 20 kg S ha^{-1} was also seen to maximally increase the number of pods per plant in soybean (Sharma *et al*. 2014). Konyak *et al*. (2016) reported that the combined application of S and Co also significantly enhanced the number of pods plant^{-1}, seed and stover yields of soybean.

4.1.10.2 Effect of zinc levels

The data showed that there was an increase in the number of pods with increasing levels of zinc at 5, 10, 15 and 20 kg Zn ha^{-1} compared to control during both the years. The maximum number of pods was noted in 20 kg Zn ha^{-1} (34.78 and 47.01) and the lowest was found with 0 kg Zn ha^{-1} (22.43 and 31.67). The number of pods showed a remarkable increase with 15 and 20 kg Zn ha^{-1} over control however the difference between the two zinc levels was found to be non-significant. The pooled data also showed significant variation with 20 kg Zn ha^{-1} (40.89) recording maximum number of pods followed by 15 kg Zn ha^{-1} (37.38) with control recording the lowest (27.05) during both the years.

Similar findings were also reported by Singh and Singh (1995) who observed that the application of 20 kg zinc oxide per hectare significantly increased number of pods per plant and number of seeds per pod of soybean.

4.1.10.3 Interaction effect of sulphur and zinc

No significant interaction was established between sulphur and zinc level.

4.1.11 Length of pods (cm)

The perusal data on length of pods (cm) of soybean as influenced by different levels of sulphur and zinc is presented and depicted in Table 4.19 and their interaction effects in Table 4.20 at harvest.

4.1.11.1 Effect of sulphur level

The sulphur level at 20 kg S ha^{-1} (3.40 cm) was observed to show notable influence in the length of pods at harvest and was at par with the application of 40 kg S ha^{-1} (3.39 cm) during the year 2017. However, no significant influence could be exerted on the length of the pods for the year 2018 and pooled data.

4.1.11.2 Effect of zinc levels

The data revealed that the different zinc levels did not have any significant influence on the length of pods.

4.1.11.3 Interaction effect of sulphur and zinc

There was no significant influence on the length of pods due to the interaction effect of sulphur and zinc.

4.1.12 Number of seeds per pod

The data on number of seeds per pod of soybean as influenced by different levels of sulphur and zinc is presented and depicted in Table 4.19 and their interaction effects in Table 4.20 at harvest.

4.1.12.1 Effect of sulphur level

The sulphur levels did not show any significant influence on the number of seeds per pod for both the years.

4.1.12.2 Effect of zinc levels

The effect of different zinc levels was found to be non-significant in either of the years.

4.1.12.3 Interaction effect of sulphur and zinc

The interaction effect between sulphur and zinc level was found to be non-significant.

4.1.13 Test weight (g)

The test weight of soybean as influenced by different levels of sulphur and zinc is presented and depicted in Table 4.21 and their interaction effects at harvest in Table 4.22.

4.1.13.1 Effect of sulphur level

The sulphur levels did not show any significant influence on the test weight for both the years.

4.1.13.2 Effect of zinc levels

The effect of different zinc levels was found to be non-significant in either of the years.

4.1.13.3 Interaction effect of sulphur and zinc

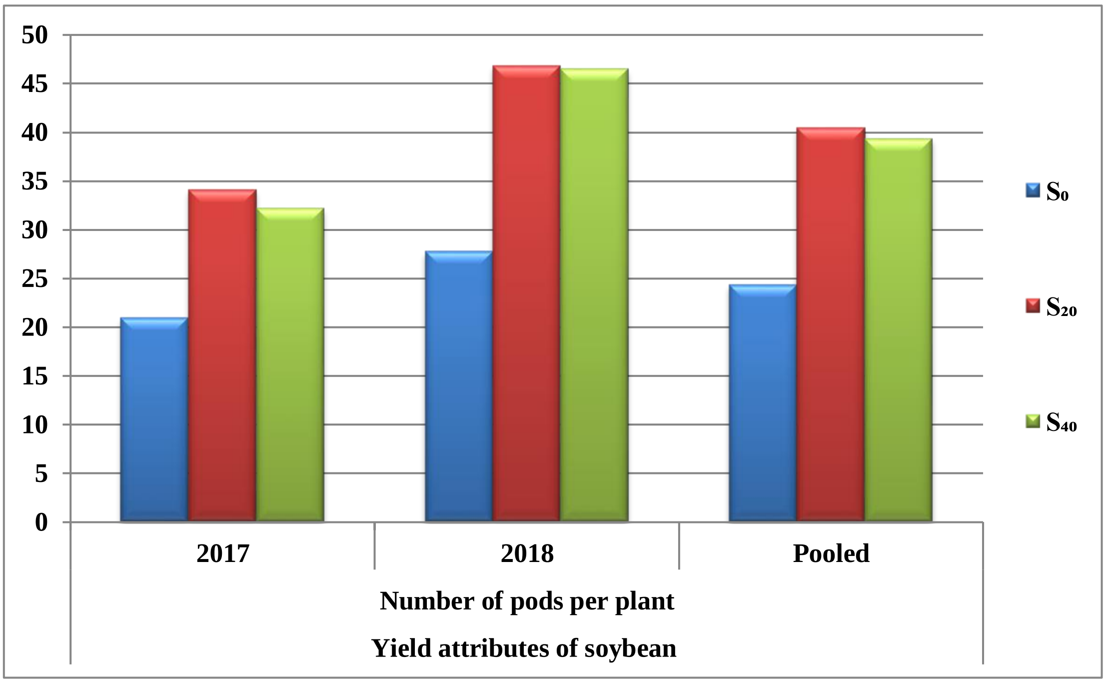
The interaction effect between sulphur and zinc level was found to be non-significant.

Table 4.19: Effect of sulphur and zinc fertilization for biofortification on yield attributes of soybean at harvest

Treatments	Yield attributes of soybean								
	Number of pods per plant			Length of pods(cm)			Number of seeds per pod		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
S_0	20.98	27.77	24.37	3.28	3.43	3.35	2.78	2.96	2.87
S_{20}	34.12	46.83	40.48	3.40	3.40	3.41	2.89	2.95	2.92
S_{40}	32.21	46.50	39.36	3.39	3.42	3.41	2.78	2.93	2.85
SEm ±	1.21	1.44	0.76	0.04	0.04	0.03	0.04	0.03	0.03
CD (P=0.05)	3.50	4.17	2.20	0.11	NS	NS	NS	NS	NS
Zn_0	22.43	31.67	27.05	3.31	3.43	3.37	2.77	2.98	2.87
Zn_5	26.98	39.36	33.17	3.33	3.40	3.37	2.92	2.96	2.94
Zn_{10}	29.73	40.66	35.19	3.39	3.40	3.39	2.78	2.89	2.83
Zn_{15}	31.60	43.16	37.38	3.29	3.46	3.38	2.79	2.98	2.88
Zn_{20}	34.78	47.01	40.89	3.47	3.39	3.43	2.82	2.93	2.88
SEm ±	1.56	1.86	0.98	0.05	0.05	0.04	0.06	0.04	0.04
CD (P=0.05)	4.52	5.38	2.85	NS	NS	NS	NS	NS	NS

Table 4.20: Interaction effects of sulphur and zinc fertilization for biofortification on yield attributes of soybean at harvest

Treatments	Yield attributes of soybean								
	Number of pods per plant			Length of pods(cm)			Number of seeds per pod		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
S_0Zn_0	9.13	10.67	9.90	3.20	3.43	3.32	2.87	2.97	2.92
S_0Zn_5	21.19	27.20	24.20	3.13	3.50	3.32	2.77	3.00	2.88
S_0Zn_{10}	23.55	28.27	25.91	3.33	3.37	3.35	2.80	2.87	2.83
S_0Zn_{15}	24.73	33.53	29.13	3.27	3.40	3.33	2.80	2.97	2.88
S_0Zn_{20}	26.27	39.20	32.73	3.47	3.43	3.45	2.67	3.00	2.83
$S_{20}Zn_0$	29.77	40.87	35.32	3.37	3.43	3.40	2.80	2.97	2.88
$S_{20}Zn_5$	30.53	45.13	37.83	3.40	3.27	3.33	2.97	2.93	2.95
$S_{20}Zn_{10}$	34.37	46.60	40.48	3.40	3.33	3.37	2.83	2.90	2.87
$S_{20}Zn_{15}$	35.67	48.33	42.00	3.43	3.47	3.48	2.80	2.97	2.88
$S_{20}Zn_{20}$	40.27	53.24	46.75	3.40	3.50	3.45	3.03	3.00	3.02
$S_{40}Zn_0$	28.40	43.47	35.93	3.37	3.43	3.40	2.63	3.00	2.82
$S_{40}Zn_5$	29.20	45.73	37.47	3.47	3.43	3.45	3.03	2.93	2.98
$S_{40}Zn_{10}$	31.27	47.11	39.19	3.43	3.50	3.47	2.70	2.90	2.80
$S_{40}Zn_{15}$	34.40	47.60	41.00	3.17	3.50	3.33	2.77	3.00	2.88
$S_{40}Zn_{20}$	37.79	48.60	43.20	3.53	3.23	3.38	2.77	2.80	2.78
SEm ±	2.70	3.22	1.70	0.09	0.09	0.07	0.10	0.07	0.06
CD (P=0.05)	NS	NS	4.93	NS	NS	NS	NS	NS	NS



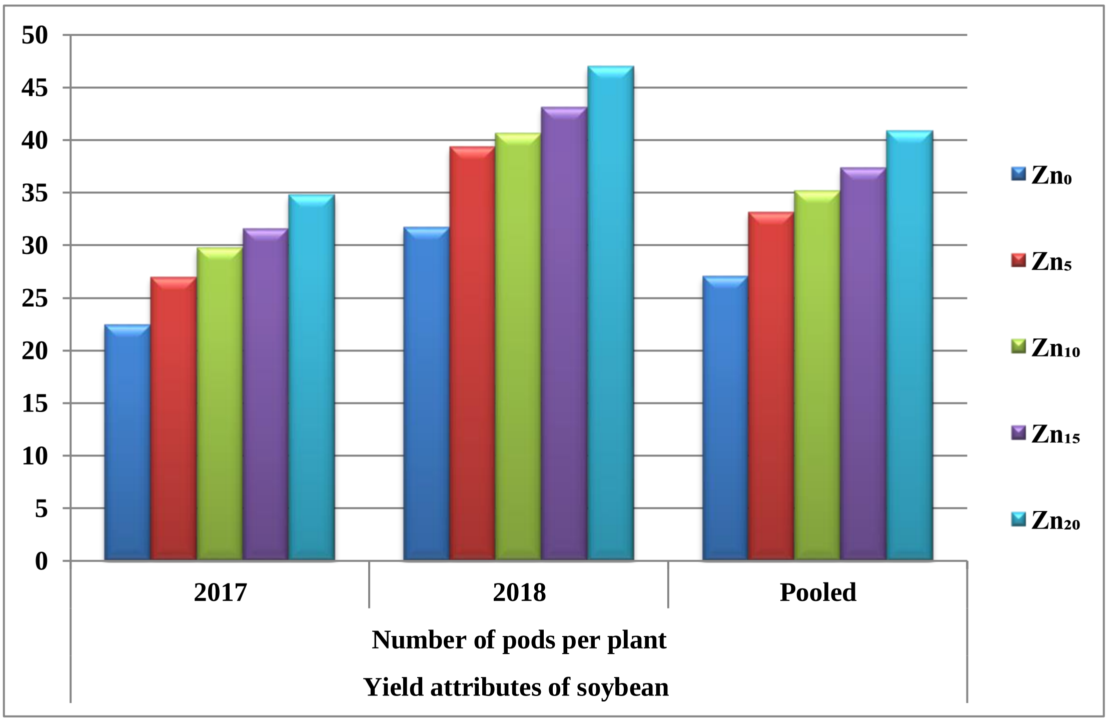


Fig 4.19: Effect of sulphur and zinc fertilization for biofortification on yield attributes of soybean at harvest.

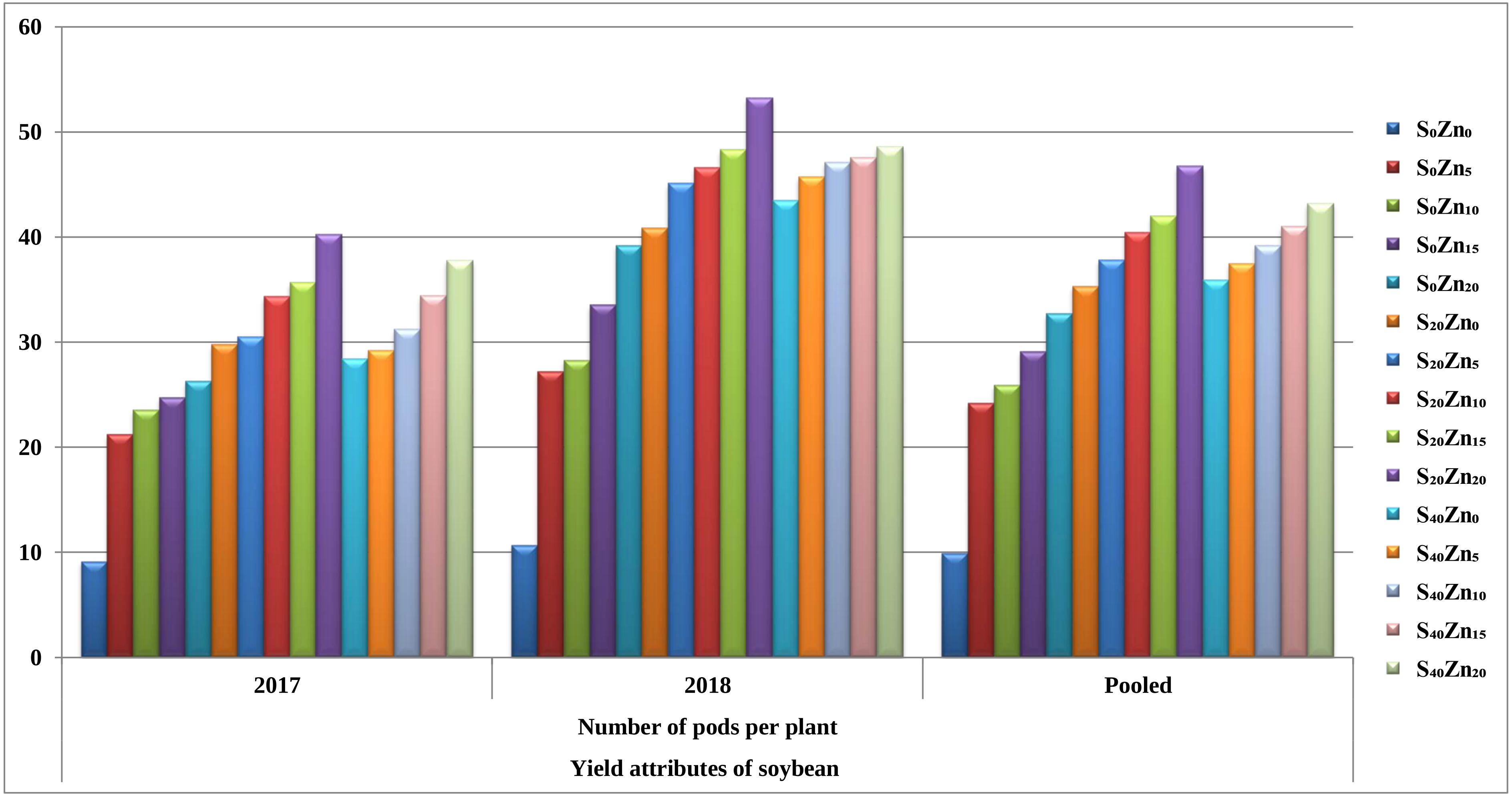


Fig 4.20: Interaction effects of sulphur and zinc fertilization for biofortification on yield attributes of soybean at harvest.

4.1.14 Seed yield (t ha^{-1})

The appraisal of the data on seed yield of soybean as influenced by different levels of sulphur and zinc is presented and depicted in Table 4.21 and Fig 4.21 and their interaction effects in Table 4.22 and Fig 4.22 at harvest.

4.1.14.1 Effect of sulphur level

The yearly data of 2017 and 2018 revealed significant variations in seed yield due to application of different levels of sulphur. A higher seed yield was observed with the application of 20 kg S ha^{-1} (1.04 t ha^{-1} and 1.09 t ha^{-1}) which was at par with 40 kg S ha^{-1} (1.02 t ha^{-1} and 0.99 t ha^{-1}) and superior over control (0.75 t ha^{-1} and 0.71 t ha^{-1}). The pooled data showed a significant increment in grain yield with 20 kg S ha^{-1} (1.07 t ha^{-1}) recording the highest seed yield followed by 40 kg S ha^{-1} (1.01 t ha^{-1}) while control recorded the lowest (0.74 t ha^{-1})

In comparison to the works done by previous researchers, the above findings that have been deduced is similar to the research carried out byAkter *et al*. (2013) who reported increased and the highest grain yield of soybean due to application of 20 kg S ha^{-1} and 40 kg S ha^{-1} treatments which were at par. Bhuiyan *et al*. (1998), Sangale *et al.* (2004), Hosmath *et al*.(2014) and Sharma *et al*. (2014) also reported the highest seed yield in soybean due to sulphur's application at 20 kg ha^{-1} compared to other sulphur levels. The increase in seed yield of soybean by S treatment might be credited to the sulphur's role in the synthesis of chloroplast protein resulting in greater photosynthetic activity by the crop thereby increasing the crop yield (Biswas and Tewatia, 1992). Even though, the findings did not replicate the previously reported works concluded by Gokhale *et al.* (2005) the results suggests that S requirement of crop on the experimental soil may have been satisfied at S_{20} and therefore further addition of increased level of sulphur was not envisaged as the higher levels of sulphur were at par (Bhattacharjee *et al*. 2013).

4.1.14.2 Effect of zinc levels

Based on the 2017 data presented, the increase in levels of zinc exhibited an increment in seed yield of soybean up to 20 kg Zn ha^{-1} (1.07 t ha^{-1}) at par with 15 kg Zn ha^{-1} (1.04 t ha^{-1}) and significantly higher over the lower levels of zinc. The subsequent year and the pooled data also reported a relatively higher seed yield with the higher supplementation of zinc levels with 20 kg Zn ha^{-1} (1.13 t ha^{-1} and 1.10 t ha^{-1}) recording the highest seed yield while the lowest was recorded in the control plot (0.71 t ha^{-1} and 0.74 t ha^{-1}).

Zinc is a structural constituent of different enzymes and proteins in many important biochemical pathways like carbohydrate metabolism, photosynthesis, auxin metabolism, conversion of sugars to starch and is required for the biosynthesis of plant growth regulator (IAA), N metabolism and so the increase in crop yield may be attributed to these factors (Suresh *et al*. 2013). Similar results were also deduced by Tomar and Sharma (2007) who reported that the increased zinc levels enhanced the crop yield by 36 per cent over untreated plot with the application of 20 kg Zn ha^{-1} along with the recommended dose of fertilizer. The finding was also in partial conformity with the work of Thenua *et al*. (2014) who outlined higher seed yield with 30 kg Zn ha^{-1} during both the years of research and it was found to be at par with 20 kg Zn ha^{-1}.

4.1.14.3 Interaction effect of sulphur and zinc

The interaction effect between sulphur and zinc level was found to be non-significant.

4.1.15 Stover yield (t ha^{-1})

The stover yield of soybean as influenced by different levels of sulphur and zinc is presented and depicted in Table 4.21 and Fig 4.21 and their interaction effects in Table 4.22 and Fig 4.22 at harvest.

4.1.15.1 Effect of sulphur level

The effect of different levels of sulphur was shown to exhibit a significant influence on the stover yield with the application of 20 kg Zn ha^{-1} (2.08 t ha^{-1}) over control (1.43 t ha^{-1}). However, no significant difference could be established between the treatments of 20 kg Zn ha^{-1} and 40 kg Zn ha^{-1} for the year 2017. The perusal of data for the year 2018 also showed similar result with the highest stover yield obtained in the treatment of 20 kg Zn ha^{-1} (1.84 t ha^{-1}) followed by 40 kg Zn ha^{-1} (1.78 t ha^{-1}) and showed significant result over control (1.59 t ha^{-1}). The pooled data showed the highest stover yield with 20 kg Zn ha^{-1}(1.97) which was found to be significantly superior to control (1.51 t ha^{-1}) and at par with 40 kg Zn ha^{-1}(1.79 t ha^{-1}).

The above findings led to similar conclusion by Mamatha *et al*. (2018) whereby graded levels of sulphur significantly increased the haulm yield of soybean. The haulm yield heightened up to application of 20 kg S ha^{-1} which was comparable with the treatments receiving 30 and 40 kg S ha^{-1} while the lowest was recorded in control. Several other researchers also reported similar findings wherein sulphur increased stover yield of soybean and the highest stover yield of soybean was obtained with 20 kg S ha^{-1}, which was statistically at par with that obtained from 40 kg S ha^{-1} application (Akter *et al*. 2013, Farhad *et al*. 2010). The treatment combinations of 20 kg S ha^{-1} and 50 kg P_2O_5 ha^{-1} treatment with common dose of nitrogen @ 30 kg ha^{-1} was also reported to increase the straw yield (Deshbhratar *et al*. 2010).

4.1.15.2 Effect of zinc levels

The data for 2017 depicted that the increase in zinc levels showed an increment in stover yield of soybean up to 20 kg Zn ha^{-1}. A significantly higher stover yield (2.15 t ha^{-1}) was observed with the treatment of 20 kg Zn ha^{-1} and showed statistical superior over 0 kg Zn ha^{-1} (1.35 t ha^{-1}), 5 kg Zn ha^{-1} (1.73 t ha^{-1}) and 10 kg Zn ha^{-1} (1.75 t ha^{-1}) and at par with 15 kg Zn ha^{-1} (1.85 kg Zn ha^{-1}). For the year 2018, the stover yield exhibited a significant increase at 20 kg Zn ha^{-1} (1.88 t ha^{-1}) and 15 kg Zn ha^{-1} (1.77 t ha^{-1}) over control (1.57 t ha^{-1}) but the difference between the two Zn levels was found to be non-significant. The pooled data showed the highest stover yield was achieved with 20 kg Zn ha^{-1} (2.02 t ha^{-1}) followed by15 kg Zn ha^{-1} (1.81 t ha^{-1}).

These basic findings are consistent with the research reporting each and alternate year of Zn application significantly increased the plant growth and yield parameters such as height, pods plant^{-1}, seeds pod^{-1}, test weight, grain and straw yield, oil and protein content (Raghuwanshi *et al*. 2017). Sale and Nazirkar (2013) also reported that zinc micronutrient application had a significant effect on grain and straw yield, nutrient uptake, and oil and protein content of soybean in treatment receiving a foliar application of Fe and Zn.

4.1.15.3 Interaction effect of sulphur and zinc

No significant interaction was established in both the years.

4.1.16 Harvest Index (%)

The experimental data on harvest index of soybean influenced by different levels of sulphur and zinc was analyzed statistically and is presented and depicted in Table 4.23 and Fig 4.23 and their interaction effects in Table 4.24 and Fig 4.24.

4.1.16.1 Effect of sulphur level

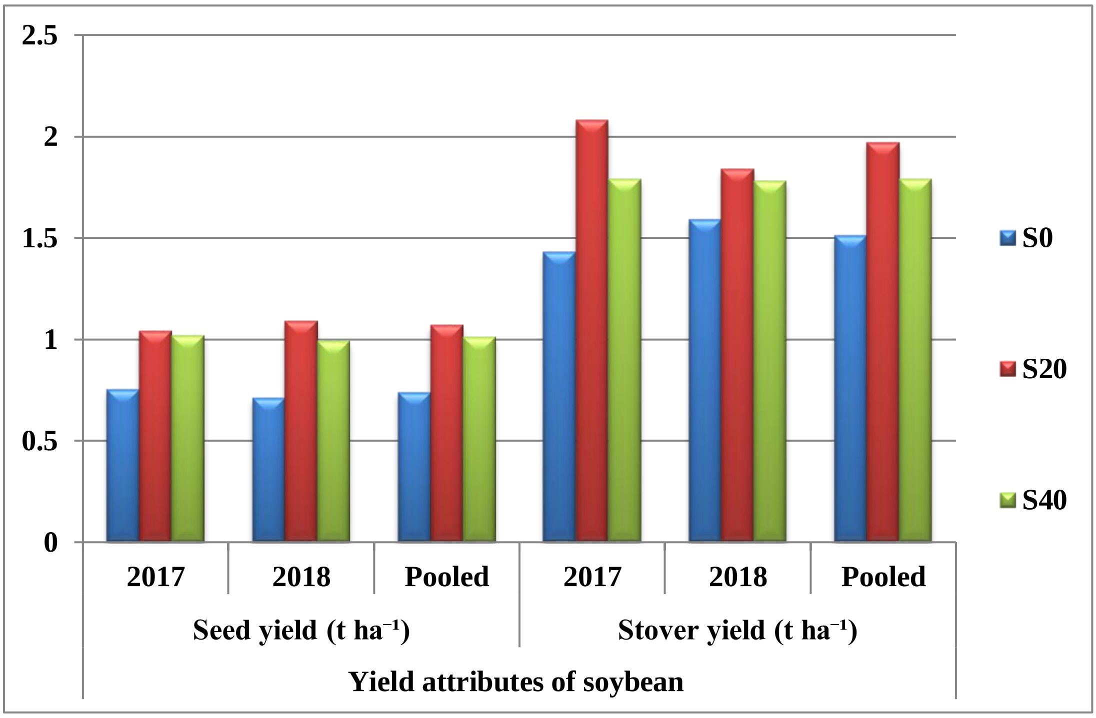
Based on the yearly data of 2017, there was no significant difference among the treatments however a higher harvest index was found in the treatment of 20 kg S ha^{-1} (36.79 %) in the subsequent year followed by 40 kg S ha^{-1} (35.62). The lowest harvest index was exhibited by 0 kg S ha^{-1} (30.80 %). No significant differences were observed in the pooled data.

Table 4.21: Effect of sulphur and zinc fertilization for biofortification on yield attributes of soybean at harvest

Treatments	Yield attributes of soybean								
	Test weight (g)			Seed yield (t ha^{-1})			Stover yield (t ha^{-1})		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
S_0	94.01	85.63	89.82	0.75	0.71	0.74	1.43	1.59	1.51
S_{20}	96.74	89.61	93.17	1.04	1.09	1.07	2.08	1.84	1.97
S_{40}	96.36	87.68	92.02	1.02	0.99	1.01	1.79	1.78	1.79
SEm ±	1.21	1.38	0.93	0.03	0.02	0.02	0.10	0.03	0.05
CD (P=0.05)	NS	NS	2.70	0.09	0.07	0.06	0.30	0.10	0.16
Zn_0	94.36	87.54	90.95	0.78	0.77	0.78	1.35	1.57	1.46
Zn_5	95.10	87.46	91.28	0.90	0.86	0.88	1.73	1.72	1.73
Zn_{10}	96.67	87.60	92.13	0.92	0.88	0.91	1.75	1.76	1.76
Zn_{15}	96.12	87.60	91.86	1.04	1.01	1.02	1.85	1.77	1.81
Zn_{20}	96.27	88.00	92.13	1.07	1.13	1.10	2.15	1.88	2.02
SEm ±	1.56	1.78	1.20	0.04	0.03	0.03	0.13	0.04	0.07
CD (P=0.05)	NS	NS	NS	0.12	0.09	0.08	0.38	0.12	0.20

Table 4.22: Interaction effects of sulphur and zinc fertilization for biofortification on yield attributes of soybean at harvest

Treatments	Yield attributes of soybean								
	Test weight (g)			Seed yield (t ha^{-1})			Stover yield (t ha^{-1})		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
S_0Zn_0	93.57	85.07	89.32	0.38	0.49	0.44	0.52	1.26	0.89
S_0Zn_5	95.34	85.10	90.22	0.70	0.70	0.70	1.54	1.63	1.59
S_0Zn_{10}	95.87	85.43	90.65	0.76	0.72	0.74	1.54	1.68	1.62
S_0Zn_{15}	92.90	85.80	89.35	0.96	0.78	0.87	1.56	1.69	1.63
S_0Zn_{20}	92.37	86.77	89.57	0.97	0.87	0.92	1.97	1.70	1.84
$S_{20}Zn_0$	94.83	88.80	91.82	0.98	0.93	0.96	1.81	1.74	1.78
$S_{20}Zn_5$	94.87	89.37	92.12	1.00	0.94	0.97	1.90	1.77	1.84
$S_{20}Zn_{10}$	97.40	89.63	93.52	1.01	0.98	1.00	1.93	1.80	1.87
$S_{20}Zn_{15}$	97.87	89.90	93.88	1.08	1.17	1.13	2.18	1.82	2.00
$S_{20}Zn_{20}$	98.73	90.33	94.53	1.15	1.41	1.28	2.60	2.09	2.35
$S_{40}Zn_0$	94.67	88.77	91.72	0.98	0.90	0.94	1.72	1.72	1.73
$S_{40}Zn_5$	95.10	87.90	91.50	0.99	0.93	0.97	1.76	1.76	1.76
$S_{40}Zn_{10}$	96.73	87.73	92.23	1.00	0.95	0.98	1.79	1.78	1.79
$S_{40}Zn_{15}$	97.60	87.10	92.35	1.07	1.06	1.07	1.80	1.81	1.81
$S_{40}Zn_{20}$	97.71	86.90	92.30	1.08	1.10	1.09	1.87	1.84	1.86
SEm ±	2.70	3.08	2.08	0.07	0.06	0.05	0.23	0.07	0.12
CD (P=0.05)	NS	NS	NS	0.21	NS	0.14	NS	NS	0.35



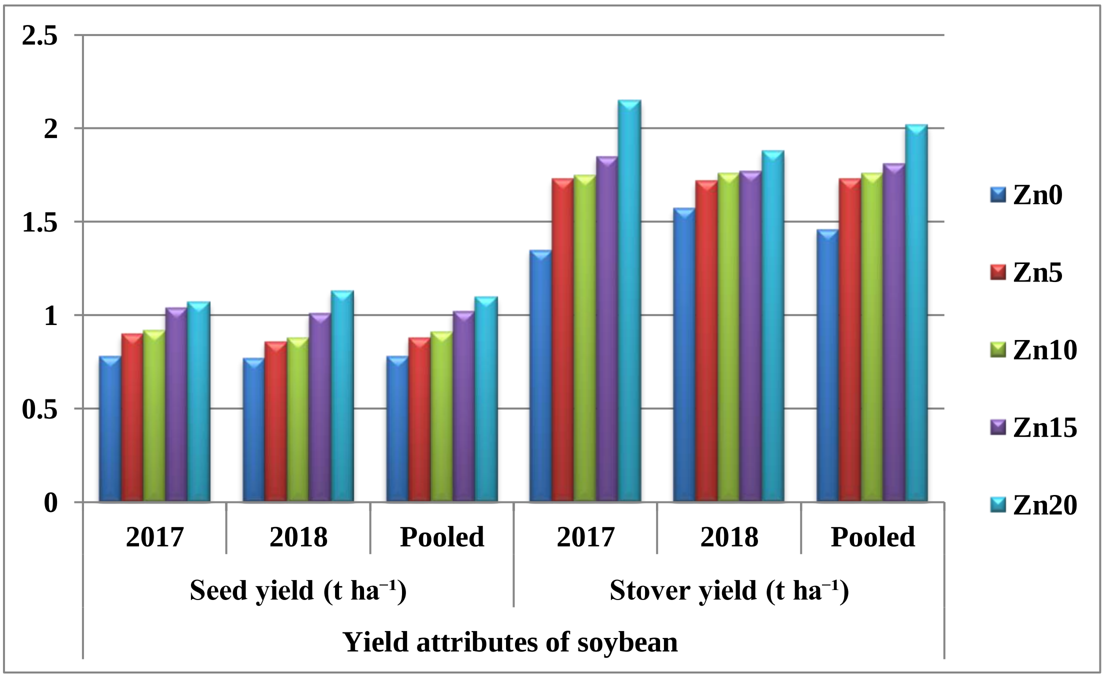


Fig 4.21: Effect of sulphur and zinc fertilization for biofortification on yield attributes of soybean at harvest.

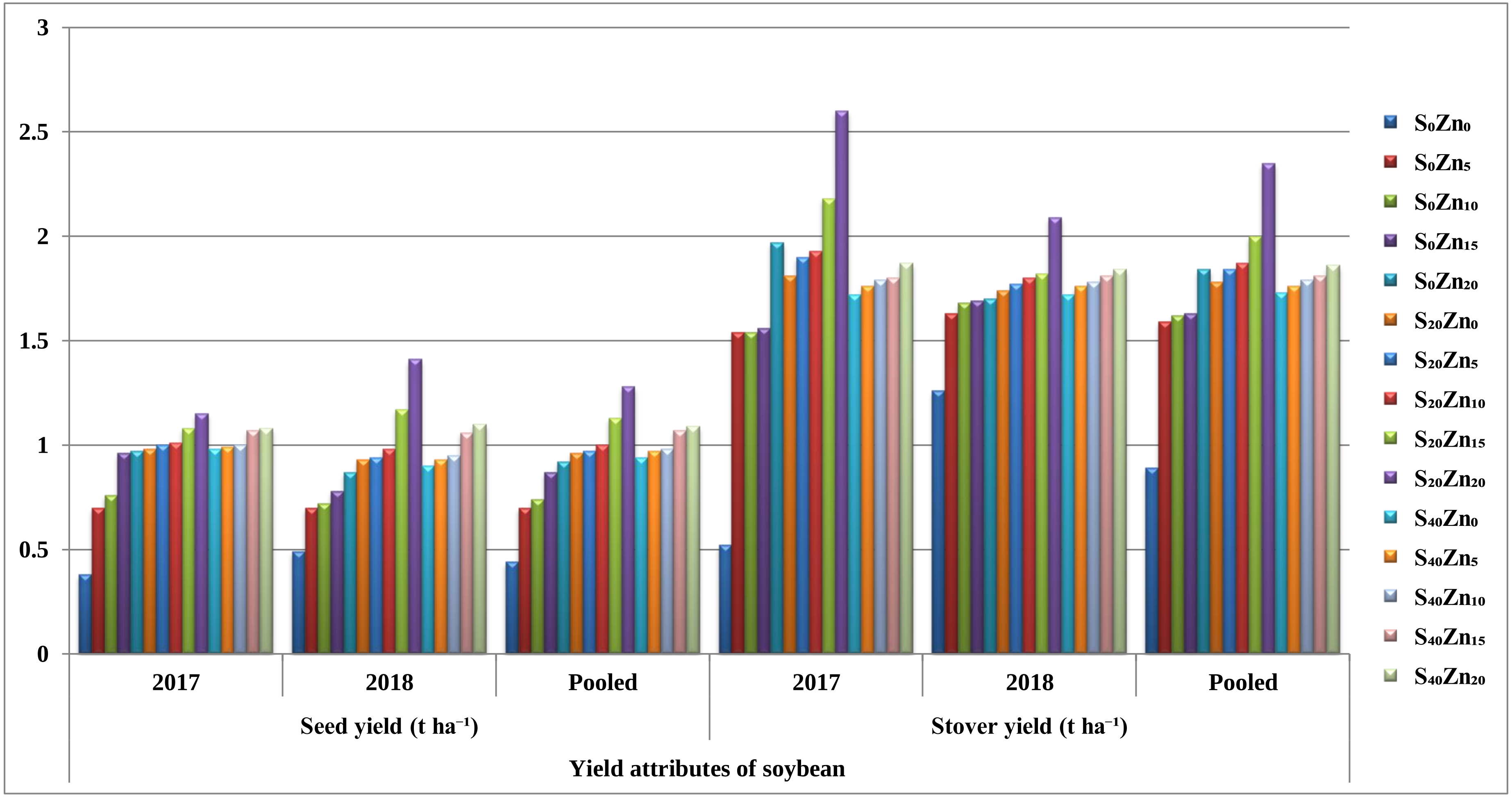


Fig 4.22: Interaction effect of sulphur and zinc fertilization for biofortification on yield attributes of soybean at harvest.

4.1.16.2 Effect of zinc levels

The experimental data for the year 2017 on the effect of different levels of zinc on the harvest index of soybean did not show any significant differences among the treatments. However, a significant difference could be observed in the next year where an increase in the zinc levels exhibited a higher harvest index. The treatments of 20 kg Zn ha^{-1}resulted in the highest harvest index (37.11%). It exhibited a statistical superior over the lower levels of zinc (0, 5, 10 kg Zn ha^{-1}) and was shown to be at par with 15 kg Zn ha^{-1} (35.86 %).The lower zinc levels were found to be at par among them. The pooled data did not show any significant difference.

4.1.16.3 Interaction effect of sulphur and zinc

No statistical inference could be established in the interaction effect between sulphur and zinc level.

4.2 Effect of sulphur and zinc biofortificationon quality of soybean

4.2.1Oil content in soybean (%)

The data on oil content in soybean influenced by different levels of sulphur and zinc is presented and depicted in Table 4.25 and Fig 4.25 and their interaction effects in Table 4.26 and Fig 4.26.

4.2.1.1 Effect of sulphur level

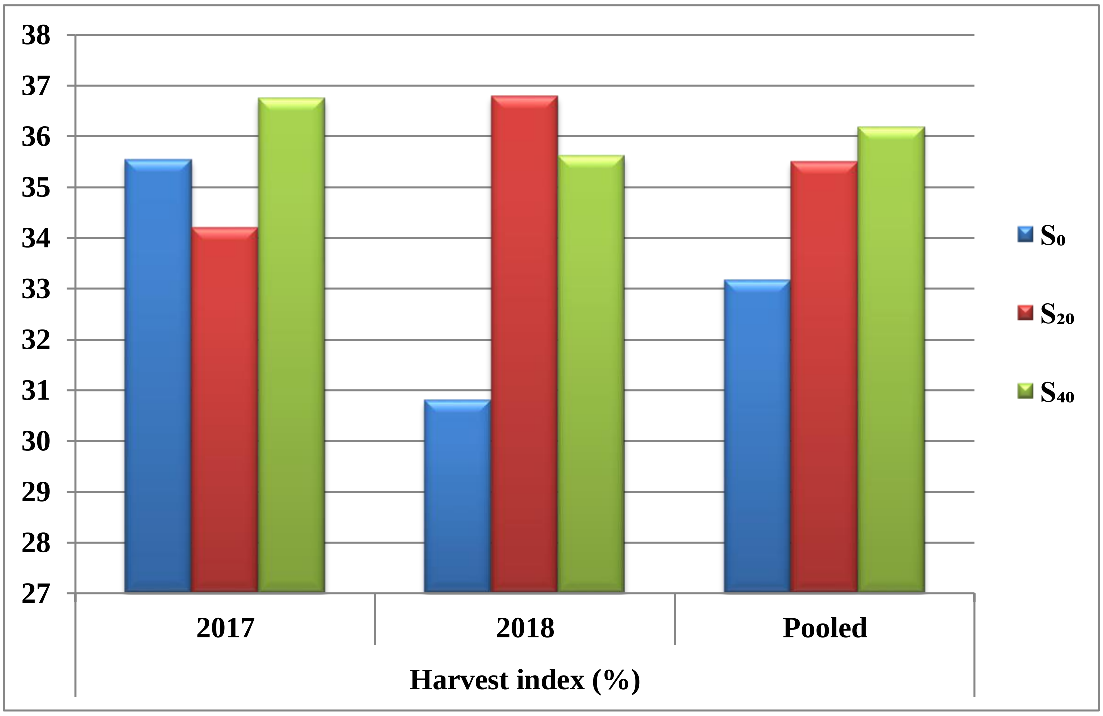
The oil content in soybean was comparatively higher with the application of 20 kg S ha^{-1} (17.69%) during 2017 while the lowest oil content was recorded at 0 kg S ha^{-1} (14.63%). In the subsequent year, not much variation could be seen as the treatments of 20 kg S ha^{-1} (17.27%) and 40 kg S ha^{-1} (17%) were at par with each other while control recorded the lowest oil content (14.91%). The pooled data also showed similar trend with 20 kg S ha^{-1}

Table 4.23: Effect of sulphur and zinc fertilization for biofortification on harvest index (%) of soybean

Treatments	Harvest index (%)		
	2017	**2018**	**Pooled**
S_0	35.54	30.80	33.17
S_{20}	34.21	36.79	35.50
S_{40}	36.75	35.62	36.19
SEm ±	1.45	0.73	0.87
CD (P=0.05)	NS	2.11	NS
Zn_0	38.05	32.42	35.24
Zn_5	34.53	33.18	33.86
Zn_{10}	34.53	33.44	33.99
Zn_{15}	36.66	35.86	36.26
Zn_{20}	33.72	37.11	35.42
SEm ±	1.88	0.94	1.13
CD (P=0.05)	NS	2.72	NS

Table 4.24: Interaction effects of sulphur and zinc fertilization for biofortification on harvest index (%) of soybean

Treatments	Harvest index (%)		
	2017	2018	Pooled
S_0Zn_0	41.54	28.11	34.83
S_0Zn_5	31.30	30.01	30.66
S_0Zn_{10}	33.51	30.36	31.94
S_0Zn_{15}	38.03	31.63	34.83
S_0Zn_{20}	33.31	33.87	33.59
$S_{20}Zn_0$	35.59	34.72	35.16
$S_{20}Zn_5$	35.55	34.86	35.21
$S_{20}Zn_{10}$	34.31	35.15	34.73
$S_{20}Zn_{15}$	34.48	39.04	36.76
$S_{20}Zn_{20}$	31.10	40.19	35.65
$S_{40}Zn_0$	37.02	34.44	35.73
$S_{40}Zn_5$	36.74	34.66	35.70
$S_{40}Zn_{10}$	35.78	34.82	35.30
$S_{40}Zn_{15}$	37.47	36.91	37.19
$S_{40}Zn_{20}$	36.74	37.26	37.01
SEm ±	3.25	1.63	1.95
CD (P=0.05)	NS	NS	NS



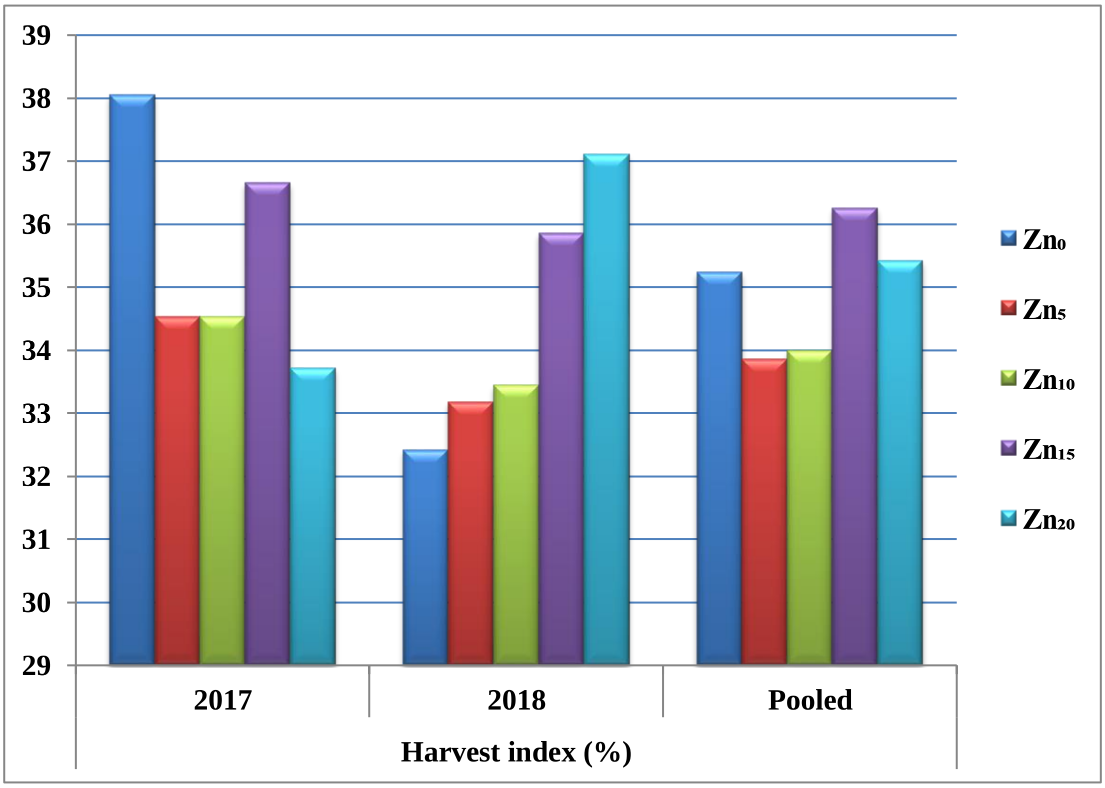


Fig 4.23: Effect of sulphur and zinc fertilization for biofortification on harvest index (%) of soybean.

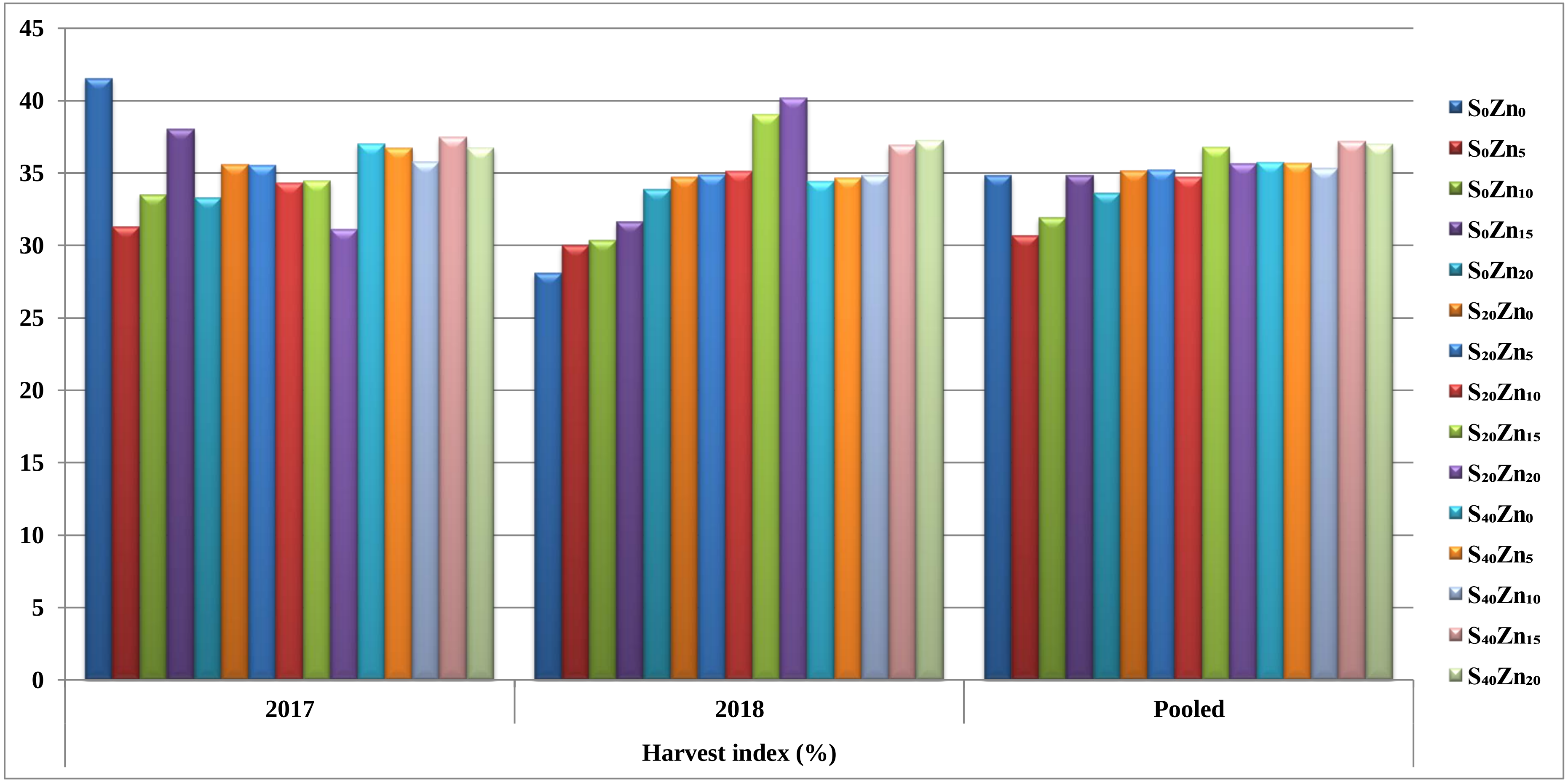


Fig 4.24: Interaction effects of sulphur and zinc fertilization for biofortification on harvest index (%) of soybean.

(17.48%) recording higher oil content and at par with 40 kg S ha^{-1} (16.95%) while control recorded the lowest (14.77%).

The requirement of sulphur in oilseeds is the highest compared to other crops and plays a vital role in oil bio syntheisis (Ahmad *et al*. 2007). It is involved in the synthesis of lipids, fatty acid synthesis acetyl-CoA enzyme activity (Ahmed and Abdin, 2000). These could be one of the probable reasons which led to an increase in the oil content of the crop. The above findings were consistent with what has been found in previous studies conducted by Farhad *et al.* (2010) and Hosmath *et al.* (2014) who also reported significant increase in the oil content of soybean with the application of sulphur @ 20 kg ha^{-1} compared to sulphur levels 10 kg ha^{-1}, 30 kg ha^{-1} and 40 kg ha^{-1}. Chauhan *et al.* (2013) reported the oil percentage increased by 1.3 and 1.1% at $K_{20}S_{20}$ Zn_5 combination dose among all other combination doses duringthe two years of experimentation.

4.2.1.2 Effect of zinc level

Based on the data, the oil content in soybean increased with the increasing levels of zinc over control (0 kg Zn ha^{-1}). A significant increase in oil content was observed with the application of 20 kg Zn ha^{-1} (17.53 %) while the lowest was recorded in control (15.03%) in the first year. In the subsequent year, control recorded the lowest oil content (15.56%) while 20 kg Zn ha^{-1} (17.19%) recorded the highest. The pooled data also showed similar trend with 20 kg Zn ha^{-1} (17.36%) recording higher oil content while control recorded the lowest (15.29%).

The results obtained were broadly in line with the works carried out by Pable *et al*. (2010) wherein the application of zinc led to increase in the oil content. Application of zinc @ 20 kg ha^{-1} also recorded at par effect in respect of oil and protein content with treatment of application of zinc @ 10 kg ha^{-1}. (Kakad *et al*. 2008)

4.2.1.3 Interaction effect of sulphur and zinc

The interaction effect between sulphur and zinc level exhibited a significant variation in the first year but showed non-significant variation in the second year with 20 kg Zn ha^{-1} recording the highest oil content. The pooled value showed the highest oil content of the crop with the addition of 20 kg Zn ha^{-1}.

4.2.2 Protein content in soybean (%)

The experimental data on harvest index of soybean influenced by different levels of sulphur and zinc was analyzed statistically and is presented and depicted in Table 4.25 and Fig 4.25 and their interaction effects in Table 4.26 and Fig 4.26.

4.2.2.1 Effect of sulphur level

Based on the data collected, there was a notable variation in the protein content of soybean with the application of different levels of sulphur. A significantly higher protein content was observed with the application of 20 kg ha^{-1} (36.47%, 36.64% and 36.55%) comparable with that of 40 S kg ha^{-1} (36.14%, 36.43% and 36.28%) and superior over control (32.69%, 35.46% and 34.08%) for both the years of experiments and pooled data.

Sulphur is required by crops for protein structure, vitamins and other structural components and also to improve plant growth and yield (Marshner, 2005; Kopriva *et al.,* 2002). It is required for the synthesis of fatty acids and S containing amino acids, such as cystine, cysteine and methionine which are essential components of protein (Havlin *et al.* 1999). The synthesis of protein in soybean is reported to be highly influenced by minerals such as phosphorus, potassium, nitrogen and sulphur (Peak *et al.,* 1997; Utsumi, *et al.,* 2002; Mahmoodi *et al.*, 2013) and so the addition of graded levels of sulphur have significantly influenced the protein content in soybean. These results are in tandem with previous works by Sharma and Sharma (2014) who concluded that gypsum @ 20 kg S ha^{-1} alone or in combination with recommended nitrogen doses improved the total storage protein, glycinin fraction of globulin, S-containing amino acids and seed yield in soybean**.** Aulakh (1995) and Farhad *et al.* 2010 also reported increase in the protein content in soybean with the application of $N_{100}S_{20}$ and $K_{40}S_{20}$ treatments respectively. The above findings were also in close conformity with the works carried out by Mamatha *et al*. (2018) and Gokhale et al. (2005) who reported increased in protein content in soybean seed over control at 30 kg S ha^{-1}.

4.2.2.2 Effect of zinc levels

The protein content in soybean grain increased with the increasing levels of Zn over control. The two levels of zinc 20 kg Zn ha^{-1} and 15 kg Zn ha^{-1} had a significant influence on the protein content over control but the difference between the two levels of Zn was found to be non-significant. The highest protein content was recorded in the zinc level of 20 kg Zn ha^{-1} (37.14 and 36.99%) while control recorded the lowest (33.09 and 34.41%) for the initial year and pooled. The data showed a non-significant influence in the second year.

The application of zinc in soil was found to enhance the zinc concentration in soybean thereby aiding in RNA and ribosome synthesis which might have resulted in accelerated protein synthesis (Pable and Patil, 2011). The works carried out by Awlad *et al.* (2003), also reported similar findings whereby zinc was involved in nitrogen and protein metabolism by controlling RNase activity, auxin biosynthesis and carbohydrate metabolism.

4.2.2.3 Interaction effect of sulphur and zinc

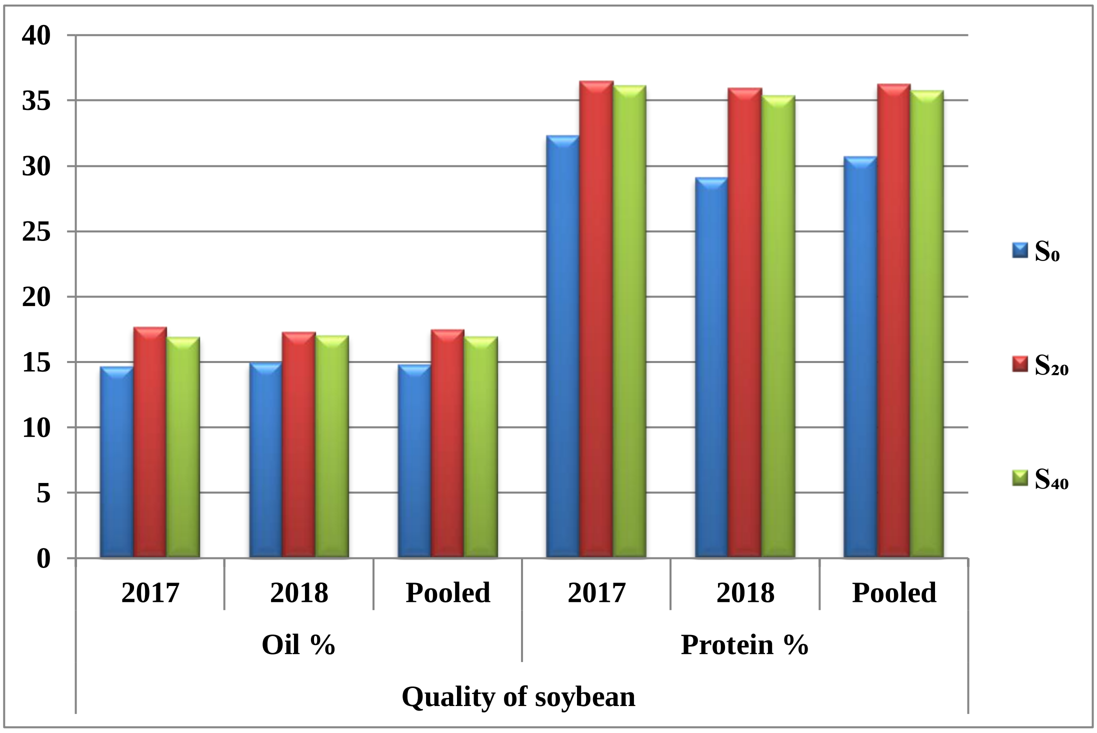
No statistical inference could be established in the interaction effect between sulphur and zinc level.

Table 4.25: Effect of sulphur and zinc fertilization for biofortification on quality of soybean

Treatments	Quality of soybean					
	Oil %			Protein %		
	2017	2018	Pooled	2017	2018	Pooled
S_0	14.63	14.91	14.77	32.69	35.46	34.08
S_{20}	17.69	17.27	17.48	36.47	36.64	36.55
S_{40}	16.91	17.00	16.95	36.14	36.43	36.28
SEm ±	0.16	0.17	0.10	0.58	0.23	0.31
CD (P=0.05)	0.48	0.48	0.29	1.67	0.66	0.89
Zn_0	15.03	15.56	15.29	33.09	35.72	34.41
Zn_5	15.90	16.04	15.97	34.71	35.87	35.29
Zn_{10}	16.71	16.36	16.53	34.86	36.09	35.48
Zn_{15}	16.87	16.82	16.84	35.70	36.35	36.02
Zn_{20}	17.53	17.19	17.36	37.14	36.84	36.99
SEm ±	0.21	0.22	0.13	0.74	0.29	0.39
CD (P=0.05)	0.62	0.63	0.37	2.16	NS	1.41

Table 4.26: Interaction effects of sulphur and zinc fertilization for biofortification on quality of soybean

Treatments	Quality of soybean					
	Oil %			Protein %		
	2017	2018	Pooled	2017	2018	Pooled
S_0Zn_0	11.43	13.87	12.65	29.06	34.98	32.02
S_0Zn_5	13.43	14.63	14.03	33.05	35.33	34.19
S_0Zn_{10}	15.57	14.83	15.20	33.17	35.42	34.29
S_0Zn_{15}	15.73	15.50	15.62	33.33	35.77	34.55
S_0Zn_{20}	17.00	15.73	16.37	34.83	35.81	35.32
$S_{20}Zn_0$	17.27	16.50	16.88	35.19	36.17	35.68
$S_{20}Zn_5$	17.43	16.87	17.15	35.59	36.19	35.89
$S_{20}Zn_{10}$	17.53	17.33	17.43	35.77	36.31	36.04
$S_{20}Zn_{15}$	17.77	17.53	17.65	36.59	36.62	36.60
$S_{20}Zn_{20}$	18.43	18.10	18.27	39.23	37.90	38.56
$S_{40}Zn_0$	16.40	16.30	16.35	35.02	36.02	35.52
$S_{40}Zn_5$	16.83	16.63	16.73	35.50	36.08	35.79
$S_{40}Zn_{10}$	17.03	16.90	16.97	35.65	36.54	36.10
$S_{40}Zn_{15}$	17.10	17.43	17.27	37.17	36.67	36.92
$S_{40}Zn_{20}$	17.17	17.73	17.45	37.36	36.81	37.08
SEm ±	0.37	0.37	0.22	1.29	1.51	0.68
CD (P=0.05)	1.07	NS	0.64	NS	NS	NS



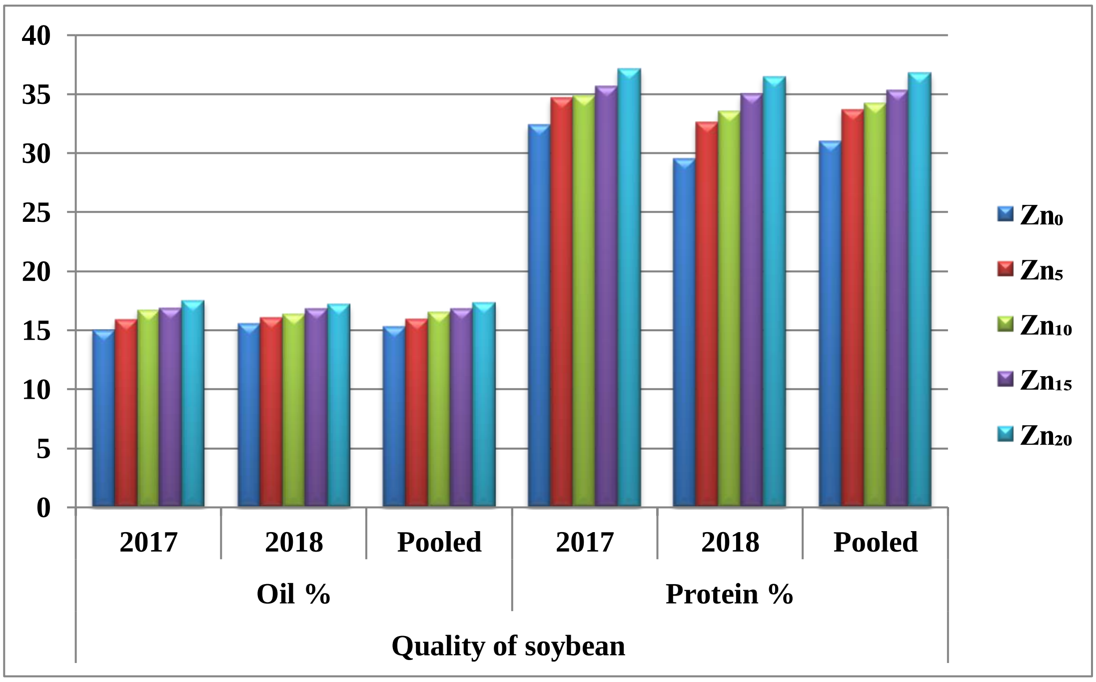


Fig 4.25: Effect of sulphur and zinc fertilization for biofortification on quality of soybean.

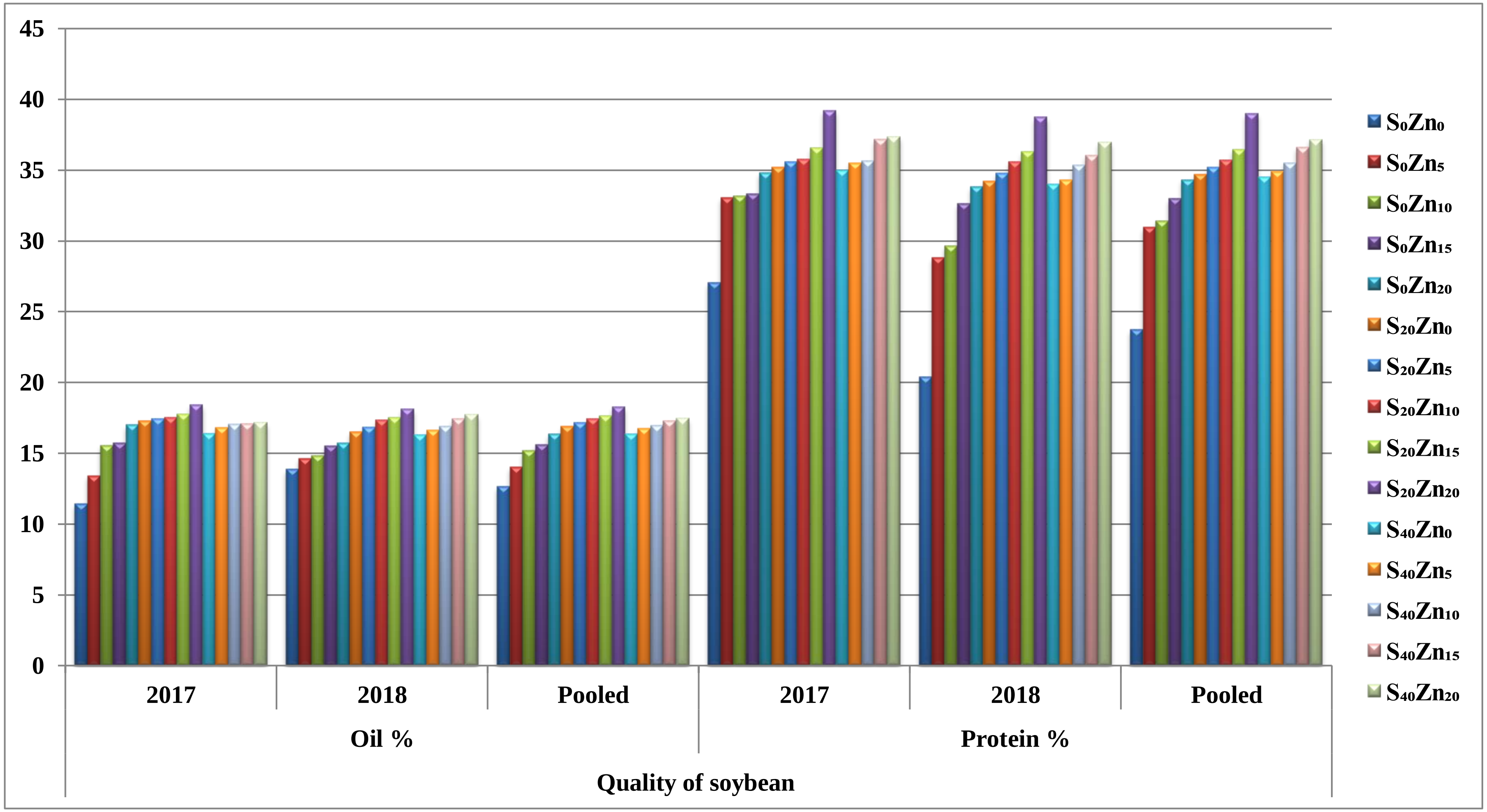


Fig 4.26: Interaction effects of sulphur and zinc fertilization for biofortification on quality of soybean.

4.3 Effect of sulphur and zinc application on nutrient (NPKS and Zn) content (%) and uptake (kg ha^{-1}) in seed and stover

4.3.1 Effect of sulphur and zinc application on nitrogen (N) content (%) and uptake (kg ha^{-1}) in seed and stover

The experimental data on nitrogen (N) content in seed influenced by different levels of sulphur and zinc was analyzed statistically and is presented and depicted in Table 4.27 and Fig 4.27 and their interaction effects in Table 4.28 and Fig 4.28.

4.3.1.1 Effect of sulphur level

A notable variation could be observed from the data generated during the year 2017 wherein the application of sulphur @ 20 kg ha^{-1} was observed to influence the nitrogen content as well as its higher uptake in the seeds (5.84% and 61.10 kg ha^{-1}) and stover (1.72% and 36 kg ha^{-1}) quite comparable with that of 40 kg S ha^{-1} (5.78% and 59.34 kg ha^{-1}) and superior over that of control (5.23% and 40.14 kg ha^{-1}). In the subsequent year, 20 kg S ha^{-1} recorded the highest nitrogen content and uptake in the seeds and stover (5.86% and 61.15 kg ha^{-1}, 2.02% and 42.66 kg ha^{-1}) followed by 40 kg S ha^{-1} (5.83% and 59.74 kg ha^{-1}, 2.01% and 35.88 kg ha^{-1}). The pooled data showed a similar trend with 20 kg S ha^{-1} exhibiting higher nitrogen content and uptake by seeds (5.85% and 61.13 kg ha^{-1}) and stover (1.87% and 39.33 kg ha^{-1}) at par with 40 kg S ha^{-1} (5.81% and 59.54 kg ha^{-1}, 1.85% and 33.04 kg ha^{-1}) and higher than that of control (5.45% and 41.47 kg ha^{-1}, 1.58% and 22.70 kg ha^{-1}).

Sulphur is known to play a vital role in the enzyme activity for the reduction of nitrate in plants. Hence, it is crucial that the N uptake increase with the sulphur application. The increase in the root activity and soil nutrient availability to the crop could also be attributed to the increased nutrient content and uptake with sulphur application (Wani *et al.*, 2000). Biswas (2006) also reported a significant influence on N content with sulphur fertilizer.

4.3.1.2 Effect of zinc levels

Based on the 2017-year data presented, an increase in nitrogen content and uptake was observed with the increasing levels of Zn. The zinc level of 20 kg Zn ha^{-1} showed the highest N content and its uptake by the seeds (5.94% and 63.73 kg ha^{-1}) and stover (1.70% and 36.71 kg ha^{-1}) at par with that of 15 kg Zn ha^{-1} (5.71% and 59.50 kg ha^{-1}, 1.68% and 31.34 kg ha^{-1}). The lower levels of zinc were found to be at par with each other. No significant observations could be established in the second year for nitrogen content however its higher uptake by the plant could be seen with the application of 20 kg Zn ha^{-1} (63.73 kg ha^{-1}). The nitrogen content in stover was also found to be non-significant. The highest nitrogen uptake in stover was observed with 20 kg Zn ha^{-1} (43.48 kg ha^{-1}) while control recorded the lowest (23.32 kg ha^{-1}). The pooled data followed the first-year variation wherein the highest nitrogen content and its uptake in seed and stover was shown in 20 kg Zn ha^{-1} (5.92% and 63.41 kg ha^{-1}, 1.85% and 40.10 kg ha^{-1}) while the lowest was recorded in the control plot (5.51% and 43.70 kg ha^{-1}, 1.63% and 22.46 kg ha^{-1}).

Rathod *et al*. (2017) also reported increase in the nitrogen content and uptake due to the application lime, zinc and boron through the soil and foliar spray along with RDF. The uptake of N, P, K, Ca, Mg and S by soybean was also significantly increased by this treatment.

4.3.1.3 Interaction effect of sulphur and zinc

Interaction effect of sulphur and zinc did not have a significant effect on nitrogen content and uptake in seed and stover.

4.3.2 Effect of sulphur and zinc application on phosphorus content (%) and uptake (kg ha^{-1}) in seed and stover

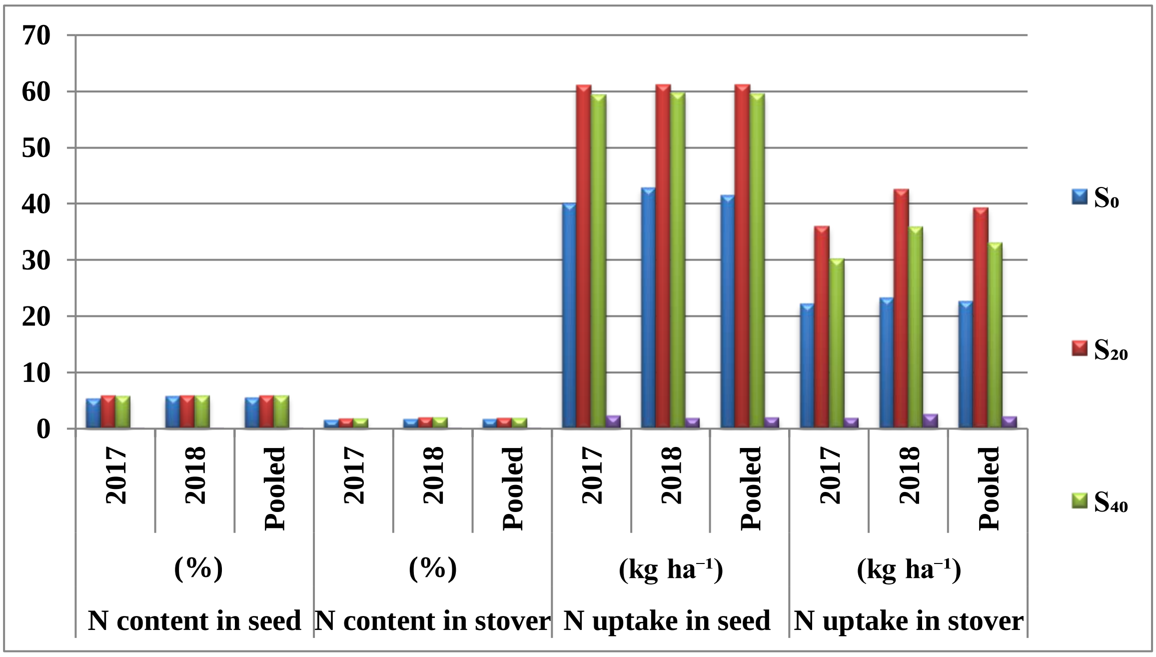
The experimental data on Phosphorus (P) content in seed and stover influenced by different levels of sulphur and zinc was analyzed statistically and

Table 4.27 Effect of sulphur and zinc fertilization for biofortification on nitrogen content (%) and uptake (kg ha^{-1}) in seed and stover of soybean at harvest

	N content in seed (%)			N content in stover (%)			N uptake in seed (kg ha^{-1})			N uptake in stover (kg ha^{-1})		
	2017	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
S_0	5.23	5.67	5.45	1.54	1.61	1.58	40.14	42.80	41.47	22.18	23.23	22.70
S_{20}	5.84	5.86	5.85	1.72	2.02	1.87	61.10	61.15	61.13	36.00	42.66	39.33
S_{40}	5.78	5.83	5.81	1.69	2.01	1.85	59.34	59.74	59.54	30.19	35.88	33.04
SEm ±	0.09	0.04	0.05	0.03	0.07	0.04	2.26	1.81	1.98	1.90	2.49	2.10
CD (P=0.05)	0.27	NS	0.14	0.08	0.20	0.11	6.56	5.23	5.74	5.50	7.21	6.09
Zn_0	5.29	5.72	5.51	1.58	1.68	1.63	42.60	44.80	43.70	21.60	23.32	22.46
Zn_5	5.55	5.74	5.65	1.62	1.81	1.72	50.06	51.54	50.80	28.40	31.65	30.02
Zn_{10}	5.58	5.77	5.68	1.66	2.00	1.83	51.75	53.30	52.53	29.24	35.19	32.22
Zn_{15}	5.71	5.82	5.77	1.68	1.93	1.81	59.50	60.09	59.80	31.34	35.99	33.66
Zn_{20}	5.94	5.89	5.92	1.70	1.99	1.85	63.73	63.09	63.41	36.71	43.48	40.10
SEm ±	0.12	0.05	0.06	0.03	0.09	0.05	2.92	2.33	2.56	2.45	3.21	2.71
CD (P=0.05)	0.35	NS	0.18	NS	NS	0.14	8.46	6.75	7.41	7.11	9.30	7.86

Table 4.28 Interaction effects of sulphur and zinc fertilization for biofortification on nitrogen content (%) and uptake (kg ha^{-1}) in seed and stover of soybean at harvest.

Treatments	N content in seed (%)			N content in stover (%)			N uptake in seed (kg ha^{-1})			N uptake in stover (kg ha^{-1})		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
S_0Zn_0	4.65	5.60	5.13	1.47	1.49	1.48	17.52	21.18	19.34	7.71	7.78	7.75
S_0Zn_5	5.29	5.65	5.47	1.51	1.66	1.58	37.10	39.53	38.32	23.19	25.66	24.42
S_0Zn_{10}	5.31	5.67	5.49	1.55	1.81	1.68	40.35	42.99	41.67	23.98	27.85	25.92
S_0Zn_{15}	5.33	5.72	5.53	1.57	1.54	1.56	51.68	54.74	53.21	24.52	23.46	23.98
S_0Zn_{20}	5.57	5.73	5.65	1.59	1.56	1.58	54.06	55.58	54.82	31.50	31.38	31.45
$S_{20}Zn_0$	5.63	5.79	5.71	1.65	1.59	1.62	55.31	56.93	56.12	29.64	28.06	28.85
$S_{20}Zn_5$	5.69	5.79	5.74	1.70	2.00	1.85	56.78	57.72	57.25	32.49	39.08	35.79
$S_{20}Zn_{10}$	5.72	5.81	5.77	1.72	2.07	1.90	57.66	58.46	58.06	33.24	39.76	36.50
$S_{20}Zn_{15}$	5.85	5.86	5.86	1.76	2.17	1.97	63.22	62.73	62.97	38.53	47.07	42.80
$S_{20}Zn_{20}$	6.28	6.06	6.17	1.77	2.29	2.03	72.54	69.93	71.23	46.10	59.34	52.72
$S_{40}Zn_0$	5.60	5.76	5.69	1.62	1.97	1.79	54.98	56.30	55.64	27.44	34.11	30.78
$S_{40}Zn_5$	5.68	5.77	5.73	1.65	1.77	1.71	56.31	57.36	56.83	29.51	30.21	29.86
$S_{40}Zn_{10}$	5.70	5.85	5.78	1.71	2.12	1.92	57.24	58.46	57.85	30.50	37.95	34.23
$S_{40}Zn_{15}$	5.95	5.87	5.91	1.72	2.08	1.90	63.61	62.80	63.21	30.98	37.43	34.20
$S_{40}Zn_{20}$	5.98	5.89	5.93	1.74	2.12	1.93	64.58	63.77	64.18	32.53	39.72	36.12
SEm ±	0.21	0.08	0.11	0.06	0.15	0.08	5.06	4.04	4.43	4.25	5.56	4.70
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	11.70	NS	NS	NS	NS



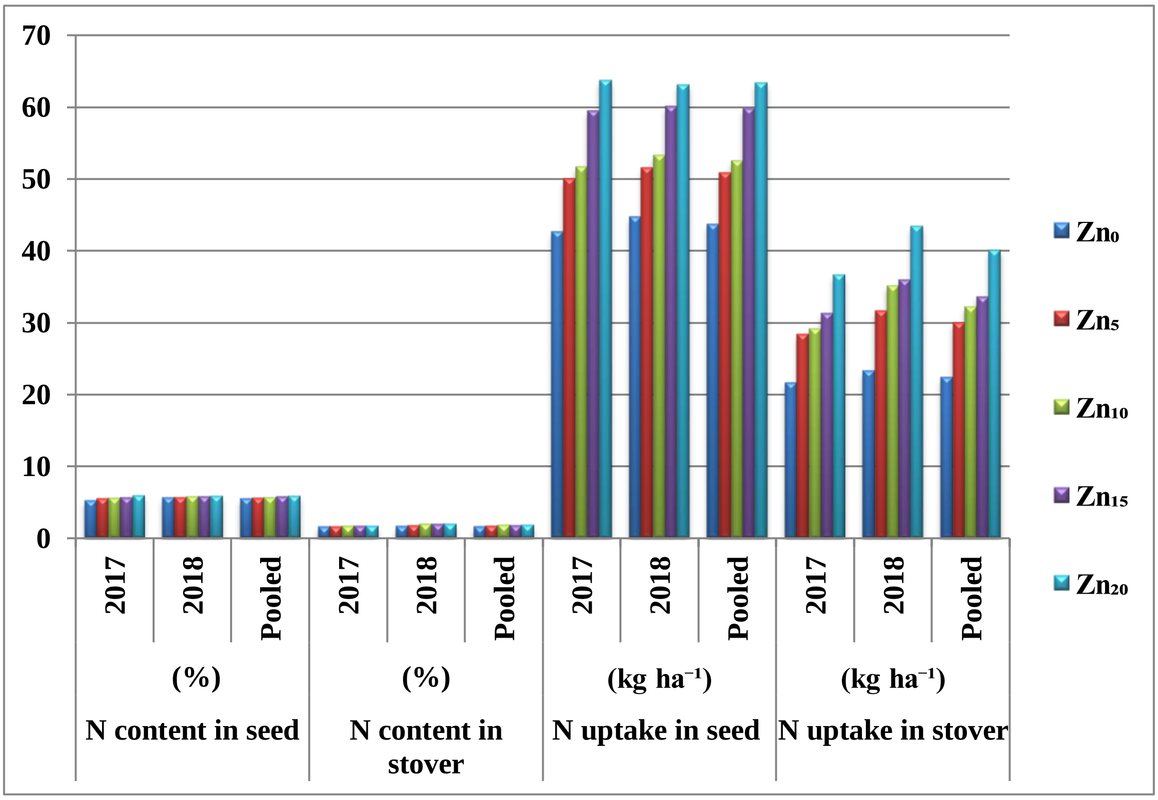


Fig 4.27 Effect of sulphur and zinc fertilization for biofortification on nitrogen content (%) and uptake (kg ha^{-1}) in seed and stover at harvest.

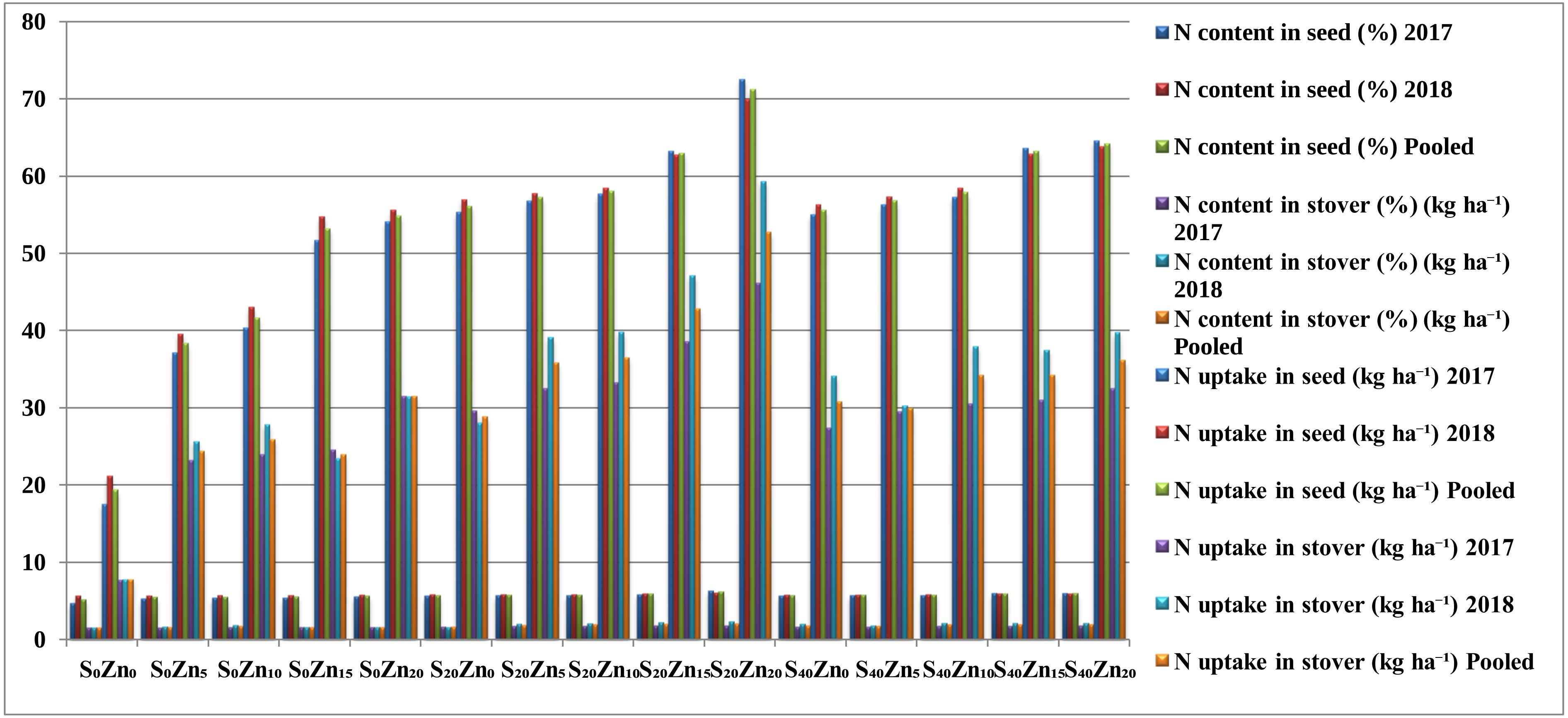


Fig 4.28 Interaction effects of sulphur and zinc fertilization for biofortification on nitrogen content (%) and uptake (kg ha^{-1}) in seed and stover at harvest.

is presented and depicted in Table 4.29 and Fig 4.29 and their interaction effects in Table 4.30 and Fig 4.30.

4.3.2.1 Effect of sulphur level

The data pertaining to phosphorus content influenced by different levels of sulphur did not exhibit any significant effect on phosphorus content in seed and stover during either of the years. However, it was observed that the treatment of 20 kg S ha^{-1} showed an increase in the phosphorus uptake in seed (2.42 kg ha^{-1} and 2.97 kg ha^{-1}) and stover (2.31 kg ha^{-1} and 3.13 kg ha^{-1}) in both the years. The pooled data showed the highest phosphorus uptake in seed and stover (2.69 kg ha^{-1} and 2.72 kg ha^{-1}) at par with 40 kg S ha^{-1} (2.20 kg ha^{-1} and 2.63 kg ha^{-1}) while control recorded the lowest (1. 99 kg ha^{-1} and 1.95 kg ha^{-1})

The increase in phosphorus uptake by the seed and stover was also well documented by Dhage *et al*. (2014) who reported the highest P uptake in the sulphur level of 40 kg S ha^{-1}.

4.3.2.2 Effect of zinc levels

The different levels of zinc did not show any significant difference of values in the phosphorus content and uptake by the seed and stover during both years. It was however projected to show an increase in the uptake of phosphorus with the different levels of zinc. In both the years, the application of 20 kg Zn ha^{-1} showed higher phosphorus uptake in seed (2.40 kg ha^{-1} and 3.03 kg ha^{-1}) and stover (2.41 kg ha^{-1} and 3.14 kg ha^{-1}) as compared to the lower levels of zinc. The pooled data replicated the same, recording the highest phosphorus uptake in zinc level of 20 kg Zn ha^{-1} (2.71 kg ha^{-1} and 2.77 kg ha^{-1}) in seed and stover respectively while the minimum phosphorus uptake was reported in control (2.07 kg ha^{-1} and 1.88 kg ha^{-1}).

The addition of zinc was reported to increase the P translocation to the leaves (Shittu and Ogunwale, 2012). The antagonism between zinc and phosphorus has been reported by many researchers. The above findings showed that although P content was not significantly influenced yet its uptake by plants increased with zinc application. Li *et al*. (2003) in a study reported that the Zn and P relationship may not always be referred to as antagonism but sometimes increasing zinc rates stimulates the concentration and uptake of phosphorus if the ratio of both the elements are maintained at an appropriate level. A study by Recena *et al.*, (2021) also reported that despite the effect of soil P on Zn adsorption and availability, the antagonism between P and Zn in plants may be expected at high P availability.

4.3.2.3 Interaction effect of sulphur and zinc

A significant influence could be established by the interaction effect of sulphur and zinc on phosphorus uptake in seed with treatment combination of $S_{20}Zn_{20}$ (2.87 kg ha^{-1}) reporting the highest phosphorus uptake in the seed.

4.3.3 Effect of sulphur and zinc application on potassium content (%) and uptake (kg ha^{-1}) in seed and stover

The experimental data on potassium (K) content and uptake in seed and stover influenced by different levels of sulphur and zinc was analyzed statistically and is presented and depicted in Table 4.31 and Fig 4.31 and their interaction effects in Table 4.32 and Fig 4.32.

4.3.3.1 Effect of sulphur level

The results presented revealed that sulphur levels recorded significant differences in potassium (K) content and uptake in seed and stover. During the first year of study, 20 kg S ha^{-1} treatment showed significant variation in the potassium (K) content and uptake by the seeds (1.25% and 13.16 kg ha^{-1}) and stover (2.20% and 45.86 kg ha^{-1}) at par with 40 kg S ha^{-1} (1.19% and 12.15 kg ha^{-1}, 2.19% and 39.26 kg ha^{-1}) while control recorded the lowest (1.17% and

8.87 kg ha^{-1}, 2.14% and 30.71 kg ha^{-1}). For the year 2018, similar variation was observed and matched with the pooled data compiled with 20 kg S ha^{-1} recording significant influence on the potassium (K) content and uptake by the seeds (1.36% and 14.26 kg ha^{-1}, 1.31% and 13.71 kg ha^{-1}) and stover (2.20% and 45.78 kg ha^{-1}, 2.20% and 45.85 kg ha^{-1}) while control recorded the lowest content and uptake of potassium in seed (1.18% and 9.04 kg ha^{-1}, 1.17% and 8.95 kg ha^{-1}) and stover (2.08% and 29.82 kg ha^{-1}, 2.11% and 30.29 kg ha^{-1}).

The synergetic effect of sulphur on potassium uptake in the crop is attributed to have resulted in the higher potassium content in seed and stover (Sahebagouda *et al*., 2019). Similar findings were also put forward by Singh *et al*. (2001) who reported increase in P and K uptake with application of sulphur gypsum.

4.3.5.2 Effect of zinc levels

The effect of zinc levels was found to be non-significant in case of K content in seed for both the years and pooled however a significant influence was observed in the potassium content in stover with the application of different levels of zinc. The highest potassium content in stover was seen in 20 kg Zn ha^{-1} (2.21 kg ha^{-1} and 2.21 kg ha^{-1}) at par with 15 kg Zn ha^{-1} (2.19 kg ha^{-1} and 2.18 kg ha^{-1}) in the initial year and pooled. The maximum uptake of potassium was observed with the highest dose of zinc application i.e. 20 kg Zn ha^{-1} in seed (13.16 kg ha^{-1}, 14.79 kg ha^{-1} and 13.97 kg ha^{-1}) and stover (47.57 kg ha^{-1}, 47.61 kg ha^{-1} and 47.61 kg ha^{-1}) for both the years and pooled.

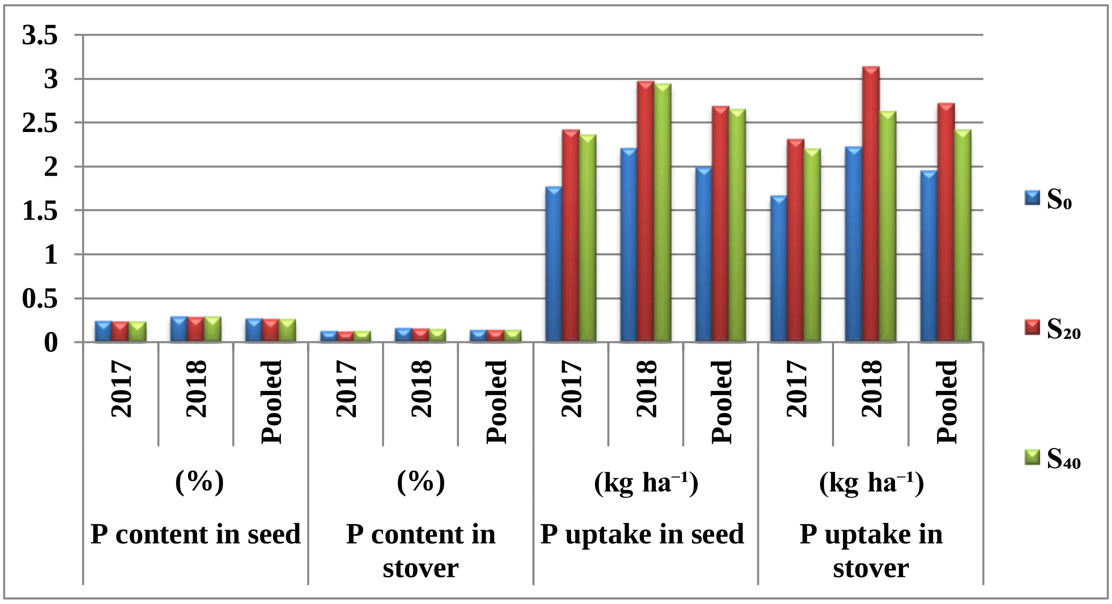
Rathod *et al*. (2017) also reported increase in the uptake of potassium due to the application lime, zinc and boron through the soil and foliar spray along with RDF.

Table 4.29 Effect of sulphur and zinc fertilization for biofortification on phosphorus content (%) and uptake (kg ha^{-1}) in seed and stover at harvest

Treatments	P content in seed (%)			P content in stover (%)			P uptake in seed (kg ha^{-1})			P uptake in stover (kg ha^{-1})		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
S_0	0.24	0.29	0.27	0.119	0.157	0.140	1.77	2.21	1.99	1.67	2.22	1.95
S_{20}	0.23	0.28	0.26	0.113	0.149	0.134	2.42	2.97	2.69	2.31	3.13	2.72
S_{40}	0.23	0.29	0.26	0.123	0.147	0.138	2.36	2.94	2.65	2.20	2.63	2.42
SEm ±	0.003	0.003	0.002	0.003	0.003	0.002	0.09	0.10	0.09	0.11	0.17	0.13
CD (P=0.05)	NS	NS	NS	NS	NS	NS	0.25	0.29	0.26	0.32	0.50	0.39
Zn_0	0.24	0.29	0.27	0.124	0.157	0.143	1.86	2.29	2.07	1.66	2.11	1.88
Zn_5	0.24	0.29	0.27	0.118	0.152	0.139	2.10	2.61	2.36	2.04	2.63	2.34
Zn_{10}	0.23	0.29	0.26	0.119	0.151	0.137	2.16	2.65	2.41	2.07	2.64	2.35
Zn_{15}	0.23	0.29	0.26	0.118	0.149	0.136	2.38	2.98	2.68	2.13	2.78	2.45
Zn_{20}	0.22	0.28	0.26	0.113	0.146	0.132	2.40	3.03	2.71	2.41	3.14	2.77
SEm ±	0.004	0.004	0.003	0.004	0.004	0.003	0.11	0.13	0.12	0.14	0.22	0.17
CD (P=0.05)	NS	NS	NS	NS	NS	NS	0.32	0.37	0.34	0.42	0.64	0.50

Table 4.30 Interaction effects of sulphur and zinc fertilization for biofortification onphosphorus content (%) and uptake(kg ha^{-1}) in seed and stover at harvest

Treatments	P content in seed (%)			P content in stover (%)			P uptake in seed (kg ha^{-1})			P uptake in stover (kg ha^{-1})		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
S_0Zn_0	0.24	0.30	0.27	0.127	0.163	0.147	0.91	1.15	1.02	0.66	0.85	0.76
S_0Zn_5	0.24	0.30	0.27	0.117	0.157	0.140	1.70	2.08	1.89	1.80	2.42	2.11
S_0Zn_{10}	0.24	0.29	0.26	0.123	0.157	0.140	1.80	2.18	1.99	1.88	2.40	2.14
S_0Zn_{15}	0.23	0.29	0.26	0.113	0.157	0.137	2.22	2.81	2.52	1.74	2.48	2.11
S_0Zn_{20}	0.23	0.29	0.26	0.117	0.150	0.137	2.20	2.85	2.52	2.29	2.98	2.63
$S_{20}Zn_0$	0.24	0.29	0.27	0.123	0.153	0.140	2.39	2.85	2.61	2.20	2.78	2.49
$S_{20}Zn_5$	0.23	0.29	0.26	0.110	0.153	0.137	2.33	2.86	2.60	2.14	2.92	2.53
$S_{20}Zn_{10}$	0.23	0.29	0.26	0.113	0.150	0.133	2.32	2.89	2.61	2.20	2.90	2.55
$S_{20}Zn_{15}$	0.23	0.29	0.26	0.113	0.147	0.133	2.50	3.09	2.79	2.34	3.27	2.80
$S_{20}Zn_{20}$	0.22	0.27	0.25	0.103	0.143	0.127	2.57	3.17	2.87	2.67	3.76	3.21
$S_{40}Zn_0$	0.23	0.29	0.26	0.123	0.153	0.143	2.28	2.86	2.57	2.11	2.68	2.40
$S_{40}Zn_5$	0.23	0.29	0.26	0.127	0.147	0.140	2.28	2.89	2.59	2.20	2.56	2.38
$S_{40}Zn_{10}$	0.24	0.29	0.26	0.120	0.147	0.137	2.36	2.87	2.62	2.14	2.62	2.38
$S_{40}Zn_{15}$	0.23	0.28	0.26	0.127	0.143	0.137	2.43	3.03	2.73	2.31	2.59	2.45
$S_{40}Zn_{20}$	0.22	0.28	0.26	0.120	0.143	0.133	2.43	3.07	2.75	2.27	2.70	2.48
SEm ±	0.007	0.007	0.005	0.007	0.007	0.005	0.19	0.22	0.20	0.25	0.38	0.30
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	0.64	0.59	NS	NS	NS



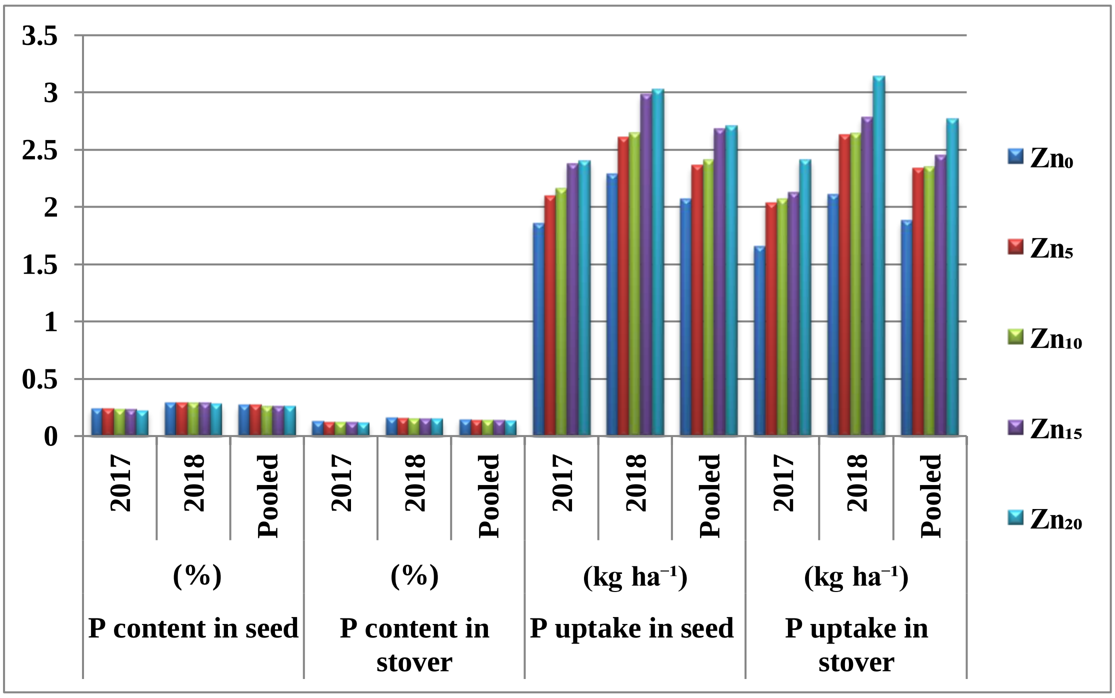


Fig 4.29 Effect of sulphur and zinc fertilization for biofortification on phosphorus content (%) and uptake (kg ha^{-1}) in seed and stover at harvest.

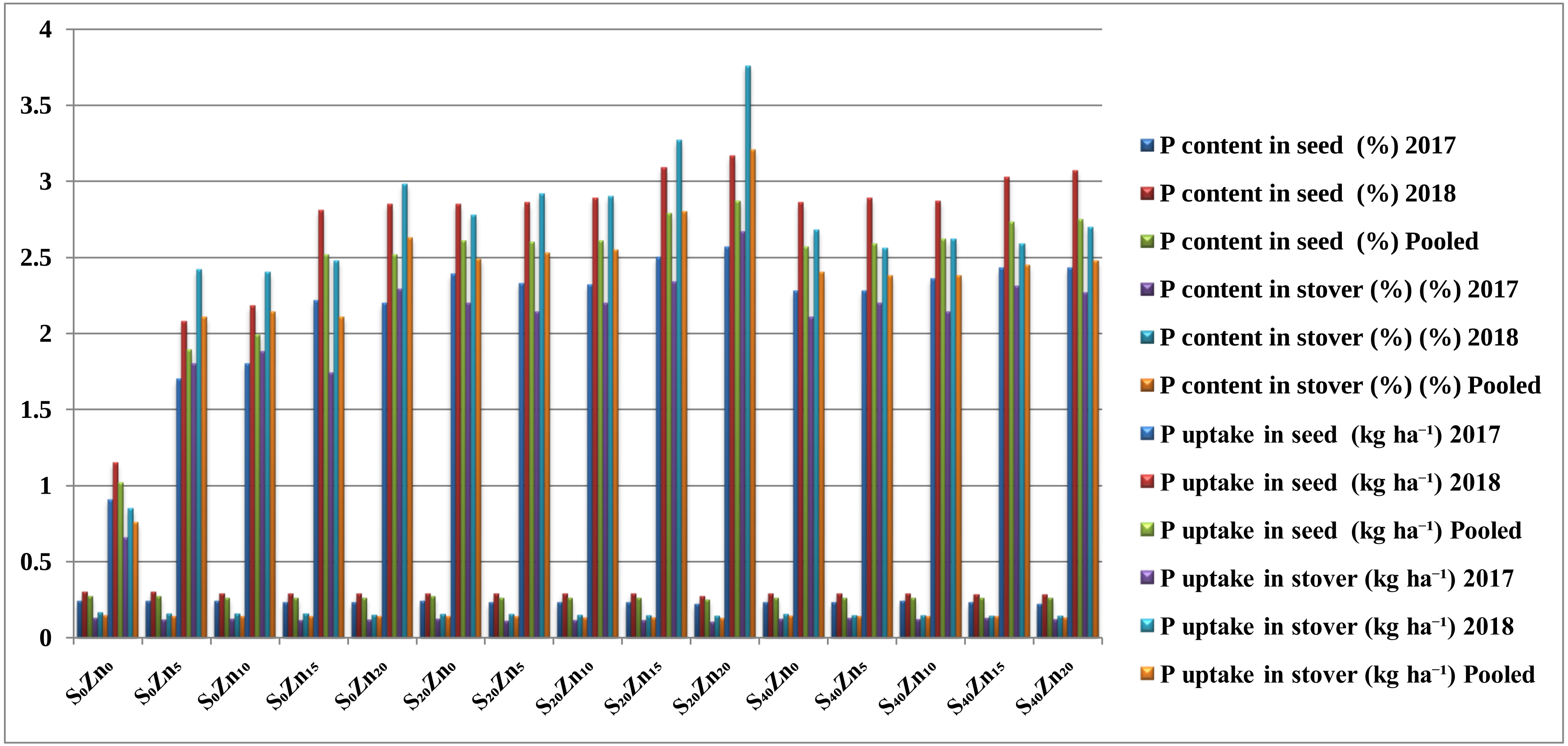


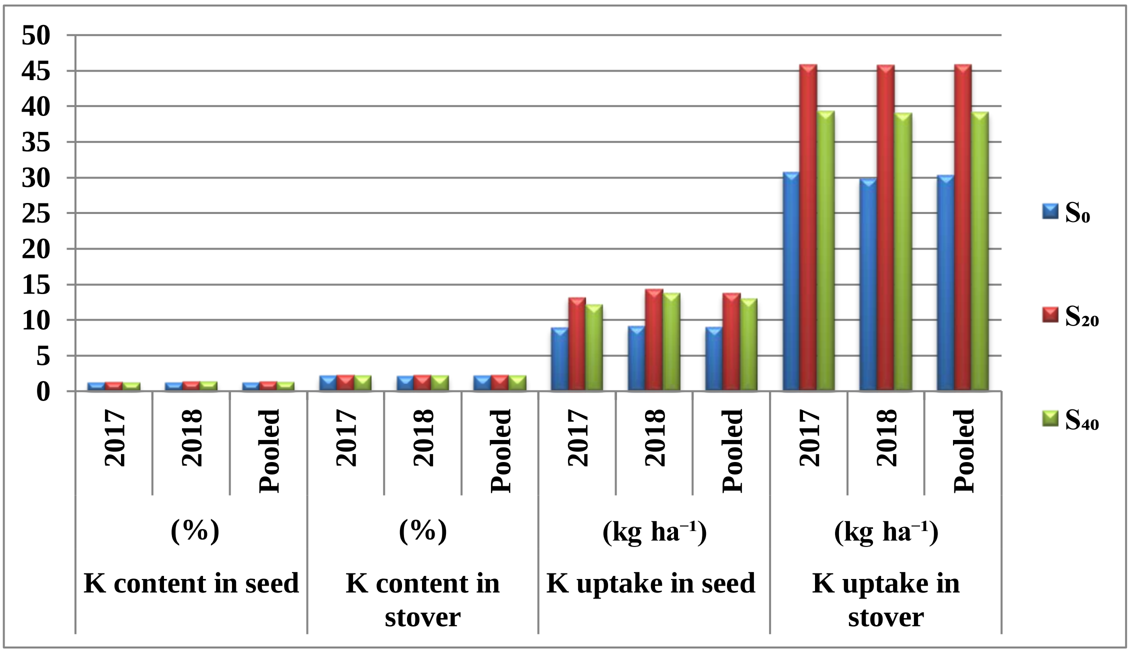
Fig 4.30 Interaction effects of sulphur and zinc fertilization for biofortification on phosphorus content (%) and uptake (kg ha^{-1}) in seed and stover at harvest.

Table 4.31 Effect of sulphur and zinc fertilization for biofortification on potassium content (%) and uptake (kg ha^{-1}) in seed and stover at harvest

Treatments	K content in seed (%)			K content in stover (%)			K uptake in seed (kg ha^{-1})			K uptake in stover (kg ha^{-1})		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
S_0	1.17	1.18	1.17	2.14	2.08	2.11	8.87	9.04	8.95	30.71	29.82	30.29
S_{20}	1.25	1.36	1.31	2.20	2.20	2.20	13.16	14.26	13.71	45.86	45.78	45.85
S_{40}	1.19	1.34	1.27	2.19	2.18	2.19	12.15	13.79	12.97	39.26	39.04	39.19
SEm ±	0.02	0.04	0.02	0.005	0.02	0.01	0.42	0.57	0.47	2.89	2.19	2.21
CD (P=0.05)	0.07	0.11	0.07	0.014	0.05	0.03	1.22	1.65	1.36	8.37	6.34	6.39
Zn_0	1.18	1.22	1.20	2.15	2.11	2.13	9.41	9.80	9.61	29.21	28.76	29.03
Zn_5	1.21	1.24	1.23	2.17	2.13	2.15	10.89	11.28	11.08	37.59	36.92	37.30
Zn_{10}	1.19	1.30	1.25	2.18	2.15	2.17	11.02	12.12	11.57	38.21	37.88	38.09
Zn_{15}	1.20	1.33	1.27	2.19	2.16	2.18	12.49	13.84	13.16	40.46	39.89	40.19
Zn_{20}	1.23	1.38	1.31	2.21	2.21	2.21	13.16	14.79	13.97	47.57	47.61	47.61
SEm ±	0.03	0.05	0.03	0.006	0.02	0.01	0.54	0.73	0.61	2.89	2.82	2.85
CD (P=0.05)	NS	NS	NS	0.018	NS	0.04	1.58	2.13	1.75	8.37	8.18	8.25

Table 4.32 Interaction effects of sulphur and zinc fertilization for biofortification on potassium content (%) and uptake (kg ha^{-1}) in seed and stover at harvest

Treatments	K content in seed (%)			K content in stover (%)			K uptake in seed (kg ha^{-1})			K uptake in stover (kg ha^{-1})		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
S_0Zn_0	1.10	1.07	1.08	2.09	2.06	2.08	4.23	4.03	4.13	10.96	10.76	10.88
S_0Zn_5	1.17	1.10	1.13	2.15	2.07	2.11	8.15	7.75	7.95	33.06	31.80	32.48
S_0Zn_{10}	1.18	1.18	1.18	2.15	2.08	2.12	8.92	8.96	8.94	33.20	32.21	32.76
S_0Zn_{15}	1.19	1.25	1.22	2.16	2.08	2.12	11.32	12.01	11.66	33.62	32.51	33.06
S_0Zn_{20}	1.21	1.28	1.25	2.17	2.11	2.14	11.71	12.45	12.09	42.71	41.81	42.26
$S_{20}Zn_0$	1.22	1.30	1.26	2.17	2.15	2.16	11.96	12.78	12.37	39.23	38.75	39.04
$S_{20}Zn_5$	1.22	1.32	1.27	2.18	2.16	2.17	12.12	13.14	12.63	41.45	41.12	41.33
$S_{20}Zn_{10}$	1.25	1.37	1.31	2.19	2.18	2.19	12.72	13.84	13.28	42.27	42.03	42.22
$S_{20}Zn_{15}$	1.26	1.38	1.32	2.21	2.21	2.21	13.67	14.92	14.29	48.17	47.64	47.90
$S_{20}Zn_{20}$	1.33	1.43	1.38	2.24	2.28	2.26	15.34	16.60	15.97	58.16	59.34	58.79
$S_{40}Zn_0$	1.23	1.28	1.26	2.18	2.12	2.15	12.05	12.58	12.31	37.45	36.78	37.17
$S_{40}Zn_5$	1.25	1.30	1.28	2.18	2.15	2.17	12.40	12.94	12.67	38.26	37.84	38.11
$S_{40}Zn_{10}$	1.16	1.35	1.26	2.19	2.20	2.19	11.41	13.55	12.48	39.15	39.38	39.29
$S_{40}Zn_{15}$	1.17	1.37	1.27	2.20	2.20	2.20	12.48	14.59	13.53	39.60	39.52	39.62
$S_{40}Zn_{20}$	1.15	1.42	1.29	2.23	2.22	2.23	12.42	15.31	13.86	41.84	41.68	41.79
SEm ± CD (P=0.05)	0.05 NS	0.08 NS	0.05 NS	0.01 NS	0.04 NS	0.02 NS	0.94 2.73	1.27 NS	1.05 NS	5.01 NS	4.89 NS	4.93 NS



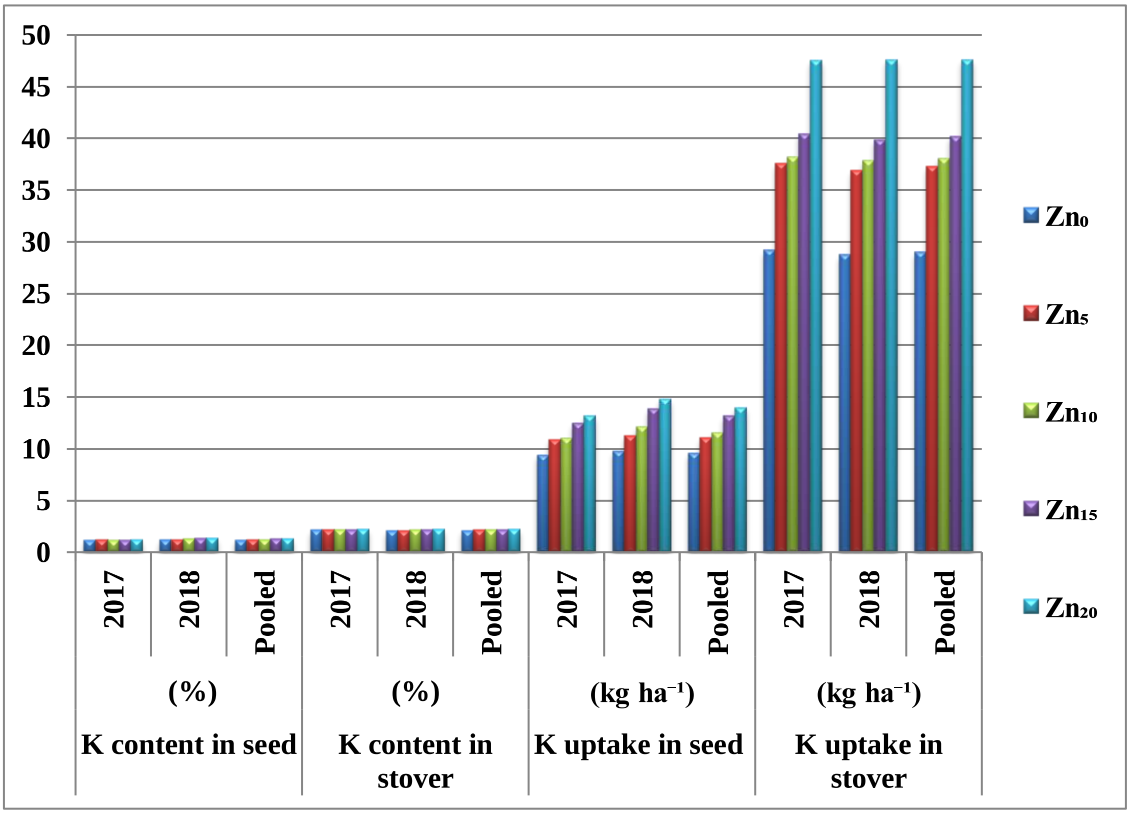


Fig 4.31 Effect of sulphur and zinc fertilization for biofortification on potassium content (%) and uptake (kg ha^{-1}) in seed and stover at harvest.

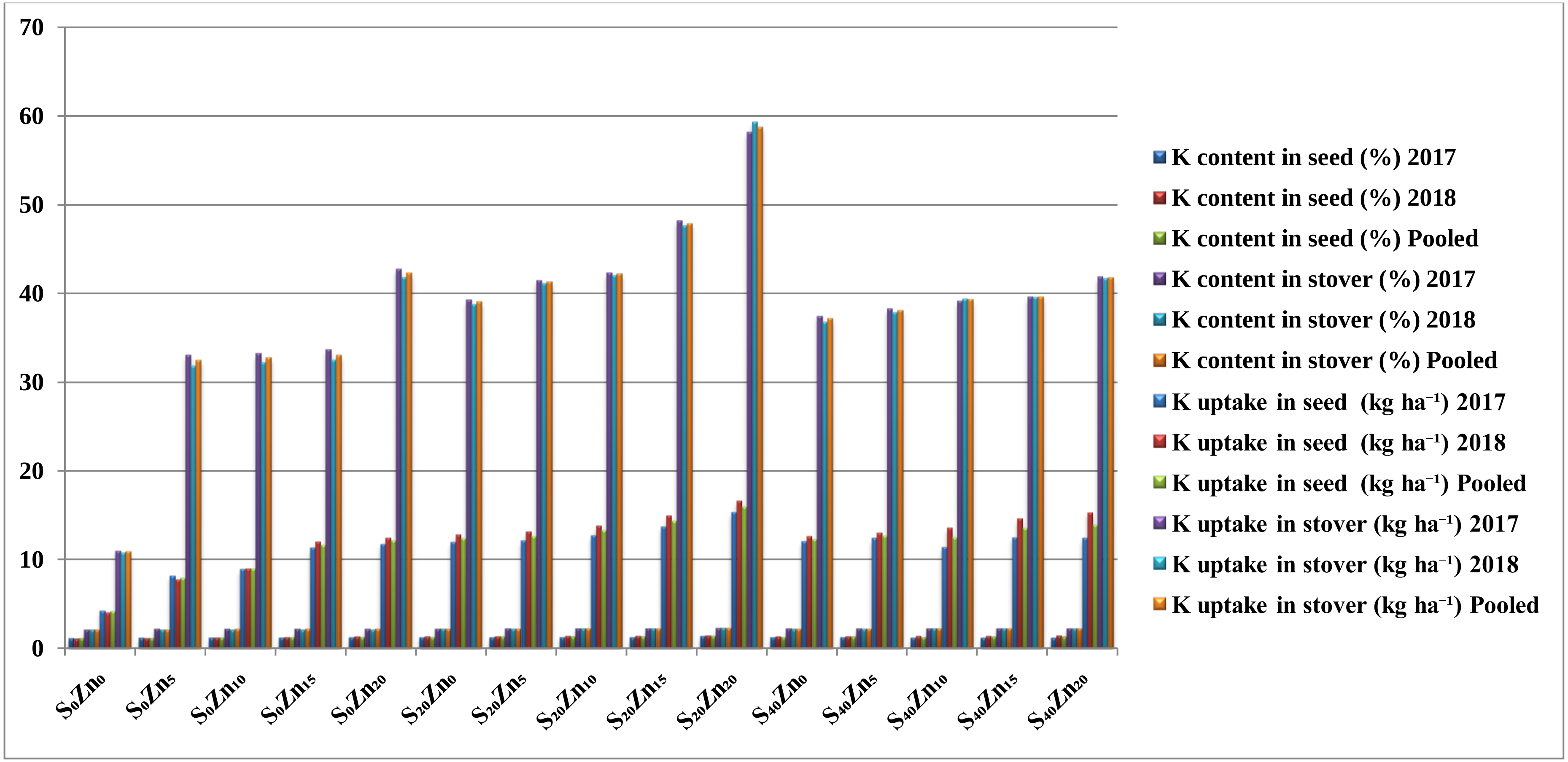


Fig 4.32 Interaction effect of sulphur and zinc fertilization for biofortification on potassium content (%) and uptake(kg ha^{-1}) in seed and stover at harvest.

4.3.5.3 Interaction effect of sulphur and zinc

Interaction effect of sulphur sources and levels exhibited non-significant variation in case of K content and uptake by seed and stover.

4.3.4 Effect of sulphur and zinc application on sulphur content (%) and uptake (kg ha^{-1}) in seed and stover

The experimental data on sulphur content (%) and uptake (kg ha^{-1}) in seed and stover influenced by different levels of sulphur and zinc was analysed statistically and is presented and depicted in Table 4.33 and Fig 4.33 and their interaction effects in Table 4.34 and Fig 4.34.

4.3.4.1 Effect of sulphur level

The data on sulphur levels showed significant variations in sulphur content and its uptake on seed and stover due to the application of different levels of sulphur during both years. A significant increase in the sulphur content and its uptake was recorded with the application of sulphur at 20 kg S ha^{-1} in seed (0.310% and 3.24 kg ha^{-1}, 0.309% and 3.23 kg ha^{-1}) and stover (0.093% and 1.93, 0.10 % and 2.24 kg ha^{-1}) which was at par with 40 kg S ha^{-1} in seed (0.303% and 3.11 kg ha^{-1}, 0.303% and 3.11 kg ha^{-1}) and stover (0.092% and 1.65 kg ha^{-1}, 0.100% and 1.78 kg ha^{-1}). Compared to the sulphur treatments, the control plot recorded lower sulphur content and uptake in seed (0.285 % and 2.16 kg ha^{-1}, 0.292 % and 2.21 kg ha^{-1}) and stover (0.073% and 1.08 kg ha^{-1}, 0.089% and 1.28 kg ha^{-1}) for both the years. The pooled data of both the years recorded similar inference with 20 kg S ha^{-1} (0.303% and 3.11 kg ha^{-1}) recording the highest content and uptake superior over control (0.289% and 1.18 kg ha^{-1}).

The findings were in close conformity with the works carried out by Vaiyapuri *et al.* (2008) and Dhanashree *et al.* (2011) who reported that the highest S uptake was found with the application of sulphur @ 30 kg ha^{-1}.

4.3.4.2 Effect of zinc levels

The sulphur content and uptake in seed and stover showed a notable increase with the application of different levels of zinc. For both years, the highest content and uptake of sulphur was observed in the treatment of 20 kg Zn ha^{-1} in the seed (0.307% and 3.29 kg ha^{-1}, 0.309% and 3.31 kg ha^{-1}) and stover (0.094% and 2.04 kg ha^{-1}, 0.106% and 2.29 kg ha^{-1}). The perusal data revealed that the control treatment recorded the lowest sulphur uptake (0.286% and 2.27 kg ha^{-1}, 0.293% and 2.30 kg ha^{-1}) in seed and stover (0.079% and 1.13 kg ha^{-1}, 0.092% and 1.29 kg ha^{-1}). A similar inference was also observed in the pooled data showing the highest sulphur content and uptake in the treatments of 20 kg Zn ha^{-1} in seed (0.308% and 3.30 kg ha^{-1}) and stover (0.102% and 2.16 kg ha^{-1}).

In line with the above findings, Rathod *et al.* (2017) also reported increase in the sulphur content and uptake with the application of lime, zinc and boron through the soil and foliar spray along with RDF.

4.3.6.3 Interaction effect of sulphur and zinc

No significant influence was observed in the interaction effect of sulphur and zinc on potassium content and its uptake on seed and stover.

.3.5 Effect of sulphur and zinc application on zinc content (mg kg^{-1}) and uptake (g ha^{-1}) in seed and stover

The experimental data on zinc (Zn) content in seed influenced by different levels of sulphur and zinc was analyzed statistically and is presented and depicted in Table 4.35 and Fig 4.35 and their interaction effects in Table 4.36 and Fig 4.36.

4.3.5.1 Effect of sulphur level

From the data generated during the years 2017 and 2018, the application of sulphur @ 20 kg ha^{-1} was observed to increase the zinc content as well as its uptake in the seeds (32.49 mg kg^{-1} and 33.85 g ha^{-1}, 31.06 mg kg^{-1} and 32.43 g ha^{-1}) and stover (21.96 mg kg^{-1} and 45.46 g ha^{-1}, 21.97 mg kg^{-1} and 46.08 g ha^{-1}) over that of control (28.03 mg kg^{-1} and 21.43 g ha^{-1}, 29.13 mg kg^{-1} and 22.17 g ha^{-1}) in seed and stover (18.58 mg kg^{-1} and 26.77g ha^{-1}, 20.04 mg kg^{-1} and 28.96 g ha^{-1}). The pooled data showed a similar trend with 20 kg S ha^{-1} treatment exhibiting higher zinc content and uptake by seeds (31.77 mg kg^{-1} and 33.14 g ha^{-1}) and stover (21.87 mg kg^{-1} and 45.99 g ha^{-1}) at par with 40 kg S ha^{-1} (30.66 mg kg^{-1} and 31.46 g ha^{-1}) in seed and stover (21.81 mg kg^{-1} and 38.80g ha^{-1}) and higher than that of control (28.58 mg kg^{-1} and 21.80g ha^{-1}) in seed and stover (19.32 mg kg^{-1} and 27.87 g ha^{-1}).

Choudhary *et al*. (2014) also reported an increase in zinc contents with increasing level of sulphur up to 30 kg S ha^{-1}

4.3.5.2 Effect of zinc levels

The zinc content and uptake in seed increased with increasing levels of zinc. For both years, the highest content and uptake of zinc was observed in the treatment of 20 kg Zn ha^{-1} in the seed (32.30 mg kg^{-1} and 34.68 g ha^{-1}, 30.92 mg kg^{-1} and 33.14 g ha^{-1}) and stover (23 mg kg^{-1} and 49.16 g ha^{-1}, 22.43 mg kg^{-1} and 48.32 g ha^{-1}). The perusal data revealed that the control treatment recorded the lowest zinc uptake (28.74 mg kg^{-1} and 23.04 g ha^{-1}, 28.79 mg kg^{-1} and 22.79 g ha^{-1}) in seed and stover (18.91 mg kg^{-1} and 25.89 g ha^{-1}, 19.96 mg kg^{-1} and 27.85 g ha^{-1}). A similar inference was also observed in the pooled data showing the highest zinc content and uptake in the treatments of 20 kg Zn ha^{-1} in seed (31.61 mg kg^{-1} and 33.91 g ha^{-1}) and stover (22.60 mg kg^{-1} and 48.99 g ha^{-1}).

The increment in the zinc content and uptake by the plant may be attributed to increased availability of levels of zinc leading to higher metabolic and photosynthesis activity in the crop and thereby aiding in higher content and uptake of zinc by the crops (Raghuwanshi *et al*. 2017). The findings were in line with the previous works of Mall *et al*. (2017) and Kulhare *et al*. (2014) who reported higher zinc uptake with Zn application. Awlad *et al*. (2003) also reported increase in zinc contents with an increasing level of zinc up to 20 kg Zn ha^{-1}. The increase in zinc uptake may be due to the synergistic interaction effect of sulphur and zinc as reported by Sahebagouda *et al*. (2019).

4.3.5.3 Interaction effect of sulphur and zinc

No significant influence was observed in the interaction effect of sulphur and zinc on zinc content and uptake by seed and stover.

4.4 Effect of sulphur and zinc application on soil pH, organic carbon (%) and nutrient - N, P, K, S and Zn (kg ha^{-1}) content of soil after harvest

The experimental data on soil organic carbon (%), pH and nutrient - N, P, K, S and Zn (kg ha^{-1}) content of soil influenced by different levels of sulphur and zinc was analyzed statistically and is presented and depicted in Table 4.37 and their interaction effects in Table 4.38.

Based on the data presented, the pH 1:2.5 (soil water ratio), organic carbon (%) of soil did not vary significantly due to different levels of sulphur and zinc application for either of the years and pooled.

4.4.1 Available soil Nitrogen (kg ha^{-1})

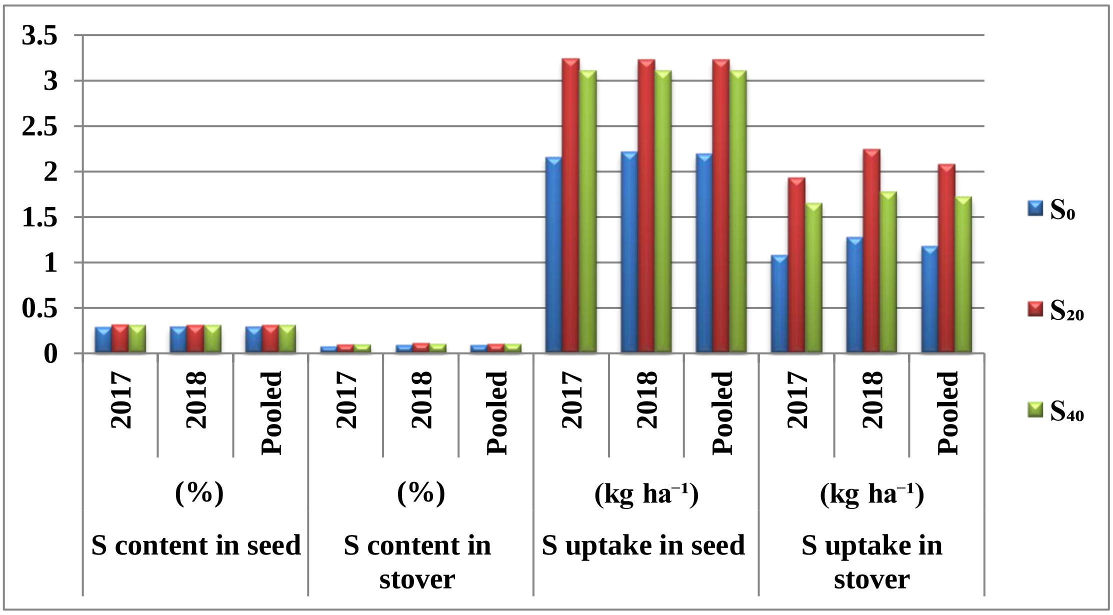
The data pertaining to available soil Nitrogen (kg ha^{-1}) after harvest of the soybean crop was analyzed statistically and presented in Table 4.39 and their interaction effects in Table 4.40.

Table 4.33 Effect of sulphur and zinc fertilization for biofortification on S content (%) and uptake (kg ha^{-1}) in seed and stover at harvest

Treatments	S content in seed (%)			S content in stover (%)			S uptake in seed (kg ha^{-1})			S uptake in stover (kg ha^{-1})		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
S_0	0.285	0.292	0.289	0.073	0.089	0.084	2.16	2.21	2.19	1.08	1.28	1.18
S_{20}	0.310	0.309	0.309	0.093	0.107	0.102	3.24	3.23	3.23	1.93	2.24	2.08
S_{40}	0.303	0.303	0.303	0.092	0.100	0.099	3.11	3.11	3.11	1.65	1.78	1.72
SEm ±	0.002	0.003	0.002	0.002	0.002	0.002	0.10	0.10	0.10	0.09	0.11	0.10
CD (P=0.05)	0.007	0.008	0.027	0.007	0.007	0.005	0.30	0.30	0.30	0.26	0.32	0.28
Zn_0	0.286	0.293	0.290	0.079	0.092	0.088	2.27	2.30	2.29	1.13	1.29	1.21
Zn_5	0.300	0.298	0.299	0.082	0.096	0.091	2.71	2.69	2.70	1.43	1.65	1.54
Zn_{10}	0.302	0.302	0.302	0.084	0.100	0.094	2.79	2.79	2.79	1.49	1.77	1.63
Zn_{15}	0.302	0.304	0.303	0.090	0.100	0.099	3.14	3.16	3.15	1.66	1.84	1.75
Zn_{20}	0.307	0.309	0.308	0.094	0.106	0.102	3.29	3.31	3.30	2.04	2.29	2.16
SEm ±	0.003	0.004	0.003	0.003	0.003	0.002	0.13	0.13	0.13	0.12	0.14	0.12
CD (P=0.05)	0.009	0.010	0.009	0.008	0.009	0.007	0.38	0.38	0.38	0.34	0.41	0.36

Table 4.34 Interaction effects of sulphur and zinc fertilization for biofortification on sulphur content (%) and uptake (kg ha^{-1}) in seed and stover at harvest

Treatments	S content in seed (%)			S content in stover (%)			S uptake in seed (kg ha^{-1})			S uptake in stover (kg ha^{-1})		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
S_0Zn_0	0.263	0.287	0.277	0.063	0.083	0.077	0.99	1.07	1.03	0.33	0.43	0.38
S_0Zn_5	0.283	0.283	0.283	0.067	0.083	0.077	1.98	1.98	1.98	1.03	1.29	1.16
S_0Zn_{10}	0.297	0.297	0.297	0.073	0.093	0.087	2.25	2.25	2.25	1.12	1.44	1.28
S_0Zn_{15}	0.290	0.297	0.293	0.080	0.090	0.090	2.79	2.84	2.81	1.25	1.40	1.32
S_0Zn_{20}	0.290	0.297	0.293	0.083	0.093	0.090	2.81	2.88	2.85	1.65	1.83	1.74
$S_{20}Zn_0$	0.303	0.303	0.303	0.090	0.103	0.097	2.99	2.99	2.99	1.63	1.87	1.75
$S_{20}Zn_5$	0.313	0.307	0.310	0.090	0.103	0.097	3.12	3.06	3.09	1.67	1.92	1.80
$S_{20}Zn_{10}$	0.307	0.307	0.307	0.087	0.107	0.100	3.08	3.08	3.08	1.68	2.08	1.88
$S_{20}Zn_{15}$	0.310	0.310	0.310	0.097	0.107	0.107	3.34	3.34	3.34	2.07	2.29	2.18
$S_{20}Zn_{20}$	0.317	0.317	0.317	0.100	0.117	0.110	3.66	3.66	3.66	2.60	3.04	2.82
$S_{40}Zn_0$	0.290	0.290	0.290	0.083	0.090	0.090	2.84	2.84	2.84	1.44	1.55	1.50
$S_{40}Zn_5$	0.303	0.303	0.303	0.090	0.100	0.100	3.02	3.02	3.02	1.59	1.75	1.67
$S_{40}Zn_{10}$	0.303	0.303	0.303	0.093	0.100	0.097	3.02	3.02	3.02	1.66	1.79	1.73
$S_{40}Zn_{15}$	0.307	0.307	0.307	0.093	0.103	0.100	3.30	3.30	3.30	1.68	1.83	1.76
$S_{40}Zn_{20}$	0.313	0.313	0.313	0.100	0.107	0.107	3.40	3.40	3.40	1.87	1.98	1.93
SEm ±	0.005	0.006	0.006	0.005	0.005	0.004	0.23	0.23	0.23	0.20	0.24	0.21
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS



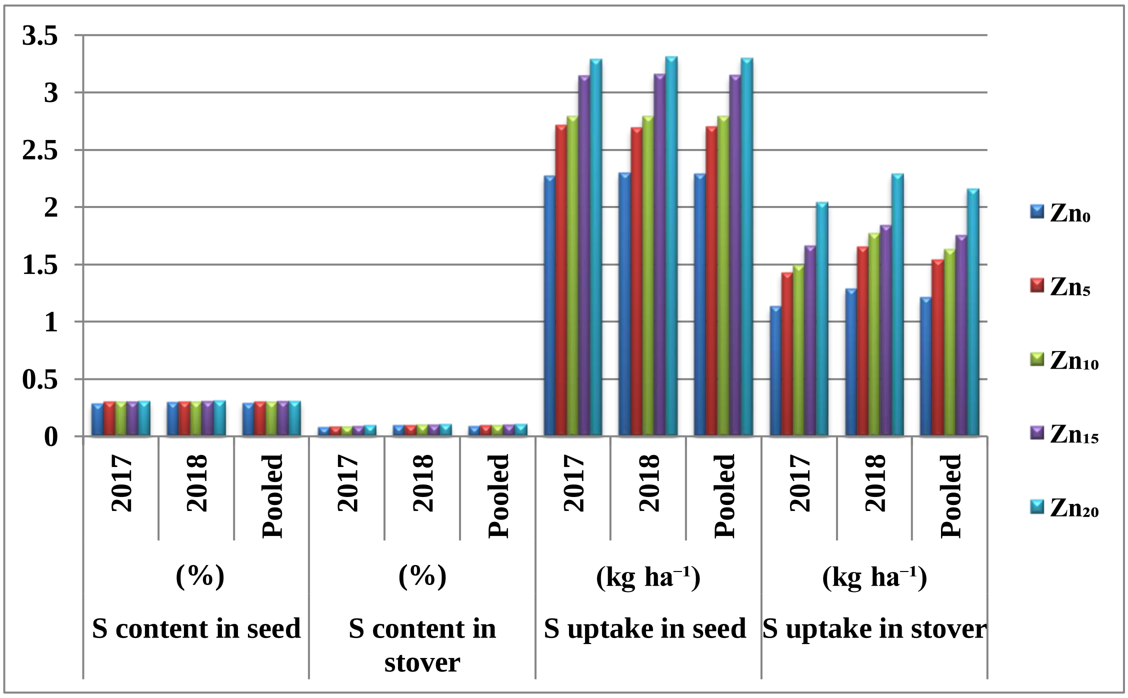


Fig 4.33 Effect of sulphur and zinc fertilization for biofortification on S content (%) and uptake (kg ha^{-1}) in seed and stover at harvest.

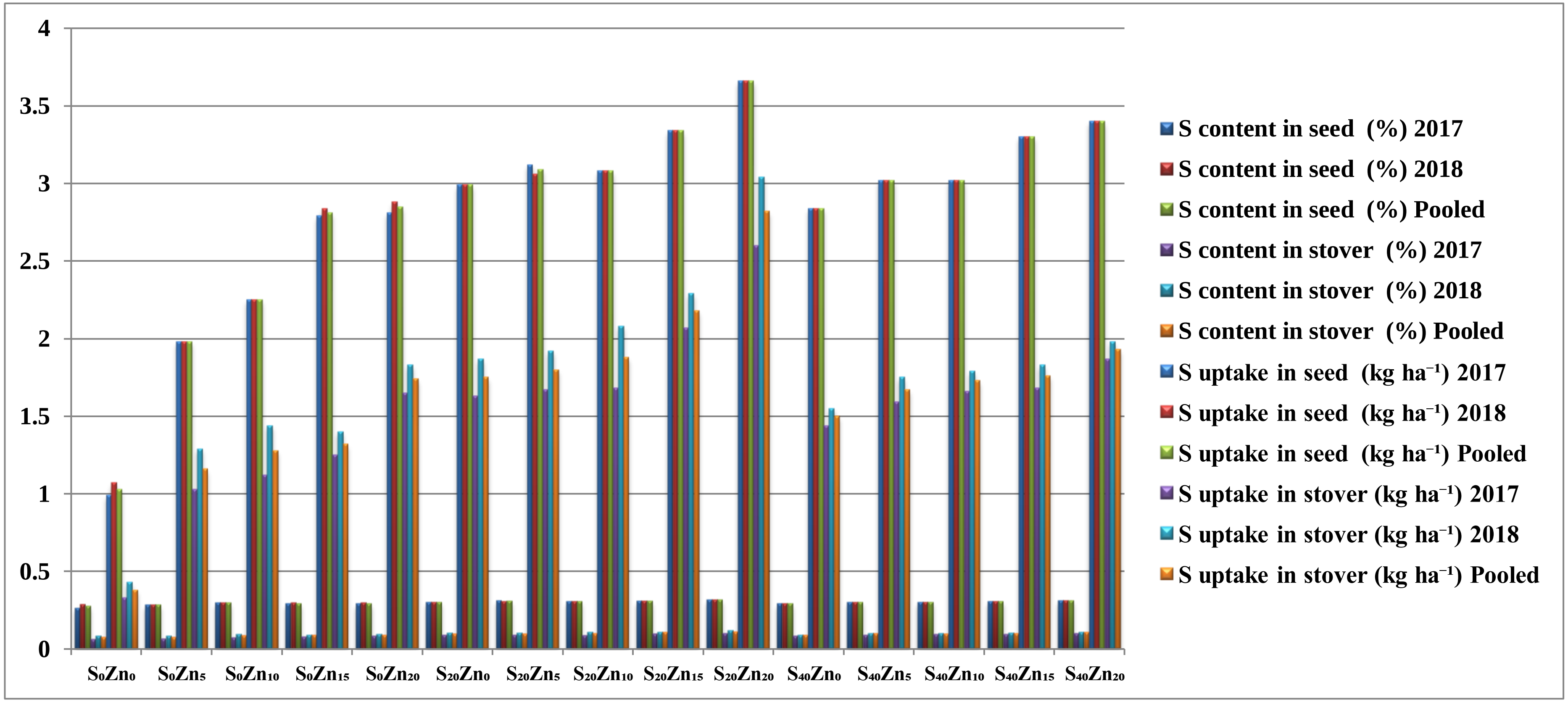


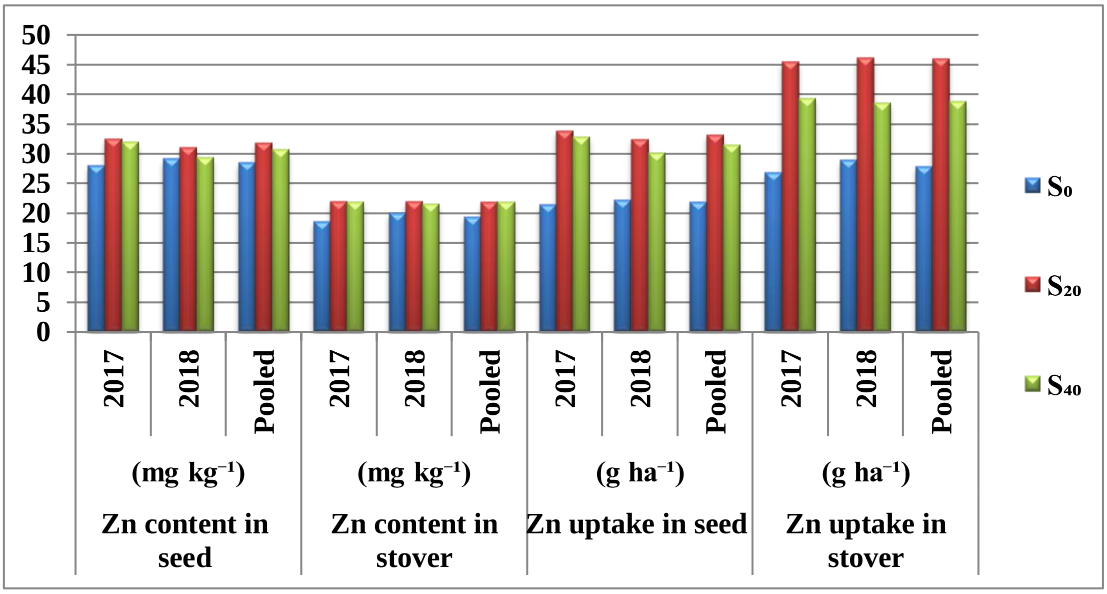
Fig 4.33 Effect of sulphur and zinc fertilization for biofortification on S content (%) and uptake (kg ha^{-1}) in seed and stover at harvest

Table 4.35 Effect of sulphur and zinc fertilization for biofortification on zinc content (mg kg^{-1}) and uptake (g ha^{-1}) in seed and stover at harvest

Treatments	Zn content in seed (mg kg^{-1})			Zn content in stover (mg kg^{-1})			Zn uptake in seed (g ha^{-1})			Zn uptake in stover (g ha^{-1})		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
S_0	28.03	29.13	28.58	18.58	20.04	19.32	21.43	22.17	21.8	26.77	28.96	27.87
S_{20}	32.49	31.06	31.77	21.96	21.97	21.87	33.85	32.43	33.14	45.46	46.08	45.99
S_{40}	31.94	29.37	30.66	21.88	21.54	21.81	32.81	30.12	31.46	39.35	38.58	38.8
SEm ±	0.32	0.24	0.23	0.45	0.27	0.28	1.05	1.00	1.01	2.00	2.19	2.00
CD (P=0.05)	0.93	0.69	0.66	1.30	0.78	0.82	3.04	2.88	2.92	5.79	6.35	5.78
Zn_0	28.74	28.79	28.77	18.91	19.96	19.44	23.04	22.79	22.92	25.89	27.85	26.87
Zn_5	30.30	29.50	29.90	20.21	20.7	20.46	27.53	26.43	26.98	35.25	35.94	35.6
Zn_{10}	31.18	29.66	30.43	20.49	21.12	20.81	28.92	27.35	28.13	36.32	36.99	36.66
Zn_{15}	31.58	30.39	30.99	21.42	21.7	21.68	32.65	31.46	32.05	39.35	40.26	39.63
Zn_{20}	32.30	30.92	31.61	23	22.43	22.6	34.68	33.14	33.91	49.16	48.32	48.99
SEm ±	0.41	0.31	0.29	0.58	0.35	0.36	1.36	1.28	1.3	2.58	2.83	2.58
CD (P=0.05)	1.20	0.89	0.85	1.68	1.00	1.06	3.93	3.72	3.77	7.48	8.2	7.47

Table 4.36 Interaction effects of sulphur and zinc fertilization for biofortification on zinc content (mg kg^{-1}) and uptake (g ha^{-1}) in seed and stover at harvest

Treatments	Zn content in seed (mg kg^{-1})			Zn content in stover (mg kg^{-1})			Zn uptake in seed (g ha^{-1})			Zn uptake in stover (g ha^{-1})		
	2017	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
S_0Zn_0	25.43	26.90	26.17	17.69	18.21	17.95	9.58	10.11	9.85	9.25	9.53	9.39
S_0Zn_5	26.81	29.86	28.33	18.33	19.29	18.82	18.73	20.91	19.82	28.23	29.71	28.97
S_0Zn_{10}	28.63	28.99	28.81	18.36	20.46	19.42	21.70	22.00	21.85	28.34	31.36	29.85
S_0Zn_{15}	29.02	29.69	29.36	19.15	21.07	20.11	27.78	28.47	28.12	29.94	32.75	31.34
S_0Zn_{20}	30.27	30.23	30.25	19.38	21.17	20.28	29.38	29.33	29.35	38.10	41.45	39.77
$S_{20}Zn_0$	30.69	29.99	30.34	19.55	20.98	20.27	30.15	29.46	29.81	35.32	37.99	36.65
$S_{20}Zn_5$	32.56	30.02	31.29	20.97	21.55	21.26	32.50	29.95	31.23	40.04	40.54	40.29
$S_{20}Zn_{10}$	32.66	31.05	31.86	21.57	21.58	21.58	32.70	31.15	31.92	42.14	41.69	41.92
$S_{20}Zn_{15}$	32.98	31.77	32.37	21.80	22.24	22.02	35.20	34.13	34.66	45.47	49.08	47.28
$S_{20}Zn_{20}$	33.55	32.45	33.00	25.93	23.52	24.22	38.69	37.43	38.06	64.32	61.11	63.79
$S_{40}Zn_0$	30.11	29.49	29.80	19.51	20.71	20.11	29.38	28.81	29.10	33.09	36.03	34.56
$S_{40}Zn_5$	31.53	28.62	30.08	21.32	21.27	21.30	31.35	28.45	29.90	37.47	37.58	37.52
$S_{40}Zn_{10}$	32.26	28.95	30.61	21.55	21.31	21.43	32.36	28.89	30.63	38.49	37.93	38.21
$S_{40}Zn_{15}$	32.75	29.70	31.23	23.31	21.81	22.89	34.98	31.78	33.38	42.63	38.96	40.28
$S_{40}Zn_{20}$	33.07	30.08	31.58	23.69	22.60	23.31	35.97	32.67	34.32	45.07	42.38	43.41
SEm ±	0.72	0.53	0.51	1.00	0.60	0.63	2.35	2.23	2.26	4.47	4.90	4.46
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	6.45	NS	NS	NS	NS



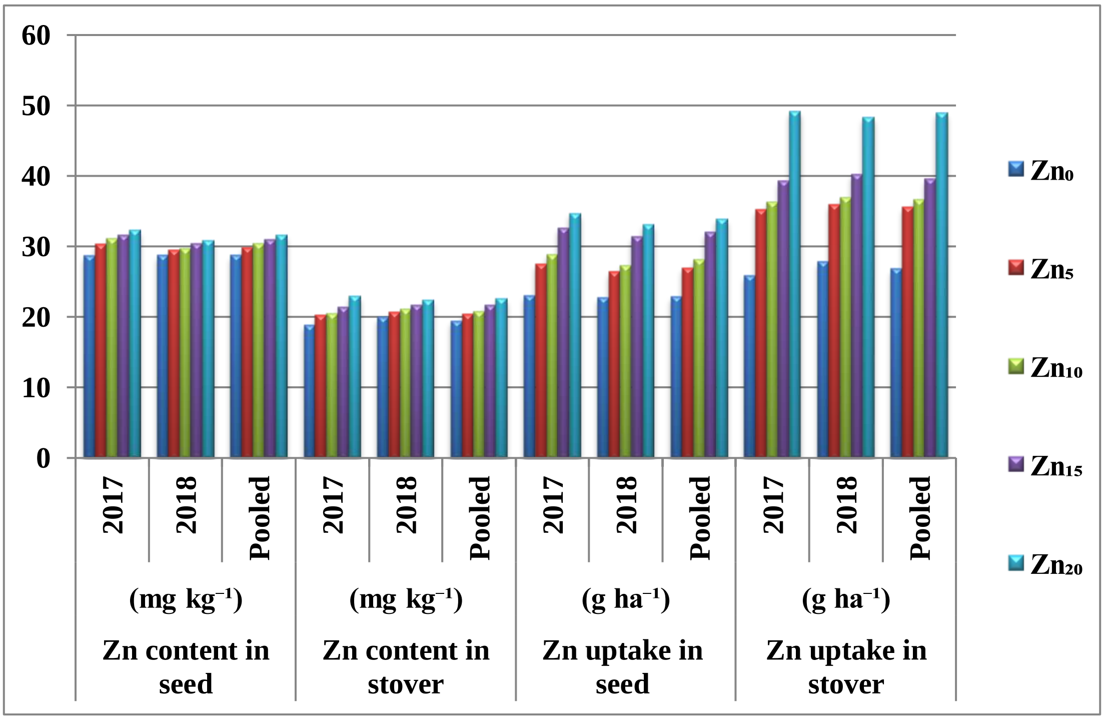


Fig 4.35 Effect of sulphur and zinc fertilization for biofortification on zinc content (mg kg^{-1}) and uptake (g ha^{-1}) in seed and stoverat harvest.

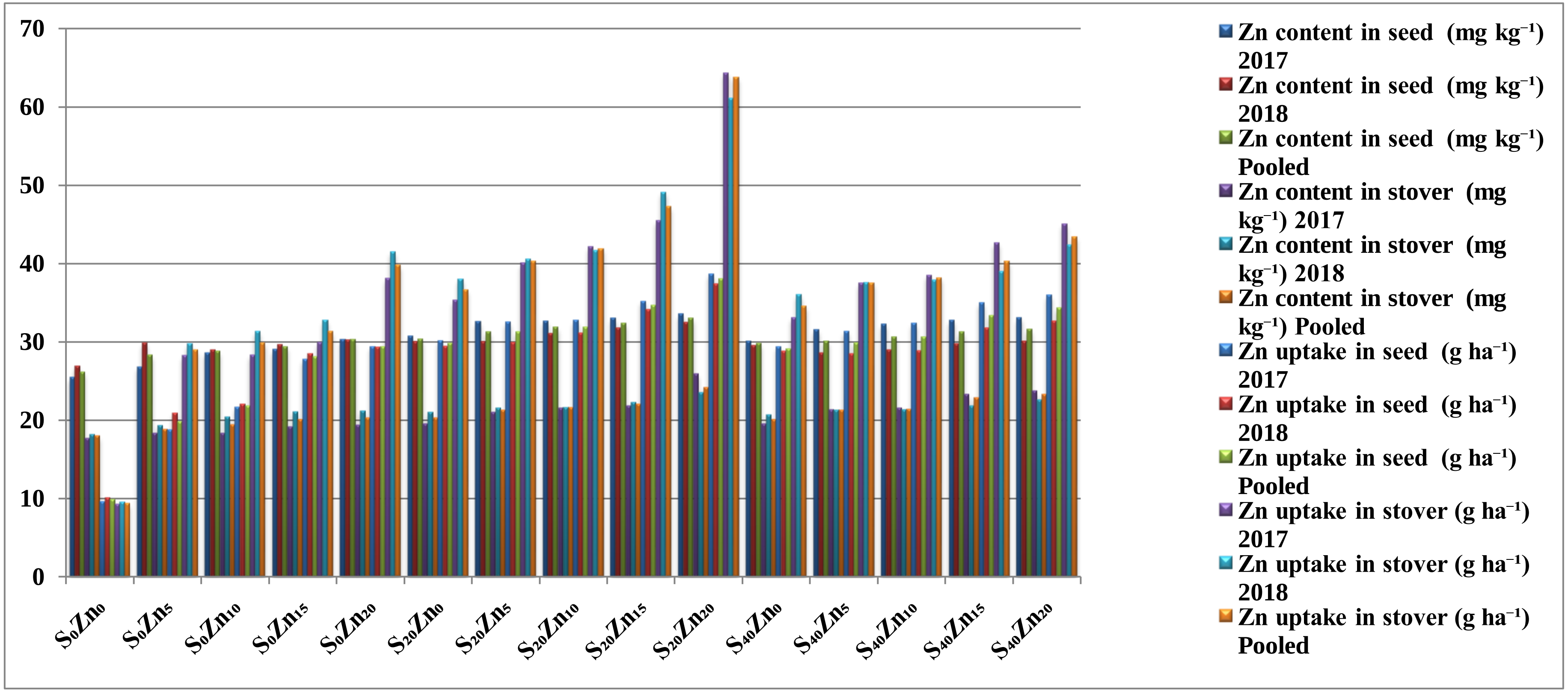


Fig 4.36 Interaction effect of sulphur and zinc fertilization for biofortification on zinc content (mg kg^{-1}) and uptake (g ha^{-1}) in seed and stover at harvest

4.4.1.1 Effect of sulphur level

Among the different levels of sulphur, the highest N remained in the treatment of 20 kg S ha^{-1} (354.61 kg ha^{-1}and 351.14 kg ha^{-1}) which was found to be at par with 40 kg S ha^{-1} (350.91 kg ha^{-1}and 347.90 kg ha^{-1}) while a lower available N content was seen in the control plot (335.79 kg ha^{-1}and 336.43 kg ha^{-1}) for both the years of experimentation. The pooled data replicated similar results to the above data and showed the highest N content in soil in 20 kg S ha^{-1} (353.21 kg ha^{-1}) while control recorded the lowest (336.11 kg ha^{-1}).

The above findings were in partial agreement with the works carried out by Wasmatkar *et al*. (2002) who reported a significant effect on the uptake of N, P, K, S and Zn at harvest by addition of 15 kg ha^{-1} sulphur.

4.4.1.2 Effect of zinc levels

The available soil Nitrogen was not significantly influenced by the different levels of zinc.

4.4.1.3 Interaction effect of sulphur and zinc

No interaction effect could be observed between the different levels of sulphur and zinc on the available soil nitrogen.

4.4.2 Available soil phosphorus (kg ha^{-1})

The data pertaining to available soil phosphorus (kg ha^{-1}) after harvest of the soybean crop was analyzed statistically and presented in Table 4.39 and their interaction effects in Table 4.40.

4.4.2.1 Effect of sulphur level

Based on the data, the available phosphorus content in soil was found to decrease with the application of 20 kg S ha^{-1} (18.82 kg ha^{-1}, 16.43 kg ha^{-1} and

17.62 kg ha^{-1}). The higher S content of (21.13 kg ha$^{-1,}$ 20.53 kg ha^{-1} and 21.13 kg ha^{-1}) was recorded in control for both the years and pooled.

A similar inference to the findings was also concluded by Gajghane *et al*., (2015) who reported the lower content of phosphorus in soil with sulphur application due to the antagonistic effect between sulphur and phosphorus.

4.4.2.2 Effect of zinc levels

The available soil phosphorus was not significantly influenced by the different levels of zinc.

4.4.2.3 Interaction effect of sulphur and zinc

The interaction effect of sulphur and zinc did not show any significant influence on the available soil phosphorus.

4.4.3 Available soil potassium (kg ha^{-1})

The data pertaining to available soil potassium (kg ha^{-1}) after harvest of the soybean crop was analysed statistically and presented in Table 4.38 and their interaction effects in Table 4.39.

4.4.3.1 Effect of sulphur level

The available potassium in soil was found to show the highest content with the application of 20 kg S ha^{-1} (258.81 kg ha^{-1} and 253.88 kg ha^{-1}) as compared to the other sulphur treatments (0 S kg ha^{-1} and 40 S kg ha^{-1}) for either of the two years of study. The pooled data showed a similar trend with the highest and lowest potassium in content in soil recorded in 20 kg S ha^{-1} (256.35 kg ha^{-1}) and control (229.03 kg ha^{-1}) respectively. The above findings were in partial conformity with the findings of Gajghane *et al*. (2015) who reported an increase in the potassium content in soil with the application of 30 kg S ha^{-1} in mustard.

4.4.3.2 Effect of zinc levels

The different levels of zinc did not have any significant effect on soil available potassium.

4.4.3.3 Interaction effect of sulphur and zinc

No significant influence was established between the interaction effect of sulphur and zinc.

4.4.4 Available soil sulphur (kg ha^{-1})

The data pertaining to available soil sulphur (kg ha^{-1}) after harvest of the soybean crop was analyzed statistically and presented in Table 4.39 and their interaction effects in Table 4.40.

4.4.4.1 Effect of sulphur level

The different levels of sulphur significantly influence the available sulphur in the soil. There was an increment in the sulphur content in soil and significantly higher available sulphur content in soil was recorded with 20 kg S ha^{-1} (19.18 kg ha^{-1}and 21.46 kg ha^{-1}) while control recorded the lowest (16.60 kg ha^{-1} and 19.45 kg ha^{-1}) in both the years. The pooled data also showed the highest soil sulphur content in soil with the application of 20 kg S ha^{-1} (20.33 kg ha^{-1}) at par with that of 40 kg S ha^{-1} (20.16 kg ha^{-1}) and superior over control (18.02 kg ha^{-1}).

An increase in the sulphur levels influences the S status in the soil and the application of sulphur fertilizer is known to increase the available S status of soils (Dhage *et al.* 2014).

4.4.4.2 Effect of zinc levels

The soil available sulphur was not significantly influenced by the different levels of zinc.

4.4.4.3 Interaction effect of sulphur and zinc

There was no significant influence established between the interaction effect of sulphur and zinc on soil sulphur content.

4.4.5 Available soil zinc (mg kg^{-1})

The data pertaining to available soil zinc (mg kg^{-1}) after harvest of the soybean crop was analyzed statistically and presented in Table 4.39 and their interaction effects in Table 4.40.

4.4.5.1 Effect of sulphur level

The sulphur levels had a significant influence influenced on available zinc content in the soil after harvest of the crop. For both the years of experiments, among the different levels of sulphur, a higher available Zn content was recorded in the treatment of 20 kg S ha^{-1} (0.68 mg kg^{-1} and 0.69 mg kg^{-1}) at par with 40 kg S ha^{-1} (0.66 mg kg^{-1} and 0.67 mg kg^{-1}) data while a lower available Zn content was seen in the control plot (0.49 mg kg^{-1} and 0.57 mg kg^{-1}). The pooled data showed a similar trend with 20 kg S ha^{-1} (0.69 mg kg^{-1}) recording the highest zinc content in soil after harvest and control the lowest (0.53 mg kg^{-1})

4.4.5.2 Effect of zinc levels

Based on the data, the zinc content in soil increased with the increasing levels of zinc over control (0 kg Zn ha^{-1}). In the first year, a significant increase in the zinc content was observed with the application of 20 kg Zn ha^{-1} (0.69 mg kg^{-1}) while the lowest was recorded in control (0.51 mg kg^{-1}). In the subsequent year, control recorded the lowest zinc content (0.59 mg kg^{-1}) while 20 kg Zn ha^{-1} (0.70 mg kg^{-1}) recorded the highest. The pooled data also showed a similar trend with 20 kg Zn ha^{-1} (0.70 mg kg^{-1}) recording higher zinc content at par with 15 kg Zn ha^{-1} (0.67 mg kg^{-1}) while control recorded the lowest (0.55 mg kg^{-1}).

The above findings were in agreement with the work done by Rohini *et al*. 2020 and Kumar and Singh (1979) who reported increasing levels of Zn significantly increased the total Zn content in soil over control.

4.4.5.3 Interaction effect of sulphur and zinc

No significant influence was established between the interaction effect of sulphur and zinc on soil zinc content.

4.5 Production economics

4.5.1 Total cost of cultivation

The prices of the inputs that were prevailing at the time of their use were considered for working out the economics of soybean.

1. Labour charges
2. Seeds
3. Fertilizers
4. Plant protection chemicals
5. Miscellaneous (marketing charges, etc.)

4.5.2 Net returns

The net return per hectare was calculated by deducting the cost of cultivation from gross returns per hectare.

Table 4.37 Effect of sulphur and zinc fertilization for biofortification on soil nutrient uptake at harvest

Treatments	Soil nutrient uptake					
	Soil pH			Organic carbon (%)		
	2017	2018	Pooled	2017	2018	Pooled
S_0	4.49	4.59	4.54	1.51	1.46	1.49
S_{20}	4.58	4.59	4.59	1.51	1.55	1.53
S_{40}	4.53	4.60	4.57	1.57	1.58	1.58
SEm ±	0.03	0.03	0.02	0.04	0.04	0.03
CD (P=0.05)	NS	NS	NS	NS	NS	NS
Zn_0	4.48	4.54	4.51	1.47	1.49	1.48
Zn_5	4.50	4.68	4.59	1.58	1.55	1.56
Zn_{10}	4.54	4.57	4.56	1.54	1.56	1.55
Zn_{15}	4.51	4.59	4.55	1.50	1.48	1.49
Zn_{20}	4.63	4.60	4.62	1.56	1.57	1.57
SEm ±	0.04	0.04	0.03	0.05	0.05	0.03
CD (P=0.05)	NS	NS	NS	NS	NS	NS

Table 4.38 Interaction effects of sulphur and zinc fertilization for biofortification on soil nutrient status at harvest

Treatments	Soil nutrient status					
	Soil pH			Organic carbon (%)		
	2017	2018	Pooled	2017	2018	Pooled
S_0Zn_0	4.43	4.63	4.53	1.30	1.37	1.34
S_0Zn_5	4.43	4.77	4.60	1.57	1.42	1.50
S_0Zn_{10}	4.57	4.53	4.55	1.54	1.56	1.55
S_0Zn_{15}	4.47	4.57	4.52	1.47	1.42	1.45
S_0Zn_{20}	4.53	4.47	4.50	1.65	1.53	1.59
$S_{20}Zn_0$	4.47	4.47	4.47	1.52	1.53	1.53
$S_{20}Zn_5$	4.53	4.63	4.58	1.48	1.55	1.52
$S_{20}Zn_{10}$	4.63	4.57	4.60	1.47	1.45	1.46
$S_{20}Zn_{15}$	4.57	4.60	4.58	1.60	1.55	1.58
$S_{20}Zn_{20}$	4.70	4.70	4.70	1.50	1.66	1.58
$S_{40}Zn_0$	4.53	4.53	4.53	1.58	1.57	1.58
$S_{40}Zn_5$	4.53	4.63	4.58	1.68	1.67	1.68
$S_{40}Zn_{10}$	4.43	4.60	4.52	1.61	1.67	1.64
$S_{40}Zn_{15}$	4.50	4.60	4.55	1.42	1.48	1.45
$S_{40}Zn_{20}$	4.67	4.63	4.65	1.54	1.53	1.54
SEm ±	0.07	0.07	0.05	0.09	0.08	0.06
CD (P=0.05)	NS	NS	NS	NS	NS	NS

Table 4.39 Effects of sulphur and zinc fertilization for biofortification on soil nutrient status at harvest

Treatments	Soil nutrient status														
	Available Nitrogen ($kg\ ha^{-1}$)			Available Phosphorus ($kg\ ha^{-1}$)			Available Potassium ($kg\ ha^{-1}$)			Available Sulphur ($kg\ ha^{-1}$)			Available Zinc ($mg\ kg^{-1}$)		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
S_0	335.79	336.43	336.11	21.73	20.53	21.13	223.16	234.90	229.03	16.60	19.45	18.02	0.49	0.57	0.53
S_{20}	354.61	351.14	353.21	18.82	16.43	17.62	258.81	253.88	256.35	19.18	21.46	20.33	0.68	0.69	0.69
S_{40}	350.91	347.90	351.41	21.13	18.74	19.94	235.40	238.41	236.91	19.04	21.28	20.16	0.66	0.67	0.67
SEm ±	2.48	2.81	2.03	0.57	0.65	0.45	7.81	5.28	5.25	0.68	0.58	0.44	0.02	0.03	0.01
CD (P=0.05)	7.19	8.13	5.89	1.66	1.87	1.30	22.63	15.31	15.21	1.97	1.67	1.28	0.06	0.07	0.04
Zn_0	340.29	335.86	338.08	21.78	19.91	20.84	230.72	230.89	230.80	17.57	19.31	18.44	0.51	0.59	0.55
Zn_5	344.28	343.82	344.05	21.16	19.04	20.10	233.75	234.24	234.00	17.77	20.44	19.11	0.59	0.62	0.61
Zn_{10}	346.37	346.40	346.39	20.41	18.67	19.54	239.66	246.08	242.87	18.13	20.68	19.41	0.61	0.65	0.63
Zn_{15}	351.31	348.19	350.87	19.91	17.80	18.85	245.12	249.17	247.14	18.62	20.97	19.80	0.67	0.67	0.67
Zn_{20}	353.25	351.51	355.16	19.54	17.42	18.48	246.37	251.63	249.00	19.28	22.24	20.77	0.69	0.70	0.70
SEm ±	3.21	3.62	2.62	0.74	0.83	0.58	10.08	6.82	6.78	0.88	0.75	0.57	0.03	0.03	0.02
CD (P=0.05)	NS	NS	7.60	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.08	NS	0.05

Table 4.40 Interaction effects of sulphur and zinc fertilization for biofortification on soil nutrient status at harvest

Treatments	Soil nutrient status														
	Available Nitrogen ($kg\ ha^{-1}$)			Available Phosphorus ($kg\ ha^{-1}$)			Available Potassium ($kg\ ha^{-1}$)			Available Sulphur ($kg\ ha^{-1}$)			Available Zinc ($mg\ kg^{-1}$)		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
S_0Zn_0	323.78	316.99	320.39	23.52	22.40	22.96	215.71	212.20	213.96	15.52	17.43	16.48	0.29	0.53	0.42
S_0Zn_5	330.01	337.46	333.74	22.40	21.28	21.84	220.42	219.89	220.15	15.68	19.51	17.59	0.48	0.55	0.52
S_0Zn_{10}	333.40	339.83	336.62	21.28	20.53	20.91	222.13	236.19	229.16	16.60	19.91	18.25	0.49	0.58	0.54
S_0Zn_{15}	344.19	343.34	343.76	20.91	19.41	20.16	227.96	259.71	243.83	17.47	20.15	18.81	0.57	0.59	0.58
S_0Zn_{20}	347.58	344.52	346.05	20.53	19.04	19.79	229.56	246.53	238.05	17.73	20.23	18.98	0.62	0.61	0.61
$S_{20}Zn_0$	349.33	345.58	347.46	19.79	17.17	18.48	246.10	247.58	246.84	18.66	20.25	19.46	0.62	0.63	0.63
$S_{20}Zn_5$	352.57	347.37	349.98	19.41	16.80	18.11	247.51	250.45	248.98	18.85	20.58	19.72	0.65	0.68	0.66
$S_{20}Zn_{10}$	354.42	351.47	352.95	18.67	16.80	17.73	263.09	253.04	258.07	18.95	20.64	19.80	0.67	0.69	0.68
$S_{20}Zn_{15}$	357.27	352.14	356.37	18.29	16.05	17.17	267.94	254.30	261.12	19.20	21.22	20.21	0.73	0.71	0.72
$S_{20}Zn_{20}$	359.45	359.16	359.31	17.92	15.31	16.61	269.43	264.05	266.74	20.26	24.62	22.44	0.74	0.77	0.76
$S_{40}Zn_0$	347.76	344.99	346.38	22.03	20.16	21.09	230.35	232.87	231.61	18.53	20.24	19.39	0.62	0.62	0.62
$S_{40}Zn_5$	350.27	346.61	348.45	21.65	19.04	20.35	233.33	232.40	232.87	18.79	21.25	20.02	0.63	0.64	0.64
$S_{40}Zn_{10}$	351.30	347.92	349.61	21.28	18.67	19.97	233.75	249.02	241.38	18.86	21.49	20.18	0.66	0.68	0.68
$S_{40}Zn_{15}$	352.48	349.10	352.46	20.53	17.92	19.23	239.46	233.50	236.48	19.18	21.54	20.36	0.70	0.70	0.70
$S_{40}Zn_{20}$	352.72	350.85	360.12	20.16	17.92	19.04	240.13	244.29	242.21	19.86	21.88	20.87	0.71	0.73	0.72
SEm ±	5.55	6.27	4.55	1.28	1.44	1.01	17.46	11.82	11.74	1.52	1.29	0.99	0.05	0.06	0.03
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

4.5.3 Benefit cost ratio

The benefit cost ratio was calculated as follows:

$$\text{Benefit cost ratio} = \frac{\text{Gross returns (₹ ha-1)}}{\text{Cost of cultivation (₹ ha}^{-1}\text{)}}$$

The production economics of the different treatments are presented in the table 4.41. The perusal of the data showed that the cost of cultivation differed for the different treatments' combinations. Among the different treatments applied, the lowest cost of cultivation was recorded in the control treatment (₹54,718.2) while the highest cost of cultivation i.e. ₹60,114.7 was incurred in the treatment combinations of 40 kg S ha^{-1} and 20 kg Zn ha^{-1}.

The gross returns (₹80,500 and ₹1,00,790) and net returns (₹23,541.3 and ₹41,231.3) were however found to be highest in the treatment combinations of 20 kg S ha^{-1} and 20 kg Zn ha^{-1} during the two years of research. The lowest gross returns (₹27,120 and ₹35,560) and a net deficit of (₹-27,598.2 and ₹-19158.2) were obtained in the treatment where no treatment combinations were applied in both the years.

In the initial year of research, the B:C ratio was found to be highest in the treatment combinations of 20 kg S ha^{-1} and 20 kg Zn ha^{-1} (1.40) followed by the combinations of 20 kg S ha^{-1} and 15 kg Zn ha^{-1} (1.33). In the subsequent year, the treatments of 20 kg S ha^{-1} and 20 kg Zn ha^{-1} (1.69) recorded the highest B.C ratio followed by 20 kg S ha^{-1} and 15 kg Zn ha^{-1} (1.43). In both the years, the control treatment recorded the lowest (0.50 and 0.65) B:C ratio as compared to all the treatments.

An appraisal of the above findings reveals that the economics of the treatments were mainly correlated with the seed yield of the crop. Although the cost of cultivation was more or less similar for most of the treatments, the greater returns were observed in treatments receiving an increase of sulphur and zinc nutrients. The nutrient levels increased the yield of the crop significantly leading to greater gross and net returns as compared to control. A similar conclusion was also reached by Gallani *et al.* 2019 who reported maximum net returns with 40 kg S per ha^{-1} and benefit cost ratio in 40 and 20 kg S ha^{-1} respectively. Devi *et al*. (2012) and Pachlaniya *et al*. (2018) also reported an increase in the cost benefit ratio with increase in levels of nutrients.

Table 4.41 Economics of treatments

Treatments interactions	Cost of cultivation (₹ ha^{-1})	Gross returns (₹ ha^{-1})		Net returns (₹ ha^{-1})		Benefit cost ratio	
		2017	2018	2017	2018	2017	2018
S_0Zn_0	54718.2	27120	35560	-27598.2	-19158.2	0.50	0.65
S_0Zn_5	55789.2	50540	50630	-5249.2	-5159.2	0.91	0.91
S_0Zn_{10}	56861.7	54740	52080	-2121.7	-4781.7	0.96	0.92
S_0Zn_{15}	57932.7	68760	56290	10827.3	-1642.7	1.19	0.97
S_0Zn_{20}	59003.7	69870	62600	10866.3	3596.3	1.18	1.06
$S_{20}Zn_0$	55273.2	70410	66840	15136.8	11566.8	1.27	1.21
$S_{20}Zn_5$	56344.2	71900	67570	15555.8	11225.8	1.28	1.20
$S_{20}Zn_{10}$	57416.7	72630	70400	15213.3	12983.3	1.26	1.23
$S_{20}Zn_{15}$	58487.7	77780	83720	19292.3	25232.3	1.33	1.43
$S_{20}Zn_{20}$	59558.7	83100	100790	23541.3	41231.3	1.40	1.69
$S_{40}Zn_0$	55829.2	70320	64720	14490.8	8890.8	1.26	1.16
$S_{40}Zn_5$	56900.2	71060	66860	14159.8	9959.8	1.25	1.18
$S_{40}Zn_{10}$	57972.7	71790	68280	13817.3	10307.3	1.24	1.18
$S_{40}Zn_{15}$	59043.7	76700	76010	17656.3	16966.3	1.30	1.29
$S_{40}Zn_{20}$	60114.7	77470	78840	17355.3	18725.3	1.29	1.31

Note:

Selling price of seed @ ₹70 kg^{-1}
Selling price of stover @ ₹1 kg^{-1}

Plate 1: General view of the experimental field

Plate 2: Vegetative growth stage of the crop

Plate 3: Crop growth stage at 25 DAS

Plate 4: Crop growth stage at 50 DAS

Plate 5: Intercultural operation- weeding

Plate 6: Weeding

Plate 7: Treatment effect of S_0 Zn_0

Plate 8: Treatment effect of S_0Zn_5

Plate 9: Treatment effect of S_0Zn_{15}

Plate 10: Treatment effect of $S_{20}Zn_0$

Plate 11: Treatment effect of $S_{20}Zn_{15}$

Plate 12: Treatment effect of $S_{20}Zn_{20}$

Plate 13: Treatment effect of $S_{40}Zn_5$

Plate 14: Flowering stage of the crop


Plate 15: Crop maturation stage


Plate 16: Pod formation

CHAPTERV

SUMMARY AND CONCLUSIONS

CHAPTER-V
SUMMARY AND CONCLUSIONS

The research entitled "Effect of sulphur and zinc fertilization for biofortification in soybean (*Glycine max* L. Merrill) under Nagaland condition" was carried out in the experimental farm of School and Agricultural Sciences (SAS), Nagaland University, during *kharif* of 2017 and 2018. The experiment was laid out in Factorial Randomized Block Design (RBD) with 15 treatments replicated thrice. This research was conducted to observe the crop growth and yield attributes quality, content and uptake of nutrients, soil nutrient status and production economics of the experiment.

The study was conducted keeping in mind the following objectives:

- To find out the suitable dose of sulphur and zinc for soybean
- To assess the effect of sulphur and zinc biofortification on the quality of soybean.
- To assess the effect of sulphur and zinc on soil chemical properties
- To find out the economics of the treatments understudy

Based on the findings of the research work, the generalized summary and conclusion are listed below:

5.1 Growth and yield parameters of soybean

The application of the different levels of treatment combinations of sulphur and zinc was proven to have an optimizing effect on the growth and development of the plant. The results showed that the sulphur treatments had by far exhibited better performance over control. In most of the growth and yield parameters, 20 kg S ha^{-1} was found to be quite comparable with the treatment of 40 kg S ha^{-1}. A higher plant height (45.84 cm), number of leaves (25.53) and branches (4.20), shoot dry weight (25.81 g plant^{-1}), leaf area index (LAR) (1.20), crop growth rate (CGR) (15.17g m^{-2} day^{-1} and number of nodules (73.70) were observed in the plant with S_{20} treatment. The Net Assimilation Rate did not show much variation with the sulphur treatment. The zinc fertilization of 20 kg Zn ha^{-1} showed greater response by the plants as compared to the control and was at par with 15 kg Zn ha^{-1} and the plant showed increased plant height (45.80 cm), number of leaves (25.62) and branches (4.19), shoot dry weight (25.33 g plant^{-1}), LAI (1.21) and number of nodules (74.22). The Crop Growth Rate (CGR) and Net Assimilation Rate however did not show significant variation at 50-75 DAS with zinc treatment.

The response of the crop growth parameters to the treatment combinations correlated in its yield and showed greater number of seeds per pod (40.48 and 40.89), seed yield of 1.94 t ha^{-1} and 1.13 t ha^{-1} and stover yield (1.97 t ha^{-1} and 2.02 t ha^{-1}) in 20 kg S ha^{-1} and 20 kg Zn ha^{-1} respectively as compared to the other levels of treatments. Though no significant establishment were made in the length of pods, number of seeds of pods, test weight and harvest index in either treatment during the two years of trial.

5.2 Quality parameters of soybean

The oil and protein content of soybean increased comparatively higher in sulphur and zinc fertilization over control. The oil content increased significantly with sulphur treatment of 20 kg S ha^{-1} (17.48%) while in the protein content it was found to be at par with 40 kg S ha^{-1}. Protein content of 36.55% and 36.28% were recorded in these two treatments respectively. The application of zinc resulted in higher oil and protein content of 17.36% and 36.99% in the treatment of 20 kg Zn ha^{-1} quite comparable with 15 Zn kg ha^{-1} (16.84% and 36.02).

5.3 Nutrient content and uptake by soybean and soil parameters

A higher nitrogen, potassium, sulphur, zinc content and uptake in both seeds and stover were recorded in 20 kg S ha^{-1} and 20 kg Zn ha^{-1} as compared to the other treatments. Though the phosphorus content in the seed did not give any significant differences however its significant uptake was seen in boththese treatments. The maximum available N, P, K, S and Zn after harvest were also recorded in the treatments of 20 kg S ha^{-1} and 20 kg Zn ha^{-1}. The pH and organic carbon did not exert any variation and was found non-significant.

5.4 Production economics of the treatments

From the production economics calculated, the highest cost of cultivation i.e. ₹60,114.7 was incurred in the treatment combinations of 40 kg S ha^{-1} and 20 kg Zn ha^{-1} while the lowest cost of cultivation was recorded in the control treatment (₹54,718.2). The gross returns (₹80,500 and ₹1,00,790) and net returns (₹23,541.3 and ₹41,1231.3) were however found to be highest in the treatment combinations of 20 kg S ha^{-1} and 20 kg Zn ha^{-1} during both the years.

The B: C ratio was found to be highest in the treatment combinations of 20 kg S ha^{-1} and 20 kg Zn ha^{-1} (1.40 and 1.69) for both the years.

CONCLUSION

1) After summarising the findings and contributions made, the treatments of 20 kg S ha^{-1} and 20 kg Zn ha^{-1} was found to be a suitable fertilizer dosage for soybean. The application of these treatments led to good results comparatively to control.

2) The quality parameter of soybean was also seen to be highly influenced by agronomic biofortification of sulphur and zinc at 20 kg S ha^{-1} and 20 kg Zn ha^{-1}.

3) The effect of sulphur and zinc on soil chemical properties showed greater crop growth, development, nutrient content and uptake with the treatments of 20 kg S ha^{-1} and 20 kg Zn $ha^{-1.}$

4) The highest gross returns, net returns and B:C cost ratio was obtained from the treatment combinations of $S_{20}Zn_{20}$

Suggestions for further research work

With continuing works done on improving the nutrients deficiencies in soil, there is also a need to do further research on the residual effects of these treatments on other crops. The nutrient requirement for each region will differ and hence more research is recommended to study the most suitable fertilizer dosage for the said regions. On farm trials should also be conducted to know the applicability and utility in the farmer's level.

CHAPTER VI

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APPENDICES

APPENDIX-A

ANOVA 1. Analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on plant height (cm) of soybean (*Glycine max* L. Merrill) during 2017.

ANALYSIS OF VARIANCE TABLE

A. 25 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	94.88578	47.44289	15.87207	3.340386
S	2	4.880444	2.440222	0.816379	3.340386
Zn	4	14.07778	3.519444	1.177434	2.714076
S X Zn	8	35.52622	4.440778	1.485667	2.291264
Error	28	83.69	2.989079	-	-

B. 50 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	34.11607	17.05804	2.897911	3.340386
S	2	497.583	248.7915	42.26604	3.340386
Zn	4	231.1244	57.7811	9.816165	2.714076
S X Zn	8	61.71068	7.713836	1.310468	2.291264
Error	28	164.82	5.886321	-	-

C. 75 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	19.82764	9.91382	2.234523	3.340386
S	2	818.9429	409.4714	92.29271	3.340386
Zn	4	323.3608	80.8402	18.22096	2.714076
S X Zn	8	52.58005	6.572507	1.481409	2.291264
Error	28	124.23	4.43666	-	-

ANOVA 2. Analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on number of leavesof soybean (*Glycine max* L. Merrill) during 2017.

ANALYSIS OF VARIANCE TABLE

A. 25 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	9.431684	4.715842	2.847347	3.340386
S	2	7.297551	3.648776	2.20307	3.340386
Zn	4	3.167902	0.791976	0.478182	2.714076
S X Zn	8	6.412871	0.801609	0.483998	2.291264
Error	28	46.37	1.656223	-	-

B. 50 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	8.30704	4.15352	1.137109	3.340386
S	2	105.4915	52.74573	14.4402	3.340386
Zn	4	50.72942	12.68236	3.472049	2.714076
S X Zn	8	11.80306	1.475382	0.403915	2.291264
Error	28	102.28	3.652701	-	-

C. 75 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	14.91084	7.45542	1.547099	3.340386
S	2	260.8638	130.4319	27.06635	3.340386
Zn	4	149.5029	37.37572	7.75596	2.714076
S X Zn	8	30.85509	3.856887	0.800355	2.291264
Error	28	134.93	4.818968	-	-

ANOVA 3. Analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on number of branches of soybean (*Glycine max* L. Merrill) during 2017.

ANALYSIS OF VARIANCE TABLE

A. 25 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	1.925778	0.962889	3.077415	3.340386
S	2	2.389778	1.194889	3.818892	3.340386
Zn	4	1.149778	0.287444	0.918679	2.714076
S X Zn	8	2.610222	0.326278	1.042791	2.291264
Error	28	8.76	0.312889	-	-

B. 50 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	1.086271	0.543136	6.863357	3.340386
S	2	7.602804	3.801402	48.03659	3.340386
Zn	4	3.559209	0.889802	11.24403	2.714076
S X Zn	8	3.215218	0.401902	5.078655	2.291264
Error	28	2.22	0.079136	-	-

C. 75 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.557671	0.278836	6.741776	3.340386
S	2	5.269671	2.634836	63.7059	3.340386
Zn	4	2.386898	0.596724	14.4278	2.714076
S X Zn	8	2.800462	0.350058	8.463809	2.291264
Error	28	1.16	0.041359	-	-

ANOVA 4. Analysis of variance as influenced by sulphur, zinc fertilization and theirinteraction effects for biofortification on shoot dry weight (g $plant^{-1}$) of soybean (*Glycine max* L. Merrill) during 2017.

ANALYSIS OF VARIANCE TABLE

A. 25 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.100813	0.050407	0.484615	3.340386
S	2	1.525813	0.762907	7.334667	3.340386
Zn	4	0.457858	0.114464	1.100474	2.714076
S X Zn	8	0.220809	0.027601	0.26536	2.291264
Error	28	2.91	0.104014	-	-

B. 50 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	20.794	10.397	3.242865	3.340386
S	2	215.5758	107.7879	33.61945	3.340386
Zn	4	93.83518	23.45879	7.316888	2.714076
S X Zn	8	33.8507	4.231338	1.31977	2.291264
Error	28	89.77	3.206117	-	-

C. 75 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	40.35697	20.17849	6.557918	3.340386
S	2	918.5815	459.2907	149.2674	3.340386
Zn	4	221.4896	55.3724	17.99578	2.714076
S X Zn	8	10.33281	1.291602	0.419765	2.291264
Error	28	86.16	3.076965	-	-

ANOVA 5. Analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on Leaf Area Index (LAI) of soybean (*Glycine max* L. Merrill) during 2017.

ANALYSIS OF VARIANCE TABLE

A. 25 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.002484	0.001242	0.081334	3.340386
S	2	0.109884	0.054942	3.597302	3.340386
Zn	4	0.07108	0.01777	1.163478	2.714076
S X Zn	8	0.171293	0.021412	1.401913	2.291264
Error	28	0.43	0.015273	-	-

B. 50 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.088573	0.044287	2.424642	3.340386
S	2	1.136653	0.568327	31.11521	3.340386
Zn	4	0.3524	0.0881	4.82337	2.714076
S X Zn	8	0.310547	0.038818	2.125257	2.291264
Error	28	0.51	0.018265	-	-

C. 75 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.002293	0.001147	0.181558	3.340386
S	2	0.997293	0.498647	78.95333	3.340386
Zn	4	0.675244	0.168811	26.72874	2.714076
S X Zn	8	0.093729	0.011716	1.855073	2.291264
Error	28	0.18	0.006316	-	-

ANOVA 6. Analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on Crop Growth Rate (CGR) (g m^{-2} day^{-1}) of soybean (*Glycine max* L. Merrill) during 2017.

ANALYSIS OF VARIANCE TABLE

A. 25 -50 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	20.30435	10.15218	2.93542	3.340386
S	2	185.0125	92.50623	26.74743	3.340386
Zn	4	82.86235	20.71559	5.989745	2.714076
S X Zn	8	34.77872	4.34734	1.256998	2.291264
Error	28	96.84	3.458509	-	-

B. 50 -75 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	118.3225	59.16123	7.081266	3.340386
S	2	244.373	122.1865	14.62503	3.340386
Zn	4	35.81266	8.953164	1.071643	2.714076
S X Zn	8	29.40248	3.675309	0.439914	2.291264
Error	28	233.93	8.354612	-	-

ANOVA 7. Analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on Relative Growth Rate (RGR) (g $g^{-1}day^{-1}$) of soybean (*Glycine max* L. Merrill) during 2017.

ANALYSIS OF VARIANCE TABLE

A. 25 -50 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.000697	0.000348	1.220218	3.340386
S	2	0.003196	0.001598	5.598381	3.340386
Zn	4	0.002871	0.000718	2.514436	2.714076
S X Zn	8	0.005579	0.000697	2.443024	2.291264
Error	28	0.01	0.000285	-	-

B. 50 -75 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.001122	0.000561	5.321214	3.340386
S	2	0.00122	0.00061	5.788036	3.340386
Zn	4	0.002339	0.000585	5.54851	2.714076
S X Zn	8	0.005215	0.000652	6.184697	2.291264
Error	28	0.00	0.000105	-	-

ANOVA 8. Analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on Net Assimilation Rate (NAR) (g m^{-2} of leaf area day^{-1}) of soybean (*Glycine max* L. Merrill) during 2017.

ANALYSIS OF VARIANCE TABLE

A. 25-50 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.000994	0.000497	2.285891	3.340386
S	2	0.002893	0.001446	6.654382	3.340386
Zn	4	0.000711	0.000178	0.817341	2.714076
S X Zn	8	0.000777	9.71E-05	0.446826	2.291264
Error	28	0.01	0.000217	-	-

B. 50-75 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.000192	9.6E-05	0.73986	3.340386
S	2	5.45E-05	2.72E-05	0.209995	3.340386
Zn	4	0.000506	0.000127	0.975691	2.714076
S X Zn	8	0.001608	0.000201	1.549549	2.291264
Error	28	0.00	0.00013	-	-

ANOVA 9. Analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on number of nodules per plant of soybean (*Glycine max* L. Merrill) during 2017.

ANALYSIS OF VARIANCE TABLE

A. 25 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	14.44444	7.222222	1.654545	3.340386
S	2	254.9778	127.4889	29.20655	3.340386
Zn	4	115.8667	28.96667	6.636	2.714076
S X Zn	8	29.46667	3.683333	0.843818	2.291264
Error	28	122.22	4.365079	-	-

B. 50 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	2.711111	1.355556	0.058099	3.340386
S	2	1534.444	767.2222	32.88319	3.340386
Zn	4	763.0222	190.7556	8.175794	2.714076
S X Zn	8	189.1111	23.63889	1.013164	2.291264
Error	28	653.29	23.33175	-	-

C. 75 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	521.7333	260.8667	3.517981	3.340386
S	2	7531.6	3765.8	50.78461	3.340386
Zn	4	2576.8	644.2	8.687516	2.714076
S X Zn	8	328.4	41.05	0.55359	2.291264
Error	28	2076.27	74.15238	-	-

ANOVA 10. Analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on yield attributes of soybean (*Glycine max* L. Merrill) during 2017.

ANALYSIS OF VARIANCE TABLE

A. Number of pods per plant

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	146.6522	73.32611	3.351299	3.340386
S	2	1513.264	756.6322	34.58115	3.340386
Zn	4	790.3359	197.584	9.030385	2.714076
S X Zn	8	174.2641	21.78301	0.995571	2.291264
Error	28	612.64	21.87991	-	-

B. Length of pods (cm)

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.076444	0.038222	1.58109	3.340386
S	2	0.136444	0.068222	2.822062	3.340386
Zn	4	0.183111	0.045778	1.893631	2.714076
S X Zn	8	0.256889	0.032111	1.328299	2.291264
Error	28	0.68	0.024175	-	-

C. Number of seeds per pod

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.439111	0.219556	7.805869	3.340386
S	2	0.113778	0.056889	2.022573	3.340386
Zn	4	0.143556	0.035889	1.275959	2.714076
S X Zn	8	0.335111	0.041889	1.489278	2.291264
Error	28	0.79	0.028127	-	-

D. Test weight (g)

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	545.7371	272.8686	12.49773	3.340386
S	2	65.76086	32.88043	1.505966	3.340386
Zn	4	32.42257	8.105642	0.371249	2.714076
S X Zn	8	57.89236	7.236546	0.331443	2.291264
Error	28	611.34	21.83345	-	-

E. Seed yield (t ha^{-1})

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.030484	0.015242	0.969705	3.340386
S	2	0.790351	0.395176	25.14093	3.340386
Zn	4	0.485036	0.121259	7.714449	2.714076
S X Zn	8	0.307404	0.038426	2.444621	2.291264
Error	28	0.44	0.015718	-	-

F. Stover yield (t ha^{-1})

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	1.411604	0.705802	4.514112	3.340386
S	2	3.245871	1.622936	10.37984	3.340386
Zn	4	2.920476	0.730119	4.669635	2.714076
S X Zn	8	1.796351	0.224544	1.436119	2.291264
Error	28	4.38	0.156355	-	-

G. Harvest index (%)

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	93.37126	46.68563	1.474805	3.340386
S	2	48.52627	24.26314	0.766476	3.340386
Zn	4	116.1209	29.03024	0.917069	2.714076
S X Zn	8	136.4754	17.05943	0.53891	2.291264
Error	28	886.35	31.65546	-	-

ANOVA 11. Analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects on quality of soybean (*Glycine max* L. Merrill) soybean at harvest during 2017.

ANALYSIS OF VARIANCE TABLE

A. Oil content %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	1.463111	0.731556	1.797294	3.340386
S	2	75.49644	37.74822	92.74024	3.340386
Zn	4	33.44756	8.361889	20.54358	2.714076
S X Zn	8	28.27244	3.534056	8.682506	2.291264
Error	28	11.40	0.407032	-	-

B. Protein content %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	11.18629	5.593147	1.120376	3.340386
S	2	131.7393	65.86963	13.1945	3.340386
Zn	4	78.88936	19.72234	3.950628	2.714076
S X Zn	8	21.67899	2.709874	0.542821	2.291264
Error	28	139.78	4.992204	-	-

ANOVA 12. Analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects on plant nutrient content (seed) of soybean (*Glycine max* L. Merrill) at harvest during 2017.

ANALYSIS OF VARIANCE TABLE

A. Nitrogen %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.286111	0.143056	1.119593	3.340386
S	2	3.369884	1.684942	13.18683	3.340386
Zn	4	2.018276	0.504569	3.948898	2.714076
S X Zn	8	0.554338	0.069292	0.5423	2.291264
Error	28	3.58	0.127775	-	-

B. Phosphorus %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	5.33E-05	2.67E-05	0.202899	3.340386
S	2	0.00028	0.00014	1.065217	3.340386
Zn	4	0.001324	0.000331	2.519324	2.714076
S X Zn	8	0.000342	4.28E-05	0.325483	2.291264
Error	28	0.00	0.000131	-	-

C. Potassium %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.096573	0.048287	6.126269	3.340386
S	2	0.060333	0.030167	3.827332	3.340386
Zn	4	0.011187	0.002797	0.354821	2.714076
S X Zn	8	0.062333	0.007792	0.988551	2.291264
Error	28	0.22	0.007882	-	-

D. Sulphur %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.00012	6E-05	0.759036	3.340386
S	2	0.005173	0.002587	32.72289	3.340386
Zn	4	0.002347	0.000587	7.421687	2.714076
S X Zn	8	0.000827	0.000103	1.307229	2.291264
Error	28	0.00	7.9E-05	-	-

E. Zinc (mg kg^{-1})

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	44.09865	22.04933	14.35865	3.340386
S	2	177.1999	88.59993	57.6968	3.340386
Zn	4	67.44597	16.86149	10.9803	2.714076
S X Zn	8	7.110058	0.888757	0.578764	2.291264
Error	28	43.00	1.535612	-	-

ANOVA 13. Analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects on plant nutrient (stover) of soybean (*Glycine max* L. Merrill) at harvest during 2017.

ANALYSIS OF VARIANCE TABLE

A. Nitrogen %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.001404	0.000702	0.0661	3.340386
S	2	0.278724	0.139362	13.11811	3.340386
Zn	4	0.086591	0.021648	2.037697	2.714076
S X Zn	8	0.001276	0.000159	0.015008	2.291264
Error	28	0.30	0.010624	-	-

B. Phosphorus %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.000271	0.000136	0.654908	3.340386
S	2	0.000991	0.000496	2.394172	3.340386
Zn	4	0.001044	0.000261	1.261503	2.714076
S X Zn	8	0.001076	0.000134	0.64954	2.291264
Error	28	0.01	0.000207	-	-

C. Potassium %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.000218	0.000109	0.309567	3.340386
S	2	0.028884	0.014442	41.05866	3.340386
Zn	4	0.022569	0.005642	16.04061	2.714076
S X Zn	8	0.003871	0.000484	1.375677	2.291264
Error	28	0.01	0.000352	-	-

D. Sulphur %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	5.33E-05	2.67E-05	0.347826	3.340386
S	2	0.003613	0.001807	23.56522	3.340386
Zn	4	0.001391	0.000348	4.536232	2.714076
S X Zn	8	0.000276	3.44E-05	0.449275	2.291264
Error	28	0.00	7.67E-05	-	-

E. Zinc (mg kg^{-1})

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	29.70175	14.85087	4.118448	3.340386
S	2	111.8664	55.93321	15.51141	3.340386
Zn	4	77.40361	19.3509	5.366397	2.714076
S X Zn	8	19.27175	2.408969	0.668056	2.291264
Error	28	100.97	3.605939	-	-

ANOVA 14. Analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects on soil nutrient status at harvest of soybean (*Glycine max* L. Merrill) during 2017.

ANALYSIS OF VARIANCE TABLE

A. Soil pH

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.005333	0.002667	0.206642	3.340386
S	2	0.065333	0.032667	2.531365	3.340386
Zn	4	0.133333	0.033333	2.583026	2.714076
S X Zn	8	0.094667	0.011833	0.916974	2.291264
Error	28	0.36	0.012905	-	-

B. Organic carbon (%)

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.012018	0.006009	0.260535	3.340386
S	2	0.032591	0.016296	0.706547	3.340386
Zn	4	0.077222	0.019306	0.837055	2.714076
S X Zn	8	0.279431	0.034929	1.514456	2.291264
Error	28	0.65	0.023064	-	-

C. Available nitrogen (kg ha^{-1})

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	1685.298	842.6491	0.274653	3.340386
S	2	29589.71	14794.86	4.822227	3.340386
Zn	4	6447.656	1611.914	0.525386	2.714076
S X Zn	8	832.4165	104.0521	0.033915	2.291264
Error	28	85905.52	3068.054	-	-

D. Available phosphorus (kg ha^{-1})

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	2.062791	1.031396	0.208619	3.340386
S	2	70.97116	35.48558	7.177608	3.340386
Zn	4	29.93835	7.484587	1.513894	2.714076
S X Zn	8	2.341547	0.292693	0.059203	2.291264
Error	28	138.43	4.943929	-	-

E. Available potassium (kg ha^{-1})

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	5344.395	2672.197	2.9203	3.340386
S	2	9847.577	4923.788	5.380942	3.340386
Zn	4	1694.326	423.5816	0.462909	2.714076
S X Zn	8	415.3076	51.91345	0.056733	2.291264
Error	28	25621.18	915.0422	-	-

F. Available sulphur (kg ha^{-1})

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	33.16727	16.58364	2.386641	3.340386
S	2	63.23592	31.61796	4.550312	3.340386
Zn	4	17.1165	4.279126	0.615832	2.714076
S X Zn	8	2.981898	0.372737	0.053643	2.291264
Error	28	194.56	6.948526	-	-

G. DTPA extractable zinc

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.025013	0.012507	1.866799	3.340386
S	2	0.34156	0.17078	25.49136	3.340386
Zn	4	0.184053	0.046013	6.86815	2.714076
S X Zn	8	0.058507	0.007313	1.09162	2.291264
Error	28	0.19	0.0067	-	-

ANOVA 15. Analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on plant height (cm) of soybean (*Glycine max* L. Merrill) during 2018.

ANALYSIS OF VARIANCE TABLE

A. 25 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	3.236818	1.618409	0.481459	3.340386
S	2	11.13836	5.569182	1.656772	3.340386
Zn	4	9.956124	2.489031	0.74046	2.714076
S X Zn	8	35.75657	4.469571	1.329649	2.291264
Error	28	94.12	3.361466	-	-

B. 50 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	29.73172	14.86586	2.624524	3.340386
S	2	569.6143	284.8071	50.28186	3.340386
Zn	4	313.2217	78.30542	13.82459	2.714076
S X Zn	8	95.6003	11.95004	2.109744	2.291264
Error	28	158.60	5.664212	-	-

C. 75 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	42.68603	21.34302	3.900738	3.340386
S	2	546.0781	273.0391	49.90175	3.340386
Zn	4	225.2955	56.32387	10.29398	2.714076
S X Zn	8	47.59158	5.948947	1.087254	2.291264
Error	28	153.20	5.471532	-	-

ANOVA 16. Analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on number of leavesof soybean (*Glycine max* L. Merrill) during 2018.

ANALYSIS OF VARIANCE TABLE

D. 25 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	3.073778	1.536889	1.717225	3.340386
S	2	1.244444	0.622222	0.695233	3.340386
Zn	4	2.839111	0.709778	0.793062	2.714076
S X Zn	8	10.03556	1.254444	1.401639	2.291264
Error	28	25.06	0.894984	-	-

E. 50 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	1.382538	0.691269	0.203638	3.340386
S	2	537.3812	268.6906	79.15231	3.340386
Zn	4	170.368	42.59201	12.54698	2.714076
S X Zn	8	16.2721	2.034013	0.59919	2.291264
Error	28	95.05	3.394602	-	-

F. 75 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	8.365204	4.182602	1.122772	3.340386
S	2	532.0741	266.0371	71.41465	3.340386
Zn	4	194.5229	48.63072	13.05437	2.714076
S X Zn	8	12.94966	1.618708	0.434524	2.291264
Error	28	104.31	3.725245	-	-

ANOVA 17. Analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on number of branchesof soybean (*Glycine max* L. Merrill) during 2018.

ANALYSIS OF VARIANCE TABLE

D. 25 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	1.475111	0.737556	2.781396	3.340386
S	2	0.360444	0.180222	0.679636	3.340386
Zn	4	2.228889	0.557222	2.101341	2.714076
S X Zn	8	3.001778	0.375222	1.415001	2.291264
Error	28	7.42	0.265175	-	-

E. 50 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.123613	0.061807	0.628256	3.340386
S	2	2.743373	1.371687	13.94301	3.340386
Zn	4	2.696258	0.674064	6.851774	2.714076
S X Zn	8	1.801049	0.225131	2.288427	2.291264
Error	28	2.75	0.098378	-	-

F. 75 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.055111	0.027556	0.609979	3.340386
S	2	1.787111	0.893556	19.78004	3.340386
Zn	4	1.279111	0.319778	7.078707	2.714076
S X Zn	8	0.806222	0.100778	2.23085	2.291264
Error	28	1.26	0.045175	-	-

ANOVA 18. Analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on shoot dry weight of leaves (g $plant^{-1}$) of soybean (*Glycine max* L. Merrill) during 2018.

ANALYSIS OF VARIANCE TABLE

D. 25 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.042036	0.021018	0.377249	3.340386
S	2	0.326354	0.163177	2.92881	3.340386
Zn	4	0.14072	0.03518	0.631436	2.714076
S X Zn	8	0.018099	0.002262	0.040608	2.291264
Error	28	1.56	0.055714	-	-

E. 50 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	5.454098	2.727049	1.018147	3.340386
S	2	115.3592	57.67961	21.53474	3.340386
Zn	4	79.21747	19.80437	7.393982	2.714076
S X Zn	8	30.78349	3.847937	1.436631	2.291264
Error	28	75.00	2.678444	-	-

F. 75 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	5.74612	2.87306	2.793258	3.340386
S	2	330.4283	165.2141	160.6252	3.340386
Zn	4	170.9823	42.74558	41.55828	2.714076
S X Zn	8	10.85152	1.35644	1.318764	2.291264
Error	28	28.80	1.02857	-	-

ANOVA 19. Analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on Leaf Area Index (LAI)of soybean (*Glycine max* L. Merrill) during 2018.

ANALYSIS OF VARIANCE TABLE

A. 25 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.127058	0.063529	3.618832	3.340386
S	2	0.009258	0.004629	0.263678	3.340386
Zn	4	0.007142	0.001786	0.101712	2.714076
S X Zn	8	0.272764	0.034096	1.942205	2.291264
Error	28	0.49	0.017555	-	-

B. 50 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.003858	0.001929	0.329573	3.340386
S	2	0.673871	0.336936	57.56927	3.340386
Zn	4	0.302511	0.075628	12.92186	2.714076
S X Zn	8	0.172062	0.021508	3.674848	2.291264
Error	28	0.16	0.005853	-	-

C. 75 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.079271	0.039636	1.720981	3.340386
S	2	1.330271	0.665136	28.88027	3.340386
Zn	4	0.635791	0.158948	6.901533	2.714076
S X Zn	8	0.171129	0.021391	0.928805	2.291264
Error	28	0.64	0.023031	-	-

ANOVA 20. Analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on Crop Growth Rate (CGR) (g m^{-2} day^{-1}) of soybean (*Glycine max* L. Merrill) during 2018.

ANALYSIS OF VARIANCE TABLE

A. 25-50 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	6.431716	3.215858	1.250609	3.340386
S	2	103.4731	51.73656	20.11974	3.340386
Zn	4	72.81946	18.20487	7.079658	2.714076
S X Zn	8	29.92578	3.740723	1.454723	2.291264
Error	28	72.00	2.571433	-	-

B. 50-75 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	15.2996	7.649802	1.354964	3.340386
S	2	55.71214	27.85607	4.933979	3.340386
Zn	4	22.90556	5.726389	1.014281	2.714076
S X Zn	8	39.50862	4.938577	0.874741	2.291264
Error	28	158.08	5.645762	-	-

ANOVA 21. Analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on soybean (*Glycine max* L. Merrill) Relative Growth Rate (RGR) (g $g^{-1}day^{-1}$) during 2018.

ANALYSIS OF VARIANCE TABLE

A. 25-50 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.00017	8.5E-05	1.137749	3.340386
S	2	0.001497	0.000748	10.0213	3.340386
Zn	4	0.00176	0.00044	5.891119	2.714076
S X Zn	8	0.002205	0.000276	3.691212	2.291264
Error	28	0.00	7.47E-05	-	-

B. 50-75 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	5.6E-05	2.8E-05	0.492454	3.340386
S	2	0.000715	0.000358	6.28475	3.340386
Zn	4	0.001108	0.000277	4.867528	2.714076
S X Zn	8	0.0024	0.0003	5.272309	2.291264
Error	28	0.00	5.69E-05	-	-

ANOVA 22. Analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on soybean (*Glycine max* L. Merrill) Net Assimilation Rate (NAR) (g m^{-2} of leaf area day^{-1}) during 2018.

ANALYSIS OF VARIANCE TABLE

C. 25-50 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.000522	0.000261	1.418462	3.340386
S	2	0.001324	0.000662	3.595947	3.340386
Zn	4	0.001168	0.000292	1.58669	2.714076
S X Zn	8	0.003036	0.000379	2.061022	2.291264
Error	28	0.01	0.000184	-	-

D. 50-75 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.000269	0.000134	2.321888	3.340386
S	2	0.000178	8.92E-05	1.542648	3.340386
Zn	4	0.000214	5.35E-05	0.92551	2.714076
S X Zn	8	0.000163	2.03E-05	0.351377	2.291264
Error	28	0.00	5.78E-05	-	-

ANOVA 23. Analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on number of nodules per plant of soybean (*Glycine max* L. Merrill) during 2018.

ANALYSIS OF VARIANCE TABLE

D. 25 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	100.8	50.4	5.255214	3.340386
S	2	1239.6	619.8	64.62661	3.340386
Zn	4	514.8	128.7	13.41956	2.714076
S X Zn	8	87.06667	10.88333	1.134806	2.291264
Error	28	268.53	9.590476	-	-

E. 50 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	296.0444	148.0222	0.907325	3.340386
S	2	11976.04	5988.022	36.70452	3.340386
Zn	4	3665.022	916.2556	5.616332	2.714076
S X Zn	8	732.8444	91.60556	0.561511	2.291264
Error	28	4567.96	163.1413	-	-

F. 75 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	552.4	276.2	3.576617	3.340386
S	2	5033.733	2516.867	32.59185	3.340386
Zn	4	2129.022	532.2556	6.892376	2.714076
S X Zn	8	1053.378	131.6722	1.705073	2.291264
Error	28	2162.27	77.22381	-	-

ANOVA 24. Analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on yield attributes of soybean (*Glycine max* L. Merrill) during 2018

ANALYSIS OF VARIANCE TABLE

H. Number of pods per plant

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	43.97148	21.98574	0.663741	3.340386
S	2	3494.939	1747.469	52.7554	3.340386
Zn	4	1082.255	270.5639	8.168215	2.714076
S X Zn	8	514.2034	64.27543	1.94045	2.291264
Error	28	927.47	33.12399	-	-

I. Length of pods (cm)

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.000444	0.000222	0.008568	3.340386
S	2	0.005778	0.002889	0.111383	3.340386
Zn	4	0.028	0.007	0.26989	2.714076
S X Zn	8	0.258667	0.032333	1.246634	2.291264
Error	28	0.73	0.025937	-	-

J. Number of seeds per pod

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.012	0.006	0.405145	3.340386
S	2	0.009333	0.004667	0.315113	3.340386
Zn	4	0.049778	0.012444	0.8403	2.714076
S X Zn	8	0.086222	0.010778	0.72776	2.291264
Error	28	0.41	0.01481	-	-

K. Test weight (g)

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	105.148	52.574	1.844828	3.340386
S	2	118.4413	59.22067	2.07806	3.340386
Zn	4	1.583556	0.395889	0.013892	2.714076
S X Zn	8	14.78978	1.848722	0.064872	2.291264
Error	28	797.95	28.49805	-	-

L. Seed yield (t ha^{-1})

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.109604	0.054802	5.891304	3.340386
S	2	1.122004	0.561002	60.30841	3.340386
Zn	4	0.683791	0.170948	18.37709	2.714076
S X Zn	8	0.149729	0.018716	2.012004	2.291264
Error	28	0.26	0.009302	-	-

M. Stover yield (t ha^{-1}):

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.009258	0.004629	0.284766	3.340386
S	2	0.518098	0.259049	15.93649	3.340386
Zn	4	0.435391	0.108848	6.696232	2.714076
S X Zn	8	0.254702	0.031838	1.958636	2.291264
Error	28	0.46	0.016255	-	-

N. Harvest index (%)

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	62.0303	31.01515	3.897704	3.340386
S	2	302.8143	151.4071	19.02748	3.340386
Zn	4	141.8478	35.46196	4.456538	2.714076
S X Zn	8	16.36172	2.045216	0.257024	2.291264
Error	28	222.80	7.957287	-	-

ANOVA 25. Analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects on quality of soybean (*Glycine max* L. Merrill) at harvest during 2018.

ANALYSIS OF VARIANCE TABLE

C. Oil content %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.641333	0.320667	0.763146	3.340386
S	2	49.81733	24.90867	59.27947	3.340386
Zn	4	14.77689	3.694222	8.79178	2.714076
S X Zn	8	0.447111	0.055889	0.133008	2.291264
Error	28	11.77	0.42019	-	-

D. Protein content %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	3.43108	1.71554	2.215855	3.340386
S	2	11.76681	5.883407	7.599225	3.340386
Zn	4	7.016769	1.754192	2.265779	2.714076
S X Zn	8	2.229698	0.278712	0.359995	2.291264
Error	28	21.68	0.774211	-	-

ANOVA 26. Analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects on plant nutrient (seed) of soybean (*Glycine max* L. Merrill) at harvest during 2018.

ANALYSIS OF VARIANCE TABLE

F. Nitrogen %

G. Phosphorus %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.064333	0.032167	1.587544	3.340386
S	2	0.308333	0.154167	7.608696	3.340386
Zn	4	0.158556	0.039639	1.956326	2.714076
S X Zn	8	0.014444	0.001806	0.089111	2.291264
Error	28	0.57	0.020262		

H. Potassium %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.064333	0.032167	1.587544	3.340386
S	2	0.308333	0.154167	7.608696	3.340386
Zn	4	0.158556	0.039639	1.956326	2.714076
S X Zn	8	0.014444	0.001806	0.089111	2.291264
Error	28	0.57	0.020262		

I. Sulphur %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.000373	0.000187	1.689655	3.340386
S	2	0.002173	0.001087	9.836207	3.340386
Zn	4	0.001298	0.000324	2.936782	2.714076
S X Zn	8	0.000382	4.78E-05	0.432471	2.291264
Error	28	0.00	0.00011		

J. Zinc (mg kg^{-1})

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	19.32827	9.664136	11.31071	3.340386
S	2	33.07287	16.53644	19.35391	3.340386
Zn	4	24.36125	6.090313	7.127978	2.714076
S X Zn	8	14.79517	1.849397	2.164496	2.291264
Error	2	19.32827	9.664136	11.31071	3.340386

ANOVA 27. Analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects on plant nutrient (stover) of soybean (*Glycine max* L. Merrill)at harvest during 2018.

ANALYSIS OF VARIANCE TABLE

A. Nitrogen %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.028818	0.014409	0.202198	3.340386
S	2	1.660058	0.830029	11.64769	3.340386
Zn	4	0.657836	0.164459	2.30783	2.714076
S X Zn	8	0.645964	0.080746	1.133092	2.291264
Error	28	2.00	0.071261		

B. Phosphorus %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.001333	0.000667	4.516129	3.340386
S	2	0.00084	0.00042	2.845161	3.340386
Zn	4	0.000658	0.000164	1.113978	2.714076
S X Zn	8	0.000116	1.44E-05	0.097849	2.291264
Error	28	0.00	0.000148		

C. Potassium %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.004271	0.002136	0.428144	3.340386
S	2	0.119791	0.059896	12.00808	3.340386
Zn	4	0.050213	0.012553	2.516739	2.714076
S X Zn	8	0.009253	0.001157	0.231893	2.291264
Error	28	0.14	0.004988		

D. Sulphur %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.000373	0.000187	2.214689	3.340386
S	2	0.002653	0.001327	15.74011	3.340386
Zn	4	0.00092	0.00023	2.728814	2.714076
S X Zn	8	0.000213	2.67E-05	0.316384	2.291264
Error	28	0.00	8.43E-05	-	-

E. Zinc (mg kg^{-1})

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	5.45268	2.72634	2.530286	3.340386
S	2	30.78629	15.39315	14.28621	3.340386
Zn	4	31.92738	7.981844	7.407862	2.714076
S X Zn	8	4.787529	0.598441	0.555407	2.291264
Error	28	30.17	1.077483		

ANOVA 28. Analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects on soil nutrient status at harvest of soybean (*Glycine max* L. Merrill) during 2018.

ANALYSIS OF VARIANCE TABLE

H. Soil pH

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.013778	0.006889	0.508197	3.340386
S	2	0.000444	0.000222	0.016393	3.340386
Zn	4	0.092444	0.023111	1.704918	2.714076
S X Zn	8	0.172889	0.021611	1.594262	2.291264
Error	28	0.38	0.013556	-	-

I. Organic carbon (%)

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.000858	0.000429	0.01944	3.340386
S	2	0.099071	0.049536	2.245266	3.340386
Zn	4	0.052076	0.013019	0.590099	2.714076
S X Zn	8	0.155551	0.019444	0.881321	2.291264
Error	28	0.62	0.022062		

J. Available Nitrogen (kg ha^{-1})

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	735.0409	367.5205	2.87585	3.340386
S	2	2107.743	1053.872	8.246552	3.340386
Zn	4	1684.18	421.0449	3.294679	2.714076
S X Zn	8	514.822	64.35275	0.503561	2.291264
Error	28	3578.27	127.7954		

K. Available Phosphorus (kg ha^{-1})

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.390258	0.195129	0.03118	3.340386
S	2	127.1683	63.58414	10.16036	3.340386
Zn	4	35.51346	8.878364	1.418708	2.714076
S X Zn	8	4.125582	0.515698	0.082405	2.291264
Error	28	175.23	6.258062		

L. Available Potassium (kg ha^{-1})

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	2465.858	1232.929	2.943576	3.340386
S	2	3059.787	1529.893	3.652568	3.340386
Zn	4	3092.201	773.0503	1.845631	2.714076
S X Zn	8	2568.145	321.0182	0.76642	2.291264
Error	28	11727.92	418.8541		

M. Available Sulphur (kg ha^{-1})

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	44.65637	22.32819	4.456988	3.340386
S	2	37.34868	18.67434	3.727634	3.340386
Zn	4	40.1649	10.04123	2.004355	2.714076
S X Zn	8	19.64223	2.455279	0.490105	2.291264
Error	28	140.27	5.009703		

N. DTPA extractable zinc

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.005951	0.002976	0.312924	3.340386
S	2	0.129551	0.064776	6.812106	3.340386
Zn	4	0.062898	0.015724	1.653657	2.714076
S X Zn	8	0.004782	0.000598	0.062865	2.291264
Error	28	0.27	0.009509		

ANOVA 29. Pooled analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on plant height (cm) of soybean (*Glycine max* L. Merrill).

ANALYSIS OF VARIANCE TABLE

D. 25 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	23.6012	11.8006	9.144396	3.340386
S	2	7.206591	3.603296	2.792227	3.340386
Zn	4	5.95892	1.48973	1.154406	2.714076
S X Zn	8	27.90759	3.488448	2.703231	2.291264
Error	28	36.13	1.290474	-	-

E. 50 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	13.51265	6.756327	3.718517	3.340386
S	2	529.7936	264.8968	145.7927	3.340386
Zn	4	269.1765	67.29413	37.03704	2.714076
S X Zn	8	73.57812	9.197265	5.061949	2.291264
Error	28	50.87	1.816942	-	-

F. 75 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	10.88491	5.442457	2.7247	3.340386
S	2	675.0923	337.5462	168.9884	3.340386
Zn	4	269.249	67.31226	33.69906	2.714076
S X Zn	8	46.85224	5.856529	2.932	2.291264
Error	28	55.93	1.997452	-	-

ANOVA 30. Pooled analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on number of leaves of soybean (*Glycine max* L. Merrill).

ANALYSIS OF VARIANCE TABLE

G. 25 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	3.09301	1.546505	2.055695	3.340386
S	2	3.63061	1.815305	2.412998	3.340386
Zn	4	1.628931	0.407233	0.541315	2.714076
S X Zn	8	6.492996	0.811624	1.078854	2.291264
Error	28	21.06	0.752303	-	-

H. 50 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	3.041453	1.520727	0.893054	3.340386
S	2	279.2164	139.6082	81.98558	3.340386
Zn	4	101.1544	25.28861	14.85086	2.714076
S X Zn	8	13.2777	1.659712	0.974674	2.291264
Error	28	47.68	1.702839	-	-

I. 75 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.459418	0.229709	0.079704	3.340386
S	2	381.3844	190.6922	66.16619	3.340386
Zn	4	170.0243	42.50608	14.74872	2.714076
S X Zn	8	17.87307	2.234134	0.775198	2.291264
Error	28	80.70	2.882018	-	-

ANOVA 31. Pooled analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on number of branches of soybean (*Glycine max* L. Merrill).

ANALYSIS OF VARIANCE TABLE

G. 25 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.401333	0.200667	1.574444	3.340386
S	2	1.147	0.5735	4.49972	3.340386
Zn	4	1.272444	0.318111	2.495921	2.714076
S X Zn	8	2.323556	0.290444	2.278847	2.291264
Error	28	3.57	0.127452	-	-

H. 50 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.167674	0.083837	2.19399	3.340386
S	2	4.661818	2.330909	60.99904	3.340386
Zn	4	3.070813	0.767703	20.09052	2.714076
S X Zn	8	2.252493	0.281562	7.368367	2.291264
Error	28	1.07	0.038212	-	-

I. 75 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.208351	0.104176	6.521907	3.340386
S	2	3.262351	1.631176	102.1197	3.340386
Zn	4	1.767591	0.441898	27.66499	2.714076
S X Zn	8	1.603182	0.200398	12.5459	2.291264
Error	28	0.45	0.015973	-	-

ANOVA 32. Pooled analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on shoot dry weight of leaves (g $plant^{-1}$) of soybean (*Glycine max* L. Merrill).

ANALYSIS OF VARIANCE TABLE

G. 25 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.01492	0.00746	0.158923	3.340386
S	2	0.79996	0.39998	8.520918	3.340386
Zn	4	0.253169	0.063292	1.348337	2.714076
S X Zn	8	0.070084	0.008761	0.186629	2.291264
Error	28	1.31	0.046941	-	-

H. 50 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	11.67377	5.836887	3.014093	3.340386
S	2	161.144	80.57201	41.60634	3.340386
Zn	4	86.27492	21.56873	11.13781	2.714076
S X Zn	8	29.37348	3.671684	1.89601	2.291264
Error	28	54.22	1.936532	-	-

I. 75 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	17.11886	8.559429	11.54347	3.340386
S	2	586.4422	293.2211	395.4455	3.340386
Zn	4	193.2751	48.31876	65.16393	2.714076
S X Zn	8	2.909747	0.363718	0.49052	2.291264
Error	28	20.76	0.741496	-	-

ANOVA 33. Pooled analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on Leaf Area Index (LAI) of soybean (*Glycine max* L. Merrill).

ANALYSIS OF VARIANCE TABLE

D. 25 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.025938	0.012969	2.257391	3.340386
S	2	0.044671	0.022336	3.887771	3.340386
Zn	4	0.018209	0.004552	0.792369	2.714076
S X Zn	8	0.152951	0.019119	3.327872	2.291264
Error	28	0.16	0.005745	-	-

E. 50 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.015773	0.007887	1.314757	3.340386
S	2	0.88912	0.44456	74.11098	3.340386
Zn	4	0.319453	0.079863	13.31373	2.714076
S X Zn	8	0.233213	0.029152	4.859768	2.291264
Error	28	0.17	0.005999	-	-

F. 75 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.026298	0.013149	1.520717	3.340386
S	2	1.161658	0.580829	67.17497	3.340386
Zn	4	0.650556	0.162639	18.80978	2.714076
S X Zn	8	0.069164	0.008646	0.99989	2.291264
Error	28	0.24	0.008647	-	-

ANOVA 34. Pooled analysis nalysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on Crop Growth Rate (CGR) (g m^{-2} day^{-1}) of soybean (*Glycine max* L. Merrill).

ANALYSIS OF VARIANCE TABLE

C. 25-50 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	12.01212	6.00606	3.013728	3.340386
S	2	140.8428	70.42141	35.33614	3.340386
Zn	4	77.6823	19.42057	9.744879	2.714076
S X Zn	8	28.91988	3.614984	1.813931	2.291264
Error	28	55.80	1.9929	-	-

D. 50-75 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	54.18457	27.09229	7.33225	3.340386
S	2	132.6263	66.31317	17.94698	3.340386
Zn	4	26.68724	6.671809	1.805657	2.714076
S X Zn	8	24.84498	3.105622	0.840505	2.291264
Error	28	103.46	3.694949	-	-

ANOVA 35. Pooled analysis of variance as influenced by sulphur, zinc fertilizationand their interaction effects for biofortification on Net Assimilation Rate (NAR) (g m^{-2} of leaf area day^{-1}) of soybean (*Glycine max* L. Merrill).

ANALYSIS OF VARIANCE TABLE

A. 25-50 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.000289	0.000145	2.065191	3.340386
S	2	0.001994	0.000997	14.24793	3.340386
Zn	4	0.000589	0.000147	2.102379	2.714076
S X Zn	8	0.001084	0.000135	1.935826	2.291264
Error	28	0.00	7E-05	-	-

B. 50-75 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	7.91E-05	3.95E-05	0.796737	3.340386
S	2	8.8E-05	4.4E-05	0.88599	3.340386
Zn	4	0.000308	7.71E-05	1.552929	2.714076
S X Zn	8	0.000613	7.66E-05	1.544032	2.291264
Error	28	0.00	4.96E-05	-	-

ANOVA 36. Pooled analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on Relative Growth Rate (RGR) (g $g^{-1}day^{-1}$) of soybean (*Glycine max* L. Merrill).

ANALYSIS OF VARIANCE TABLE

C. 25-50 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.000298	0.000149	1.492761	3.340386
S	2	0.002238	0.001119	11.2036	3.340386
Zn	4	0.002221	0.000555	5.558415	2.714076
S X Zn	8	0.003513	0.000439	4.396457	2.291264
Error	28	0.00	9.99E-05	-	-

D. 50-75 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.000418	0.000209	4.854489	3.340386
S	2	0.000944	0.000472	10.95511	3.340386
Zn	4	0.001672	0.000418	9.705366	2.714076
S X Zn	8	0.003593	0.000449	10.42944	2.291264
Error	28	0.00	4.31E-05	-	-

ANOVA 37. Pooled analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on number of nodules per plant of soybean (*Glycine max* L. Merrill).

ANALYSIS OF VARIANCE TABLE

G. 25 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	45.81111	22.90556	4.821417	3.340386
S	2	654.7444	327.3722	68.90895	3.340386
Zn	4	279.0778	69.76944	14.68585	2.714076
S X Zn	8	53.42222	6.677778	1.405613	2.291264
Error	28	133.02	4.750794	-	-

H. 50 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	73.03333	36.51667	0.80543	3.340386
S	2	5488.233	2744.117	60.52563	3.340386
Zn	4	1934.278	483.5694	10.66585	2.714076
S X Zn	8	326.9889	40.87361	0.901529	2.291264
Error	28	1269.47	45.3381	-	-

I. 75 DAS

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	493.7333	246.8667	5.486942	3.340386
S	2	6204.033	3102.017	68.94647	3.340386
Zn	4	2343.444	585.8611	13.02155	2.714076
S X Zn	8	605.5222	75.69028	1.682318	2.291264
Error	28	1259.77	44.99167	-	-

ANOVA 38. Pooled analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects for biofortification on yield attributes of soybean (*Glycine max* L. Merrill).

ANALYSIS OF VARIANCE TABLE

O. Number of pods per plant

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	14.32206	7.161029	0.824134	3.340386
S	2	2425.06	1212.53	139.5452	3.340386
Zn	4	959.8993	239.9748	27.61772	2.714076
S X Zn	8	277.641	34.70513	3.994072	2.291264
Error	28	243.30	8.68916	-	-

P. Length of pods (cm)

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.023444	0.011722	0.849095	3.340386
S	2	0.028444	0.014222	1.030181	3.340386
Zn	4	0.021111	0.005278	0.382294	2.714076
S X Zn	8	0.094889	0.011861	0.859155	2.291264
Error	28	0.39	0.013806	-	-

Q. Number of seeds per pod

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.148778	0.074389	6.257009	3.340386
S	2	0.036111	0.018056	1.518692	3.340386
Zn	4	0.051444	0.012861	1.081776	2.714076
S X Zn	8	0.092222	0.011528	0.969626	2.291264
Error	28	0.33	0.011889	-	-

R. Test weight (g)

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	272.0102	136.0051	10.47237	3.340386
S	2	87.06358	43.53179	3.35194	3.340386
Zn	4	10.24832	2.56208	0.19728	2.714076
S X Zn	8	11.98695	1.498368	0.115374	2.291264
Error	28	363.64	12.98704	-	-

S. Seed yield (t ha^{-1})

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.036964	0.018482	2.571624	3.340386
S	2	0.939284	0.469642	65.34622	3.340386
Zn	4	0.566476	0.141619	19.70491	2.714076
S X Zn	8	0.149071	0.018634	2.592727	2.291264
Error	28	0.20	0.007187	-	-

T. Stover yield (t ha^{-1}):

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.363871	0.181936	4.109342	3.340386
S	2	1.574751	0.787376	17.78429	3.340386
Zn	4	1.406453	0.351613	7.941819	2.714076
S X Zn	8	0.81996	0.102495	2.315034	2.291264
Error	28	1.24	0.044274	-	-

U. Harvest index (%)

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	9.762093	4.881047	0.427352	3.340386
S	2	74.96505	37.48253	3.281724	3.340386
Zn	4	37.27928	9.31982	0.815982	2.714076
S X Zn	8	19.21915	2.402393	0.210338	2.291264
Error	28	319.80	11.4216	-	-

ANOVA 39. Pooled analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects on quality of soybean (*Glycine max* L. Merrill) at harvest.

ANALYSIS OF VARIANCE TABLE

E. Oil content %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.175444	0.087722	0.597686	3.340386
S	2	61.67144	30.83572	210.0958	3.340386
Zn	4	22.89856	5.724639	39.00419	2.714076
S X Zn	8	8.182444	1.022806	6.968772	2.291264
Error	28	4.11	0.14677	-	-

F. Protein content %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	21.57659	10.7883	3.680606	3.340386
S	2	281.4771	140.7385	48.01529	3.340386
Zn	4	169.4093	42.35232	14.4492	2.714076
S X Zn	8	82.15606	10.26951	3.503613	2.291264
Error	28	82.07	2.931119	-	-

ANOVA 40. Pooled analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects on plant nutrient (seed) of soybean (*Glycine max* L. Merrill) at harvest.

ANALYSIS OF VARIANCE TABLE

K. Nitrogen %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.01036	0.00518	0.261126	3.340386
S	2	0.821373	0.410687	20.70291	3.340386
Zn	4	0.299347	0.074837	3.772553	2.714076
S X Zn	8	0.16416	0.02052	1.034423	2.291264
Error	28	0.56	0.019837	-	-

L. Phosphorus %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.003604	0.001802	0.21079	3.340386
S	2	0.142698	0.071349	8.345054	3.340386
Zn	4	0.058778	0.014694	1.71868	2.714076
S X Zn	8	0.027169	0.003396	0.397213	2.291264
Error	28	0.24	0.00855	-	-

M. Potassium %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.003604	0.001802	0.21079	3.340386
S	2	0.142698	0.071349	8.345054	3.340386
Zn	4	0.058778	0.014694	1.71868	2.714076
S X Zn	8	0.027169	0.003396	0.397213	2.291264
Error	28	0.24	0.00855	-	-

N. Sulphur %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.000218	0.000109	1.180723	3.340386
S	2	0.003391	0.001696	18.38554	3.340386
Zn	4	0.001591	0.000398	4.313253	2.714076
S X Zn	8	0.000409	5.11E-05	0.554217	2.291264
Error	28	0.00	9.22E-05	-	-

O. Zinc (mg kg^{-1})

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	29.62092	14.81046	19.25067	3.340386
S	2	78.58646	39.29323	51.07342	3.340386
Zn	4	42.34723	10.58681	13.76075	2.714076
S X Zn	8	4.938409	0.617301	0.802369	2.291264
Error	28	21.54	0.769348	-	-

ANOVA 41. Pooled analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects on plant nutrient (stover) of soybean (*Glycine max* L. Merrill) at harvest.

ANALYSIS OF VARIANCE TABLE

A. Nitrogen %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.01036	0.00518	0.261126	3.340386
S	2	0.821373	0.410687	20.70291	3.340386
Zn	4	0.299347	0.074837	3.772553	2.714076
S X Zn	8	0.16416	0.02052	1.034423	2.291264
Error	28	0.56	0.019837	-	-

B. Phosphorus %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.001333	0.000667	4.516129	3.340386
S	2	0.00084	0.00042	2.845161	3.340386
Zn	4	0.000658	0.000164	1.113978	2.714076
S X Zn	8	0.000116	1.44E-05	0.097849	2.291264
Error	28	0.00	0.000148	-	-

C. Potassium %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.00124	0.00062	0.447115	3.340386
S	2	0.06636	0.03318	23.92788	3.340386
Zn	4	0.032391	0.008098	5.839744	2.714076
S X Zn	8	0.003662	0.000458	0.330128	2.291264
Error	28	0.04	0.001387	-	-

D. Sulphur %

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	5.78E-05	2.89E-05	0.548193	3.340386
S	2	0.002751	0.001376	26.10241	3.340386
Zn	4	0.001213	0.000303	5.756024	2.714076
S X Zn	8	0.000227	2.83E-05	0.537651	2.291264
Error	28	0.00	5.27E-05	-	-

E. Zinc (mg kg^{-1})

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	4.61356	2.30678	1.931886	3.340386
S	2	63.73157	31.86579	26.68701	3.340386
Zn	4	52.05903	13.01476	10.89962	2.714076
S X Zn	8	4.890782	0.611348	0.511992	2.291264
Error	28	33.43	1.194056	-	-

ANOVA 42. Pooled analysis of variance as influenced by sulphur, zinc fertilization and their interaction effects on soil nutrient status after harvest of soybean (*Glycine max* L. Merrill).

ANALYSIS OF VARIANCE TABLE

O. Soil pH

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.008778	0.004389	0.665864	3.340386
S	2	0.016444	0.008222	1.247441	3.340386
Zn	4	0.058111	0.014528	2.204094	2.714076
S X Zn	8	0.075222	0.009403	1.42655	2.291264
Error	28	0.18	0.006591	-	-

P. Organic carbon (%)

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.003338	0.001669	0.158334	3.340386
S	2	0.061671	0.030836	2.925486	3.340386
Zn	4	0.063058	0.015764	1.495633	2.714076
S X Zn	8	0.176062	0.022008	2.087962	2.291264
Error	28	0.30	0.01054	-	-

Q. Available Nitrogen (kg ha^{-1})

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	63.39728	31.69864	0.53508	3.340386
S	2	2349.96	1174.98	19.83391	3.340386
Zn	4	1093.21	273.3026	4.613406	2.714076
S X Zn	8	438.8438	54.85547	0.925972	2.291264
Error	28	1658.75	59.24095	-	-

R. Available Phosphorus (kg ha^{-1})

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.008778	0.004389	0.665864	3.340386
S	2	0.016444	0.008222	1.247441	3.340386
Zn	4	0.058111	0.014528	2.204094	2.714076
S X Zn	8	0.075222	0.009403	1.42655	2.291264
Error	28	0.18	0.006591	-	-

S. Available Potassium (kg ha^{-1})

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	305.6884	152.8442	0.369742	3.340386
S	2	5931.871	2965.936	7.174839	3.340386
Zn	4	2321.61	580.4026	1.404041	2.714076
S X Zn	8	611.3437	76.41797	0.184861	2.291264
Error	28	11574.64	413.3801	-	-

T. Available Sulphur (kg ha^{-1})

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	2.185631	1.092816	0.374688	3.340386
S	2	49.49888	24.74944	8.485713	3.340386
Zn	4	26.74861	6.687152	2.292789	2.714076
S X Zn	8	6.962938	0.870367	0.298418	2.291264
Error	28	81.66	2.916601	-	-

U. DTPA extractable zinc

Source of variation	Degree of freedom	Sum of squares	Mean Sum of Squares	Fcal	Ftab
REP	2	0.001791	0.000896	0.282142	3.340386
S	2	0.220484	0.110242	34.73151	3.340386
Zn	4	0.112369	0.028092	8.850378	2.714076
S X Zn	8	0.009938	0.001242	0.391359	2.291264
Error	28	0.09	0.003174	-	-

APPENDIX-B

A. COMMON COST OF CULTIVATION (₹ ha^{-1})

Sl. No	Operations	No. of unit	Rate (₹)	Cost (₹ ha^{-1})
1.	Land Preparation	Twosummer ploughing twice by tractor followed by levelling	1000	2000
2.	Sowing			
	Seed	60 kg ha^{-1}	₹ 60 kg^{-1}	3600
	Seed treatment with Bavistin (2g kg^{-1} seed)	120 g	₹174/100g	208.80
	Labour required for sowing	15 labours	400	6000
3.	Application of manures and fertilizers	7 labours	400	2800
4.	Plant protection measures	-	-	1000
5.	Harvesting	10 labours	400	4000
6.	Drying	5 labours	400	2000
7.	Threshing and cleaning	15 labours	400	6000
8.	Miscellaneous			1000
TOTAL				₹ 28,608.8

B. COST OF VARIABLE INPUTS FOR NUTRIENT MANAGEMENT

Sl.No	Inputs	No. of unit	Rate (₹ $unit^{-1}$)	Cost (₹ ha^{-1})
	NUTRIENT MANAGEMENT			
B1	a) FYM	5 t ha^{-1}	₹ 1500 t^{-1}	7,500
	b) Rhizobium (20g/kg seed)	1.2 kg	₹ 70	84
	c) DAP	130.4 kg ha^{-1}	₹ 25 kg^{-1}	3,260
	d) MOP	66.6 kg ha^{-1}	₹ 19 kg^{-1}	1,265.4
TOTAL				12,109.4
B2	Elemental Sulphur			
	i. S_{20}	22.2 kg ha^{-1}	₹ 25 kg^{-1}	555
	ii. S_{40}	44.44 kg ha^{-1}	₹ 25 kg^{-1}	1,111
	TOTAL			1,666
B3	Zinc Oxide			
	i.Zn_5	7.14 kg ha^{-1}	₹ 150 kg^{-1}	1,071
	ii.Zn_{10}	14.29 kg ha^{-1}	₹ 150 kg^{-1}	2,143.5
	iii.Zn_{15}	21.43 kg ha^{-1}	₹ 150 kg^{-1}	3,214.5
	iv.Zn_{20}	28.57 kg ha^{-1}	₹ 150 kg^{-1}	4,285.5
TOTAL				10,714.5

C. COST OF VARIABLE INPUTS FOR WEED MANAGEMENT

Sl. No	Item	No. of unit	Rate (₹ $unit^{-1}$)	Cost (₹ ha^{-1})
WEED MANAGEMENT				
C1	Three hand weeding i) Labour requirement for 1^{st} weeding	15 labours	400	6000
	ii) Labour requirement for 2^{nd} weeding	10 labours	400	4000
	iii) Labour requirement for 3^{rd} weeding	10 labours	400	4000
TOTAL				14,000

APPENDIX-C

Abstract of Paper Publication

Effect of Sulphur and Zinc Fertilization on Growth and Yield of Soybean [*Glycine max* (L.) Merrill] under Nagaland Condition.

Imsong, W., Tzudir, L., Longkumer, L.T., Gohain, T. and Kawikhonliu, Z. (2023). Effect of Sulphur and Zinc Fertilization on Growth and Yield of Soybean (*Glycine max* L. Merrill) under Nagaland Condition. *Agricultural Science Digest*. doi: 10.18805/ag.D-5758.

ABSTRACT

Background: A field experiment was conducted at the Experimental Research Farm of School and Agricultural Sciences and Rural Development (SASRD), Nagaland University, during the *kharif* season of 2017 and 2018 to study the effect of sulphur and zinc fertilization for biofortification in soybean [*Glycine max* (L.) Merrill] under Nagaland condition.

Methods: The experiment was laid out in a Factorial Randomized Block Design (RBD) with 15 treatments combinations *viz* sulphur (0 kg ha^{-1}, 20 kg ha^{-1} and 40 kg ha^{-1}), zinc (0 kg ha^{-1}, 5 kg ha^{-1}, 10 kg ha^{-1}, 15 kg ha^{-1} and 20 kg ha^{-1}) replicated thrice.

Result: The results obtained showed that the plant growth and yield attributes were significantly influenced by the treatment combination of $S_{20}Zn_{20}$. The application of 20 kg S ha^{-1} showed higher plant height, number of leaves and branches per plant, shoot dry weight, leaf area index (LAI), crop growth rate (CGR), number of nodules and was found to be quite comparable with the treatment of 40 kg S ha^{-1}. The zinc fertilization of 20 kg Zn ha^{-1} showed a greater response by the plant and showed increase in growth attributes and was at par with 15 kg Zn ha^{-1}. A higher number of pods, seed yield of and stover yield were observed in 20 kg S ha^{-1} and 20 kg Zn ha^{-1} fertilization respectively as compared to the other levels of treatments. However, the length of pods, number of seeds per pod, test weight and harvest index did not differ significantly by the treatments.

Key words: Biofortification, Fertilization, Soybean, Sulphur, Zinc.

Effect of Sulphur and Zinc Fertilization on the Quality and Economics of Soybean(G*lycine max* L. Merrill) under Nagaland Condition.

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ABSTRACT: The role of nutrients is profound in playing a vital role in the quality of soybean crops and as such its supplementation to the crop is pertinent for increased productivity. In relation to this, a field experiment was conducted at the Experimental Research Farm of School and Agricultural Sciences and Rural Development (SASRD), Nagaland University, during the *kharif* season of 2017 and 2018 to study the effect of different levels of sulphur and zinc fertilization on the quality and economics of soybean (*Glycine max* L. Merrill) under Nagaland condition. The experiment was laid out in a Factorial Randomized Block Design (RBD) with 15 treatments combinations *viz* sulphur @ 0 kg ha^{-1}, 20 kg ha^{-1}, 40 kg ha^{-1}, zinc @ 0 kg ha^{-1}, 5 kg ha^{-1}, 10 kg ha^{-1}, 15 kg ha^{-1} and 20 kg ha^{-1} replicated thrice. The results from the two years study showed that the oil and protein content in the crop were significantly influenced by the treatment combination of $S_{20}Zn_{20}$ as compared to the other levels of treatments. A higher oil and protein content were observed with the application of 20 kg S ha^{-1} which was comparatively at par with the application of 40 kg S ha^{-1} and superior over control while 20 kg Zn ha^{-1} fertilization recorded significantly the highest oil and protein content followed by the application of 15 kg Zn ha^{-1}. In terms of the economics of the treatments, $S_{20}Zn_{20}$ gave the highest gross returns, net returns and B:C ratio followed by $S_{20}Zn_{15}$ for both the years and pooled. Thus, based on the results of the two years experiment, the treatment combinations of $S_{20}Zn_{20}$ was found to be a suitable fertilizer dosage for soybean.