RESPONSE OF SOYBEAN (*Glycine max* L. Merril) TO SOURCES AND LEVELS OF ZINC

Thesis

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of

Doctor of Philosophy

in

Agricultural Chemistry and Soil Science

by

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2022

DECLARATION

I, Ms. Sentimenla, 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 "Response of Soybean (*Glycine max* L. Merril) toSources and Levels of Zinc" submitted to Nagaland University in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy (Agriculture) in Agricultural Chemistry and Soil Science is the record of research work carried out by Ms. Sentimenla, Registration No.Ph.D./ACSS/00212 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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CERTIFICATE – II

VIVA VOCE ON THESIS OF DOCTOR OF PHILOSOPHY IN AGRICULTURAL CHEMISTRY AND SOIL SCIENCE

This is to certify that the thesis entitled "Response of Soybean (*Glycine max* L. Merril) to Sources and Levels of Zinc" submitted by Ms.Sentimenla, Admission No. 263/18, Registration No. Ph.D./ACSS/00212 to the NAGALAND UNIVERSITY in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy in Agricultural Chemistry and Soil Science 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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Date: (SENTIMENLA)

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LIST OF ABBREVIATIONS

BD	-	Bulk Density
B	-	Boron
C.D	-	Critical Difference
@	-	at a rate of
cm	-	Centimeter
DAS	-	Days after Sowing
ºC	-	Degree Celsius
Cmol	-	Centimol
CEC	-	Cation Exchange Capacity
dSm^{-1}	-	Decisiemens per meter
E	-	East
EC	-	Electrical conductivity
et al.	-	et allia (and others/co-workers)
Fig.	-	Figure
g	-	Gram
H+	-	Hydrogen
ha	-	Hectare
i.e.	-	Id est (that is)
kg	-	Kilogram
LR	-	Lime requirement
m	-	Meter

mg	-	Milligram
N	-	North
N	-	Nitrogen
NS	-	Non-significant
NU	-	Nagaland University
No.	-	Number
OC	-	Organic Carbon
%	-	Per cent
P	-	Phosphorus
PD	-	Particle Density
pH	-	Negative logarithm of H^+ ion concentration
PPM	-	Parts Per Million
K	-	Potassium
RDF	-	Recommended Dose of Fertilizers
SASRD	-	School of Agricultural Sciences and Rural Development
Sl. No.	-	Serial number
S	-	South
S	-	Sulphur
S	-	Significant
SEm±	-	Standard error of mean
Viz.	-	Namely
Zn	-	Zinc

ABSTRACT

Field experiments were conducted during the kharif season in soybean crop at the Experimental Research Farm, School of Agricultural Sciences and Rural Development (SASRD), Medziphema Campus, Nagaland University in 2019 and at the State Horticulture Nursery, Green Park, Dimapur in 2020, which was grown under the acidic upland soil condition. Treatments consisted of four Zn sources such as Zinc 21% ($ZnSO_4$ 7 H_2O) @ 1, 2.5, 5 kg ha^{-1}, Zinc 33% ($ZnSO_4$ H_2O) @ 1, 2.5, 5 kg ha^{-1}, Zn-EDTA 12% @ 1, 2.5, 5 kg ha^{-1}, Liquid ZnO @ 300, 600, 900 ml ha^{-1}and RDF @ 20: 60: 40: 30: 1.5 (N, P_2O_5, K_2O, S, B) kg ha^{-1} and three replications. Liming was also done @ 1/10 of LR prior to 20 days before sowing. During the first and second year, the growth parameters such as plant height, no. of nodules, fresh weight and dry weight of nodules at the time of flowering were found to be optimum at Zn treatment of T_9 (5 kg $ZnSO_4$ H_2O ha^{-1} + RDF). The lowest was recorded at treatment T_1 (control). The seed and stover yield of soybean were also found to be increased with Zn fertilization. The highest was recorded at treatment T_9 (5 kg $ZnSO_4$ H_2O ha^{-1} + RDF) and the lowest was recorded at T_1 (control). The yield attributes such as no. of pods plant^{-1} and no. of seeds pod^{-1} were found to be increased with Zn fertilization with the maximum yield attributes recorded at T_9 (5 kg $ZnSO_4$ H_2O ha^{-1} + RDF) whereas in test weight, it was observed to be non-significant as there was less variation among the response to Zn sources. The lowest were recorded at T_1 (control). The nutrient content and uptake of N, K and Zn were observed to be increased with Zn sources where the highest nutrient content and uptake was recorded at T_9 (5 kg $ZnSO_4$ H_2O ha^{-1} + RDF) except P where less variation was observed to Zn treatments. The lowest were recorded in the untreated plot (T_1). The protein and oil content in soybean were positively influenced with Zn sources. The maximum protein and oil content was recorded at treatment T_9 (5 kg $ZnSO_4$ H_2O ha^{-1} + RDF). The lowest were being recorded in T_1 (control). The soil fertility status of the postharvest soil such as

N, K and Zn were also increased positively with the maximum being recorded at Zn treatment of T_9 (5 kg $ZnSO_4$ H_2O ha^{-1} + RDF) except S and P. The soil physicochemical properties such as pH, OC, CEC, Particle density, Bulk density and Pore space were also observed to be non-significant with the application of various Zn sources in the post-harvest soil. The pooled data also show similar observations from the two consecutive years. It was observed that the plant height, no. of nodules, fresh weight and dry weight of nodules at the time of flowering were found to be positively influenced with Zn fertilization with maximum being recorded at T_9 (5 kg $ZnSO_4$ H_2O ha^{-1} + RDF). The lowest was recorded at treatment T_1 (control). The yield and yield attributes of soybean were also increased with Zn application. The maximum seed and stover yield, no. of pods $plant^{-1}$ and no. of seeds pod^{-1} were recorded at treatment T_9 (5 kg $ZnSO_4$ H_2O ha^{-1} + RDF) and the lowest was recorded at T_1 (control). However the test weight was observed to be non-significant. The N, K and Zn content and uptake were found to be increased with Zn application where the maximum nutrient content and uptake was recorded at T_9 (5 kg $ZnSO_4$ H_2O ha^{-1} + RDF) except P. The lowest were recorded in T_1 (control). The protein and oil content in soybean were increased with Zn treatments and the maximum was being recorded at treatment T_9 (5 kg $ZnSO_4$ H_2O ha^{-1} + RDF). The lowest were recorded in T_1 (control). Zn application also increased the available soil N, K and Zn of the postharvest soil except P and S. The maximum were recorded at T_9 (5 kg $ZnSO_4$ H_2O ha^{-1} + RDF). The soil pH, OC, CEC, Particle density, Bulk density and Pore space of the postharvest soil were found to be non-significant with Zn treatments. From the experiment conducted,it was observed that soybean responded well to Zn fertilization. The application of Zn @ T_9 (5 kg $ZnSO_4$ H_2O ha^{-1} + RDF) significantly increased all the growth parameters, yield and yield attributes, nutrient content and uptake and quality of soybean grown under acidic foothill condition of Nagaland.

CHAPTER 1

INTRODUCTION

INTRODUCTION

Soybean is now the second largest oilseed crop in India next to groundnut. Though soybean is a legume, yet it is widely used as oilseed crop due to its very poor cook ability and digestibility on account of the inherent presence of trypsin inhibitor, thus it cannot be utilized as a pulse. It is also knownas the golden bean of the twentieth century. It grows in a varied ranged of soil and agro-climatic conditions. It has emerged as an important commercial crop in many countries and the international trade of soybean is also spread globally (Ian *et al.*2014).It is native to East Asia. Soybean is gaining importance on account of its unique characteristics and adaptability to varied agro climatic conditions. It has unmatched composition of 40 % protein and 20 % oil and nutritional superiority on account of containing essential amino acids, unsaturated fatty acids, carbohydrates, vitamins and minerals. Soybean protein is rich in valuable amino acid lysine (5%) in which most cereals are deficient. In addition, it contains a good amount of minerals, salts and vitamins (thiamine and riboflavin) and its sprouting grains contain a considerable amount of vitamin C (Orhevba, 2011).

It is a major oilseed crop grown widely under the rainfed condition in the central and peninsular parts of India. Over the years it has increased the cropping intensity and profitability per unit land area owing to a number of varieties developed (Agarwal *et al*. 2013). Soybean crop is grown mainly in the states of Madhya Pradesh, Maharastra, Rajasthan, Telangana, Chhattisgarh, Gujarat and Karnataka. About 53% of the crop area under this crop falls in Madhya Pradesh. Soybean meal is a highly demanded product worldwide. A continuous increase in the production, exports, imports and consumption of soybean oil has been observed each year. The total area and production of soybean in the world in 2019-20 is 120.50 million hectares and 333.67 million tons with Brazil leading the world production followed by USA, Argentina, China and India (Agricultural Market Intelligence Centre, PJTSAU, 2021). The world production and consumption of soybean oil in million metric tons is 360.08 and 57.05 (Statista Research and Analysis, 2019).

It is known as the wonder crop because it is the richest, cheapest and easiest source of best quality proteins and fats having a vast multiplicity of uses as food and industrial products. As per the latest data, in India the total area under soybean is 113.339 lakh ha and 114.832 lakh tons productivity (SOPA, 2018). Soybean builds up the soil fertility by fixing atmospheric nitrogen in soil. This is another way of meeting the demand of N required by the crops (Ciampitti*et al*. 2021). This biological N fixation meets the demand of N in plants which on an average ranges from 40 to 70 %. This N fixation also depends on the environmental condition as well as the symbiotic association between the host and the bacteria (Hungria and Vargas, 2000; Pauferro*et al*. 2010; Collino*et al*. 2015; Santachiara*et al*. 2017) It can be used as fodder, forage, silage, etc. It is excellent nutritive foods for livestock and poultry. It is processed for human consumption and made into products such as soymilk, soy flour, soy protein, tofu and fermented food products. It is also used in many non-food industrial products.

In Nagaland it is cultivated as a kitchen garden crop and consumed as pulse crop by the people. It grows well in slopes and terraces. It is consumed by every household in Nagaland in the form of fermented soybean as a traditional food from time immemorial particularly in the Zunheboto district of Nagaland. Fermented soybean is highly digestible plant protein which is low in fats, rich in antioxidant with various health benefits (Tamang, 2015). Soybean is another oilseed crop of Nagaland but grown as pulse in the name of Naga Dal. Soybean is grown in almost all the districts of the state irrespective of elevation and irrigation facilities. It is commonly cultivated under rain fed condition in the jhum fields. It is cultivated at an area of 25,040 ha with the productivity of 1.25 mt ha^{-1} (Statistical handbook of Nagaland, 2018). Besides, being a main item in almost every household, it also has the capacity to enhance soil fertility through nitrogen fixation. Under the prevailing agro climatic conditions of Nagaland, this crop also plays a major role in improving soil health and generating farmers' income.

Zinc is an important micronutrient essential for plants, animals and human. Even though it is required in small amount, yet it is an important vital micronutrient. It performs many catalytic functions in the plant besides transformation of carbohydrates, chlorophyll and protein synthesis,nucleic acid and lipid metabolisms (Kelarestaghi*et al.* 2007;Marschner, 1986; Pahlsson, 1989). The deficiency of Zinc was first discovered in human in 1961 (Roohani*et al.* 2013). Zinc deficiency is a serious problem in humans causing malnutrition in the world. It occurs in places where people dietary intake is more of cereals than animal/protein foods. Susceptible groups to zinc deficiency include children, adolescents, pregnant and lactating women. Its deficiency causes stunted growth, dermatitis, night blindness and delay in wound healing, poor immune and reproductive systems. Zinc deficiency is widely spread among the population whose diet is cereal based. It therefore not only affects the plant growth and yield but also human beings which are roughly crossing 3 billion people globally (Hussain *et al*. 2015). Zinc plays a pivotal role in immune system of human beings as well as primary functions of cell in all living organisms (Vidyashree*et al*. 2016).The deficiency of zinc in developing countries ranked 5th and 11th globally (Sharma *et al*. 2013). On an average, a daily intake of 15 mg zinc per day is necessary to enhance growth and strengthen the immune systems (Evans, 1986 and Roohani*et al.* 2013). Zinc deficiency is found in soil worldwide which is a major concern in production of food crops. Most of the crops respond well to application of zinc (Welch, 2002) and there is a strong relationship between the concentration of zinc in tissues and the growth and yield of crops (Katyal*et al,* 1983). It occurs as a free ion or as a complex form in plants. Zinc can also be incorporated as a protein component which can also act as a functional, structural or regulatory cofactor of a number of enzymes (Brown *et al.* 1993). Zinc plays an important role in the biosynthesis of auxins and gibberellins (Masev*et al*. 1966). It helps in the formation of chlorophyll, carbohydrates, conversion of starches to sugars, growth regulation and elongation of stem. It also withstands cold temperatures in the presence of Zn in plant tissue. The role of Zn in plants defense against pest and diseases is of crucial importance. It has been observed that application of Zn in plants reduced various symptoms in crops (Grewal *et al*. 1996; Li *et al*. 2016; Machado *et al*. 2018). The deficiency of Zn in plants significantly reduced the carbohydrate, protein synthesis, chlorophyll formation and uniform maturity. It causes growth stunt, chlorosis, spikelet sterility, reduce water uptake and transport (Hafeez *et al.* 2013 and Wasim, 2007). About 30% of the cultivable soils of the world contain low availability of zinc in plants (Sillanpaa, 1990). The deficiency of Zn in soil is also due to its availability to crops in small amount and the remaining total zinc is fixed as insoluble or unexchangeable form which makes it difficult for zinc availability to the crops (Stahl and James, 1991). Zinc deficiency in Indian soil accounts to about 49% affecting 1/3rd of the country's acidic soils (Athokpam*et al.* 2018). In Indian soil, its deficiency is also expected to increase further to 63% by the year 2025 (Arunachalam *et al.* 2013). Various factors such as mineral composition of parent material, intensity of weathering, soil type and climate determines the amount of zinc present in the soil (Hafeez *et al.* 2013). Soils such as sandy, highly leached acid soils, low organic soils have low in soil available zinc (Khoshru*et al.* 2020). In the northeast region of India, there is variability in availability of micronutrients due to variation in climatic conditions, soils and topography (Bandyopadhyay *et al.* 2018). The deficiency is even more severe in the North-Eastern region of India consisting of 60% soil acidity (Kumar *et al*., 2016) and micronutrient deficiency (Singh *et al*., 2007). This might be one of the reasons behind lower crop productivity in the region. Zinc deficiency is also increased by 4.62 % in Nagaland (Shukla *et al.* 2018). Zinc deficiency in this region may be because of excessive leaching and runoff and removal of the nutrient by the crop continuously without restoring it (Bandyopadhyay *et al.* 2018 and Chen *et al.* 2002).Adequate zinc fertilization is therefore crucial to exploit the yield potential of crops. In order to increase productivity, correction of Zn deficiency is therefore, necessary which in turn requires the precise evaluation of available Zn in the soil (Singh *et al*. 2018). For a soil to be healthy and productive, it should contain about 1-200 ppm of Zn (Rudani*et al*. 2018). However the information on the micronutrient availability is limited in this region and hence further research is required to understand the factors leading to Zn deficiency. Knowing the limitations of Zn deficiency in this region, a two years research on the topic "Response of Soybean (*Glycine max* L. Merril)to Sources and Levels of Zinc" was conducted under the following objectives:

OBJECTIVES

1. To study the response of soybean to sources and levels of Zn on growth, yield and quality.

2. To study the nutrient (NPKS & Zn) content and uptake by soybean as affected by Zn.

3. To study the effect of sources and levels of Zn on Physico-Chemical properties of soil.

4. To study the response of soybean to sources and levels of Zn on soil fertility.

CHAPTER II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

The details obtained with relevance to the present research entitled "Response of Soybean (*Glycine max* L. Merril) to Sources and Levels of Zinc" has been presented in this chapter.

2.1 Effect of Zinc on growth, yield and quality of soybean

2.1.1 Effect on plant height

Ahmadi (2010) observed increased in plant height of rapeseed through soil application of Zn.

Dashadi*et al*. (2013) revealed that the increased in plant height of lentil might be due to the pivotal role played by the Zn nutrition in auxin production which led to maximizing the cells and thereby enhanced plant growth.

Debnath *et al*. (2018) observed significant increase in plant height of cowpea at T_9 (RDF+B1.5+Zn5.0) (55.8 cm) as compared to all other treatments at 5% level ofsignificance.

Dube *et al*. (2001) observed that the soil application of 5 mg kg^{-1} Zn enhanced the plant height of pigeon pea.

Haider *et al*. (2018) observed that the soil application of $ZnSO_4$ at 10 mg kg^{-1} showed significant effect on plant height in mung bean.

Kayan *et al*. (2015) observed significant interaction of Zn source x dose in plant height of Chickpea from the variance analysis.

Khan *et al*. (2007) observed significant increase in the plant height of rice crop with Zn treatment @ 10 kg Zn ha^{-1} which was found statistically at par with 15 kg Zn ha^{-1}.

Khorgamy and Farnia (2009) also reported increased in plant height due to Zn application in Chickpea.

Krishna (1995) stated that the significant influenced of Zn on growth parameters might be due to its involvement on tryptophan synthesis which is a precursor of growth hormone auxin. This auxin plays an important role in elongation of cells thereby enhances the growth and development processes in plants.

Kulhare*et al*. (2014) also reported significant increase in plant height of soybean with the application of Zn.

Lakshmi *et al*. (2017) revealed that the plant height of black gram was significantly influenced by the foliar application of secondary nutrients and zinc.

Muindi*et al*. (2020) reported that soil application of 4 kg ha^{-1} $ZnSO_4$ gave the highest plant height as compared to the foliar application of zinc in green gram.

Panneerselvam and Stalin (2014) observed that application of zinc significantly increased the plant height and other growth attributes in maize which may be due to stimulatory effect of zinc on the physiological as well as metabolic processes of the plant.

Praveena*et al*. (2018) observed that the foliar application of 0.2 % B at 20 and 35 DAS along with basal soil application of $ZnSO_4$ @ 5 kg ha^{-1} in Green Gram significantly increased the plant height.

Quddus*et al*. (2014) observed that the application of Zn significantly increased the plant height of lentil in low Ganges river flood plain. The highest plant height recorded 27.8 cm @ Zn levels of 3.0 kg ha^{-1} which was found statistically at par to 2.0 and 1.0 kg Zn ha^{-1} over control.

Raghuwanshi*et al*. (2017) observed that the plant height of Soybean was increased with the increasing levels of Zn @ 10.0 kg Zn ha^{-1} at 30, 45 and 90 DAS over control which was statistically at par with 10 kg Zn ha^{-1}.

Ram and Kattiyar (2013) observed that the application of 10 kg Zn ha^{-1} in summer mungbean significantly increased the plant height.

Samreen*et al*. (2017) observed that the treatment of mung bean with different Zn concentrations on the average significantly increased the plant height by 23.4% higher than that of control.

Sangwan and Raj (2004) reported significant increase in plant height with the application of 15 kg $ZnSO_4$ ha^{-1} in chick pea as compared to no zinc application.

Shah *et al*. (2016) reported increased in plant height of pigeon pea with the soil application of $ZnSO_4$ @ 20 kg ha^{-1}.

Singh *et al*. (2013) reported significant influenced on plant height of lentil at different levels of Zn. Maximum plant height of 42.2 cm was observed with 0.08% foliar application of Zn over control.

Taha and El-Habbasha (2011) observed that the plant height of chick pea was significantly increased with increasing levels of Zn fertilization under sandy soil condition.

Tayyeba*et al*. (2017) reported that theapplication of Zn @ 2 μM significantly enhanced the plant height in mung beans.

Thamke (2017) observed increased in plant height of pigeon pea with the soil application of $ZnSO_4$ @ 15 kg ha^{-1}.

Tripathi *et al*. (2011) observed the highest plant height at 100% RDF + 2 t FYM + 40 kg S + 25 kg $ZnSO_4$ + 1 kg B ha^{-1} + Azotobacter (seed treatment) in Indian mustard.

Ullah *et al*. (2018) reported that the application of Zn significantly increased the plant height of chickpea @ 10 kg Zn ha^{-1}.

Upadhyay *et al*. (2016) observed that application of 15 kg Zn ha^{-1} significantly increased plant height over control in cowpea.

Usman *et al*. (2014) observed that the plant height of green gram was significantly increased at the rate of soil application of 15 kg $ZnSO_4$ ha^{-1} (T_3) which was found at par with the treatments at 20 kg$ZnSO_4$ ha^{-1}(T_4) and 25 kg$ZnSO_4$ ha^{-1}(T_5).This increased in growth of mung bean might be due to the enhanced chlorophyll concentration, root absorption and photosynthetic activity leading to increased plant height.

2.1.2 Effect on number of nodules at flowering stage

Abdulameer (2010) observed that there was increased in the nodulation of bean crop with Zn application thereby enhanced the number of nodules.

Ahmad *et al*. (2013) revealed that the nodulation in mung bean crop was enhanced with the fertilization of micronutrients (Zn, Fe & Mo) and rhizobium. This increased in nodulation thereby enhances the nitrogen fixation.

Awlad*et al*. (2003) also reported increased in the no. of nodules with the increasing level of Zn in Soybean.

Balai*et al*. (2017) observed significant increase in the number of nodules plant-1 with the application of Zn up to 6 kg ha^{-1}in chickpea.

Chauhan *et al*. (2013) observed increased in nodulation of soybean by 91% with the application of Zn @ 5 kg ha^{-1} during the consecutive years of study.

Das *et al*. (2012) observed that the increase in the number of nodules and dry weight of nodules depend on the availability of Zn nutrition.

Debnath *et al*. (2018) observed that soil application of Zn @ 7.5 kg ha^{-1} along with RDF recorded highest number of nodules $plant^{-1}$ in cowpea.

Edulamudi*et al*. (2017) reported increased in the number of nodules plant^{-1} with Zn concentration up to 1000 μg g^{-1} in horse gram.

Khan *et al*. (2018) observed the number of nodules and weight of nodules plant^{-1} were increased with Zn application 10 kg ha^{-1} in mung bean crop.

Kobraee*et al*. (2011) revealed that the number of nodules and weight of nodules were significantly increased with Zn application.

Khorgamy and farina (2009) reported that the application of $ZnSO_4$ @ 20 kg ha^{-1} enhanced root nodulation in Chickpea

Kumar *et al*. (2020) observed highest number of nodules plant^{-1} (29.75) in chickpea with the application of 6 kg $FeSO_4$ ha^{-1} along with 4 kg $ZnSO_4$ ha$^{-1.}$

Kuniya*et al*. (2018) observed significant increase in the no. of root nodules with the application of 5.0 kg Zn ha^{-1} in cluster bean.

Pavadai*et al*. (2004) observed that the Zn fertilization positively enhanced the nodulation in black gram.

Raghuwanshi*et al*. (2018) observed that the no. of nodules was increased with the increasing levels of Zn 10 kg Zn ha^{-1} over control in soybean crop.

Ram and Kattiyar (2013) found significant improvement in nodulation @ 10 kg Zn ha^{-1} in mungbean.

Raouf Seyed Sharifi (2016) observed that application of nano ZnO as Zn3 increased the number of nodules per plant by 49% in soybean.

Upadhyay *et al*. (2016) reported maximum number of nodule per plant and active nodule at 15 kg Zn per ha^{-1} while minimum in control in Cowpea.

Yashona*et al*. (2018) showed positive response to nodulation in chick pea, cluster bean, mung bean, soybean and pigeon pea with the application of Zn.

2.1.3 Effect on nodule fresh and dry weight at the time offlowering

Ahlawat *et al*. (2007) also reported increased in nodulation and nodule dry weight with Zn fertilization.

Das *et al*. (2012) observed Increased in nodule dry weight ranging from 2.75 to 16.87 % at 10 kg $ZnSO_4$ ha^{-1} and 4.27 to 32.82 % at 25 kg $ZnSO_4$ ha^{-1} as compared to control.

Debnath (2018) observed that the dry weight of nodules were significantly increased at 60 DAS from the treatment T_7 (RDF+Zn7.5) over treatment T_1 (RDF) which indicates that nodulations were enhanced with the application of zinc.

Edulamudi*et al*. (2017) observed increased in dry weight of nodules $plant^{-1}$ after 30 and 45 days of sowing, with increasing levels of Zn up to 75 mg g^{-1}. This increased in nodulation might be due to the enhanced rooting system with the application of Zn.

Gour*et al*. (2014) observed that the nodulation, fresh and dry weight of nodules were significantly increased with the treatment application of 100 % RDF +$ZnSO_4$ @ 25kgha^{-1} + $MgSO_4$ @ 25 kg ha^{-1}. Fertilization with $ZnSO_4$ and $MgSO_4$ might create conducive environment for nodule formation.

Kuniya*et al*. (2018) observed significant increase in the nodules fresh and dry weight with the application of 5.0 kg Zn ha^{-1} in cluster bean.

Raouf Seyed Sharifi (2016) reported increased in the fresh weight of nodules $plant^{-1}$ by 60.33% with the application of nano ZnO as Zn3 in soybean.

Ram *et al*. (2018) observed that the significant increase in nodules fresh weight $plant^{-1}$ in mung bean crop with the increasing levels of Zn fertilization upto 10 kg Zn ha^{-1} might be due to enhanced nodulation and establishment of better root system.

Singh *et al*. (2015) observed increased in nodule dry weight with the increased Zn doses where maximum (41.3 mg/plant at 90 DAS) and minimum (27.3 mg/plant at 60 DAS) were recorded at Zn4 (0.08%) and Zn1 (0.0%) respectively.

Upadhyay *et al*. (2016) observed significant increase in fresh weight of nodules plant^{-1} at 15 kg Zn ha^{-1} in cowpea over control.

2.1.4 Effect on seed and stover yield

Adekiya*et al*. (2018) reported increased in the root yield of sweet potato at the application of 5 kg ha^{-1} of $ZnSO_4$ during consecutive years.

Ahmed *et al*. (2017) observed significant influenced of Zn application in capsicum. The highest average yield of 29.2 t ha^{-1} was recorded with the application 3 kg Zn ha^{-1}which was followed by 4 kg and 2 kg Zn ha^{-1}.

Afolabi *et al*. (2020) reported that Zn also plays an important role in enzymatic activity and catalyzation which enhance the growth and yield attributes. This might be another factor for increasing the stover yield in maize plant.

Bhadauria*et al*. (2012) observed that the increased in seed yield of mustard with Zn fertilization might be due to the direct involvement of Zn in the transfer of photosynthates in seeds thus enhancing seed yield.

Erenoglu*et al*. (2002) observed increased in grain yield of bread and durum wheat with soil Zn application.

Faujdar *et al*. (2014) observed that application of Zn @ 5 kg ha^{-1} significantly increased the grain and stover yield by 17.6 and 16.2 % as compared to control in maize.

Habbasha*et al*. (2013) observed significant increase in straw yield of chickpea with 0.2% $ZnSO_4$ application.

Hossain *et al*. (2019) reported significant increase in the seed yield of lentil at 2 kg Zn ha^{-1} during all the years and all locations.

Jalal *et al*. (2021) reported that soil application of Zn significantly increased the grain yield of common bean by 13.6 and 13.5% in 2019 and 2020 respectively.

Khorgamy and Farina (2009) reported that the soil application of $ZnSO_4$ @ 20 kg ha^{-1} significantly increased the seed yield in chickpea cultivars.

Kumar *et al*. (2020) recorded maximum seed yield of 2457.15 kg ha^{-1} with the application of 6 kg $FeSO_4$ ha^{-1} and 3 kg $ZnSO_4$ ha^{-1} in chickpea.

Kuniya*et al*. (2018) reported significant increase in straw yield of cluster bean with the application of 5 kg Zn ha^{-1}.

Lakshmi *et al*. (2017) revealed that foliar application of secondary nutrients and Zn significantly influenced the dry matter production of Black gram.

Liu *et al*. (2016) observed that Zn application of 30 kg $ZnSO_4$ $7H_2O$ hm^{-2} increased chlorophyll content in leaves, improved photosynthesis, and increased grain yield of summer maize.

Mali *et al*. (2003) observed that in mung bean the application of Zn 5 kg ha^{-1} along with S 60 kg ha^{-1} recorded higher seed yield to about 67 %over control.

Maumba*et al*. (2013) observed that the stover yield of rice were significantly highest at the rate of 30 kg ha^{-1} $ZnSO_4$.

Muindi*et al*. (2020) observed significant increase in grain yield of green gram with soil application of Zn as compared to foliar application.

Nandanware*et al*. (2007) observed that the application of Zn at 5 kg ha^{-1} significantly increased the grain and stover yield of soybean over control.

Pable*et al*. (2010) observed an increase the grain and straw yield of soybean with Zn application over control.

Patel *et al*. (2011) observed increased in yield and yield attributes of rainfed Cowpea with the application of $ZnSO_4$ @ 25 kg ha^{-1}.

Patel *et al*. (2017) stated that the increased in the straw yield of green gram could be due to the positive effect of Zn nutrition in producing auxin which thereby improved the cell elongation and plant growth.

Pooja *et al*. (2019) also recorded higher seed yield of 2065 kg ha^{-1} in the treatment receiving RPP + 6 kg Fe ha^{-1} + 4 kg Zn ha^{-1} in chick pea. The lower seed yield was recorded in the treatment receiving RPP alone. The highest straw yield of 1734 kg ha^{-1} was recorded with the treatment of RPP + 6 kg Fe ha^{-1} + 4 kg Zn ha^{-1}. The lowest was recorded in the treatment receiving RPP alone.

Quddus*et al*. (2011) reported significant increase in seed yield of mung bean with the application of Zn for both the years 2008 and 2009. The highest seed yield of 2865 kg ha^{-1} was obtained from T_3 treatment (1.5 kg Zn ha^{-1}) in 2008 which was significantly higher than T_1 (Control). Similar trend was also observed in 2009.

Raghuwanshi*et al*. (2018) reported that Zn fertilization @ 5.0 kg ha^{-1} significantly enhanced the grain yield by 37.33% and straw yield by 62.23% as compared over control.

Rahman *et al*. (2015) reported that Zn application increased the seed and stover yield of mungbean. The highest yield was recorded at Zn_2 (3 kg Zn ha^{-1}) and the lowest seed yield was observed at Zn_0 and for stover yield, it was recorded at Zn_0 and Zn_1.

Roy *et al*. (2014) observed increased in straw yield of green gram by 56% with the application of 5.5 kg Zn ha^{-1} and 0.1% Zn spray.

Ruffo *et al*. (2016) also reported that Zn application @ 11 kg ha^{-1} significantly increased the yield in maize (11,530 kg ha^{-1}) than in control treatment (10,540 kg ha^{-1}).

Shanmugasundaram and Savitri (2005) reported significant increase in grain yield with application of 37.5 kg ha^{-1} zinc than 12.5 kg $ZnSO_4$ ha^{-1} in maize.

Shivay*et al*. (2014) observed that the straw yield of chickpea were significantly increased with the increasing level of Zn up to 7.5kg Zn $ha^{-1}$and the yield of chick pea grains were significantly increased @ 5 kg Zn ha^{-1} beyond which the yield decreased.

Singh and Badhoria (1984) stated that the favorable effect of soil Zn application on growth of green gram might be due to its direct influence on auxin production which in turn enhanced the elongation processes of plant development.

Singh *et al*. (2011) observed that the combine application of N, P, K, S, Zn, Mo (20:50:20:20:15:1 kg ha^{-1}) resulted in significant increase in the stover yield of urd bean.

Singh *et al*. (2012) showed that the seed and straw yield was significantly increased to 9.8 % and 11.4% in chickpea with the application of 5 kg Zn ha^{-1}.He had also opined that Zn plays an important role in increasing the seed yield by acting as a catalyst for various metabolic and physiological processes.

Singh *et al*. (2013) observed that foliar application of Zn in late sown Lentil give maximum yield as compared to plots in control.

Singh *et al*. (2015) found that foliar application of Zn in late sown Lentil significantly increased shoot dry weight with application of Zn_1 (0.0%) and Zn_4 (0.08%), respectively.

Singh *et al*. (2021) stated that the increased in the stover yield of maize might be due to the positive effect of Zn fertilization on the dry matter of plants.

Thamke (2017) observed that the application of 15 kg $ZnSO_4$ ha^{-1} along with RDF increased the seed yield in pigeon pea.

Togay*et al*. (2004) revealed that application of Zn significantly increased the dry matter production of dry beans.

Upadhyay (2016) reported significant increase in the grain yield of cowpea at 15 kg Zn ha^{-1} due to the influenced of zinc on the synthesis of IAA which indirectly enhanced the growth, development and uptake of nutrient.

Usman *et al*. (2014) observed significant increase in grain and stover yield of chickpea at 20 kg ha^{-1} $ZnSO_4$.

2.1.5 Effect on Yield Attributes

Aboyeji*et al*. (2020) observed that with the increasing levels of Zn fertilization, yield attributes such as number of pods $plot^{-1}$ and the number of seeds $plot^{-1}$ were increased. The highest values were recorded at 8 kg Zn ha^{-1} and the lowest were recorded at control.

Ali and Mahmoud (2013) observed significant increase in the number of pods $plant^{-1}$ over control through foliar application of 500 mg l^{-1} Zn to mung bean.

Afshar *et al*. (2017) reported that the test weight of durum and spring wheat was not increase significantly with Zn application.

Balai*et al*. (2017) observed that the test weight of chickpea was found to be non- significant due to the application of different levels Zn and P.

Boorbooi*et al*. (2012) observed that Zn application @ 0, 5 and 10 mg $ZnSO_4$ kg^{-1} soil did not significantly affects the 1000 grain weight in barley crop.

Choudhary (2006) reported significant increase in no. of seeds pod^{-1} with Zn fertilization upto 5 kg ha^{-1} in cluster bean.

Dube *et al*. (2001) showed positive responses to graded 1 to 25 mg kg^{-1} soil Zn amendment. The enhancement in production of seeds pod^{-1} in pigeon pea was highest at 5 mg kg^{-1} Zn added to soil.

Diapari*et al*. (2014) observed that Zn fertilization in chick pea could not produce significant effect on grain weight.

Firdous *et al*. (2018) observed that the application of different levels of Zn in wheat did not improve the test weight of seeds significantly.

Haider *et al*. (2018) observed that soil application of $ZnSO_4$ at 10 mg Zn kg^{-1} gave the highest no. of pods $plant^{-1}$ and seeds pod^{-1}in mung bean.

Hidoto*et al*. (2017) reported that the seed weight of chickpea was found to be non- significant with Zn fertilization.

Hugar*et al*. (2000) observed that at higher levels of Zn and Mo the number of seeds per pod were higher as compared to lower levels in soybean.

Khathoon*et al*. (2016) observed that the test weight of sunflower seeds was not influenced by Zn fertilization and it was found to be non-significant.

Kumar *et al*. (2019) observed that the 1000-grain weight of maize-wheat cropping system was not significantly increased with Zn fertilization.

Lakshmi *et al*. (2017) observed that the no. of pods $plant^{-1}$ and no. of seeds pod^{-1}in Black gram were increased with the application of T_6 + foliar application $ZnSO_4$ @ 0.2 per cent (T_8) treatment which was at par with RDF + foliar application of 1% each of $CaNO_3$, $MgNO_3$ and S (T_6).

Malik *et al*. (2015) observed increased in the number of pods in Mung bean crop with 20 ppm Zn application.

Masih *et al*. (2020) reported that Zn fertilization significantly increased the number of pods $plant^{-1}$, grains pod^{-1} except in test weight of green gram. This increased in the yield attributes might be due to the enhancement of flowers into pods through Zn application.

Mishra *et al*. (2017) observed that the test weight of late sown wheat crop was not effected significantly with increasing levels of Zn application.

Moghadam *et al*. (2012) observed that foliar spray of Zn @ 0, 1 and 2 L ha^{-1} did not show any significant effect on 1000 grain weight of wheat crop.

Muindi et al. (2020) reported significant increase in the no. of pods $plant^{-1}$ with soil application of Zn as compared to foliar Zn treatments in green gram.

Nadergoli*et al*. (2011) observed that soil application of $ZnSO_4$ @20 kg Zn ha^{-1} in common bean gives the highest number of pods per $plant^{-1}$ and seeds pod^{-1} which was found at par with $ZnSO_4$ 15 and 25 kg Zn ha^{-1}.

Patel *et al*. (2011) observed that the application of Zn and Fe significantly increased the number of pods $plant^{-1}$ in rain fed cowpea.

Potarzycki*et al*. (2015) observed significant increase in the no. of grains cob^{-1} of maize with Zn application.

Praveena*et al*. (2018) observed that in kharif green gram ,the highest number of seeds pod^{-1} (6.90) was recorded under basal application of Zn @ 5.5 kg ha^{-1} over control which might be due to the role of Zn in seed setting.

Ram and Katiyar (2013) found that the application of 10 kg Zn ha^{-1} to mung bean resulted in significant improvement in the number of pods $plant^{-1}$.

Ramesh (2002) observed that the foliar application of $ZnSO_4$ @ 0.5% to moth bean resulted in significantly enhanced (p=0.05) number of pods $plant^{-1}$ over control.

Raouf Seyed Sharifi (2016) concluded that application of high Zn rates (0.9 g L^{-1}) in soybean increased the number of pods $plant^{-1}$.

Sangwan and Raj (2004) observed significant increase in the number of pods $plant^{-1}$ in chickpea with the application of Zn at 15 kg ha^{-1}.

Shah *et al*. (2016) concluded that the number of pods $plant^{-1}$ and the number of seeds pod^{-1}in pigeon pea significantly enhanced with the application of Zn @ 20 kg ha^{-1}.

Sharma *et al*. (2010) observed increased in the number of seeds pod^{-1} in a shallow black soil of Karnataka in south India through the seed treatment of $ZnSO_4$ @ 4 g kg^{-1}.

Singh *et al*. (2011) reported that the 1000-grain weight (g) was not influenced by the levels of Zn fertilization and it was observed to be influenced by its genetic characters and not by management practices in rice-lentil cropping systems.

Singh *et al*. (2012) reported an increased in the number of pods plant^{-1} in chickpea by 17% through combined application of 25 kg $ZnSO_4$ along with FYM @ 5t ha^{-1} as compared to no Zn application.

Srikanth Babu *et al*. (2012) revealed that the application of $ZnSO_4$ @ 20 kg ha^{-1} significantly increased the number of pods plant^{-1} and the number of seeds pod^{-1}as compared to no Zn application.

Taliee and Sayadian, (2000) stated that Zn helps in the biosynthesis of plant growth regulator, carbohydrate and N metabolic process which enhanced the yield and yield attributes in chick pea.

Thamke (2017) observed that the application of 15 kg $ZnSO_4$ ha^{-1} along with RDF increased the no. of pods in pigeon pea.

Tiwari *et al*. (2018) observed that application of Zn fertilization along with RDF, biofertilizers and ammonium molybdate did not show significant effect on 1000 seed weight of lentil.

Upadhyay *et al*. (2016) also observed non-significant effect of N and Zn fertilization on test weight of cowpea crop and significant increase in the no. of pods plant^{-1} and the number of seeds pod^{-1}in cowpea at 15 kg Zn ha^{-1} as compared to control.

Usman *et al*. (2014) stated that the increased in the number of seeds per pod^{-1} could be due to Zn treatment in plant which further led to enhance stamens and pollen thereby increasing seed yield.

Welduaet *al*. (2012) observed that Zn fertilization significantly increased the no. of seeds pod^{-1} in faba bean which also indicates that the grain yield also increased significantly with increased with this yield attributes as it is positively correlated and major contributors of grain yield.

2.1.6 Effect on oil and protein content

Adekiyaet *al*. (2018) observed that application of $ZnSO_4$ @ 5 kg ha^{-1} enhances the quality of sweet potato plant. This improvement in its quality might be due to the involvement of Zn in photosynthesis, chlorophyll and carbohydrate development.

Afsahiet *al*. (2020) observed that the application of zinc foliar of 5 g L^{-1} obtained the highest oil content in canola crop.

Aytec (2007) observed significant increase in oil contents of soybean seeds with successive zinc rates.

Balaiet *al*. (2017) reported that the protein content in seed increased at the increasing levels of zinc. The application of 6.0 kg Zn ha^{-1} recorded the highest protein content over control.

Bhadauriaet *al*. (2012) revealed that Zinc acts as an important activator of enzymes such as cysteine disulphydrase, dihydropeptilaseglycyleglycine dipeptidase in plants. Thus Zn fertilization might have led to activation of various enzymes which are involved in increasing the oil content in plants.

Brown, *et al*. (1993) revealed that Zn nutrition increased the protein content in plants because Zn is actively involved in the synthesis of protein, nucleic acid and cell division which thereby enhances the protein content.

Chavan *et al*. (2012) reported that soil application of Zn @ 40 kg ha^{-1} gives the highest protein content in cowpea.

Choudhary *et al*. (2015) and Chakmak (2000) stated that Zn plays an important role in activating certain enzymes which improved the lipid membranes and increased oil content in seeds.

Hugar*et al*. (2000) observed that the application of Zn and Mo through seed treatment and foliar spray resulted in the highest oil content of Soybean.

Jat*et al*. (2021) observed significant effect on oil content of Soybean seeds with the soil application of zinc @ 6 kg ha^{-1} during the year 2016 and 2017. The maximum oil content was 21.84, 22.40 & 22.12% in seeds.

Kelarestaghi*et al*. (2007) also reported that in bread Wheat use of zinc fertilizer increased the protein percentage up to 25 and 40%, respectively.

Khurana *et al*. (2001) reported that in sunflower seeds, the oil content was highest (23.4%) at 0.65 mg Zn L^{-1}.

Kumar *et al*. (2015) reported that the increasing levels of Zn fertilization @ 10 kg Zn ha^{-1} significantly increased the crude protein and fibre content in baby corn as compared to no application.

Lokhande*et al*. (2018) observed that in green gram, the increase in protein content with Zn application may be attributed to its involvement in N metabolism.

Mahilane*et al*. (2018) found that the application of different levels of zinc and molybdenum in summer black gram had a significant effect on oil content (%) and protein content in seed.

Mirzapour*et al*. (2006) observed that the maximum content of seed oil was achieved under the Zn10 treatment in sunflower.

Moussavi-Nik *et al*. (2012) reported that Zn plays an important role in the synthesis of indole acetic acid synthesis as a result of amino acids and therefore enhanced protein content.

Nezami*et al*. (2012) observed that Zn application had a significant effect on seed oil % in the first year, and on seed nitrogen content.

Patel *et al*. (2011) found that the application of 5 kg of Zn ha^{-1} under Zn deficient soil increased the content of total crude protein in Cowpea.

Patil *et al*. (2017) observed that Zn application in maize @ 15 kg $ZnSO_4$ significantly increased the quality parameters such as protein content (12.67 %), protein yield (760.14 kg ha^{-1}) and soluble protein in grain (5.39 mg kg^{-1}).

Pooja *et al*. (2019) observed higher protein content due to the application of RPP + 6 kg Fe ha^{-1} +4 kg Zn ha^{-1} in Chickpea.

Poshtmasari*et al*. (2008) reported significant effects on protein content at 1% levels of probability where the highest protein content in seeds of Common bean was obtained at 20 mg Zn kg^{-1} soil.

Praveena*et al*. (2017) observed that there is a significant gradual increase in crude protein content of mung bean with an increase in the dose of zinc application.

Raghavendra *et al*. (2020) observed that the highest oil yield of sunflower was obtained with the soil application of $ZnSO_4$ @ 10 kg ha^{-1} + Foliar spray of $FeSO_4$@ 0.5 % along with RDF and FYM @ 8 t ha^{-1} (2,268kg ha^{-1} and 937 kg ha^{-1} respectively).

Raghuwanshi*et al*. (2018) reported that in Soybean, the highest oil content was recorded at 5.0 kg Zn ha^{-1}(11.68%) as compared to control.

Ram and Katiyar (2013) recorded the highest protein content in mung bean with soil application of 10 kg Zn ha^{-1}.

Raouf Seyed Sharifi (2016) observed that the oil content in Soybean seeds were progressively increased with increasing levels of Zn up to 0.9 g L^{-1} nano ZnO. The oil content was 16.8, 15.4 and 12.5 % in comparison with Zn0.

Shahrokhi *et al*. (2012) revealed that the increased in the photosynthetic activity and chlorophyll content in the plant leaves might also be another reason for the increased in protein content.

Sharma *et al*.(2010) observed that treating the pigeon pea seeds with $ZnSO_4$ 4 g ha^{-1} significantly increased the protein content.

Shivay*et al*. (2014) observed that in chickpea, protein content in the seeds significantly increased with increased in the levels of Zn from 2.5 kg ha^{-1} to 7.0 kg Zn ha^{-1}.

Singh *et al*. (2012) also reported significant increase in the protein content of chickpea with increasing levels of Zn over control. This increased in protein content might be due to the involvement of Zn in N metabolism in plants.

Singh *et al*. (2017) observed significant increase in the protein content (21.39%) and oil content of soybean with the application of 30 kg Zn ha^{-1}.

Sultana *et al*. (2020) observed that the highest oil content in mustard seeds was found at 3 kg Zn ha^{-1}.

Tahir *et al*. (2009) stated that the application of zinc significantly increased the quality parameters such as crude protein, soluble protein and protein yield of maize from his experiment.

Taliee and Sayadian (2000) stated that Zn plays an important role in enhancing protein content in plant due to its involvement in N metabolism which thereby enhanced the quality of seeds.

2.2 Effect of Zinc on Nutrient content (NPKZn) and uptake in soybean

Aboyeji*et al*. (2020) observed that the application of Zn nutrient @ 8 kg Zn ha^{-1} significantly increased the available nutrient elements such as K, Ca and Mg except P which was found reduced in groundnut.

Adekiya*et al*. (2018) observed that the increased in the total N uptake with increased in the levels of $ZnSO_4$ application in sweet potato might be due to the synergistic interaction between N and Zn.

Alloway (2004) stated that the increase in the uptake of K with Zn nutrition might be due to the synergistic effect of K and Zn.

Arya and Singh (2000) observed that the Zn uptake by grain and straw of maize were significantly increased with the increasing levels of Zn @30 kg Zn ha^{-1} as compared to lower levels.

Ashoka *et al*. (2008) revealed that the use of Zn fertilization enhances the absorption of N, K and Znin baby corn-chickpea sequence.

Azab (2015) observed that the combined application of NPK inorganic fertilizers and zinc 1.5% significantly increased the uptake of NPK and N, P, K, Cu, Fe, Mn and Zn content in maize grains over control.

Balai*et al*. (2017) observed that fertilization with Zn significantly increased nitrogen and Zn content except P in seed and straw of chickpea at 6.0 kg Zn ha^{-1}.

Baligah*et al*. (2020) revealed that Zn fertilization significantly enhances the uptake of macro nutrient N, K and micronutrient Zn expect P nutrient in common bean crop.

Chaudhary *et al*. (2014) reported a significant increase in the uptake of N and K except P with the increasing levels of Zn upto 5 and 7.5 kg ha^{-1} in green gram and wheat crop.

Chavan *et al*. (2012) observed that the uptake of N, P, K and Zn in seed and stover of cowpea was enhanced due to enhance protein synthesis.

Choudhary (2006) reported significant increase in N and Zn concentration and uptake in seed and straw of cluster bean with Zn fertilization upto 5 kg ha^{-1} over control.

Dewal and Pareek (2004) observed that the P uptake in wheat crop was found non-significant with the increasing levels of Zn application.

Haider *et al*. (2018) observed that the maximum Zn contents in grain were recorded at higher levels of Zn application i.e.10 mg Zn kg^{-1}.

Hidoto*et al*. (2017) observed that the foliar application of zinc gave the highest Zn content in grain and straw of chickpea as compared to both soil application and seed priming across locations.

Jain (2007) observed significant increase in N and Zn content and uptake with the application of 5 kg Zn ha^{-1} which was at par with 7.5 kg Zn ha^{-1} in seed and straw whereas it showed decreased in P content and uptake in seed and straw at 5 kg Zn ha^{-1}.

Jain and Dahama (2005) observed that the application of 9 kg Zn ha^{-1} significantly increased the uptake and content of N, P, K, S and Zn than lower levels in maize.

Jan *et al*. (2013) and Rahman *et al*. (2002) stated that the significant effect of Zn levels on the increased in the content and uptake of N by grain and straw of wheat and rice might be because of the positive effect of Zn on N content and uptake by grain and straw.

Jarallah*et al*. (2017) showed that the increasing levels of Zn application @ 10, 20, 30 and 40 kg ha^{-1} significantly enhanced the N and Zn uptake by grain and straw of wheat crop. The N uptake by grain was 17.1, 43.4, 37.3 and 31.7 % and the N uptake by straw was 16.0, 33.5, 26.8 and 26.7 % as compared to control. The Zn uptake by grain was 52.2, 76.7, 100.8 and 112.3 % and the Zn uptake by straw was 64.8, 128.5, 130.4 and 142.0 % as compared to control.

Jat*et al*. (2014) reported that the highest Zn uptake in wheat grain and straw was recorded under 9 kg Zn ha^{-1} with an increased by 54 and 48 % respectively over control.

Kadam *et al*. (2002) also showed significant increase in the concentration and uptake of zinc with application of 5 kg Zn ha^{-1} in soybean plant grown on inceptisols.

Kamakar*et al*. (2015) observed that in mung bean, the highest concentrations of N, P, K and Zn in seed and stover were recorded at Zn2 (3 kg Zn ha^{-1}).

Kanwal*et al*. (2020) observed increased in the concentration of Zn in grains with increased in the levels of Zn application. The maximum % of Zn in mung bean seeds was 56 % which was recorded at basal application of 15 kg Zn ha^{-1} over control.

Keram*et al*. (2012) observed that nutrient uptake of N, K and Zn except total P increased significantly with the application of recommended NPK+ Zn @ 20 kg ha^{-1} in wheat. The total P was recorded highest at control. This increased in nutrient uptake of N, K and Zn might be due to the synergistic interaction among N, K and Zn.

Khan *et al*. (2002) observed that the N, K & Zn content in grain and straw of rice was significantly increased with Zn fertilization @ 15 kg Zn ha^{-1} except P concentration. This increased in N concentration might be due to the enhanced enzymatic activity and recycling of the plant organic nutrients with Zn fertilization. The decreased in the P concentration might be due to the antagonistic effect of Zn on absorption of P.

Khan *et al*. (2007) and Alam*et al*. (2000) also reported that Zn fertilization decreases the absorption of Pin rice and wheat crop.

Khan *et al*. (2014) observed reduction in the uptake of soil P with Zn application due to the antagonistic relation of Zn with P which leads to lower P uptake by crop.

Lobell (2009) stated that Zn and P nutrient are both essential nutrient for plant growth, however these two nutrients application might be antagonistic at certain point where it leads to imbalances of nutrients and ultimately reduces crop yield.

Mahdi *et al*. (2012) observed that the N and Zn content and uptake by fodder maize increased significantly with Zn application of 10 kg Zn ha^{-1}.

Meena *et al*. (2020) reported that the increasing levels of phosphor-enriched compost and zinc up to 4 t ha^{-1} and 4 kg ha^{-1} respectively significantly increased the nutrient content (N, K and Zn) and uptake (N, P, K and Zn) in seed and stover of black gram.

Meena *et al*., (2021) revealed that application of Zn @ 6 kg ha^{-1} significantly increased the N, K and Zn content in seed and stover of black gram as compared to control. Whereas P content in seed and stover was not significantly increased.

Pandey *et al*. (2017) observed that the uptake of K by wheat grain and straw was increased with Zn fertilization as compared to control.

Patel *et al*. (2011) revealed that the application of 12.5 kg $ZnSO_4ha^{-1}$ gave the highest uptake of N, P, K and S in grain and straw of rain-fed Cowpea. In addition, total Zn uptake by cowpea plants was also improved by the application of Zn fertilization.

Rohini *et al*. (2020) observed that the concentration and uptake of zinc in Soybean plant increased with soil application of zinc up to Zn @ 4.5 kg ha^{-1} over rest of the Zn levels which further reduced afterwards.

Sammauria (2007) observed in Fenugreek that application of Zn at 5 kg ha^{-1} significantly increased N and Zn content and uptake in seed and straw and K uptake.

Seema *et al*. (2014) observed that the N content in seeds was increased significantly with Zn application in green gram.

Shivay*et al.* (2014) observed significant increase in N uptake in grain and straw of cowpea at increasing Zn levels from 2.5 to 7.5 kg ha^{-1}.

Singh *et al*. (2009) stated that the increase in K uptake with the increasing levels of Zn levels could be due to the increase in K content and yield of cabbage.

Singh *et al*. (2012) observed decreased in P uptake by chickpea at higher level of Zn (5 and 10 kg Zn ha^{-1}) over 2.5 kg Zn ha^{-1} which may be due to the antagonistic relationship between P and Zn. However, a significant increase in the Zn content of grain and straw of chickpea was observed with increasing dose of Zn by 6.6 mg kg^{-1} and 6.2 mg kg^{-1} over control.This indicates an antagonistic relationship between P and Zn nutrition of chick pea.

Singh *et al*. (2017) observed that the increased in the uptake of N was due to the positive effect of Zn on the photosynthetic and metabolic activities which translocate the photosynthates produced to various parts of the plant and thus enhanced the N uptake in the maize crop.

Solanki *et al*. (2017) reported significant increase in the uptake of Zn in seed and straw of summer green gram with the application of Zn @ 5.0 kg ha^{-1}.

Srivastava *et al*. (2016) observed significant increase in K nutrient uptake with Zn fertilization under rice-wheat rotation system. This is due to the positive interaction of Zn which enhances the uptake of soil K by the plant.

Umesh and Shankar (2013) observed that Zn uptake was significantly enhanced with the application of Zn 12.5 kg ha^{-1} in pigeon pea.

2.3 Effect of Zinc on Soil physico-chemical properties in soybean

Arun *et al*. (2014) observed that the soil physico-chemical properties such as soil bulk density, particle density, pore space, pH and EC was found non-significant after pea crop harvest with the levels of N, P, K, Zn and Rhizobium.

Chethan*et al*. (2018) reported that the Soil physical properties of the postharvest soil such as PD, BD and Pore space were observed to be non-significant with the fertilization of NPK + Zn in pea crop.

Gupta *et al*. (2018) observed that the soil physical and chemical properties of the postharvest soil in maize crop such as pH, EC and OC were found to be non- significant with various levels of Zn and P treatment.

Keram*et al*. (2012) reported that the soil pH, EC and OC of the postharvest soil were found to be non-significant with various Zn treatments in wheat crop.

Meena *et al*. (2018) observed non-significant increase in CEC and bulk density of the soil after harvest of mung bean.

Meena *et al*. (2018) observed that particle density and porosity of the soil were not increased significantly with the application of $ZnSO_4$ after the harvest of mustard crop.

Ranpariya*et al*. (2017) observed that the postharvest soil pH, EC and OC were not significantly increased with Zn application summer green gram.

Sharma *et al*. (2021) observed non-significant effect on soil pH, EC and OC at various levels of Zn in wheat crop after harvest.

Singh *et al*. (2017) reported that the application of Zn at various sources and levels had a non-significant effect on soil OC after the harvest of maize crop.

Singh *et al*. (2021) observed that the increasing levels of NPK and Zn decreased the bulk density and particle density in baby corn crop. This could be due to the non-significant effect of the various nutrient sources and levels on bulk density and particle density in one cropping season.

Tiwari *et al*. (2006) observed non-significant increase in soil pH and EC with Zn application after wheat harvest.

Upadhyay *et al*. (2016) observed that the combined application of S, Zn and NPK in mustard was found to be non-significant on soil pH, EC, OC and bulk density.

Varalakshmi *et al*. (2021) observed that the application of Zn at increasing rates decreased the physico-chemical properties such as soil pH, EC and bulk density under rice-wheat cropping system.

2.4 Effect of Zinc on Soil fertility of soybean after harvest

Adekiya*et al*. (2018) studied that the soil available N, K and Zn except P increased with the increasing levels of $ZnSO_4$ @ 20 kg ha^{-1} applied in Sweet Potato crop in both the consecutive years.

Balai*et al*. (2017) observed that the increasing levels of Zinc application upto 6.0 kg ha^{-1} significantly increased the available N, K and Zn except P status in soil after harvest of Chickpea.

Gupta *et al*. (2018) observed that the combined application of P and Zn significantly increased the Soil available N and K after harvest of maize crop.

Jat*et al*. (2012) observed that in mustard, the application of Zn significantly increased the available soil N status might be due to the synergistic interaction between Zn and soil N.This increased in soil Zn could also be due to enhancement of the incorporation of inorganic Zn into solubilization, diffusivity and mobilization.

Karan *et al*. (2014) revealed that the available N, K, Zn showed increasing trend but P in the soil showed decreasing trend with the increasing levels of zinc in lentil.

Keramet *al*. (2012) observed that Zn application @ 20 kg kg^{-1} along with RDF significantly increased the soil DTPA-Zn status.

Kulandaivelet *al*. (2004) stated that the amount of exchangeable Zinc on the clay complexes might be responsible for increase in the soil Zn content.

Meena *et al*. (2006) observed that Zn fertilization in mustard increased the available Zn status in the soil. This increased in the soil might be due to chelation of Zn which effectively maintain the Zn status in the soil solution.

Meena *et al*. (2018) and Kumawat (2012) also reported similar antagonistic effect between Zn and P with Zn applicationthereby decreasing the soil P status in mustard and fennel crop.

Meena *et al*. (2018) observed that the increased in the level of Zn enriched FYM significantly increased the available N and Zn of the post-harvest soil in mung bean crop. However soil P show a non-significant effect with the Zn enrichment.

Pandey *et al*. (2016) observed that there was a decreased in the available S in the soil after harvest of wheat crop with Zn fertilization over control.

Pandey *et al*. (2019) reported significant increase in the soil status of Zn with the application of zinc. The highest soil zinc content was found @ 20 kg $ZnSO_4$ ha^{-1} treated plot in cluster bean crop.

Prasad *et al*. (2016) stated that Zn has a positive interaction with soil nutrients such as K which leads to increase in soil available K and increased crop yield.

Raghuwanshiet *al*. (2006)observed that the availability of Zn was significantly increased @10 kg Zn ha^{-1} over control in the soil after soybean harvest.

Ranpariyaet *al*. (2017) observed that the application of Zn @ 10 kg $ZnSO_4$ ha^{-1} significantly increased the available Zn in the soil after harvest of the summer greengram.

Ranade-Malvi. (2011) opined that micronutrient Zn has a synergistic effect on macronutrient K so the increase in Zn availability optimizes the uptake of soil K.

Singh *et al*. (2017) observed that the available P of the postharvest soil was not significantly increased with the sources and levels of Zn in maize.

Thenua*et al*. (2014) observed that the status of available S in the soil was found to be non-significant with Zn treatments after soybean crop harvest.

Chapter III

Materials and Methods

MATERIALS AND METHODS

The present investigation entitled "Response of Soybean (*Glycine max* L. Merril) to Sources and Levels of Zinc" was conducted at the Experimental Research Farm, School of Agricultural Sciences and Rural Development (SASRD), Medziphema campus, Nagaland University in 2019 and at the State Horticulture Nursery, Green Park, Dimapur in 2020 during the Kharif season. The details of materials used and techniques adopted during the course of investigation are briefly described in this chapter.

3.1 Experimental site

Location 1 - Experimental research farm, School of Agricultural Science and Rural Development (SASRD), Medziphema campus, Nagaland University, 2019.
Geographical Location - 25˚45′10″N Latitude and 93˚51′04″E Longitude.
Elevation – 310 m above mean sea level

Location 2 - State Horticulture Nursery, Green Park, Dimapur, 2020.
Geographical Location - 25˚51′30″N Latitude and 93˚45′54″E Longitude.
Elevation - 170 m above mean sea level.

3.2. Climatic condition

Location 1- Experimental research farm, School of Agricultural Science and Rural Development (SASRD), 2019.
Climate - Humid sub-tropical zone.
Average rainfall - 173.4 to 274.5 mm per annum.
Temperature - Maximum and minimum temperature ranged from 33.5˚ to 16.3˚C during the growing period (Table 3.1).

Location 2 - State Horticulture Nursery, Green Park, Dimapur, 2020.

Climate – Humid sub-tropical zone.

Average rainfall – 53.92 to 233.5 mm per annum

Temperature - Maximum and minimum temperature ranged from 34.71 to 23.14˚C during the growing period (Table 3.1).

Table 3.1: Meteorological Data for two different sites

Month	2019					2020				
	Temp		RH		Rainfall (mm)	Temp		RH		Rainfall (mm)
	Max	Min	Max	Min		Max	Min	Max	Min	
June	33.5	24.1	91	69	195.0	34.19	24.67	91	72	168.0
July	33.0	24.9	93	72	271.3	34.41	25.35	91	70	192.5
August	34.1	24.9	93	73	274.5	34.71	26.25	91	70	53.92
September	32.7	23.9	94	72	173.4	33.89	25.32	91	69	139.92
October	30.3	21.7	95	73	244.8	32.14	23.14	91	72	233.5

Source: ICAR, Medziphema and Soil and Water Conservation Department, Dimapur

3.3. Characteristics of the experimental soil

The soil used for experimentation was collected from two different locations i.e., (i) Experimental research farm, School of Agricultural Science and Rural Development (SASRD) and (ii) State Horticulture Nursery, Green Park, Dimapur. The composite soil samples were collected from a depth of 0-15 cm and mixed well prior to analysis for initialsoil physicochemical properties. The results of analysis are presented in table 3.2.

Table 3.2: Soil condition of two different locations

Initial soil parameters status		First Year (SASRD Experimental Farm) - 2019	Second Year (State Horticulture Nursery, Green Park Dimapur) - 2020
pH		5.72	5.68
EC(dsm^{-1})		0.22	0.23
OC (%)		0.50	0.52
CEC {cmol(p+)kg^{-1}}		12.66	13.18
N(kg ha^{-1})		206.21	219.10
P(kg ha^{-1})		14.15	14.29
K(kg ha^{-1})		108.67	119.12
Zn(mg kg^{-1})		0.20	0.22
S(Kg ha^{-1})		9.57	9.93
Bulk density (g cm^{-3})		1.17	1.19
Particle density (g cm^{-3})		2.26	2.27
Pore space (%)		48.23	47.58
Particle size analysis (%)	Sand	65.0	58.1
	Silt	31.5	28.5
	Clay	26.3	30.7
Textural class		Sandy clay loam	Sandy clay loam
Order		Alfisols	Alfisols
Family		Fine Typic Kanhapludalfs	Fine Typic Kanhapludalfs

3.4 Experimental details

3.4.1 Experimental design

The details of the experiment conducted consist of the following components:

Crop : Soybean (*Glycine max* L.Merril)

Variety : JS 97-52

Experimental design :Randomized Block Design.

Plot size : 2.70 m x 2.00 m

Spacing :45 cm x 10cm (Row to Row X Plant to Plant)

Number of treatments : 13

Number of replications : 3

Total number of plots : 39

3.4.2 Treatment Details

The treatment consisted of the following:

1. Zinc 21% ($ZnSO_4$ $7H_2O$): 1, 2.5, 5 kg ha^{-1}
2. Zinc 33% ($ZnSO_4$ H_2O): 1, 2.5, 5 kg ha^{-1}
3. Zn-EDTA 12%: 1, 2.5, 5 kg ha^{-1}
4. Liquid Zinc oxide: 300, 600, 900 ml ha^{-1}

- RDF was applied @ 20: 60: 40: 30: 1.5 (N: P: K: S: B) in all the plots irrespective of the treatment
- Lime was added @ 1/10 of LR before 20 days of sowing

Symbols assigned	Treatments
T_1	0 (Control)
T_2	RDF +1 kg $ZnSO_4$ $7H_2O$
T_3	RDF+1 kg $ZnSO_4H_2O$
T_4	RDF + 1 kg Zn-EDTA
T_5	RDF + 2.5 kg $ZnSO_4$ $7H_2O$
T_6	RDF + 2.5 kg $ZnSO_4$ H_2O
T_7	RDF + 2.5 kg Zn-EDTA
T_8	RDF + 5 kg $ZnSO_4$ $7H_2O$
T_9	RDF + 5 kg $ZnSO_4H_2O$
T_{10}	RDF + 5 kg Zn-EDTA
T_{11}	300 ml ha^{-1}Liquid ZnO
T_{12}	600 ml ha^{-1} Liquid ZnO
T_{13}	900 ml ha^{-1} Liquid ZnO

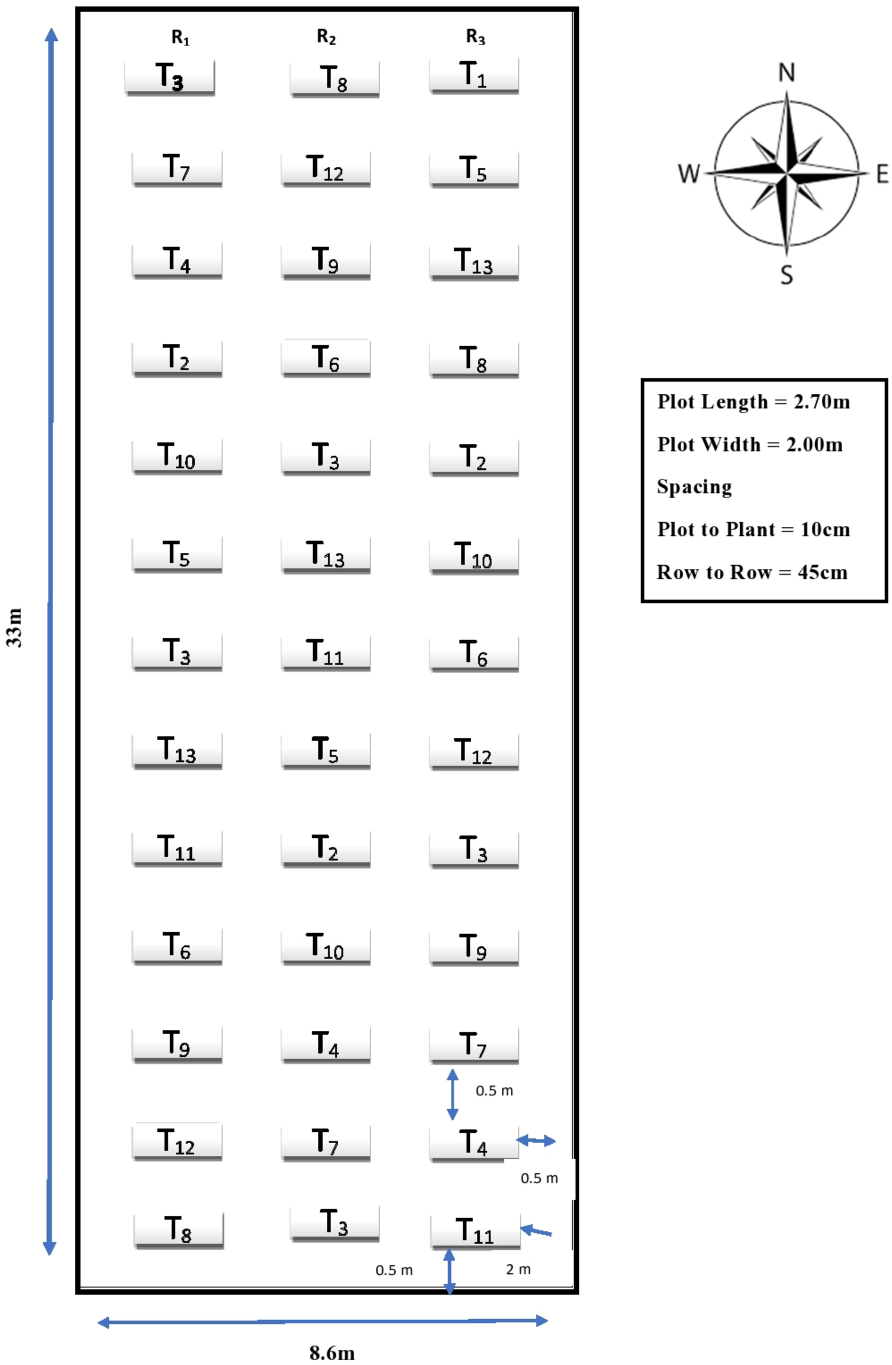

Fig 1. Field layout of the experimental plot in randomized block design

Fig 2: Experimental research farm of SASRD, Medziphema campus

Fig 3: State Horticulture Nursery, Green Park, Dimapur

3.4.3 Experimental procedure

A rectangular plot with uniform soil fertility and even topography was selected for conducting the field experiment in both the locations i.e., The experimental research farm of SASRD, Medziphema campus, Nagaland University during 2019 and State Horticulture Nursery, Green Park, Dimapur during 2020. Recommended dose of fertilizer was applied @ 20: 60: 40: 30: 1.5 (N: P: K: S: B) in all the plots irrespective of the treatment. Lime was also added @ 1/10 of LR before 20 days of sowing. Half dose of N and full dose of P, K, S and B were applied one day before sowing. The remaining half dose of N was applied as top dressing at 15 DAS. Different sources and levels of Zinc were applied as treatment. The treatments consisted of Zinc 21% ($ZnSO_4$ $7H_2O$): 1, 2.5, 5 kg ha^{-1}, Zinc 33% ($ZnSO_4$ H_2O): 1, 2.5, 5 kg ha^{-1}, Zn-EDTA 12%: 1, 2.5, 5 kg ha^{-1} and Liquid ZnO: 300, 600, 900 ml ha^{-1}. After the soil was properly mixed with the fertilizers and lime, the seeds were sown at optimum moisture so as to ensure good germination. The seeds were sown on 17th June 2019 and 15th June 2020 using JS 97-52 variety. Weeding and hoeing was done in the field from time to time to control weeds. A spacing distance of 10 cm plant to plant and 45 cm row to row is maintained. Right cultivation practices were also adopted throughout the crop growing period.

3.4.4 Harvesting and threshing

The crop was harvested 8th of Oct. 2019 and 5th Oct. 2020. The plants were harvested from each plot carefully and keep separately with proper label and tag. It is sundried and threshed to separate the seeds from the pod. The threshed clean seeds were then collected and recorded for further analysis.

3.5 Observations

3.5.1 Plant height (cm) (30, 60 and 90 DAS)

The plant height was measured from the ground level to the top of the plants in centimeter (cm) at 30, 60 and 90 DAS. The average height of the plant for each treatment was calculated.

3.5.2 No. of nodules at flowering stage

About five plants from each plot were uprooted carefully without damaging the roots with the help of khurpi. The nodule number was counted from each treatment at flowering stage and the mean datas were calculated.

3.5.3 Nodule fresh and dry weight (g) at the time of flowering

About five plants from each plot were uprooted carefully without damaging the roots with the help of khurpi. The nodules were washed and then the fresh weight was taken from each plant. It is then dried and the weight was recorded for each plant separately.

3.5.4 Number of pods plant^{-1}

After harvesting the plant, pods from a number of five tagged plants were counted from each plot and the mean of each number of pods plant^{-1} was recorded.

3.5.5 Number of seeds pod^{-1}

From the pods of sample plant in each treatment, the number of seeds pods^{-1} was counted and the mean has been calculated as number of seeds pod^{-1}.

3.5.6 Test weight (g)

Test weight is the weight of 1000 grains. 100 viable grains were counted from the threshed grains and their weight was recorded which was multiplied by a factor of 10 for each treatment.

3.5.7 Seed yield (kg ha^{-1})

After proper sun drying of the seeds, the grain yield of each plot was taken on treatment basis and the yield per plot of each treatment was obtained as kg ha^{-1}.

3.5.8 Stover yield (kg ha^{-1})

The plant harvested from each plot was sun dried for about a week and their weight was taken and stover yield was obtained by deducting grain yield from total weight of the plant.

3.6 Plant analysis

After threshing, the seed and stover were separated, air dried and finally oven dried at a temperature of 60 °C to 70 °C to attain a constant weight. The dried seed and stover samples were then grounded in a Willy Mill and kept in polythene bags for chemical analysis. The powdered seed and stover samples were analyzed for N, P, K, S and Zn content.

3.6.1 Estimation of N in stover and seeds

Nitrogen content in seeds and stover was estimated using modified kjeldhal method as described by Black (1965). 1.0 g powdered sample was digested with concentrated H_2SO_4 in presence of digestion mixture ($CuSO_4$ + K_2SO_4) till the digest gave clear bluish green colour. The digested sample was further diluted carefully with distill water to known volume. Then a known volume of aliquot was transferred to distillation unit (Micro kjeldahl - apparatus) and liberated ammonia was trapped in boric acid containing mixed indicator. Later it was titrated against standard H_2SO_4 and the amount of ammonia liberated was estimated in the form of nitrogen.

3.6.2 Digestion of plant samples for other nutrients

1.0 g powdered sample was pre-digested with di-acid mixture of conc. HNO_3 and $HClO_4$ in the ratio 9:2:1 and kept over hot plate for digestion till colorless thread like structures were obtained. Dilute with distilled H_2O and transferred to a 100 ml volumetric flask by filtering through Whatman No. 42.Finally the volume of extract was made to 100 ml with distilled H_2O and reserved it or further analysis.

3.6.2.1 Estimation of P in seeds and stover

Phosphorous in both seeds and stover were determined by vanado-molybdate yellow colour method as outlined by Jackson (1973) using spectrophotometer at 470 nm.

3.6.2.2 Estimation of K in seeds and stover

Potassium in both seeds and stover were determined by flame photometry after making appropriate dilution as described by Chapman and Pratt (1961).

3.6.2.3 Estimation of S in seeds and stover

Sulphur in both seeds and stover were determinedturbimetrically as described by Chesnin and Yien (1950).

3.6.2.4 Estimation of Zn in seeds and stover

Zinc content in seeds and stover was determined in di-acid of the plant samples by using AAS as described by Singh *et al*. (1999).

3.6.3 Estimation of protein and oil content % in seeds

The protein content in seeds was calculated for each treatment by multiplying the seed N by a factor of 6.25 which can be written as:

% Protein = 6.25 x N % in seed

Seed samples of 5 g each from all the treatments (plot wise) were taken for extraction of oil. The crushed samples were placed in a thimble and extracted with light petroleum ether for 6 hours in a soxhlet extraction unit as per method described by AOAC (1960). The extract was transferred to weight flask, the solvent distilled of and the last traces of solvent and moisture being removed by treating the flask at 100-150□ C. Then, the flask was cooled and reweighed; the formula used for calculation of per cent oil in seed was as follows:

$$\% \text{ Oil} = \frac{(W2-W1) \times 100}{X}$$

Where,

W2= weight of the empty flask (g)

W1= weight of empty flask + weight of oil (g)

X = weight of sample taken for extraction (g)

3.7. Nutrient uptake

The nutrient uptake values of N, P, K and Zn by soybean crop were calculated by using the nutrient content (%) in plant and corresponding yield. The uptake values of nutrients were calculated using the following relationship.

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

3.8 Soil analysis

Soil samples were collected from each pot after harvest of the crop. The soil samples were air dried in shade, ground using mortar and pestle and sieved through 2 mm sieve and stored in polythene bags with proper labeling for the analysis of various soil parameters using standard methods as mentioned below.

3.8.1Soil mechanical analysis

The sand, silt and clay fractions of the soil were determined by using International pipette method (Piper, 1966).

3.8.2 Soil pH

The soil pH was analyzed using Glass electrode pH meter (Richards, 1954).

3.8.3 Organic carbon

Organic carbon content in soil was determined by Rapid titration method outlined by Walkley and Black (1934) and expressed in percentage as described by Jackson (1973).

3.8.4 Electrical conductivity (EC)

The electrical conductivity (EC) was determined using Conductivity Bridge (Richards, 1954).

3.8.5 Cation exchange capacity (CEC)

The CEC of the soil was determined using 1 N NH_4OAc at pH 7.0 (Chapman, 1965).

3.8.6 Bulk Density

Bulk Density was determined by dividing the weight of soil with the volume of soil as described by Chopra and Kanwar (1976).

3.8.7 Particle Density

Particle Density was determined by the Pycnometer method as described by Baruah and Barthakur (1997).

3.8.8 Porosity

Porosity of the soil was obtained by using the relation between bulk density and particle density as:

Total Porosity (%) = (1- Bulk Density/ Particle Density) x100

3.8.9 Available N

The available nitrogen in soil was determined using alkaline potassium permanganate method as described by Subbiah and Asija (1956).

3.8.10 Available P

The available phosphorus in soil was determined by Brays and Kurtz method (1945).

3.8.11 Available K

The available potassium in soil was determined by flame photometric method using neutral normal ammonium acetate (pH 7.0) (Jackson, 1973).

3.8.12 Available S

The available sulphur in soil was determined by turbidimetric method

(Chesnin and Yien,1950).

3.8.13 Available Zn

The available zinc in the soil was determined by DTPA extraction and AAS method (Lindsay and Norvell, 1978).

3.9 Analysis of data

The collected data is processed, classified, tabulated and systematically and statistically analyzed by applying the techniques of analysis of variance and the significance of different source of variations was tested by 'F' test (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

The results obtained from the experiment on "Response of Soybean (*Glycine max* L. Merril) to Sources and levels of Zinc" carried out during 2019 and 2020 are presented in this chapter. The performance of the crop under various treatments is illustrated by the use of tables and graphs incorporated at appropriate places. The data recorded were analyzed and significant variations have been discussed.

4.1. To study the response of soybean to sources and levels of zinc on growth, yield and quality

4.1.1 Growth parameters

4.1.1.1 Effect on plant height

The response of various sources and levels of Zn on plant height are presented in table 4.1 and fig 4, 5&6. It was observed that there was a significant increase in the plant height of soybean at 30 and 60 DAS during both the years 2019 and 2020. However at 90 DAS, the plant height could not produce significant results during the two consecutive years. The pooled data from the two years also showed significant effect on plant height. The maximum height at 30, 60 and 90 DAS were (31.63, 31.90, 31.77 cm), (36.87, 36.91, 36.89 cm) and (38.24, 38.11, 38.18 cm) which was recorded at treatment T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}). Other Zn treatments such as T_8 (RDF + 5 kg $ZnSO_4$ $7H_2O$ ha^{-1}) and T_{10} (RDF + 5 kg Zn-EDTA ha^{-1}) were found to closely follow T_9. The lowest data at 30, 60 and 90 DAS were recorded in the control plot during the two consecutive years and pooled. The data recorded at control were (26.12, 27.31, 26.72 cm), (33.23, 33.56, 33.40 cm) and (35.12, 35.80, 35.46 cm). Usman *et al*. (2014) also observed that the plant height of green gram was significantly increased at the rate of 15 kg $ZnSO_4$ ha^{-1} (T_3)ofsoil application which was found at par with the treatments at 20 kg $ZnSO_4$ ha^{-1} (T_4) and 25 kg

$ZnSO_4$ ha^{-1} (T_5). Khan *et al*. (2007) showed that the Zn application in rice crop was found significant @ 10 kg Zn ha^{-1} which was statistically at par with 15 kg Zn ha^{-1}. Similar observations were also reported by Haider *et al*. (2018) with the soil application of $ZnSO_4$ at 10 mg kg^{-1} which showed significant effect on plant height in mung bean. This increased in plant height may be due to application of Zn sources in the experimental field of low Zn soil status which improved the plant growth (Jangir *et al*., 2015). Zinc is also an essential micronutrient which plays an important role in cell elongation, differentiation and metabolism leading to enhance plant growth (Kuldeep *et al*., 2018 and Raghuwanshi*et al*., 2017). Zinc also increased the rate of photosynthetic activity and formation of chlorophyll which thereby accelerates the plant meristem activity leading to increase in internode length (Maurya *et al*., 2010).Zinc fertilization enhances the plant height significantly as a result of stimulatory effect of Zn on various physiological and metabolic processes of plant (Panneerselvam and Stalin., 2014).Krishna (1995) also stated that the significant influenced of Zn on growth parameters might be due to its involvement on tryptophan synthesis which is a precursor of growth hormone auxin. This auxin plays an important role in elongation of cells thereby enhances the growth and development processes in plants.

4.1.1.2. Effect on the no. of nodules at flowering stage

The no. of nodules at flowering stage was found to increase with the application of various sources and levels of Zn are shown in table 4.2 and fig 7. There was a significant increase in the no. of nodules at flowering stage at the treatment level of T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) which was found closely followed by T_8 (RDF + 5 kg $ZnSO_4$ $7H_2O$ ha^{-1}) and T_{10} (RDF + 5kg Zn-EDTA ha^{-1}) treatments during the two consecutive years. The pooled data also recorded significant increase in the no. of nodules at flowering stage at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) treatment. The highest no. of nodules recorded in the two consecutive years was 46.70 and 45.10 and in pooled, the recorded data was 45.90. The lowest data was recorded in the control plot *i.e.* 32.30, 29.60 and 30.95. The significant increase in the no. of root nodules was reported by Kuniya*et al.* (2018) with the application of 5.0 kg Zn ha^{-1} in cluster bean crop. Similar observation was also made by Chauhan *et al.* (2013) in soybean with the application of Zn @ 5 kg ha^{-1} which increased the nodulation by 91 %. Yashona*et al.* (2018) also showed positive response to nodulation in chickpea, cluster bean, mung bean, soybean and pigeon pea with the application of Zn. Zinc plays an important role in leghaemoglobin synthesis, nodulation and leghaemoglobin content for the increase in the availability of Zinc (Das *et al*., 2012). Edulamudi*et al*. (2019) also reported that the increase in nodulation with the application of Zn might be due to the enhanced rooting system. Similar findings were also reported by Khorgamy and farina (2009) in chick pea with the application of $ZnSO_4$ @ 20 kg ha^{-1} which thereby enhanced the root nodulation. Ahmad *et al*. (2013) also revealed that the nodulation in mung bean crop was enhanced with the fertilization of micronutrients (Zn, Fe & Mo) and rhizobium. This increased in nodulation thereby enhanced the nitrogen fixation.

4.1.1.3 Effect on nodule fresh weight (g) at the time of flowering

The nodules fresh weight was found to be significantly influenced at the time of flowering with the application of zinc sources and levels at 2019, 2020 and pooled respectively (Table 4.3 and fig 8). During the consecutive years and pooled, the maximum fresh weight of nodules were recorded at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) *i.e.* 0.36, 0.37 and 0.37 g which was followed by T_8 (RDF + 5 kg $ZnSO_4$ $7H_2O$ ha^{-1}) and T_{10} (RDF + 5 kg Zn-EDTA ha^{-1}). The lowest was recorded at control *i.e.* 0.18, 0.18 and 0.18 g. Kuniya*et al*. (2018) and Upadhyay *et al*. (2016) also observed significant increase in the nodules fresh weight with the application of 5.0 kg Zn ha^{-1} in cluster bean and 15 kg Zn ha^{-1} application in cowpea over control.Gour*et al.* (2014) also revealed that the nodulation and fresh weight of nodules were significantly increased with the treatment application of 100 % RDF +$ZnSO_4$ @ 25kg ha^{-1} + $MgSO_4$ @ 25 kgha^{-1}. Fertilization with $ZnSO_4$ and $MgSO_4$ might have created conducive environment for nodule formation. This significant increase in nodules fresh weight plant^{-1} was also observed in mung bean with increased in the levels of zinc fertilization upto10 kg Zn ha^{-1} which might be due to enhanced nodulation and establishment of better root system (Ram *et al*., 2018).

4.1.1.4 Effect on nodule dry weight (g)at the time of flowering

From the experiment conducted, it was observed that the nodule dry weight of soybean was significantly influenced at the time of flowering during 2019, 2020 and pooled respectively as shown in table 4.4 and fig 9. The maximum nodule dry weight was recorded in treatment T_9 (RDF + 5Kg $ZnSO_4$ H_2O ha^{-1}) and their values are 0.13, 0.12 and 0.13 g. This was followed by treatments - T_8 (RDF + 5 Kg $ZnSO_4$ $7H_2O$ ha^{-1}) and T_{10} (RDF + 5 Kg Zn-EDTA ha^{-1}). The lowest value was recorded in the control plot *i.e.* 0.06, 0.05 and 0.05 g. Edulamudi*et al*. (2017) observed increased in dry weight of nodules plant^{-1} after 30 and 45 days of sowing with increasing levels of Zn up to 75 mg g^{-1}. Das *et al*. (2012) also observed increased in nodule dry weight ranging from 2.75 to 16.87 % at 10 kg $ZnSO_4$ ha^{-1} and 4.27 to 32.82 % at 25 kg $ZnSO_4$ ha^{-1} in chickpea as compared to control. This increased in nodulation might be due to the enhanced rooting system with the application of Zn. Similar findings was also reported by Tiwari *et al*. (2018). Debnath (2018) also revealed that the dry weight of nodules were significantly increased at 60 DAS from the treatment T_7 (RDF+Zn7.5) over treatment T_1 (RDF) which indicates that nodulations were enhanced with the application of Zn. Similar observation was reported by Ahlawat *et al*. (2007) which revealed that Zn fertilization increased the root growth, nodule formations and dry weight of nodules.

Table 4.1: Effect of the sources and levels of Zn on plant height of soybean at variousgrowth stages

Treatments	30 DAS			60 DAS			90 DAS		
	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled
T_1	26.12	27.31	26.72	33.23	33.56	33.40	35.12	35.80	35.46
T_2	26.78	27.54	27.16	33.79	33.90	33.85	35.63	36.10	35.87
T_3	28.35	29.13	28.74	34.13	34.38	34.26	35.90	36.65	36.28
T_4	27.94	29.62	28.78	34.69	34.60	34.64	36.75	36.98	36.87
T_5	29.50	28.97	29.24	34.58	33.76	34.17	35.50	36.05	35.78
T_6	29.69	30.45	30.07	34.90	35.00	34.95	36.53	36.55	36.54
T_7	30.10	30.61	30.36	35.39	34.90	35.15	36.90	36.30	36.60
T_8	30.75	30.85	30.8	35.99	35.22	35.61	37.37	37.13	37.25
T_9	31.63	31.90	31.77	36.87	36.91	36.89	38.24	38.11	38.18
T_{10}	30.33	30.71	30.52	35.85	35.17	35.78	36.99	36.73	36.67
T_{11}	28.49	30.30	29.40	35.40	35.15	35.28	36.69	36.45	36.57
T_{12}	29.15	29.70	29.43	35.10	35.12	35.11	35.40	36.40	35.90
T_{13}	29.23	29.85	29.54	35.16	35.09	35.13	35.71	36.33	36.02
SEm±	0.02	0.02	0.01	0.01	0.01	0.01	4.40	4.53	3.16
C.D at 5%	0.05	0.05	0.03	0.04	0.03	0.03	NS	NS	NS

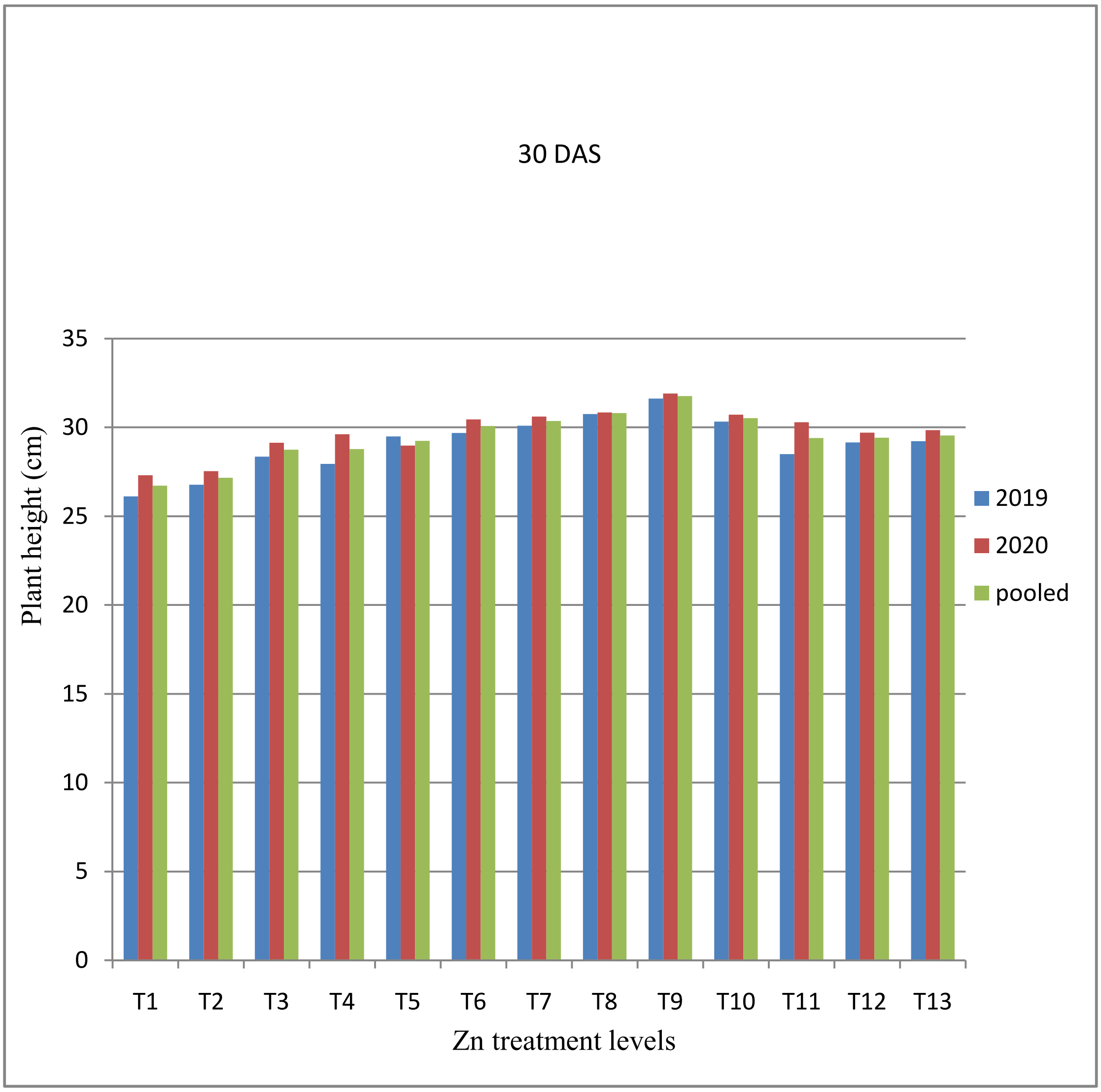

Fig 4: Effect of the sources and levels of Zn on plant height of soybean at 30 DAS

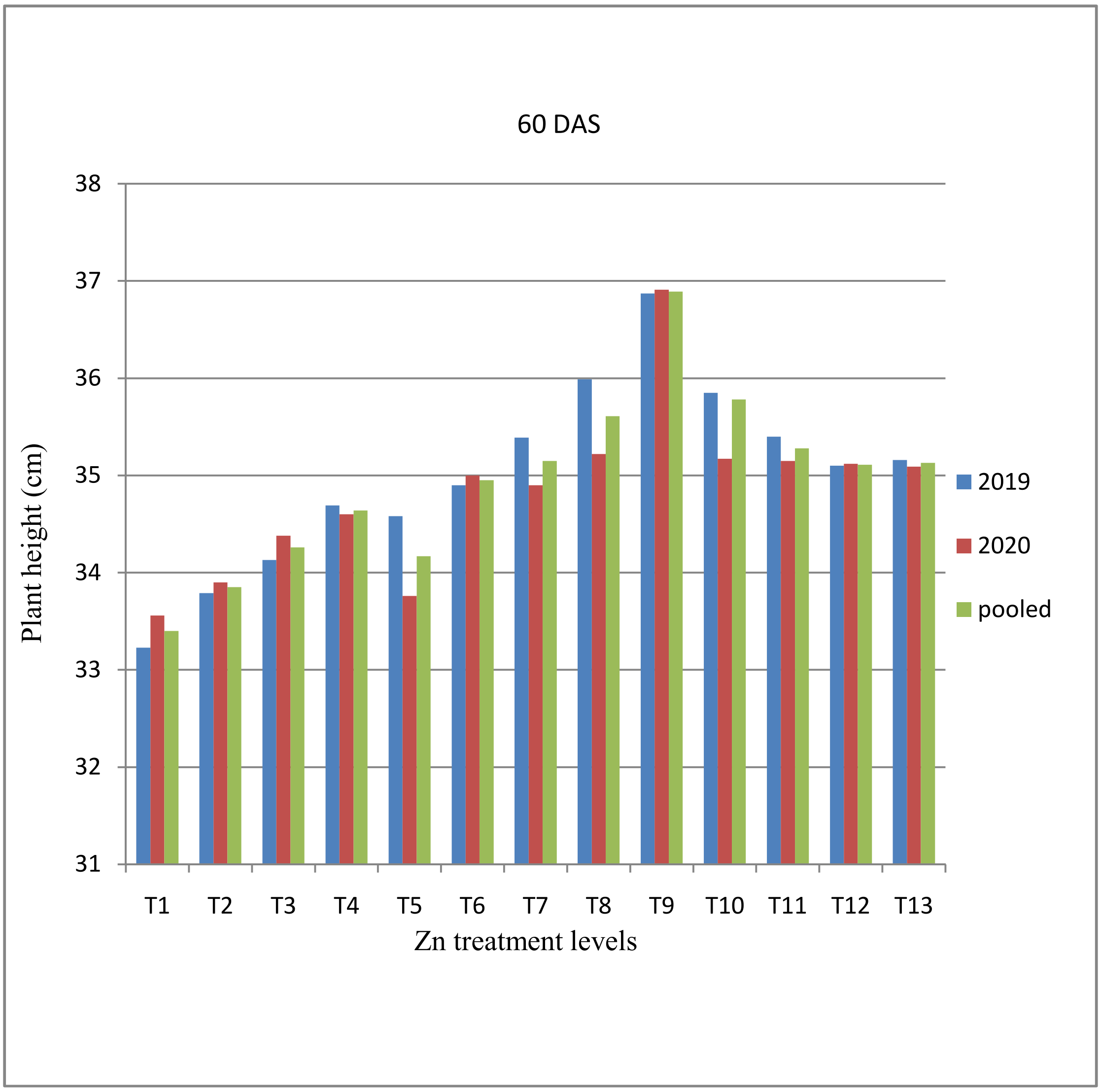

Fig 5: Effect of the sources and levels of Zn on plant height of soybean at 60 DAS

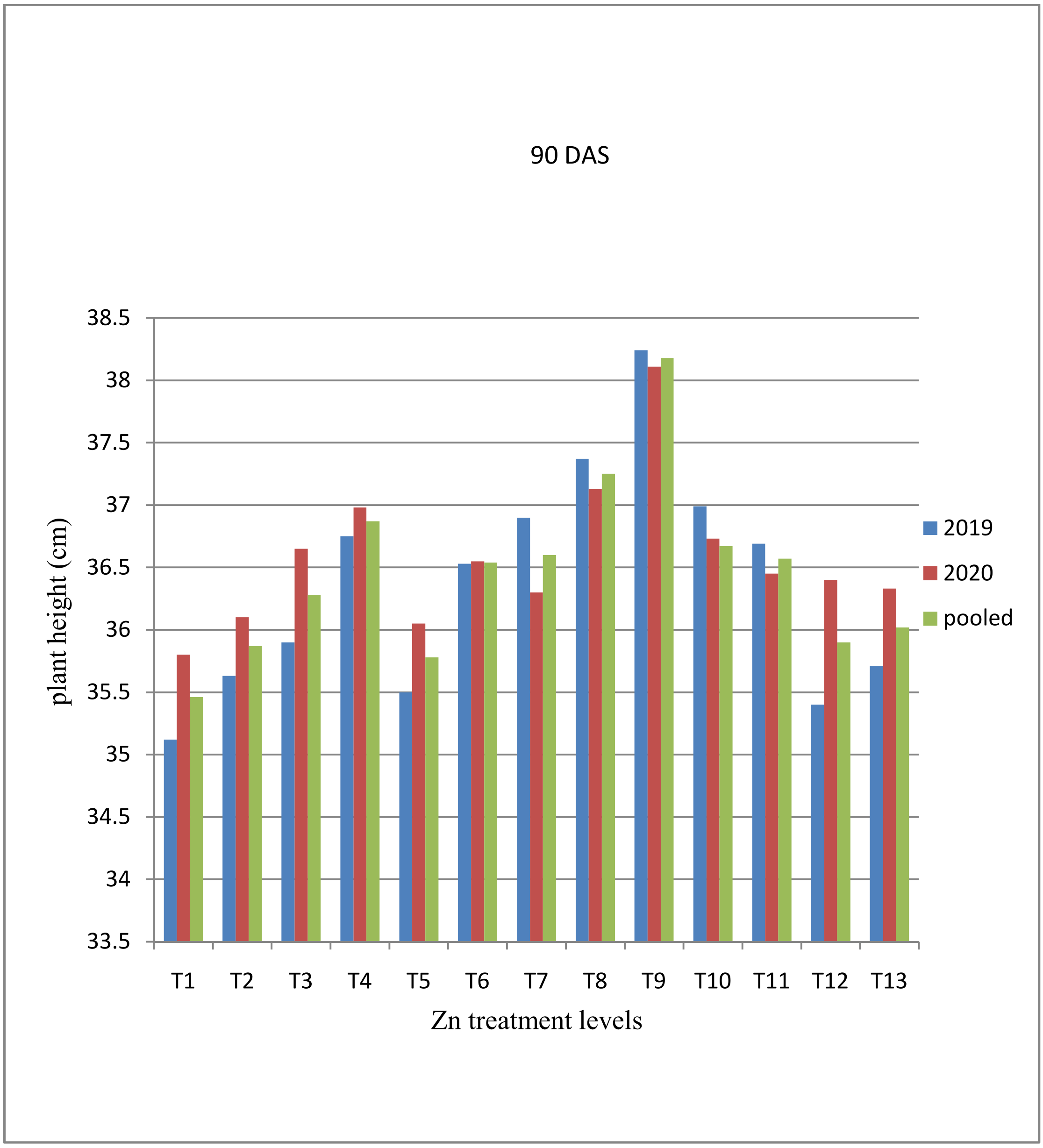

Fig 6: Effect of the sources and levels of Zn on plant height of soybean at 90 DAS

Table 4.2: Effect of the sources and levels of Zn on the number of nodules at flowering stage

Treatments	No. of nodules		
	2019	2020	Pooled
T_1	32.30	29.60	30.95
T_2	29.30	38.10	33.70
T_3	26.00	32.80	29.40
T_4	30.30	28.70	29.50
T_5	38.10	29.90	34.00
T_6	32.40	37.20	34.80
T_7	36.70	36.67	36.69
T_8	41.30	40.60	40.95
T_9	46.70	45.10	45.90
T_{10}	40.00	40.20	40.10
T_{11}	25.60	30.80	28.20
T_{12}	24.10	28.90	26.50
T_{13}	26.40	29.70	30.05
SEm±	0.29	0.34	0.22
C.D at 5%	0.83	0.98	0.63

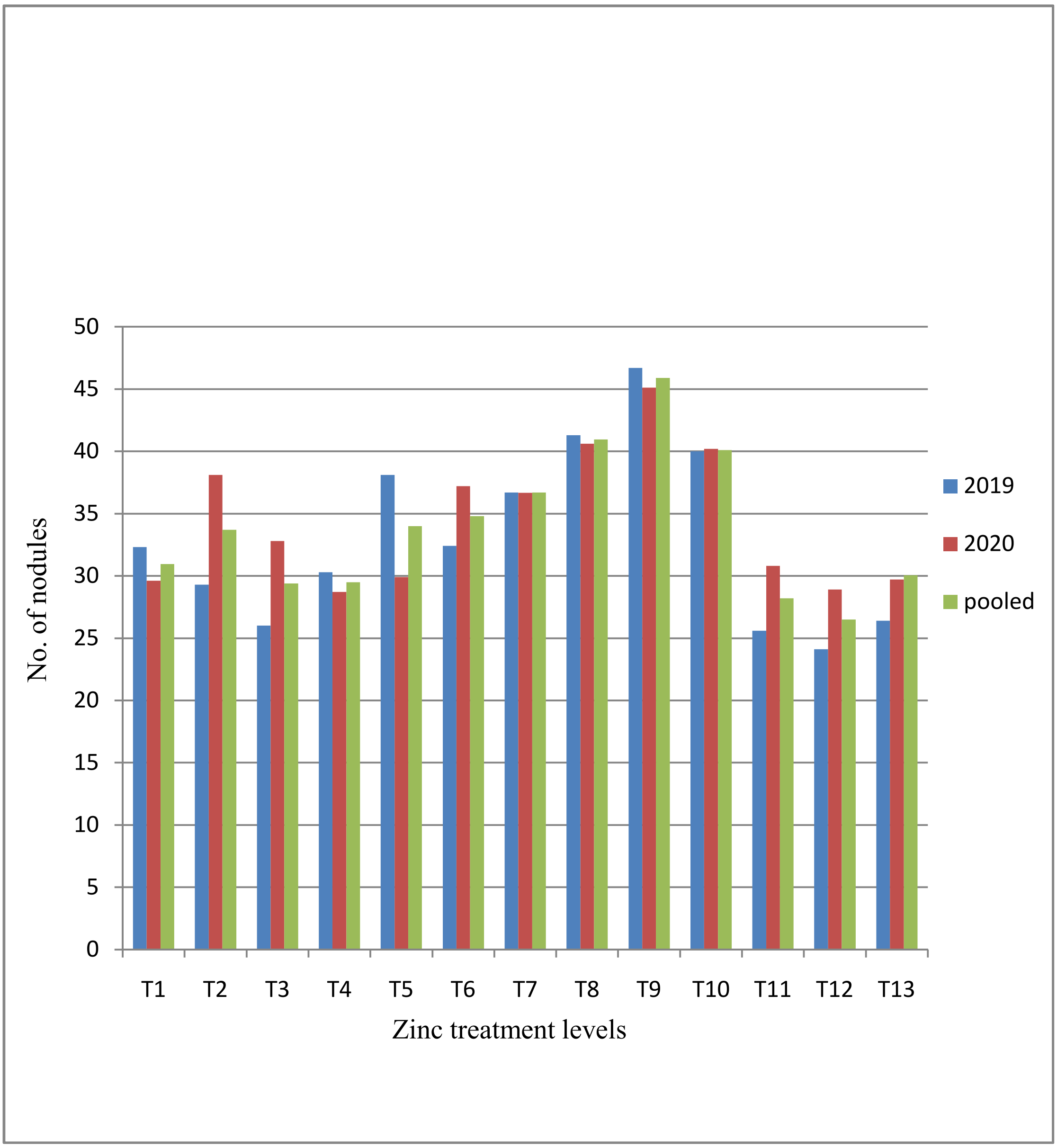

Fig 7: Effect of the sources and levels of Zn on the number of nodules at flowering stage

Table 4.3: Effect of the sources and levels of Zn on fresh weight of nodules at flowering stage

Treatments	Fresh weight of nodules (g)		
	2019	2020	Pooled
T_1	0.18	0.18	0.18
T_2	0.19	0.20	0.20
T_3	0.24	0.24	0.24
T_4	0.30	0.29	0.31
T_5	0.26	0.28	0.27
T_6	0.31	0.27	0.29
T_7	0.30	0.28	0.29
T_8	0.34	0.32	0.33
T_9	0.36	0.37	0.37
T_{10}	0.33	0.31	0.32
T_{11}	0.26	0.25	0.26
T_{12}	0.25	0.24	0.25
T_{13}	0.24	0.22	0.23
SEm±	0.01	0.01	0.01
C.D at 5%	0.02	0.04	0.02

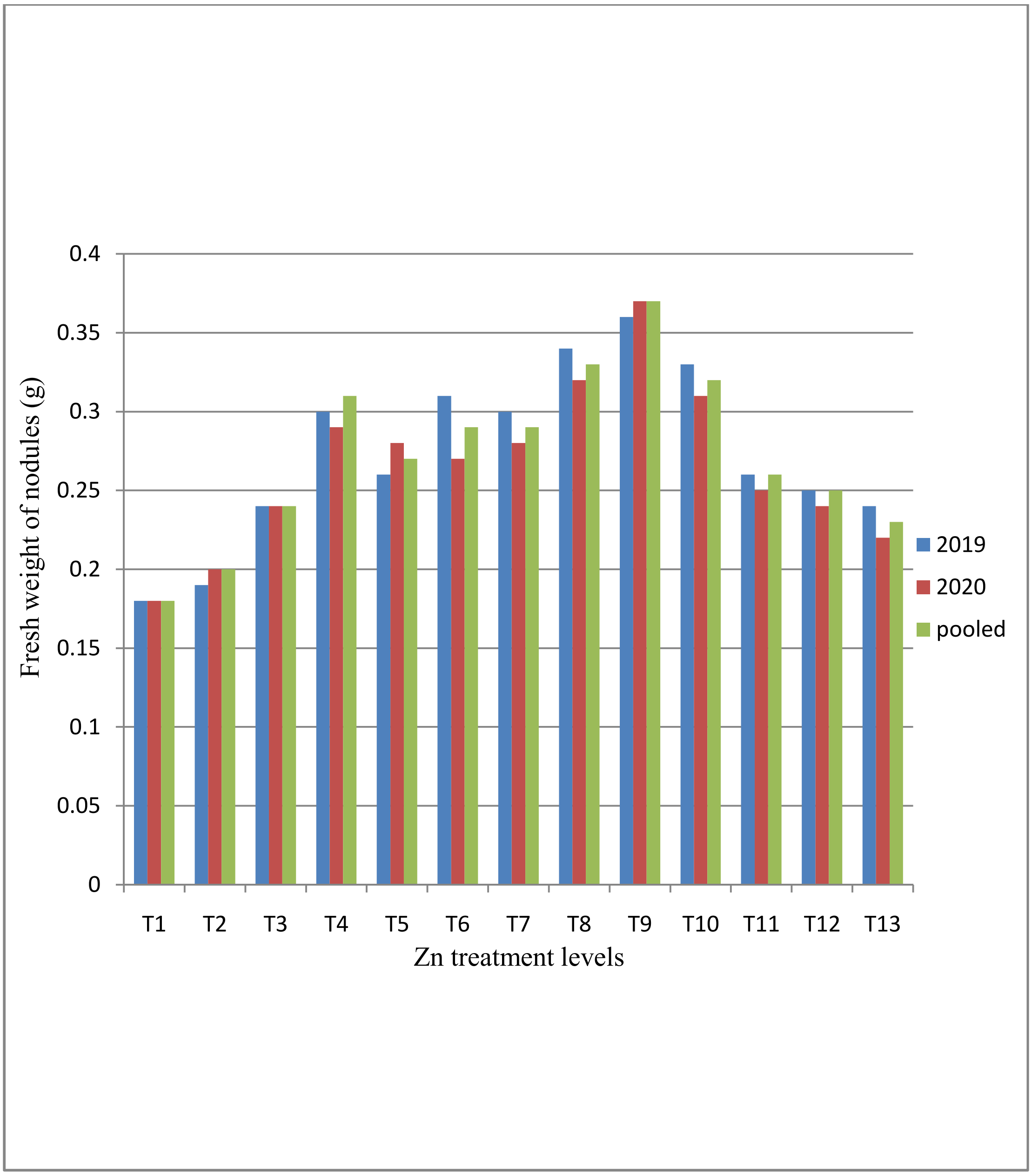

Fig 8: Effect of the sources and levels of Zn on the fresh weight of nodules at flowering stage

Table 4.4: Effect of the sources and levels of Zn on dry weight of nodules at flowering stage

Treatments	Dry weight of nodules (g)		
	2019	2020	Pooled
T_1	0.06	0.05	0.05
T_2	0.06	0.04	0.05
T_3	0.06	0.04	0.05
T_4	0.09	0.07	0.08
T_5	0.10	0.06	0.08
T_6	0.10	0.08	0.09
T_7	0.09	0.06	0.08
T_8	0.12	0.11	0.12
T_9	0.13	0.12	0.13
T_{10}	0.12	0.11	0.11
T_{11}	0.08	0.09	0.09
T_{12}	0.09	0.07	0.08
T_{13}	0.06	0.07	0.07
SEm±	0.02	0.01	0.01
C.D at 5%	0.04	0.03	0.03

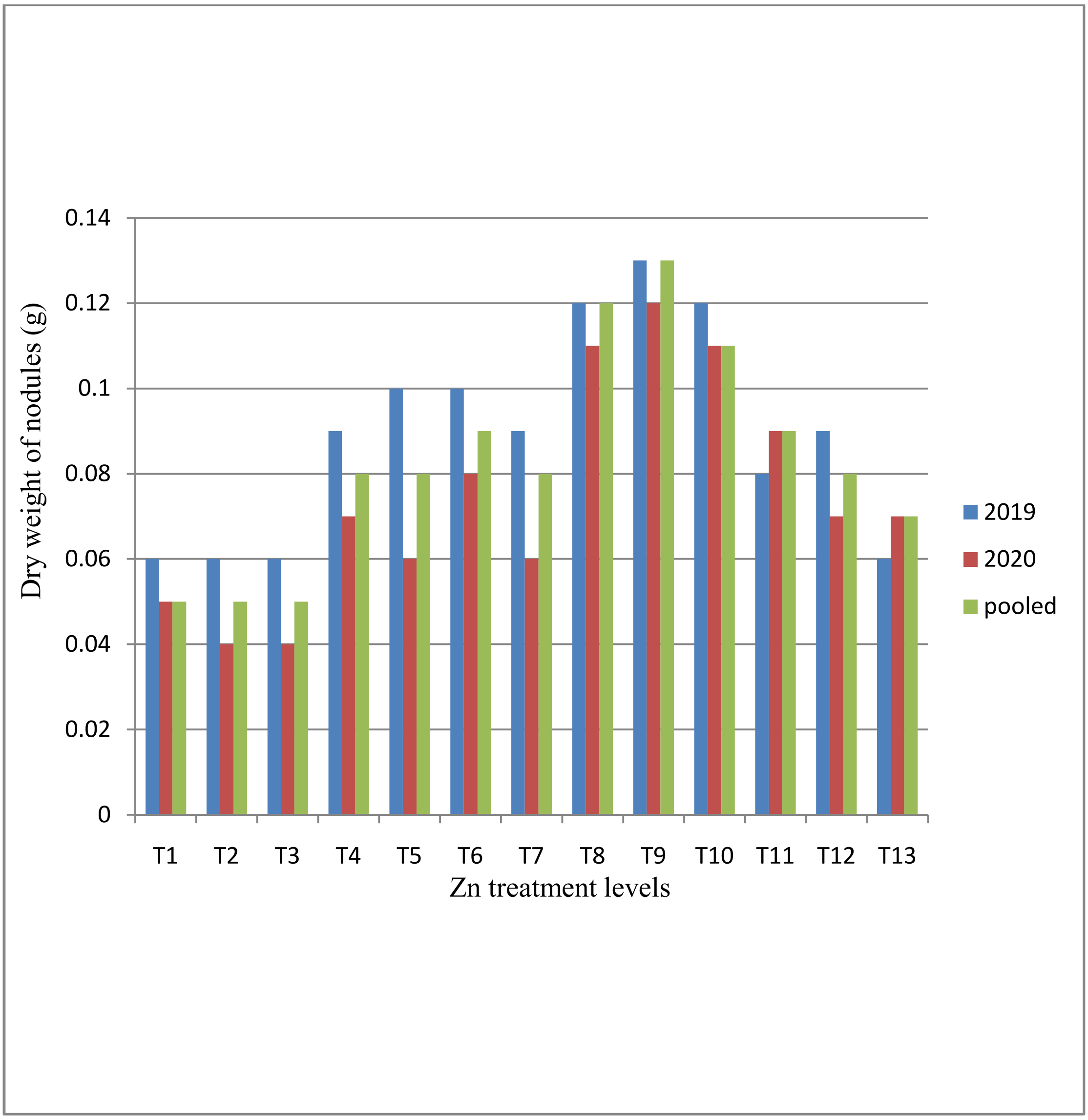

Fig 9: Effect of the sources and levels of Zn on the dry weight of nodules at flowering stage

4.1.2. Effect on yield

4.1.2.1. Effect on seed yield (kg ha^{-1})

The response of soybean to sources and levels of Zn on seed yield is presented in the table 4.5 and fig 10. Zn fertilization was found to influence the seed yield significantly. The maximum seed yield of 1814.50 and 1837.90 kg ha^{-1} was observed at treatment T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) which was found at par with treatment T_8 (RDF + 5 kg $ZnSO_4$ $7H_2O$ ha^{-1}) and the lowest recorded was 1406.40 and 1424.20 kg ha^{-1} at T_1 (control) during 2019 and 2020. The pooled data also showed significant effect with the maximum seed yield of 1826.20 kg ha^{-1} observed at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) and the lowest being recorded was 1415.30 kg ha^{-1} at T_1 (control). The significant increase in seed yield of mung bean with the application of Zn fertilizer for both the consecutive years of 2008 and 2009 was reported by Quddus*et al*. (2011). The highest seed yield of 2865 kg ha^{-1} was obtained from T_3 treatment (1.5 kg Zn ha^{-1}) in 2008 which was significantly higher than T_1 (Control).Similar trend was also observed in 2009. Similar significant seed yield results were also reported in chick pea and soybean with the application of Zn at 5 kg ha^{-1} by Shivay*et al*. (2014) and Nandanware*t al*. (2007). Ruffo *et al*. (2016) also reported that Zn application @ 11 kg ha^{-1} significantly results in enhanced yield in maize (11,530 kg ha^{-1}) than in control treatment (10,540 kg ha^{-1}). Zn application of 30 kg $ZnSO_4$ $7H_2O$ hm^{-2} increased the chlorophyll content in leaves, improved photosynthesis, and increased grain yield of summer maize (Liu *et al*., 2016). Upadhyay (2016) also reported significant increase in the grain yield of cowpea at 15 kg Zn ha^{-1} due to the influenced of Zn on the synthesis of IAA which indirectly enhanced the growth, development and uptake of nutrient. Zinc is an important component in enhancing the activity of a large number of enzymes leading toall round growth development and hence increased in seed yield (Prasad, 2007).The grain yield is also enhanced significantly with increased in yield attributes as Zn is positively correlated and major contributors of grain yield (Weldua*et al*., 2012).

Bhadauria*et al*. (2012) stated that the increased in seed yield of mustard with Zn fertilization might be due to the direct involvement of Zn in the transfer of photosynthates in seeds thereby enhancing seed yield.

4.1.2.2.Effect on stover yield (kg ha^{-1})

There was a significant increase in the stover yield of soybean during 2019 and 2020 respectively. Similar trend was also observed in pooled data as shown in table 4.6 and fig 11. The highest stover yield of 2198.10 and 2226.30 kg ha^{-1} was recorded at treatment T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) which was found at par with T_8 (RDF + 5 kg $ZnSO_4$ $7H_2O$ ha^{-1}) and the lowest stover yield of 1687.60 and 1663.80 kg ha^{-1} was recorded at T_1 (control) during both the years. Similarly in pooled data, the maximum stover yield of 2212.20 kg ha^{-1} was recorded at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) and the lowest of 1675.70 kg ha^{-1} was recorded in T_1 (control). Shivay*et al*. (2014) opined that the straw yield of chickpea was significantly increased with the increasing level of Zn up to 7.5kg Zn ha^{-1}and Faujdar *et al*. (2014) also observed that application of Zn @ 5 kg ha^{-1} significantly increased the stover yield by 16.2 % as compared to control in maize. The application of 5 kg Zn ha^{-1} was also shown to increase the stover yield of cluster bean (Kuniya*et al*., 2018). Singh *et al*. (2012) also observed that the straw yield was significantly increased to 11.4% in chickpea with the application of 5 kg Zn ha^{-1}. Similar trend in stover yield of soybean were also observed by Nandanwar*et al.* (2007) and Pable*et al*. (2010) with Zn application over control. This increased in stover yield may be due to Zn nutrition leading to increase in protoplasmic constituents, cell division and elongation, photosynthesis, respiration, biochemical and physiological activities (Maurya *et al*. 2010 and Patel *et al*., 2013). Zinc also plays an important role in enzymatic activity and catalyzation which enhance the growth and yield attributes. This might be another factor for increasing the stover yield in plant (Afolabi *et al*., 2020).Singh *et al*. (2021) also opined similar observation due to the positive effect of Zn fertilization on the dry matter of plants.

Table 4.5: Effect of the sources and levels of Zn on seed yield

Treatments	Seed yield (kg ha^{-1})		
	2019	2020	Pooled
T_1	1406.40	1424.20	1415.30
T_2	1496.70	1493.60	1495.15
T_3	1529.90	1541.70	1535.80
T_4	1586.60	1599.10	1592.85
T_5	1617.00	1630.40	1623.70
T_6	1706.30	1739.40	1722.85
T_7	1693.40	1718.90	1706.15
T_8	1767.80	1749.50	1758.65
T_9	1814.50	1837.90	1826.20
T_{10}	1649.80	1706.30	1678.05
T_{11}	1590.90	1585.90	1588.40
T_{12}	1535.10	1550.10	1542.60
T_{13}	1558.30	1526.60	1542.45
SEm±	0.13	0.02	0.07
C.D at 5%	0.37	0.05	0.19

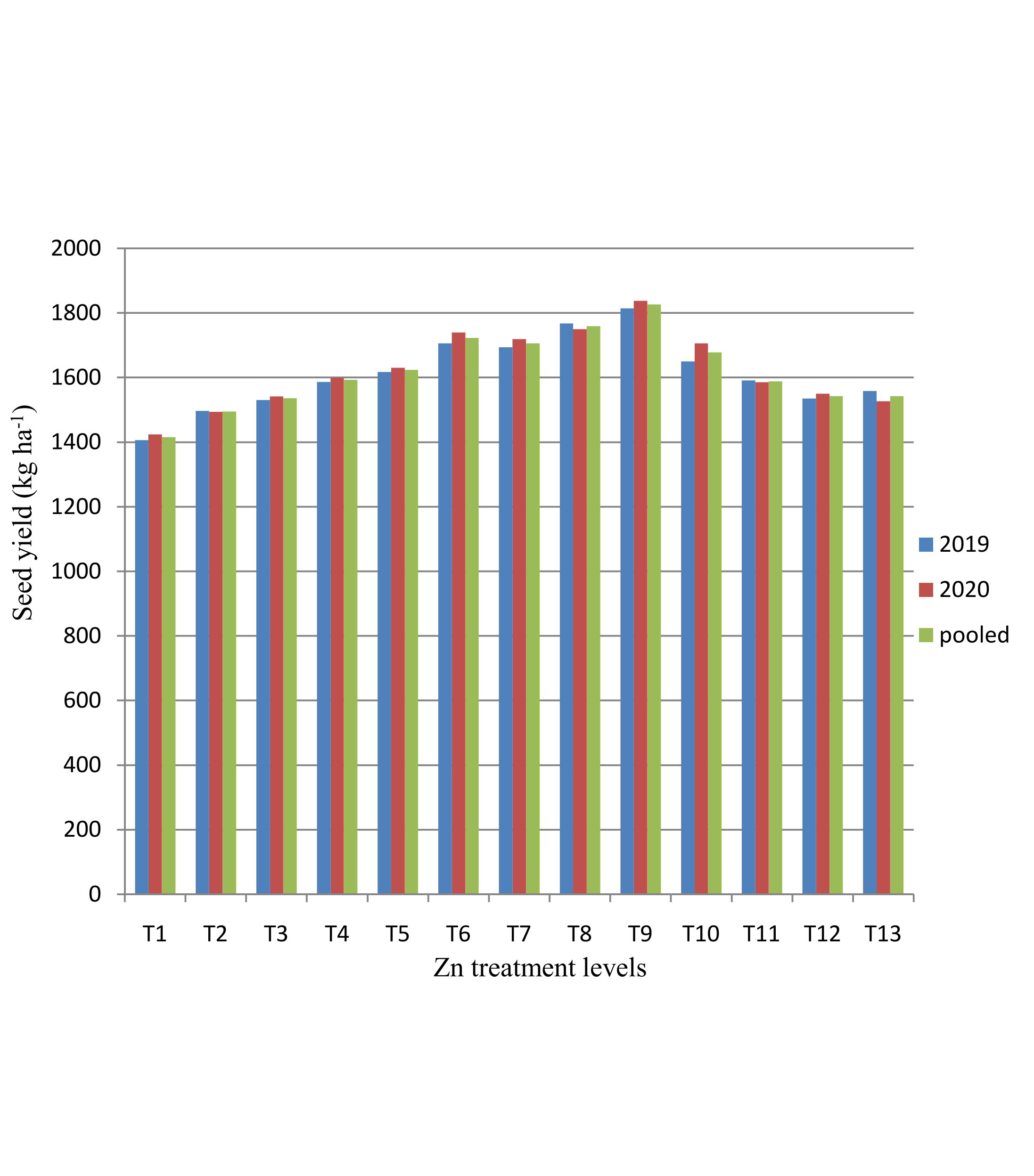

Fig 10: Effect of the sources and levels of Zn on the seed yield

Table 4.6: Effect of the sources and levels of Zn on stover yield

Treatments	Stover yield (kg ha^{-1})		
	2019	2020	Pooled
T_1	1687.60	1663.80	1675.70
T_2	1778.90	1753.70	1766.30
T_3	1760.37	1799.30	1779.83
T_4	1930.40	1989.30	1959.85
T_5	1998.10	2113.70	2055.90
T_6	2096.90	2122.30	2109.60
T_7	2019.30	2131.90	2075.60
T_8	2135.20	2197.90	2166.55
T_9	2198.10	2226.30	2212.20
T_{10}	2010.60	2088.50	2049.55
T_{11}	1976.60	1968.70	1972.65
T_{12}	1816.10	1843.90	1830.00
T_{13}	1869.40	1828.90	1849.15
SEm±	9.24	7.49	5.95
C.D at 5%	26.98	21.85	16.91

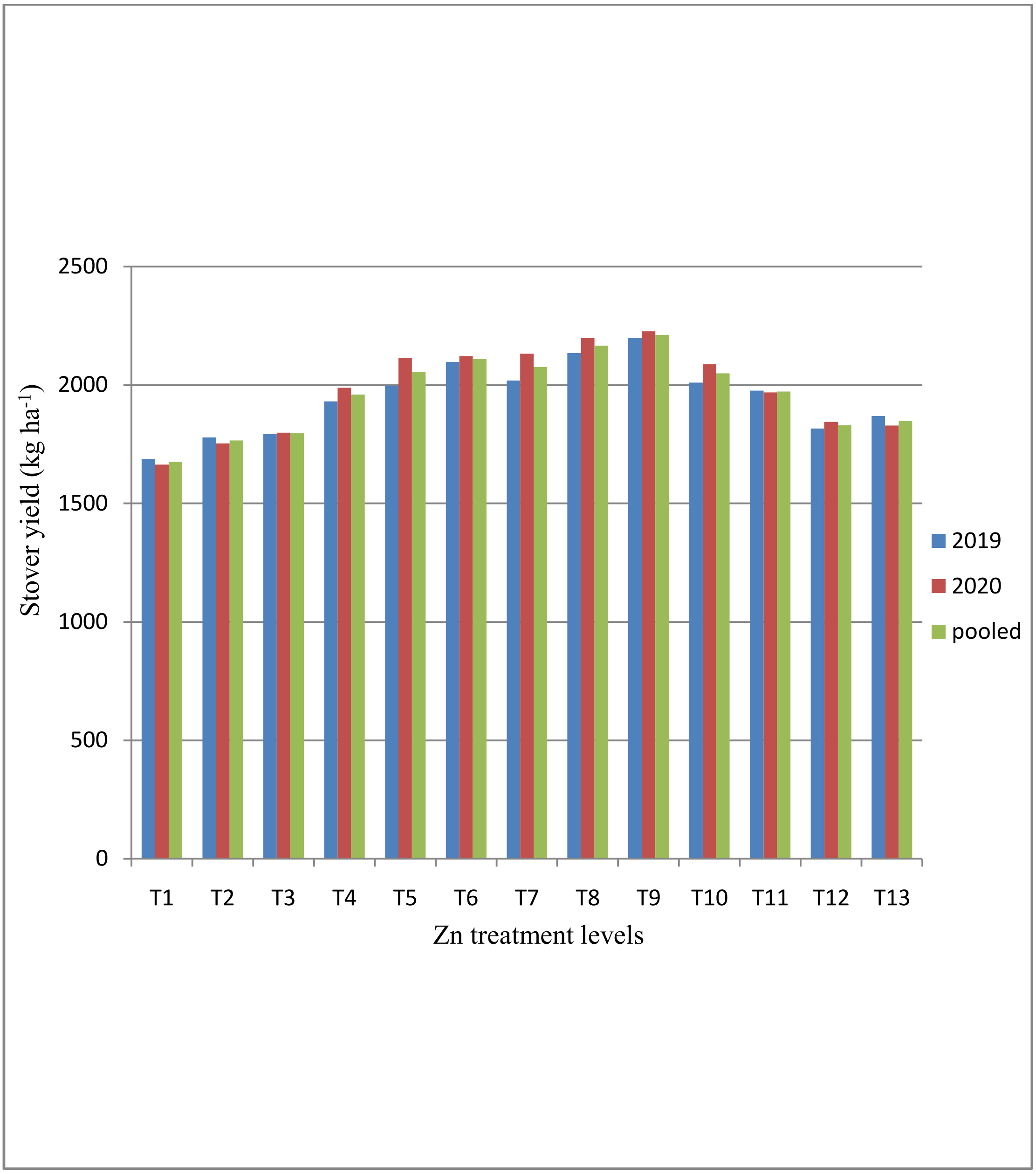

Fig 11: Effect of the sources and levels of Zn on the stover yield

4.1.3. Yield attributes

4.1.3.1. Effect on number of pods plant^{-1}

It is apparent from the given table 4.7 and fig 12 that during 2019 and 2020, there was significant increase in the number of pods plant^{-1} in soybean. The maximum number of pods plant^{-1} recorded at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) was 104.30 and 107.20 which was closely followed by treatment T_8 (RDF + 5 kg $ZnSO_4$ $7H_2O$ ha^{-1}) and T_{10} (RDF + 5 kg Zn-EDTA ha^{-1}). The lowest was recorded at T_1 (control) *i.e.*76.30 and 63.30. Similarly, significant effect was also observed from pooled data during both the years. The maximum number of pods plant^{-1} was 105.75 at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) and lowest recorded was 68.80 at T_1 (control). It is also evident from Srikanth Babu *et al.* (2012) that the application of $ZnSO_4$ @ 20 kg ha^{-1} in pigeon pea significantly increased the number of pods plant^{-1} as compared to no zinc application. Singh *et al.* (2012) also revealed that the number of pods plant^{-1} in chickpea was increased by 17% through combined application of 25 kg $ZnSO_4$ along with FYM @ 5t ha^{-1} as compared to no Zn application. Muindi*et al.* (2020) also reported significant increase in the no. of pods plant^{-1} with soil application of Zn as compared to foliar Zn treatments in green gram. This might be due to the role of Zn in biosynthesis of IAA, regulation of auxin concentration, primordial initiation for reproductive parts, higher enzymes and physiological activities that helps in better translocation of desired metabolites to the yield attributing plant parts (Raghuwanshi*et al.*, 2017 and Michail*et al.*, 2004). Nadergoli*et al.* (2011) observed that soil application of $ZnSO_4$ @ 20 kg Zn ha^{-1} in common bean gives the highest number of pods plant^{-1} which was found at par with 15 and 25 kg $ZnSO_4$ ha^{-1}. Similar observation was also made by Ram *et al.* (2018) in mung bean where Zn application enhances the vegetative and reproductive parts of the plant thereby increasing the yield attributing characters.More number of pods per plant under these treatments might be due to the more number of branches and dry matter accumulation per plant (Meena *et al.*, 2017). Masih *et al.* (2020) observed similar increased in the number of pods plant^{-1} with Zn application. This increased in the yield attributes might be due to the enhancement of flowers into pods through Zn application.

4.1.3.2. Effect on number of seeds pod^{-1}

From the data recorded, it was observed that Zn application significantly increased the number of seeds pods^{-1} in soybean during 2019, 2020 and pooled respectively as shown in table 4.8 and fig 13. During 2019 and 2020, the maximum number of seeds pod^{-1} recorded at treatment T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) were 3.93 and 3.63. The lowest was recorded at T_1 (control) i.e.,2.03 and 2.00. This was followed closely by T_8 (RDF + 5 kg $ZnSO_4$ $7H_2O$ ha^{-1}) and T_{10} (RDF + 5 kg Zn-EDTA ha^{-1}). From the pooled data, the maximum number of seeds pod^{-1} recorded was 3.78 at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) and the lowest recorded was 2.02 at T_1 (control). Dube *et al*. (2001) showed positive response to graded 1 to 25 mg kg^{-1} soil Zn amendment. The enhancement in production of seeds pod^{-1} in pigeon pea was highest at 5 mg kg^{-1} Zn added to soil. Haider *et al*. (2018) also revealed that the soil Zn application at 10 mg Zn kg^{-1} produced the highest seeds pod^{-1} in mung bean.Similar observation was made byPraveena*et al*. (2018) in kharif green gram where the highest no. of seeds pod^{-1} (6.90) was recorded under basal application of zinc @ 5.5 kg ha^{-1} over control which might be due to the role of zinc in seed setting. Usman *et al*. (2014) also stated that the increased in the number of seeds per pod^{-1} could be due to Zn treatment in plant which further led to enhance stamens and pollen thereby increasing seed yield.Masih *et al*. (2020) also reported that Zn fertilization significantly increased the number of pods plant^{-1} and grains pod^{-1} in green gram. This increased in the yield attributes might be due to the enhancement of flowers into pods through Zn application. Weldua*et al*. (2012) also observed that Zn fertilization significantly increased the no. of seeds pod^{-1} in faba bean. This increased in seeds pod^{-1} might be due to the positive influence of Zn application on tryptophan synthesis which is a precursor of growth hormone production in plants (Vinod Kumar *et al*. 2020). Zn helps in the biosynthesis of plant growth regulator, carbohydrate and N metabolic process which enhanced the yield and yield attributes in chick pea (Taliee and Sayadian, 2000).

4.1.3.3. Effect on test weight (g)

The data on test weight shown in table 4.9 and fig 14 indicates that the application of Zn sources in soybean had a non-significant effect on test weight in both the years and pooled. The maximum test weight was observed at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) during 2019 and 2020 *i.e.* 72.54 and 73.67 g. The lowest was observed in T_1 (control) *i.e*. 68.40 and 70.13 g. From the pooled data, the maximum test weight recorded was 73.11 g at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) and the lowest was 69.27 g which was recorded at T_1 (control). Balai*et al*. (2017) observed that the test weight of chickpea was found to be non- significant with the application of different levels of Zn and P. It was also observed by Khathoon*et al*. (2016) that the test weight of sunflower seeds was positively influenced by Zn fertilization and it was found to be non-significant. In late sown wheat crop, application of Zn at various levels did not significantly affect the test weight of the grain (Mishra *et al*., 2017).Moghadam *et al*. (2012) observed that foliar spray of Zn @ 0, 1 and 2 l ha^{-1} did not show any significant effect on 1000 grain weight of wheat crop as well as Boorbooi*et al*. (2012) also observed that Zn application @ 0, 5 and 10 mg $ZnSO_4$ kg^{-1} soil did not significantly affects the 1000 grain weight in barley crop. Upadhyay *et al*. (2016) and Tiwari *et al*. (2018) also observed non-significant effect on 1000 seed weight with Zn fertilization in cowpea and lentil crops and similarly Masih *et al*. (2020) also reported that Zn fertilization did not significantly increased the test weight of green gram. The 1000-grain weight (g) was not positively influenced by the levels of Zn fertilization and it was observed to be influenced by its genetic characters and not by management practices in rice-lentil cropping systems (Singh *et al*. 2011).

Table 4.7: Effect of the sources and levels of Zn on the number of pods $plant^{-1}$

Treatments	No. of pods $plant^{-1}$		
	2019	2020	Pooled
T_1	76.30	63.30	68.80
T_2	80.43	83.80	81.95
T_3	84.83	84.70	78.00
T_4	88.50	82.30	85.4
T_5	89.30	89.30	88.30
T_6	81.57	87.00	84.29
T_7	84.43	88.70	86.57
T_8	94.53	96.30	95.42
T_9	104.30	107.20	105.75
T_{10}	94.47	91.00	92.74
T_{11}	64.63	63.70	64.17
T_{12}	66.70	65.10	65.90
T_{13}	64.70	69.00	66.85
SEm±	0.75	0.43	0.43
C.D at 5%	2.13	1.21	1.24

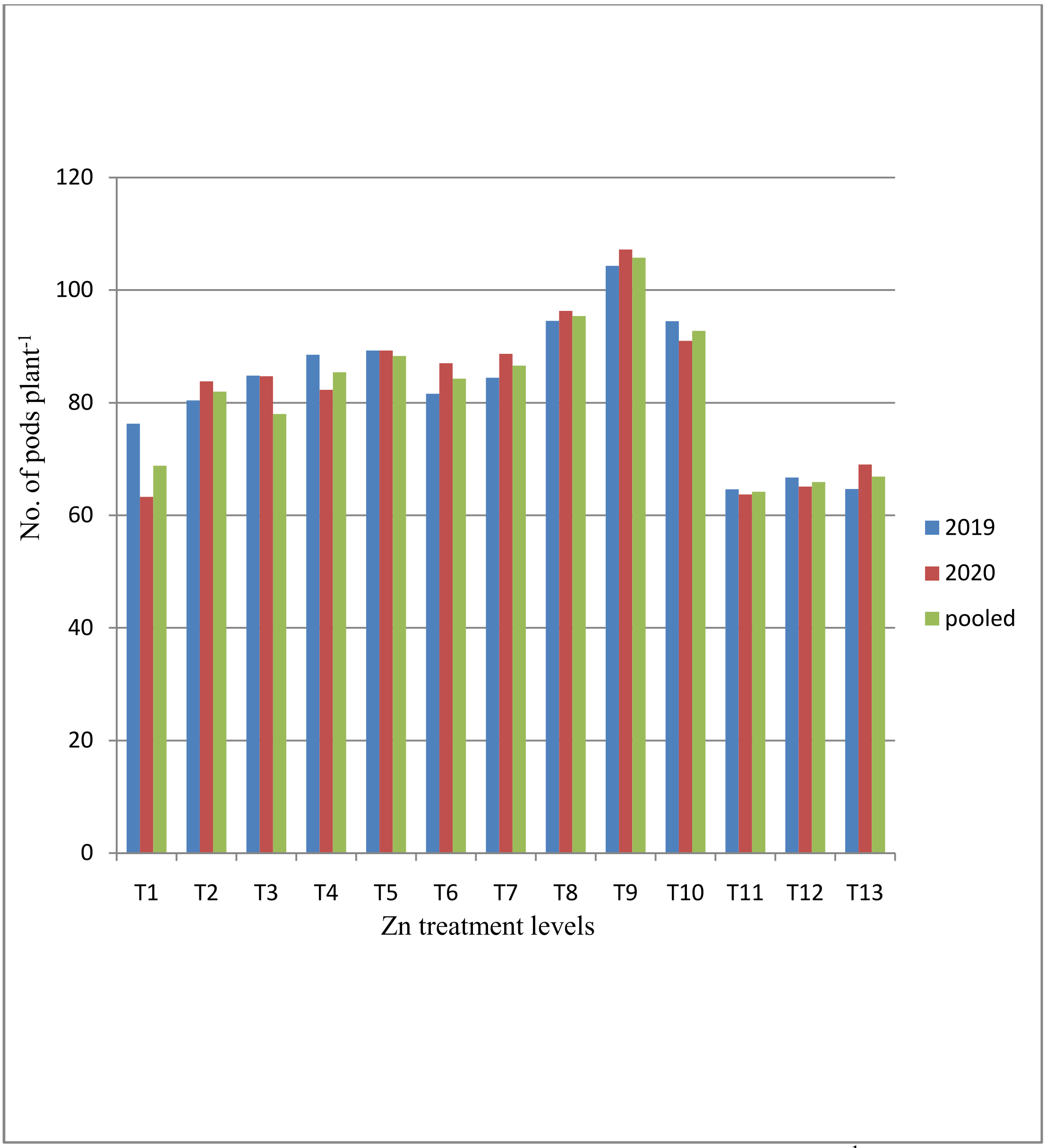

Fig 12: Effect of the sources and levels of Zn on the no. of pods plant^{-1}

Table 4.8: Effect of the sources and levels of Zn on the number of seeds $pods^{-1}$

Treatments	No. of seeds $pods^{-1}$		
	2019	2020	Pooled
T_1	2.53	2.34	2.44
T_2	2.53	2.87	2.70
T_3	2.67	3.00	2.84
T_4	3.07	2.67	2.87
T_5	2.30	3.30	2.80
T_6	3.30	3.00	3.15
T_7	2.53	3.23	2.88
T_8	3.23	3.33	3.28
T_9	3.93	3.63	3.78
T_{10}	2.67	2.33	2.50
T_{11}	2.10	2.00	2.05
T_{12}	2.03	2.67	2.35
T_{13}	2.67	2.07	2.37
SEm±	0.34	0.30	0.23
C.D at 5%	1.00	0.87	0.65

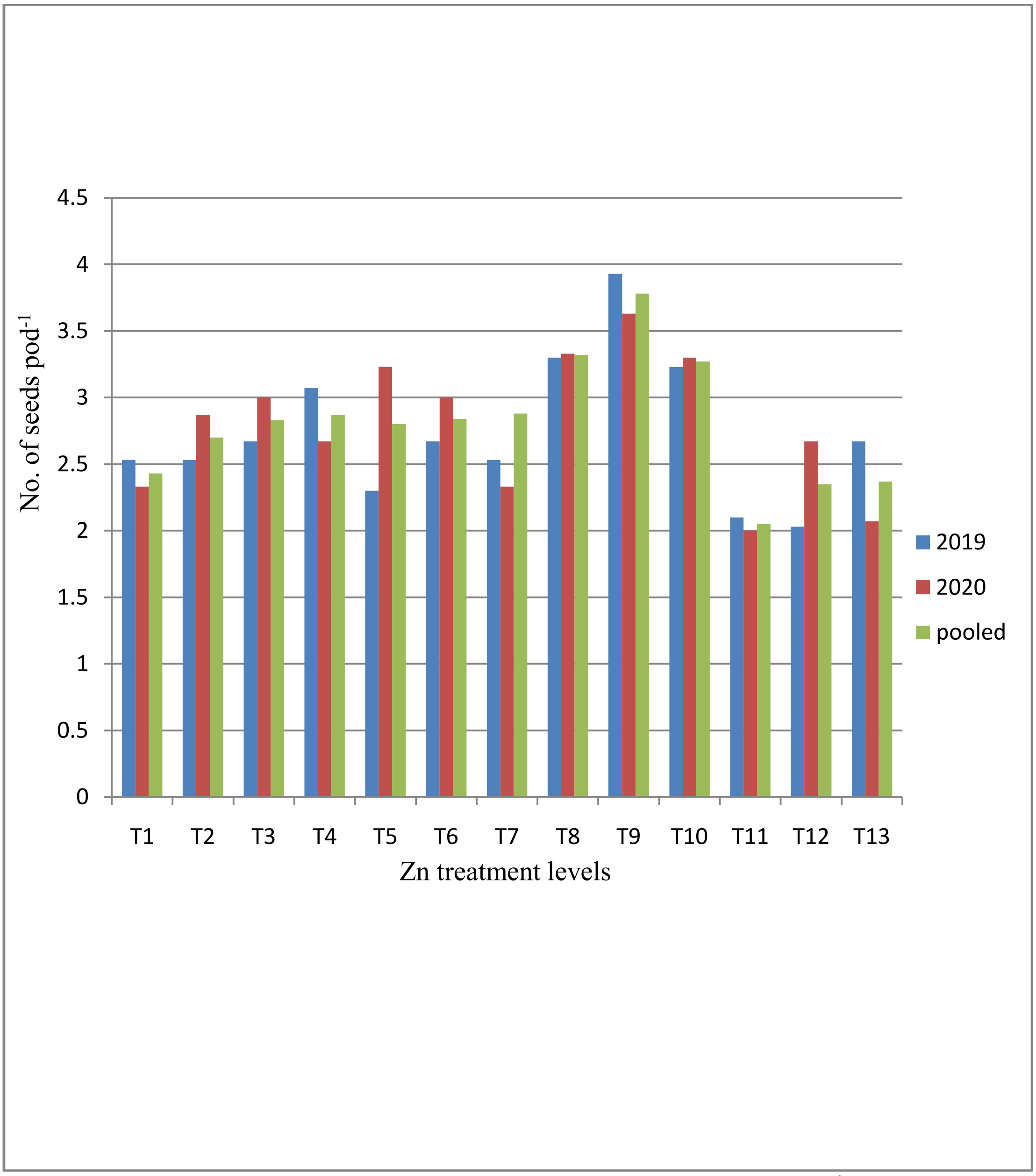

Fig 13: Effect of the sources and levels of Zn on the no. of seeds pod^{-1}

Table 4.9: Effect of the sources and levels of Zn on the test weight

Treatments	Test weight (g)		
	2019	2020	Pooled
T_1	68.40	70.13	69.27
T_2	70.11	72.04	71.08
T_3	70.67	72.33	71.50
T_4	70.00	72.19	71.10
T_5	71.64	72.16	71.90
T_6	70.67	72.33	71.50
T_7	72.07	72.04	72.06
T_8	72.39	72.35	72.37
T_9	72.54	73.67	73.11
T_{10}	72.35	72.33	72.34
T_{11}	71.37	71.29	71.33
T_{12}	71.17	71.30	71.24
T_{13}	70.83	71.80	71.32
SEm±	6.52	7.99	5.16
C.D at 5%	NS	NS	NS

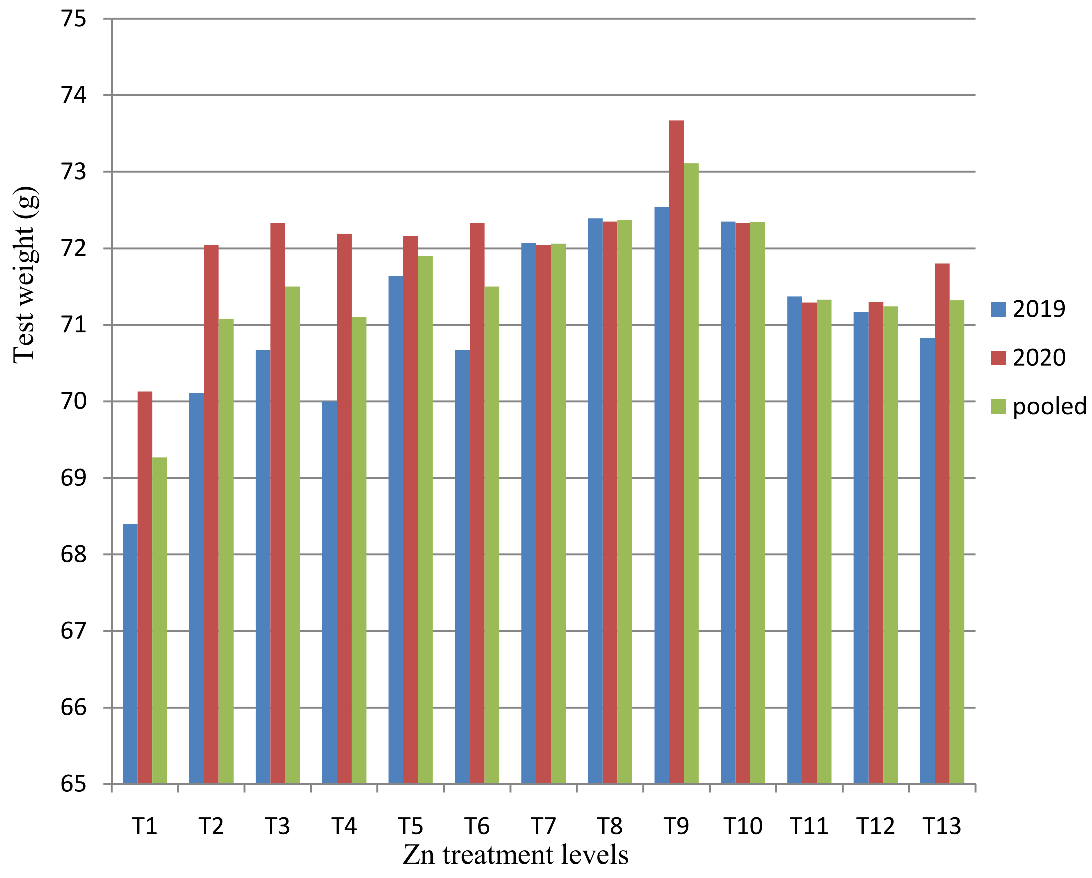

Fig 14: Effect of the sources and levels of Zn on the test weight of seeds

4.1.4. Quality

4.1.4.1. Effect on protein content (%)

The protein content in soybean as affected by various sources and levels of Zn are shown in the table 4.10 and fig 15. Zinc nutrition had a significant increased on protein content during 2019, 2020 and pooled respectively. The protein content was recorded highest at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) with 39.38 and 38.69 % which was closely followed by T_8 (RDF + 5 kg $ZnSO_47H_2O$ ha^{-1}) and T_{10} (RDF + 5 kg Zn-EDTA ha^{-1}) during both the years. The lowest protein content of 33.50 and 34.38 % was recorded at T_1 (control). From the pooled data, it was observed that the protein content was recorded maximum at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) with 39.04 % and the minimum was recorded at T_1 (control) with 33.94 %. Poshtmasari*et al.* (2008) reported significant effects on protein content at 1% levels of probability where the highest protein content in seeds of common bean was obtained at 20 mg Zn kg^{-1} soil. Significant increase in the protein content in chickpea was reported by Shivay*et al.* (2014) with the increasing Zn levels from 2.5 kg to 7.0 kg Zn ha^{-1}. The increase in protein content with Zn application may be attributed to its involvement in N metabolism which were reported by Lokhande*et al.* (2018) and Singh *et al.* (2012) in green gram and chickpea. This increased in protein content might be due to the application of Zn sources in plants which plays an important role in the structural and catalytic components of protein and enzymes for growth and development in plants (Broadley*et al.*, 2007). The increased in the nitrogen content in seed might have also increased the protein content in chickpea with increasing levels of Zinc (Balai*et al.*, 2017).Zinc plays an important role in the synthesis ofindole acetic acid (IAA) synthesis as a result of amino acids and thereby enhanced protein content (Moussavi-Nik *et al.*, 2012). Shahrokhi *et al.* (2012) and Adekiya*et al.* (2018) also opined that the increased in the activity of photosynthesis, chlorophyll content and carbohydrate development in the plant leaves might also be attributed to the increased in protein content.Zinc nutrition plays an important role in enhancing protein content in plant due to its involvement in N metabolism which thereby enhanced the quality of seeds Taliee and Sayadian (2000).

4.1.4.2. Effect on oil content (%)

During the year 2019 and 2020, the Zn sources had a significant effect on oil content in soybean is shown in the table 4.11 and fig 16. From the data recorded, it was observed that Zn application significantly increased the oil content during both the years and pooled. The maximum oil content in soybean recorded was 23.96 and 23.79 % at treatment T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) which was found at par with T_8 (RDF + 5kg $ZnSO_4$ $7H_2O$ ha^{-1}) during both the years. The lowest oil content of 19.24 and 19.02 % was observed at T_1 (control). From the pooled data, it was observed that the maximum oil content recorded was 23.88 % @ T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) and the lowest oil content recorded was 19.13 % at T_1 (control). The significant effect on oil content of soybean seeds was observed by Jat*et al*. (2021) with the soil application of Zn @ 6 kg ha^{-1} during the year 2016 and 2017. The maximum oil content was 21.84, 22.40 & 22.12 % in seeds. Similar observation were also made by Sultana *et al*. (2020) in mustard where the highest oil content was found at 3 kg Zn ha^{-1} and Raghuwanshi*et al*. (2018) also recorded the highest oil content in soybean at 5.0 kg Zn ha^{-1} (11.68%) as compared to control. Meena *et al*. (2017) reported that Zn fertilization significantly increased the oil content (19.94%) in soybean grains at 125% RDP + 5 kg Zn ha^{-1} (T_6) over other treatments. Choudhary *et al*. (2015) and Chakmak (2000) stated that Zn plays an important role in activating certain enzymes which improved the lipid membranes and increased oil content in seeds.This increased in oil content in soybean might be due to the activation of NADPH dependent dehydrogenase which is involved in synthesis of fat with Zn application. Zinc also increased the plant mass weight thereby increasing the carbohydrate production and oil percentage in seeds (Morshedi and Naghibi. 2004).Bhadauria*et al*. (2012) also revealed that Zn acts as an important activator of enzymes such as cysteine disulphydrase, dihydropeptilaseglycyleglycine dipeptidase in plants. Thus Zn fertilization might have led to activation of various enzymes which are involved in increasing the oil content in plants.

Table 4.10: Effect of the sources and levels of zinc on protein content in soybean

Treatments	Protein content in seed (%)		
	2019	2020	Pooled
T_1	33.50	34.38	33.94
T_2	36.69	35.56	36.13
T_3	36.56	35.94	36.25
T_4	36.31	36.25	36.28
T_5	36.69	35.31	36.00
T_6	36.25	35.50	35.88
T_7	35.94	35.19	35.57
T_8	37.69	36.75	37.22
T_9	39.38	38.69	39.04
T_{10}	37.56	36.69	37.13
T_{11}	35.25	35.59	35.42
T_{12}	35.44	34.88	35.16
T_{13}	34.88	34.49	34.69
SEm±	0.02	0.02	0.01
C.D at 5%	0.05	0.05	0.03

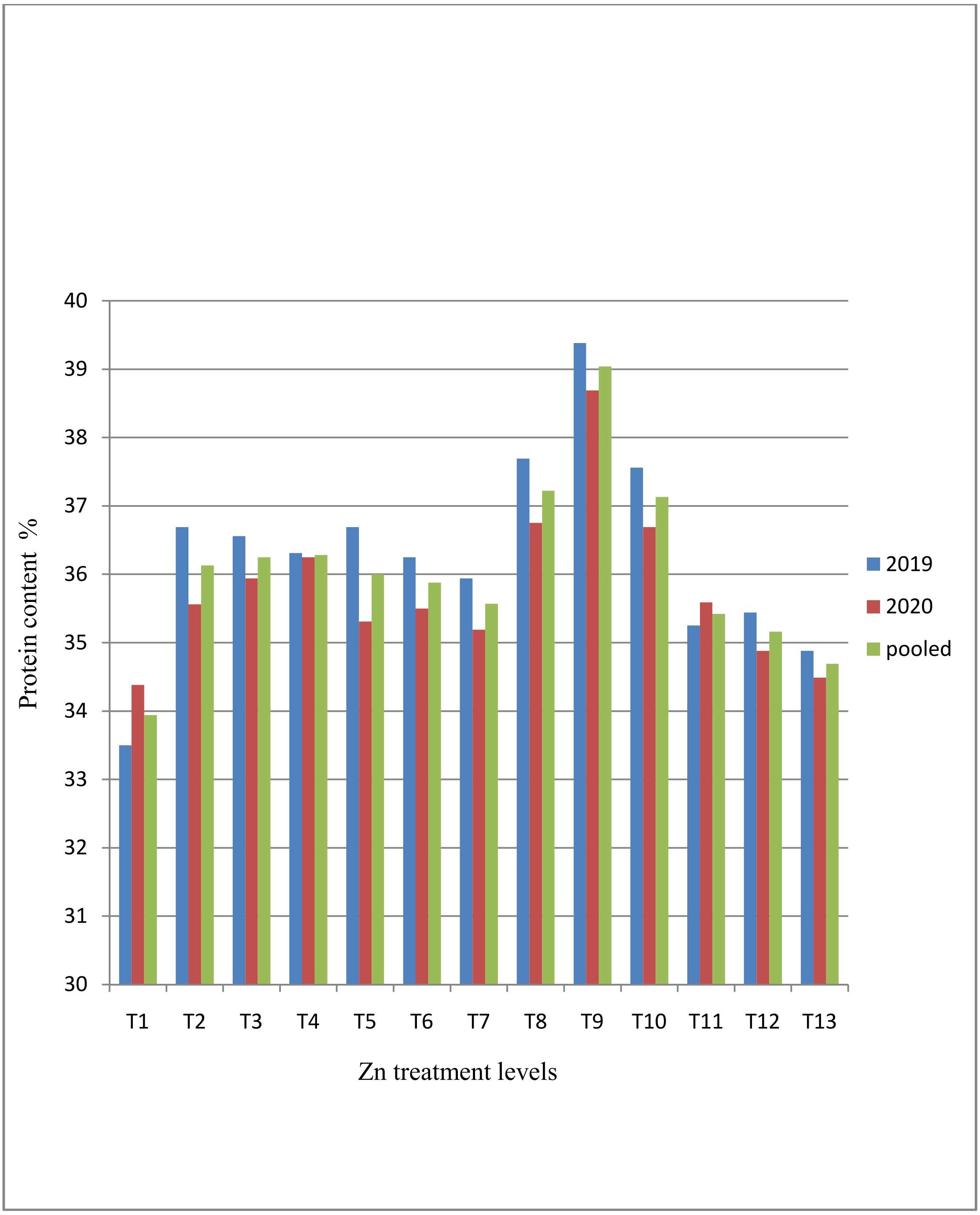

Fig 15: Effect of the sources and levels of Zn on protein content

Table 4.11: Effect of the sources and levels of Zn on oil content in soybean

Treatments	Oil content in seed (%)		
	2019	2020	Pooled
T_1	19.24	19.02	19.13
T_2	20.96	20.15	20.56
T_3	21.83	20.82	21.33
T_4	22.14	21.04	21.59
T_5	21.31	21.19	21.55
T_6	22.39	21.28	21.84
T_7	22.80	20.63	21.72
T_8	23.84	22.56	23.20
T_9	23.96	23.79	23.88
T_{10}	22.35	21.59	21.97
T_{11}	20.12	20.52	20.32
T_{12}	19.49	20.57	20.03
T_{13}	19.97	19.77	19.87
SEm±	0.22	0.02	0.11
C.D at 5%	0.64	0.05	0.35

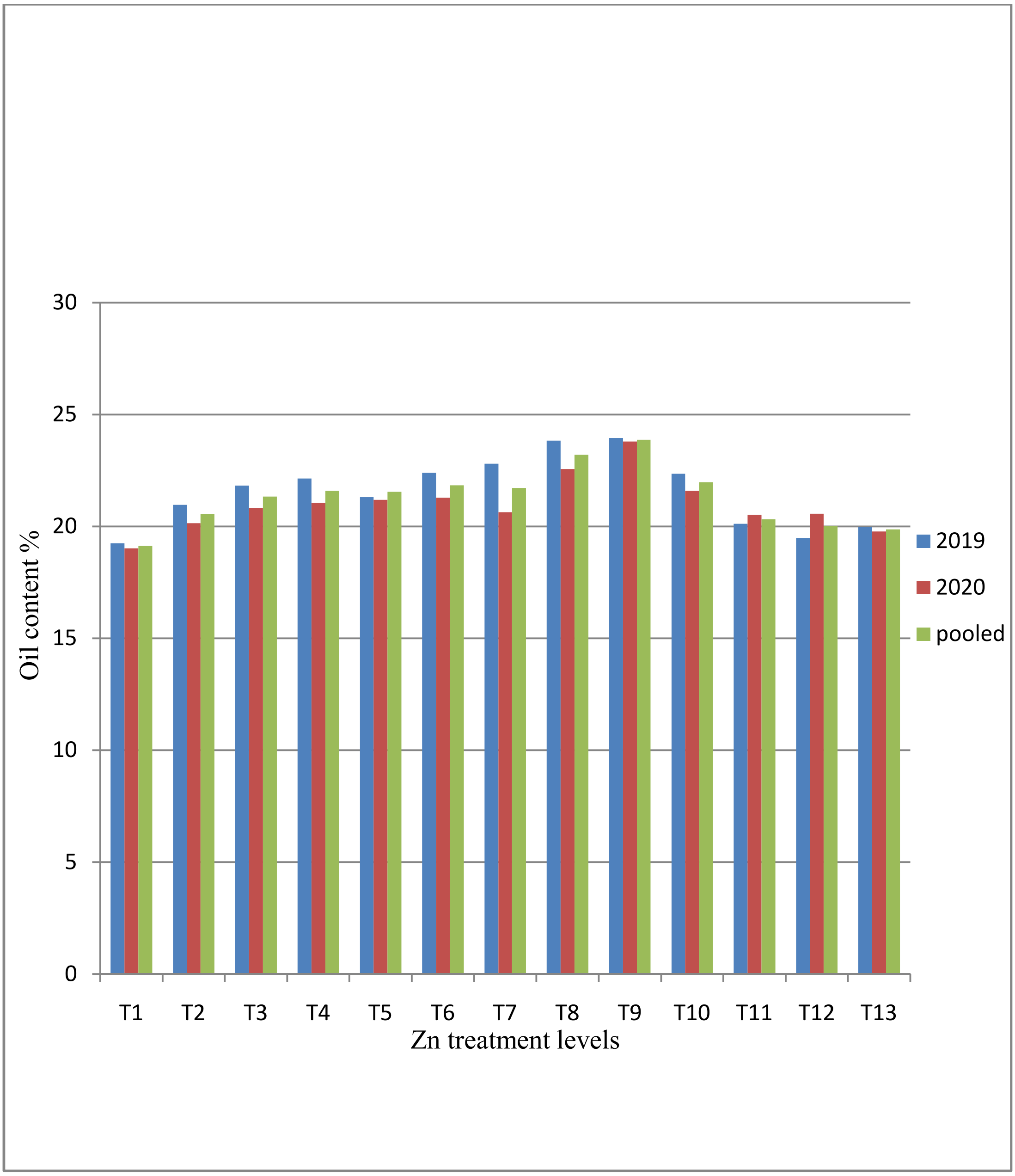

Fig 16: Effect of the sources and levels of Zn on oil content

4.2. To study the nutrient (NPK&Zn) content and uptake by soybean as effected by Zn.

4.2.1. Effect on N content (%) and uptake (kg ha^{-1})

The N content and uptake in seed and stover of soybean with various levels of Zn sources revealed that it showed positive response. From the observation made, it was observed that the N content in seed and stover of soybean was increased significantly with Zn application during 2019 and 2020 respectively as shown in table 4.12 and fig 17&18. The maximum N content in seed recorded was 6.30 and 6.19 % and in stover it was 1.71 and 1.69 % with treatment T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) which was closely followed by T_8 and T_{10}. The lowest recorded in seed was 5.36, 5.50 % and 1.53, 1.48 % in stover at T_1 (control). In the pooled data, N content in seed and stover was significantly increased with the maximum N content in seed recorded was 6.25 % and 1.70 % in stover @ T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}). The lowest was observed in the treatment T_1 (control) where the recorded data was 5.43% and and 1.51 % respectively. The highest N uptake in seed and stover during 2019 and 2020 was recorded at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) i.e., 114.31, 113.77 kg ha^{-1} in seed and 37.59, 37.62 kg ha^{-1} in stover which was followed by T_8 and T_{10} treatment. The lowest was recorded in T_1 (control) and T_{11} (300 ml ha^{-1} liquid ZnO) as shown in table 4.13 and fig 19&20. From the pooled data, it was observed that the maximum N uptake in seed and stover was 114.04 kg ha^{-1} and and 37.61 kg ha^{-1} @ T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}). This significant increase in N content and uptake in seed and stover was also observed in black gram crop with the application of Zn at 6 kg ha^{-1} as compared to the rest of the treatment (Meena *et al*., 2021). Shivay*et al*. (2014) also observed significant increase in N uptake in grain and straw of cowpea at increasing Zn levels from 2.5 to 7.5 kg ha^{-1}. The significant response of Zn fertilization on green gram @ 5 kg ha^{-1} on the N content and uptake in seed and stover was also reported by Solanki *et al*. (2017). Balai*et al.* (2017) also observed that this significant increase in N content and uptake in seed and stover of chickpea with increasing levels of Zn treatment @ 6 kg Zn ha^{-1} could be due to the synthesis of protein, carbohydrates and fats on various enzymes such as dehydrogenease, proteinase and peptidase which positively enhanced the N content and uptake in seed and stover.Similar finding was also reported by Singh *et al*. (2017) on maize where the increased in the uptake of N was attributed to the positive effect of Zn on the photosynthetic and metabolic activity which thereby translocates the photosynthates produced to various parts of the plant and thus enhanced the N uptake.Jan *et al*. (2013) and Rahman *et al*. (2002) stated that the significant effect of Zn levels on the increased in the content and uptake of N by grain and straw of wheat and rice might be because of the positive effect of Zn on N content and uptake by grain and straw.Similar observation was also reported byAdekiya*et al*. (2018) in sweet potato where the total N uptake was increased with increased in the levels of $ZnSO_4$ application which might be due to the synergistic interaction between N and Zn.

4.2.2. Effect on P content (%) and uptake (kg ha^{-1})

The P content in seed and stover of soybean was not significantly affected with various levels of Zn sources during 2019 and 2020 as shown in table 4.14 and fig 21&22. Pooled data also show non-significant effect on P content in seed and stover. The maximum P content in seed and stover was recorded at T_1 (control) with 0.22, 0.21 % in seed and 0.20, 0.18% in stover. Maximum P content of 0.21 and 0.19 % in seed and stover was observed at T_1 (control) from the pooled data. The P uptake in seed and stover was also found non-significant (table 4.15 and fig 23&24) with the maximum P uptake in seed recorded at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) *i.e.* 3.63 and 3.49 kg ha^{-1}. In stover, it was recorded at T_1 (control) i.e., 3.38, 2.99 kg ha^{-1}. From the pooled data, the maximum P uptake of 3.56 and 3.19 kg ha^{-1} was recorded at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) in seed and T_1 in stover than with rest of the treatment applied. Singh *et al*. (2012) observed decreased in P uptake by seed and stover of chickpea at higher levels of Zn (5 and 10 kg Zn ha^{-1}) over 2.5 kg Zn ha^{-1}. Chaudhary *et al*. (2014) also reported non-significant increase in the uptake of P in grain and straw with the increasing levels of Zn upto 5 and 7.5 kg ha^{-1} in green gram and wheat crop.Aboyeji*et al*. (2020) also observed that the application of Zn nutrient @ 8 kg Zn ha^{-1} significantly increased the available nutrient elements such as K, Ca and Mg except P which was found reduced in groundnut. This decreased in P content and uptake with increasing Zn levels might be due to the antagonistic effect between Zn and P. Similar observation was also reported by Singh *et al*. (2017) and Khan *et al*. (2002). Singh *et al*. (2012) also supplemented the findings of others by stating that in chick pea, the P content and uptake in grain and straw were significantly decreased with increased in the levels of Zn fertilization. This indicates an antagonistic relationship between P and Zn nutrition. Samreen*et al*. (2017) also reported that the high Zn uptake efficiency may depress root phosphorous uptake and may also involve in a high rate of Zn transport from roots to shoot via the xylem, and this may hinder P translocation from roots to shoot. Meena *et al*. (2021) also revealed that the Zn was observed to inhibit the translocation of P which results in decreased phosphorus content in seed and stover of blackgram with the increasing levels of Zn fertilization. Similar report was also obtained from Dewal and Pareek (2004) in wheat crop.Zn and P nutrients are both essential for plant growth, however these two nutrients application might be antagonistic at certain point where it leads to imbalances of nutrients and ultimately reduces crop yield (Lobell, 2009).

4.2.3. Effect on K content (%) and uptake (kg ha^{-1})

During the years 2019 and 2020, it was observed that application of various levels of Zn sources in soybean significantly increased the K content and uptake in seed and stover. The K content in seed and stover was found maximum @ T_9 (RDF + 5kg $ZnSO_4$ H_2O ha^{-1}) *i.e.*, 1.69, 1.63 % in seed and 2.62, 2.42 % in stover. The lowest was recorded at T_1 (control). From the pooled analysis, it was also observed that the K content and uptake in seed and stover was significantly increased at treatment T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) *i.e.* 1.66 % in seed and 2.52 % in stover. The lowest K content was recorded at T_1 (control) as shown in table 4.16 and fig 25&26. From the observations conducted, it was revealed that the K uptake in seed and stover of soybean was increased significantly with Zn application during both the year and pooled respectively. The highest K uptake was 30.67, 29.96 kg ha^{-1} in seed and 57.59, 53.88 kg ha^{-1} in stover which was recorded at T_9 (RDF + 5 Kg $ZnSO_4$ H_2O ha^{-1}) and the lowest K uptake was recorded at T_1 (control). From the pooled data, it was observed that the maximum K uptake in seed was 30.32 kg ha^{-1} and 55.74 kg ha^{-1} in stover. The lowest was recorded at control (T_1) as shown in table 4.17 and fig 27&28. This significant increase in the concentration and uptake of Zn with application of 5 kg Zn ha^{-1} in soybean plant grown on inceptisols was reported by Kadam *et al*. (2002). Meena *et al*. (2021) revealed that application of Zn @ 6 kg ha^{-1} significantly increased the K content in seed and stover of blackgram as compared to control.SimilarlySammauria (2007) and Chaudhary *et al*. (2014) observed that the application of Zn at increasing levels significantly increased the K uptake in seed and straw of fenugreek and green gram-wheat. This significant increase in content and uptake of K by the crop might be due to the positive effect between K and Zn which was brought about by the improved enzymatic activity and metabolic processes in the plant (Meena *et al*., 2021). Srivastava *et al*. (2016) and Alloway (2004) also stated that the significant increase in K nutrient uptake with Zn fertilization is due to the synergistic interaction of Zn which enhances the uptake of soil K by the plant. Similar observation was also reported by Shivay*et al*. (2015)in basmati rice. This increased in K uptake due to Zn increasing Zn levels could also be due to enhance protein synthesis, increased in K content and yield factors (Chavan *et al*., 2012 and Singh *et al*., 2009).

4.2.4. Effect on S content (%) and uptake(kg ha^{-1})

The S content in seed and stover of soybean was found to be non significant with the application of various sources and levels of zinc as shown in table 4.18 and fig 29 & 30 in both the years and pooled. The maximum S content was observed at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) *i.e.*0.19, 0.18 and 0.19 % in seed and 0.32, 0.30 and 0.31 % in stover. The uptake of S in seed and stover of soybean had been found to be non significant with various zinc fertilization during 2019, 2020 and pooled respectively as shown in table 4.19 and fig 31 & 32. The maximum nutrient uptake was recorded at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) *i.e.* 3.53, 3.31 and 3.42 kg ha^{-1} in seed and 6.98, 6.59 and 6.79 kg ha^{-1} in stover.

4.2.5. Effect on Zn content (mg kg^{-1}) and uptake(g ha^{-1})

The Zn content and uptake in seed and stover of soybean using various Zn sources and its levels had a significant effect during both the years. Treatment T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) gave the highest Zn content of 53.69 and 63.65 mg kg^{-1}in seed and 28.33 and 28.65 mg kg^{-1} in stover which was found at par with T_8 and T_{10} with rest of the other treatments. The minimum Zn content of 30.34 and 28.97 mg kg^{-1} in seed was observed at T_{13} and 20.12, and 21.48 mg kg^{-1} in stover was recorded at T_1 (control) as shown in table 4.20 and fig 33&34. In pooled data, the Zn content in seed and stover significantly increased with Zn application. The maximum Zn content of 58.67 mg kg^{-1} was recorded in seed and 28.49 mg kg^{-1} in stover at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}). The lowest was recorded at T_{13}in seed and T_1(control) in stover.The highest Zn uptake in seed and stover during 2019 and 2020 was recorded at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) i.e., 97.42 and 116.98 g ha^{-1} in seed and 62.27 and 63.78 g ha^{-1} in stover which was followed by T_8 and T_{10} treatment. The lowest was recorded at T_{13} in seed and control (T_1) in stover.The pooled data analysis also revealed that the Zn uptake in seed and stover was significantly increased with 107.20 g ha^{-1} in seed and 63.03 g ha^{-1} in stover as shown in table 4.21 and fig 35 &36. The lowest was recorded at T_{13} in seed and T_1 (control) in stover. Kadam *et al*. (2002) also showed significant increase in the concentration and uptake of Zn with application of 5 kg Zn ha^{-1} in soybean plant grown on inceptisols. Sammauria (2007) observed that the application of Zn at 5 kg ha^{-1} in fenugreek significantly increased the Zn uptake in seed and
straw. Balai*et al*. (2017) observed that fertilization with Zn significantly increased Zn content in seed and straw of chick pea at 6.0 kg Zn ha^{-1} whereas

Baligah*et al*. (2020) revealed that Zn fertilization significantly enhanced the uptake of micronutrient Zn nutrient in common bean crop. Chaudhary *et al*. (2014) reported a significant increase in the uptake of Zn with the increasing levels of Zn upto 5 and 7.5 kg ha^{-1} in green gram and wheat crop. Meena *et al*. (2021) also revealed that application of Zn @ 6 kg ha^{-1} significantly increased the Zn content in seed and stover of black gram as compared to control.This positive increased in the Zn content and uptake by seed and stover might be resulted from increasing levels of Zn fertilization in the soil solution which might be another reason to enhance the Zn absorption through phloem. This positive increased in the Zn concentration in seed and stover might also be due to the production of photosynthates resulted from photosynthetic and metabolic activity which is then transported to various parts of the plant (Jat*et al*., 2014).

Table 4.12: Effect of the sources and levels of Zn on N content in seed and stover

Treatments	N (%) in seed			N (%) in stover		
	2019	2020	Pooled	2019	2020	Pooled
T_1	5.67	5.58	5.63	1.53	1.48	1.51
T_2	5.87	5.69	5.78	1.55	1.51	1.53
T_3	5.87	5.75	5.81	1.51	1.49	1.50
T_4	5.81	5.80	5.81	1.47	1.45	1.46
T_5	5.87	5.65	5.76	1.51	1.59	1.55
T_6	5.80	5.68	5.74	1.53	1.54	1.54
T_7	5.75	5.63	5.69	1.55	1.52	1.54
T_8	6.03	5.88	5.96	1.67	1.66	1.66
T_9	6.30	6.19	6.25	1.71	1.69	1.70
T_{10}	6.01	5.87	5.94	1.65	1.64	1.65
T_{11}	5.64	5.69	5.67	1.34	1.30	1.32
T_{12}	5.36	5.50	5.43	1.46	1.31	1.39
T_{13}	5.58	5.52	5.55	1.31	1.38	1.35
SEm±	0.02	0.01	0.01	0.01	0.01	0.01
C.D at 5%	0.04	0.03	0.03	0.02	0.03	0.02

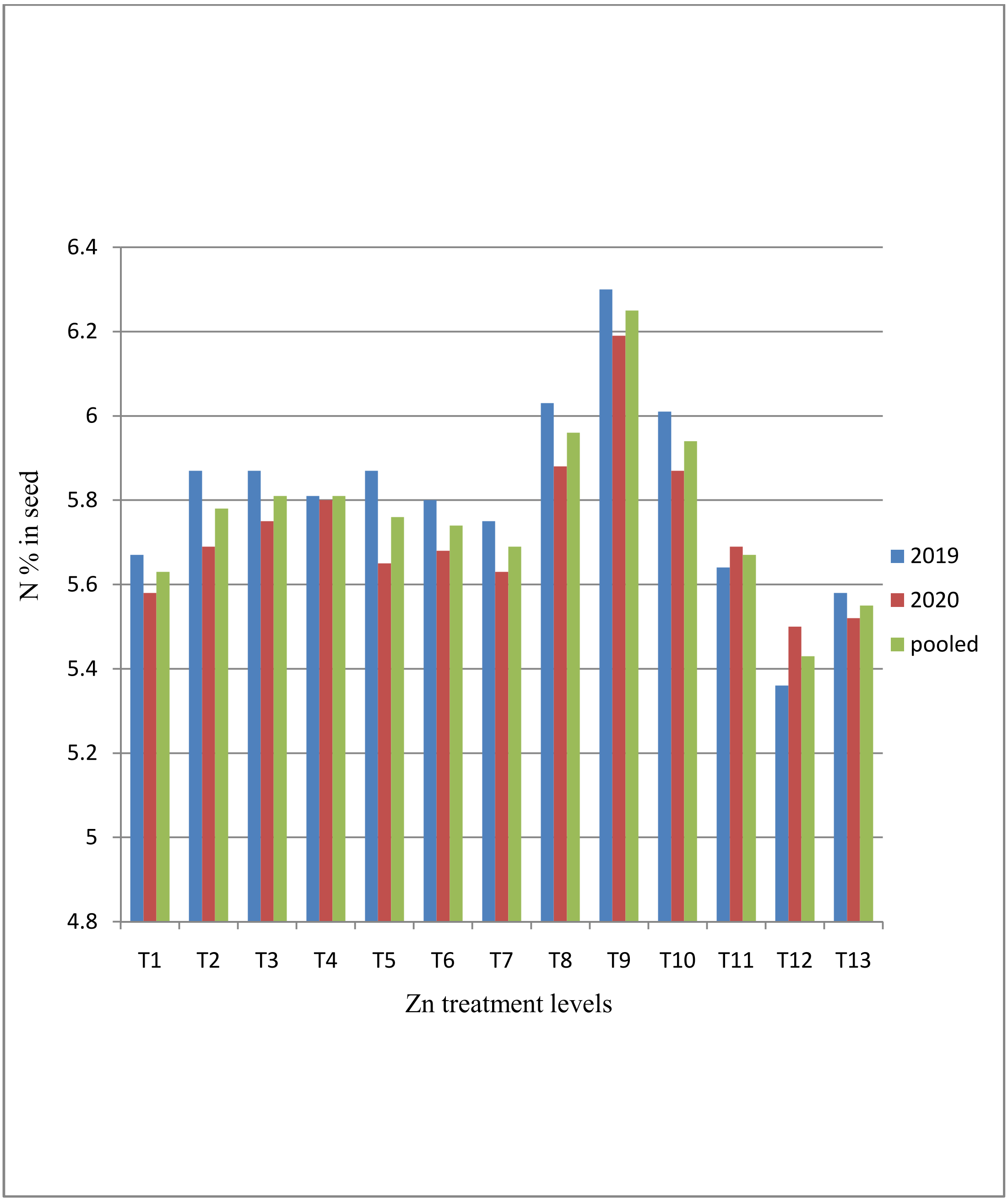

Fig 17: Effect of the sources and levels of Zn on N content in seed

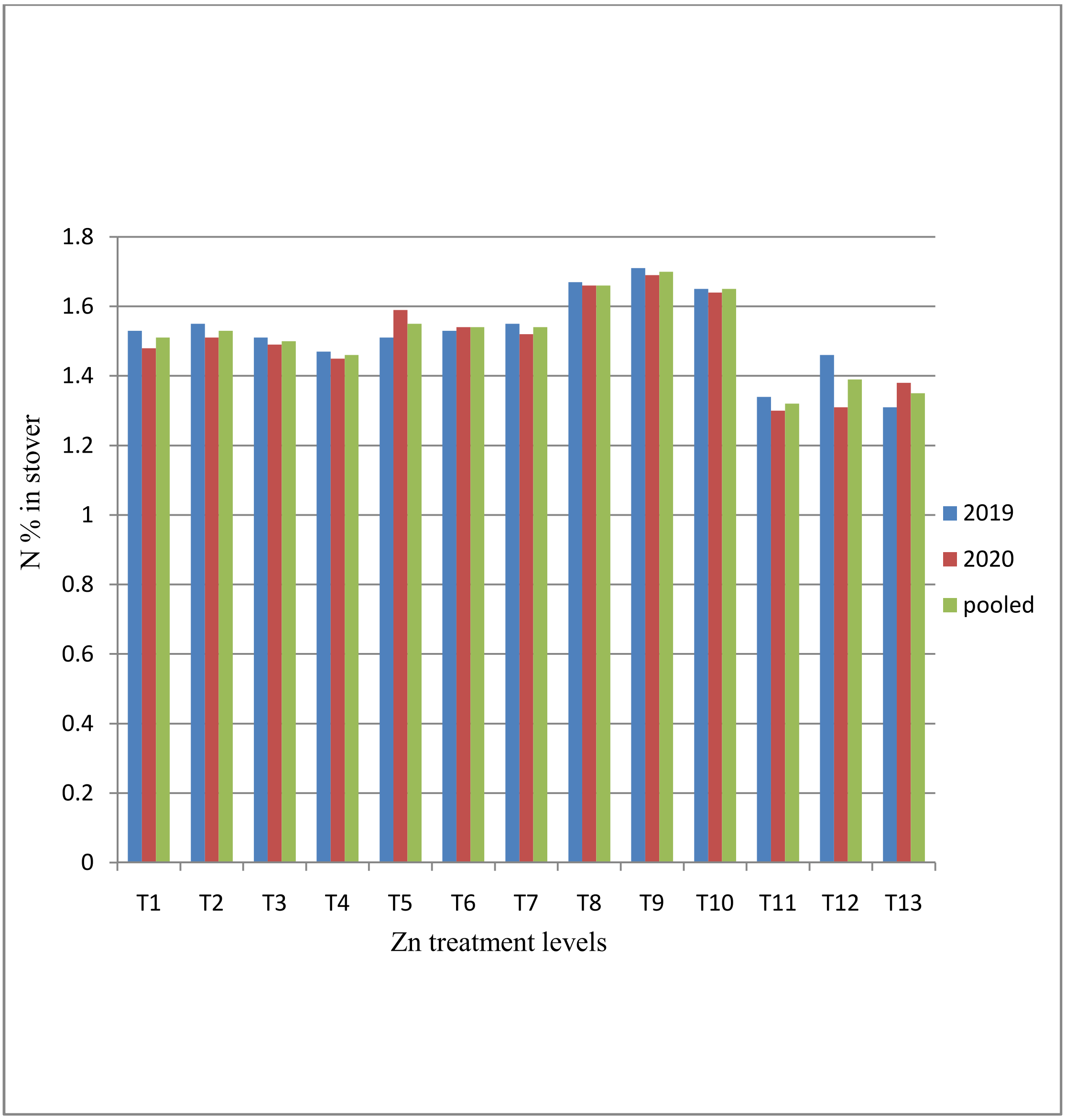

Fig 18: Effect of the sources and levels of Zn on N content in stover

Table 4.13: Effect of the sources and levels of Zn on N uptake in seed and stover

Treatments	N uptake in seed (kg ha^{-1})			N uptake in stover (kg ha^{-1})		
	2019	2020	Pooled	2019	2020	Pooled
T1	79.75	79.47	79.61	32.55	32.28	32.42
T2	87.86	84.99	86.43	27.57	26.81	27.19
T3	89.50	88.65	89.08	27.26	26.81	27.04
T4	92.18	92.75	92.47	28.38	28.84	28.61
T5	94.92	92.12	93.52	30.17	33.61	31.89
T6	98.97	98.80	98.89	32.08	32.68	32.38
T7	97.37	96.77	97.07	31.30	32.40	31.85
T8	106.36	102.87	104.62	35.66	36.49	36.08
T9	114.31	113.77	114.04	37.59	37.62	37.61
T10	99.15	100.16	99.66	33.17	34.25	33.71
T11	89.73	90.23	89.98	25.89	30.47	28.18
T12	82.28	85.26	83.77	29.44	27.36	28.40
T13	86.95	84.27	85.61	28.63	28.79	28.71
SEm±	0.03	0.01	0.02	0.01	0.01	0.01
C.D at 5%	0.09	0.02	0.04	0.03	0.03	0.02

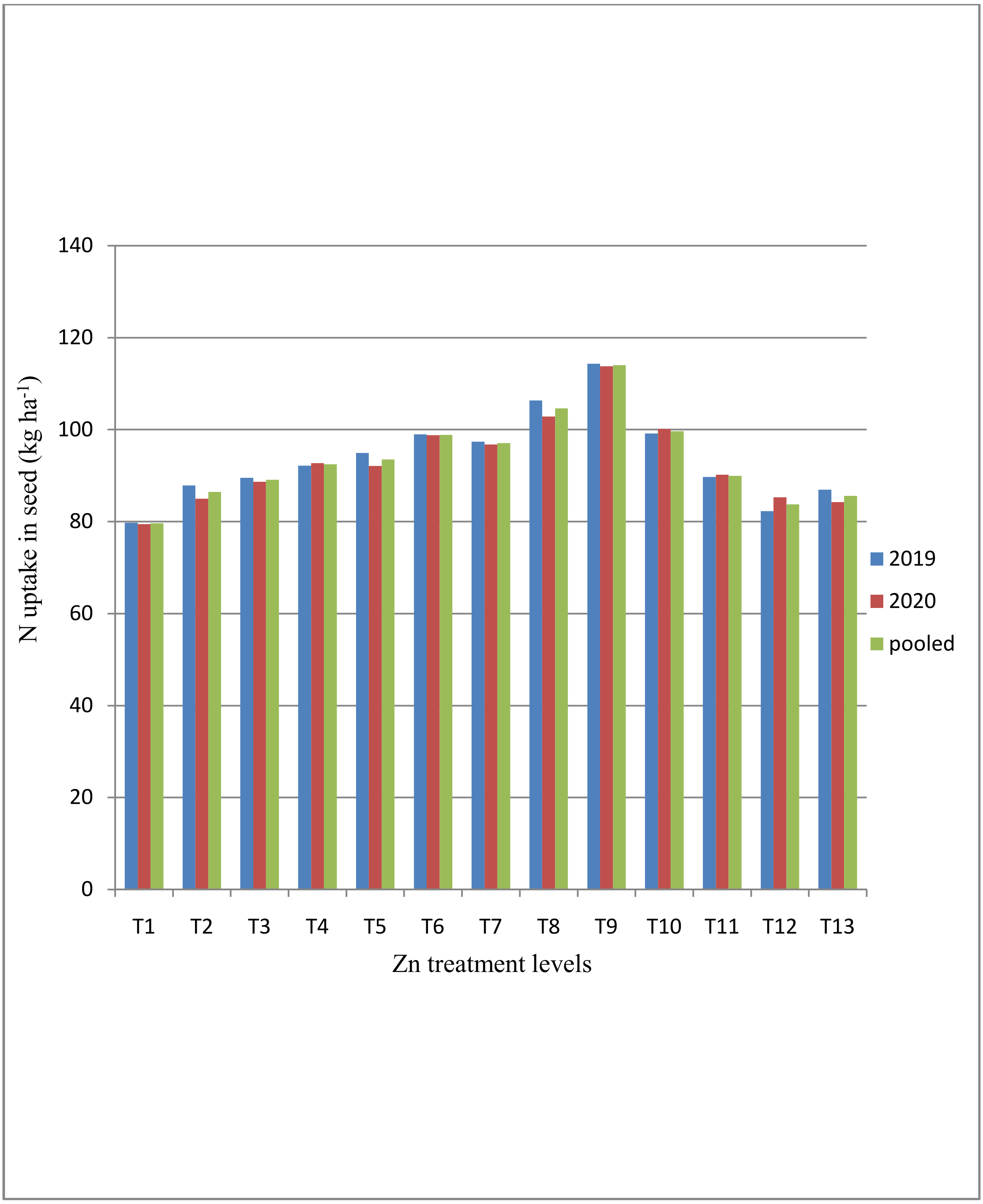

Fig 19: Effect of the sources and levels of Zn on N uptake in seed

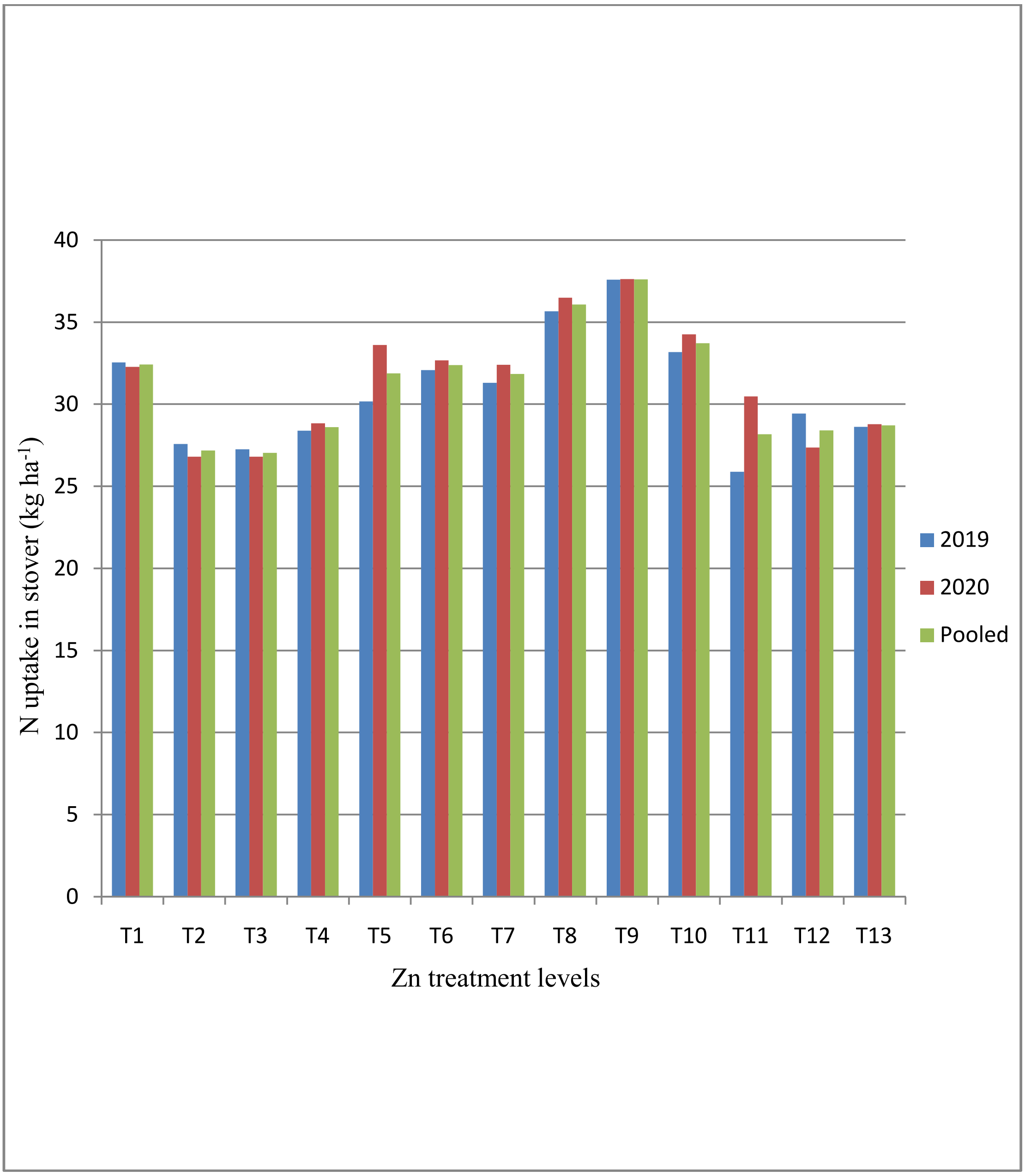

Fig 20: Effect of the sources and levels of Zn on N uptake in stover

Table 4.14: Effect of the sources and levels of Zn on P content in seed and stover

Treatments	P (%) in seed			P (%) in stover		
	2019	2020	Pooled	2019	2020	Pooled
T_1	0.22	0.21	0.21	0.20	0.18	0.19
T_2	0.14	0.13	0.14	0.12	0.13	0.13
T_3	0.13	0.18	0.15	0.13	0.12	0.13
T_4	0.14	0.18	0.16	0.12	0.11	0.12
T_5	0.16	0.15	0.15	0.13	0.10	0.12
T_6	0.13	0.16	0.15	0.11	0.13	0.12
T_7	0.15	0.15	0.15	0.12	0.10	0.11
T_8	0.18	0.17	0.17	0.12	0.12	0.12
T_9	0.20	0.19	0.20	0.17	0.14	0.16
T_{10}	0.14	0.16	0.15	0.17	0.13	0.15
T_{11}	0.13	0.17	0.15	0.10	0.12	0.11
T_{12}	0.13	0.15	0.14	0.11	0.12	0.12
T_{13}	0.14	0.16	0.15	0.13	0.14	0.14
SEm±	0.02	0.02	0.02	0.03	0.02	0.02
C.D at 5%	NS	NS	NS	NS	NS	NS

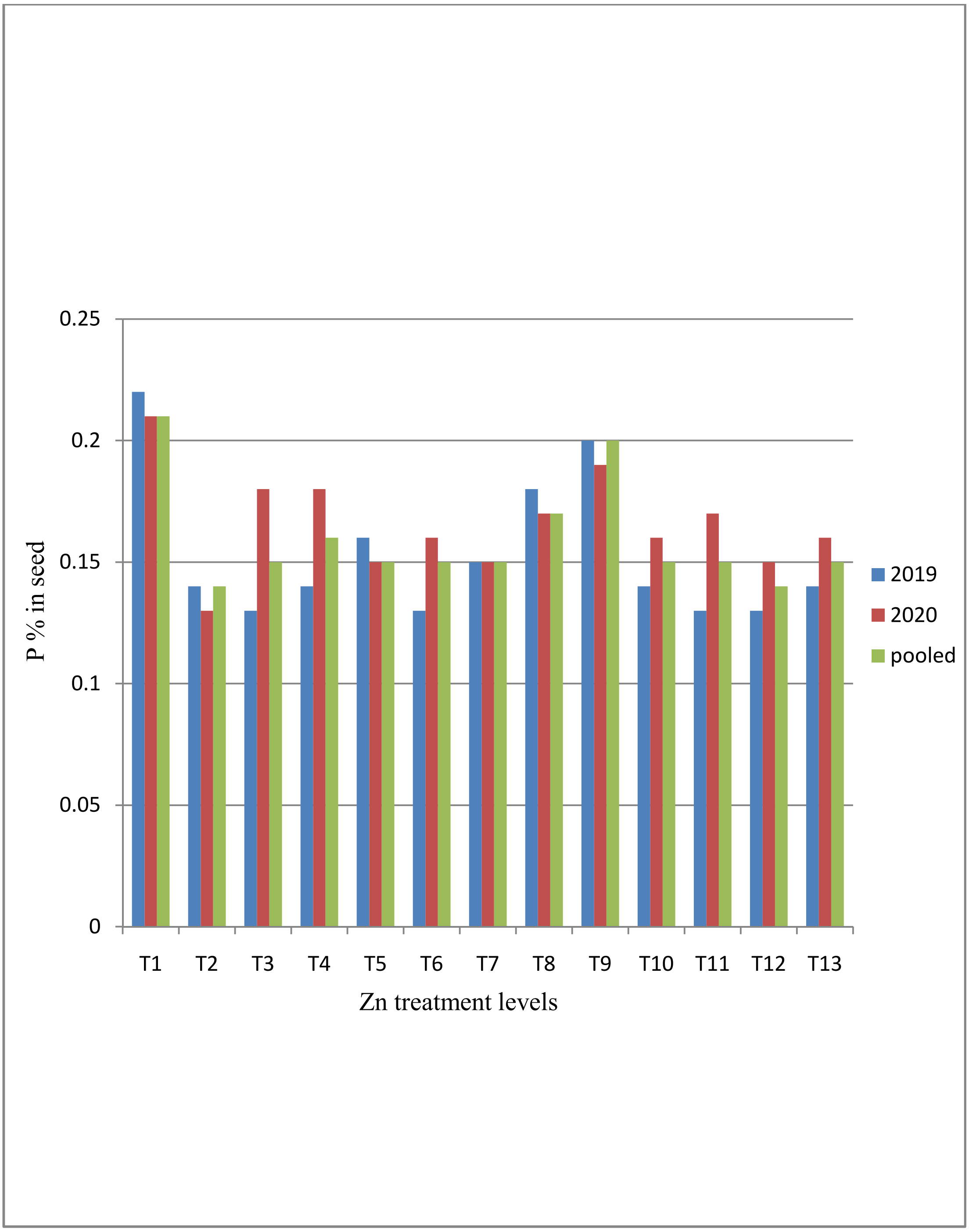

Fig 21: Effect of the sources and levels of Zn on P content in seed

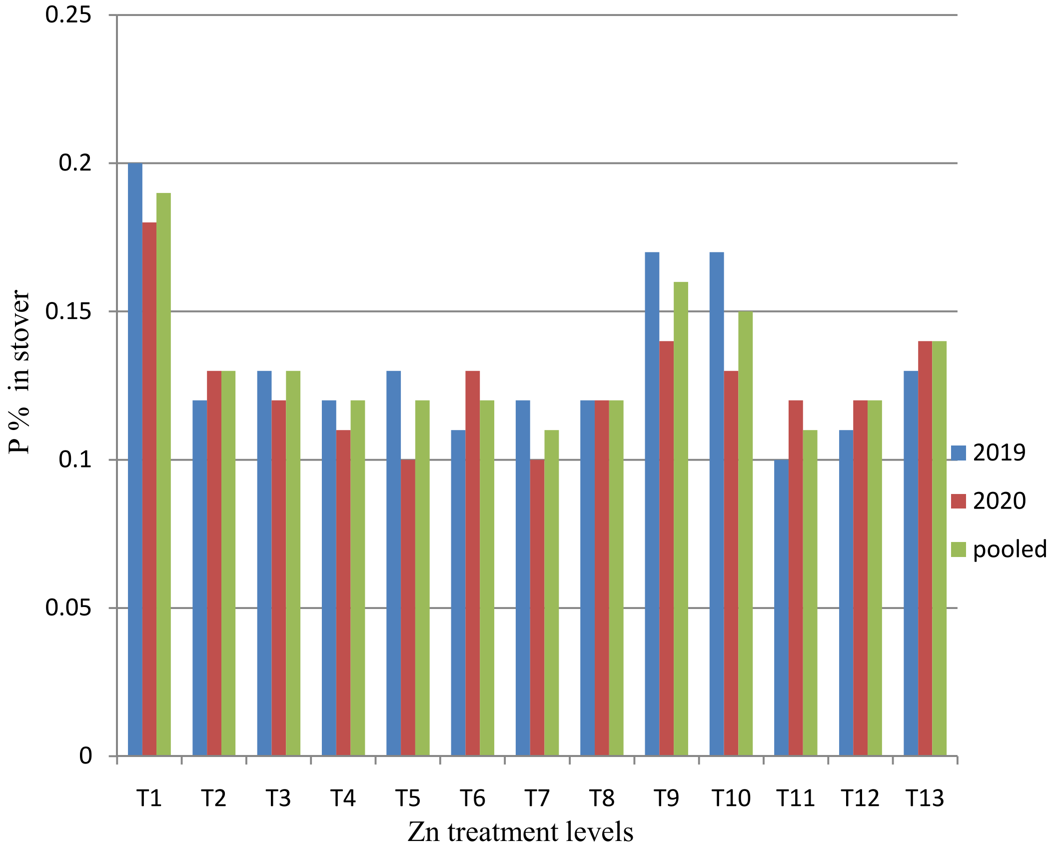

Fig 22: Effect of the sources and levels of zinc on P content in stover

Table 4.15: Effect of the sources and levels of Zn on P uptake in seed and stover

Treatments	P uptake in seed (kg ha^{-1})			P uptake in stover (kg ha^{-1})		
	2019	2020	Pooled	2019	2020	Pooled
T_1	3.09	2.99	3.04	3.38	2.99	3.19
T_2	3.10	2.73	2.92	2.13	2.28	2.21
T_3	1.99	2.78	2.39	2.33	2.16	2.25
T_4	2.22	2.88	2.55	2.57	1.95	2.26
T_5	2.59	2.45	2.52	2.60	2.08	2.34
T_6	2.48	2.78	2.63	2.30	2.76	2.53
T_7	2.54	2.58	2.56	1.94	2.13	2.04
T_8	3.18	2.97	3.08	2.56	2.64	2.60
T_9	3.63	3.49	3.56	2.84	2.41	2.63
T_{10}	2.31	2.73	2.52	2.61	2.81	2.71
T_{11}	2.06	2.70	2.38	1.98	2.57	2.27
T12	2.00	2.33	2.17	2.00	2.21	2.11
T_{13}	2.18	2.44	2.31	2.44	2.56	2.50
SEm±	0.64	0.57	0.43	0.48	0.50	0.35
C.D at 5%	NS	NS	NS	NS	NS	NS

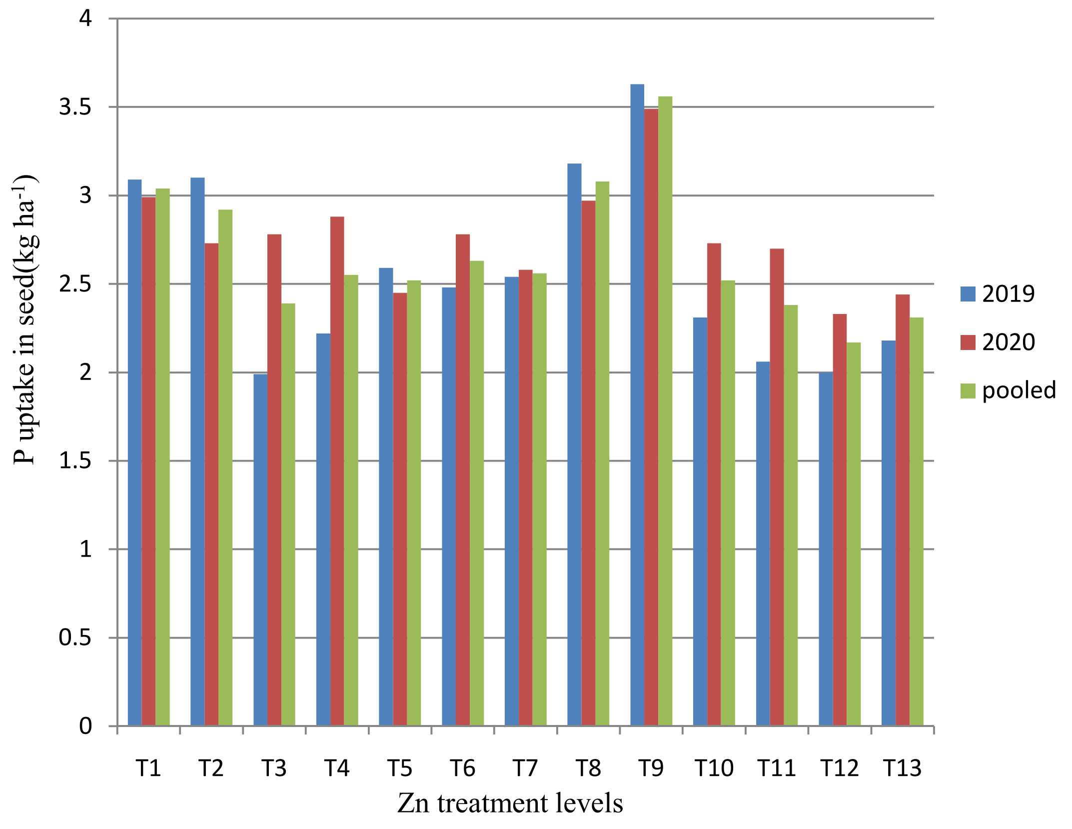

Fig 23: Effect of the sources and levels of Zn on P uptake in seed

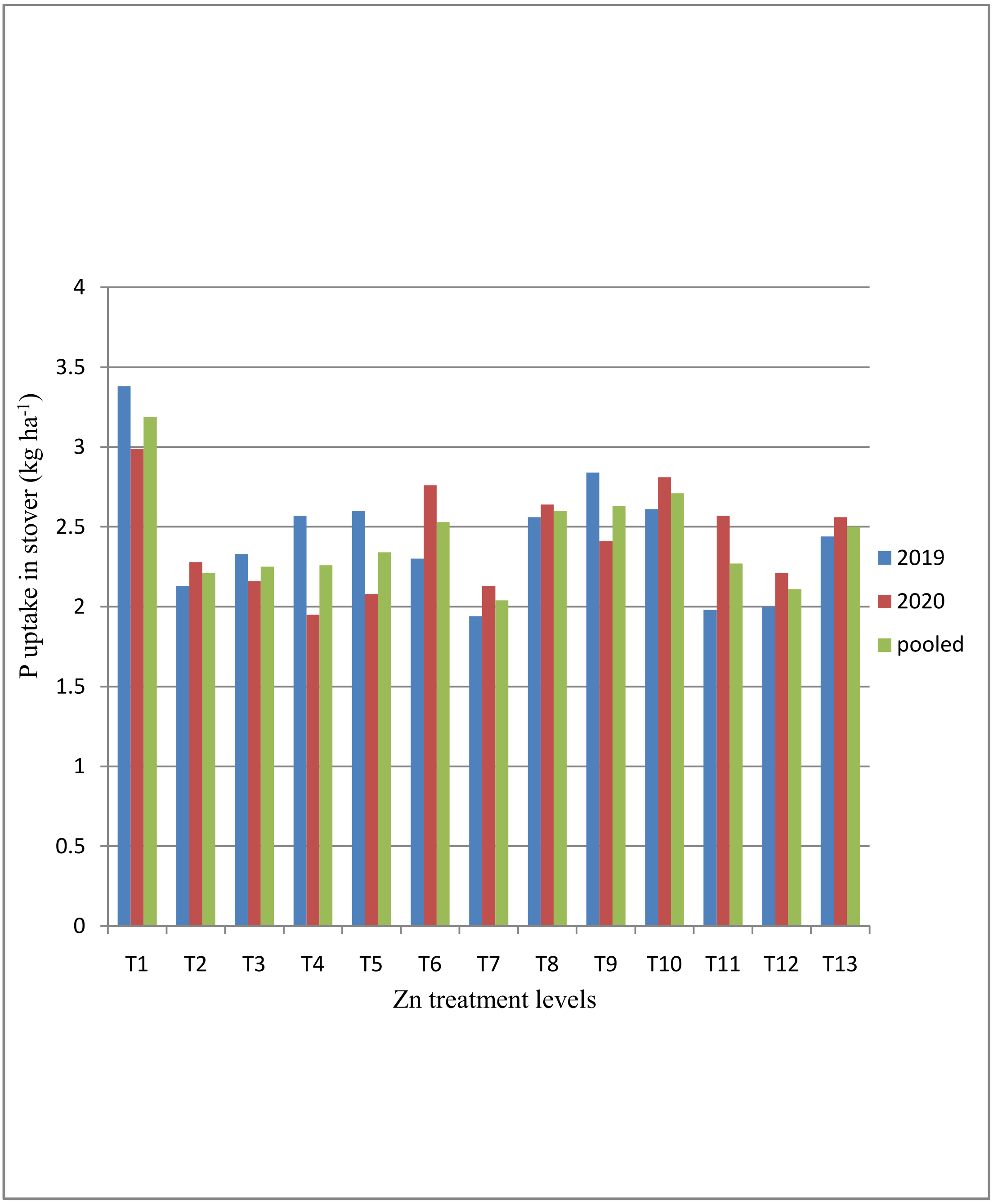

Fig 24: Effect of the sources and levels of Zn on P uptake in stover

Table 4.16: Effect of the sources and levels of Zn on K content in seed and stover

Treatments	K (%) in seed			K (%) in stover		
	2019	2020	Pooled	2019	2020	Pooled
T_1	1.12	1.13	1.13	2.03	2.16	2.10
T_2	1.18	1.05	1.12	2.18	2.30	2.24
T_3	1.34	1.19	1.27	2.31	2.19	2.25
T_4	1.31	1.21	1.26	2.41	2.30	2.36
T_5	1.28	1.36	1.32	2.42	2.20	2.31
T_6	1.44	1.31	1.38	2.37	2.21	2.29
T_7	1.52	1.49	1.51	2.33	2.28	2.30
T_8	1.63	1.59	1.61	2.55	2.33	2.44
T_9	1.69	1.63	1.66	2.62	2.42	2.52
T_{10}	1.60	1.55	1.58	2.45	2.35	2.40
T_{11}	1.56	1.50	1.53	2.33	2.29	2.31
T_{12}	1.35	1.28	1.32	2.28	2.07	2.18
T_{13}	1.41	1.31	1.36	2.39	2.16	2.28
SEm±	0.01	0.01	0.01	0.01	0.01	0.01
C.D at 5%	0.03	0.02	0.02	0.03	0.04	0.02

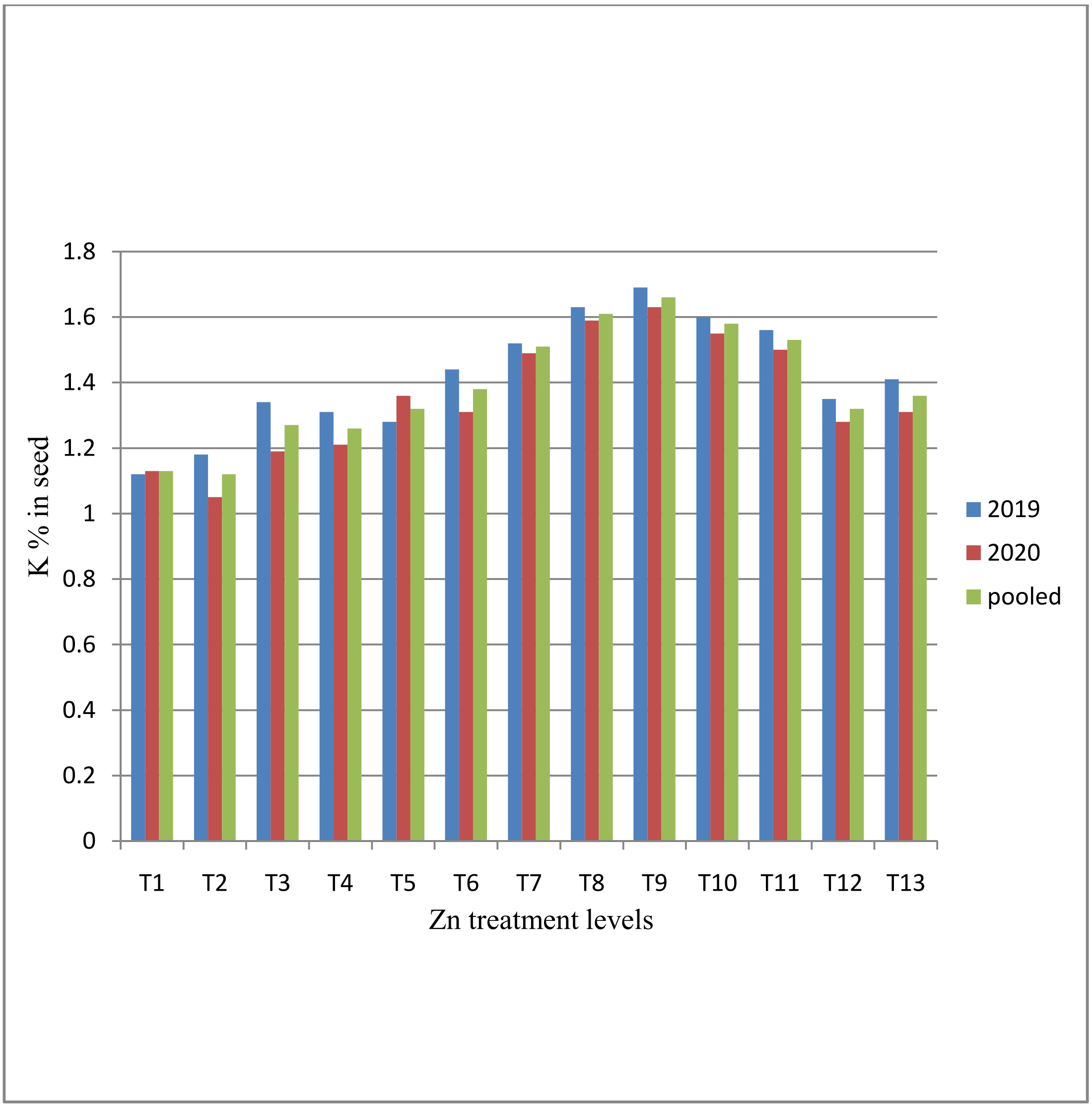

Fig 25: Effect of the sources and levels of Zn on K content in seed

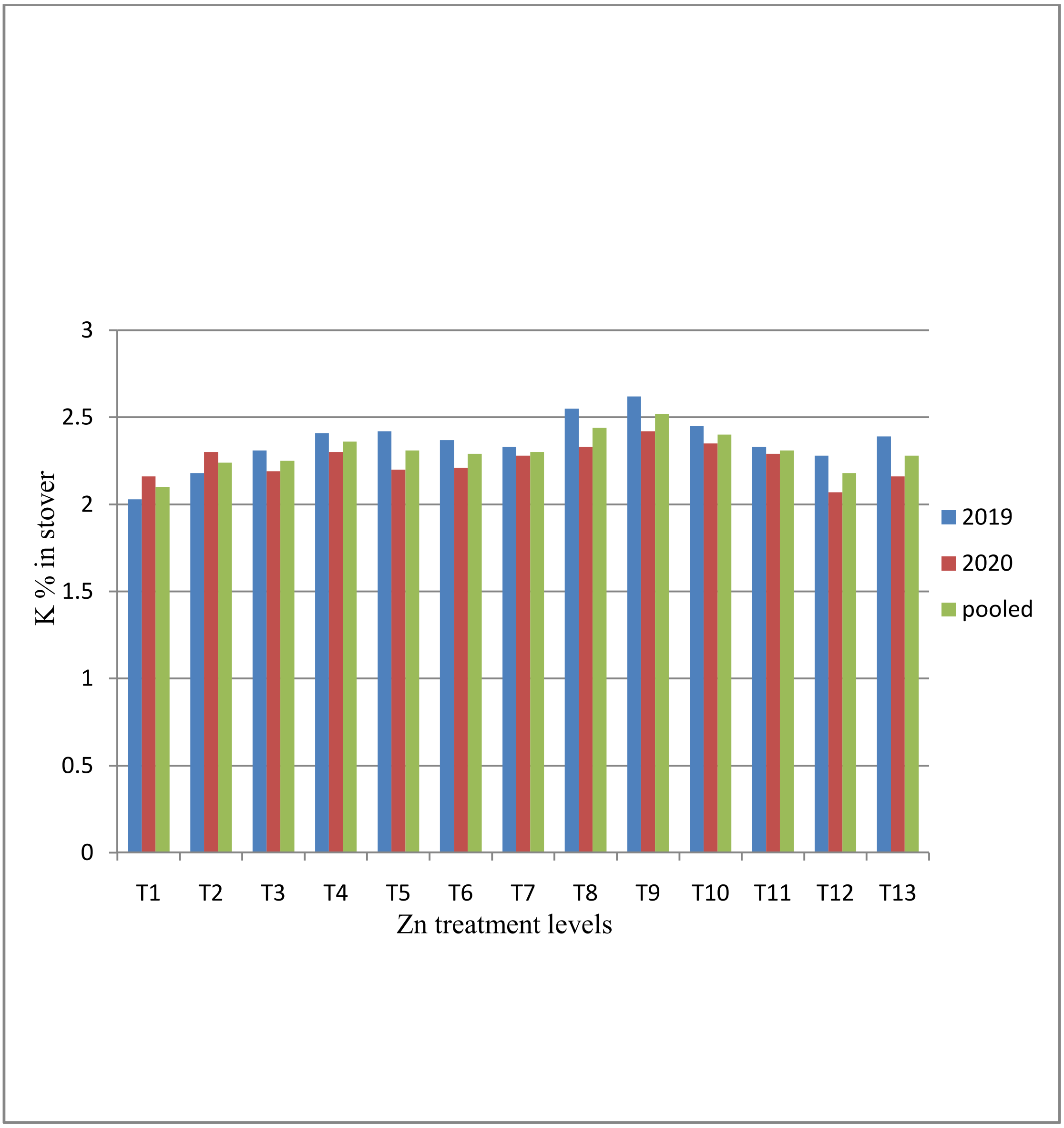

Fig 26: Effect of the sources and levels of Zn on K content in stover

Table 4.17: Effect of the sources and levels of Zn on K uptake in seed and stover

Treatments	K uptake in seed (kg ha^{-1})			K uptake in stover (kg ha^{-1})		
	2019	2020	Pooled	2019	2020	Pooled
T_1	15.75	16.39	16.07	34.26	35.94	35.10
T_2	17.66	15.68	16.67	38.78	40.34	39.56
T_3	20.50	18.35	19.43	41.43	38.86	40.15
T_4	20.78	19.35	20.07	46.52	45.75	46.14
T_5	20.70	22.17	21.44	48.35	46.50	47.43
T_6	24.57	22.79	23.68	48.65	46.90	47.78
T_7	25.74	25.61	25.68	46.44	48.61	47.53
T_8	28.82	27.33	28.07	54.44	51.21	52.83
T_9	30.67	29.96	30.32	57.59	53.88	55.74
T_{10}	26.40	25.57	25.99	49.46	49.08	49.27
T_{11}	24.82	24.02	24.42	46.05	45.08	45.57
T12	20.72	19.84	20.28	41.41	38.17	39.79
T_{13}	21.97	20.00	20.99	44.68	41.33	43.01
SEm±	0.01	0.17	0.09	0.01	0.01	0.01
C.D at 5%	0.03	0.49	0.24	0.04	0.04	0.03

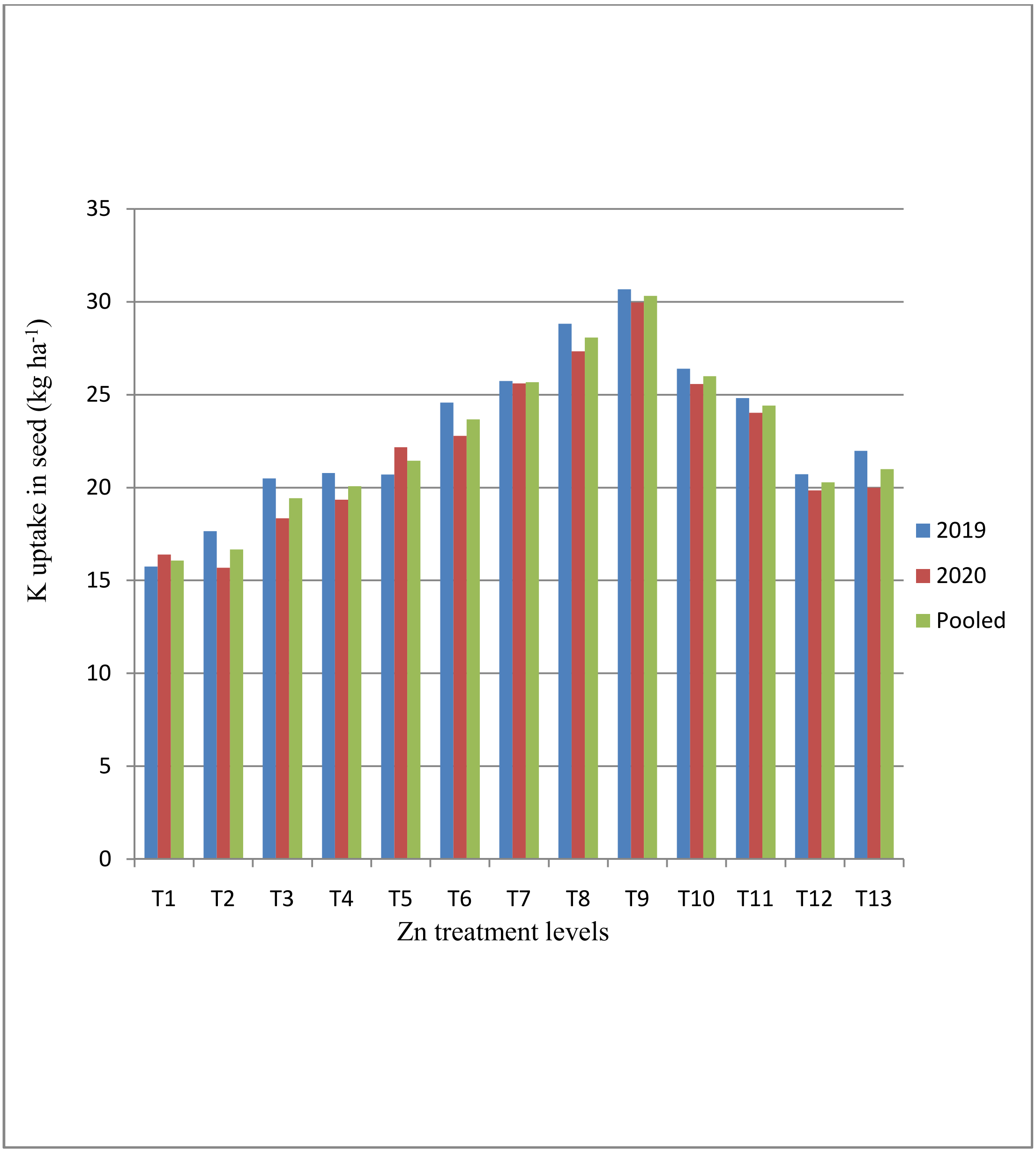

Fig 27: Effect of the sources and levels of Zn on K uptake in seed

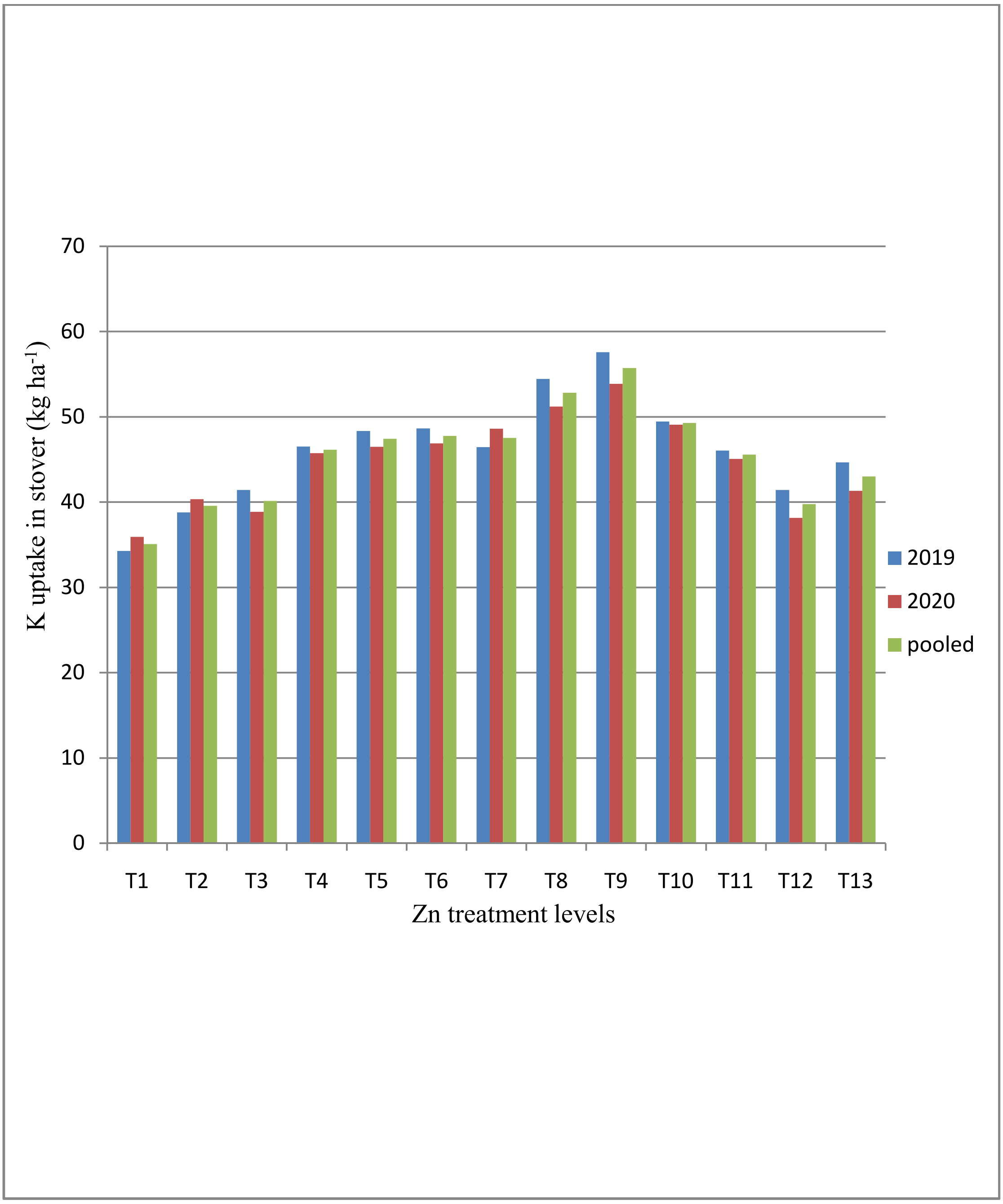

Fig 28: Effect of the sources and levels of Zn on K uptake in stover

Table 4.18: Effect of the sources and levels of Zn on S content in seed and stover

Treatments	S (%) in seed			S (%) in stover		
	2019	2020	Pooled	2019	2020	Pooled
T_1	0.15	0.15	0.15	0.30	0.28	0.29
T_2	0.14	0.14	0.14	0.29	0.27	0.28
T_3	0.15	0.14	0.15	0.32	0.28	0.30
T_4	0.14	0.14	0.14	0.28	0.27	0.28
T_5	0.16	0.15	0.16	0.26	0.27	0.27
T_6	0.15	0.15	0.15	0.25	0.25	0.25
T_7	0.14	0.15	0.15	0.26	0.27	0.27
T_8	0.18	0.16	0.17	0.25	0.27	0.26
T_9	0.19	0.18	0.19	0.32	0.30	0.31
T_{10}	0.17	0.16	0.17	0.30	0.28	0.29
T_{11}	0.16	0.16	0.16	0.27	0.27	0.27
T_{12}	0.17	0.16	0.17	0.29	0.27	0.28
T_{13}	0.16	0.16	0.16	0.29	0.27	0.28
SEm±	0.01	0.01	0.01	0.02	0.02	0.01
C.D at 5%	NS	NS	NS	NS	NS	NS

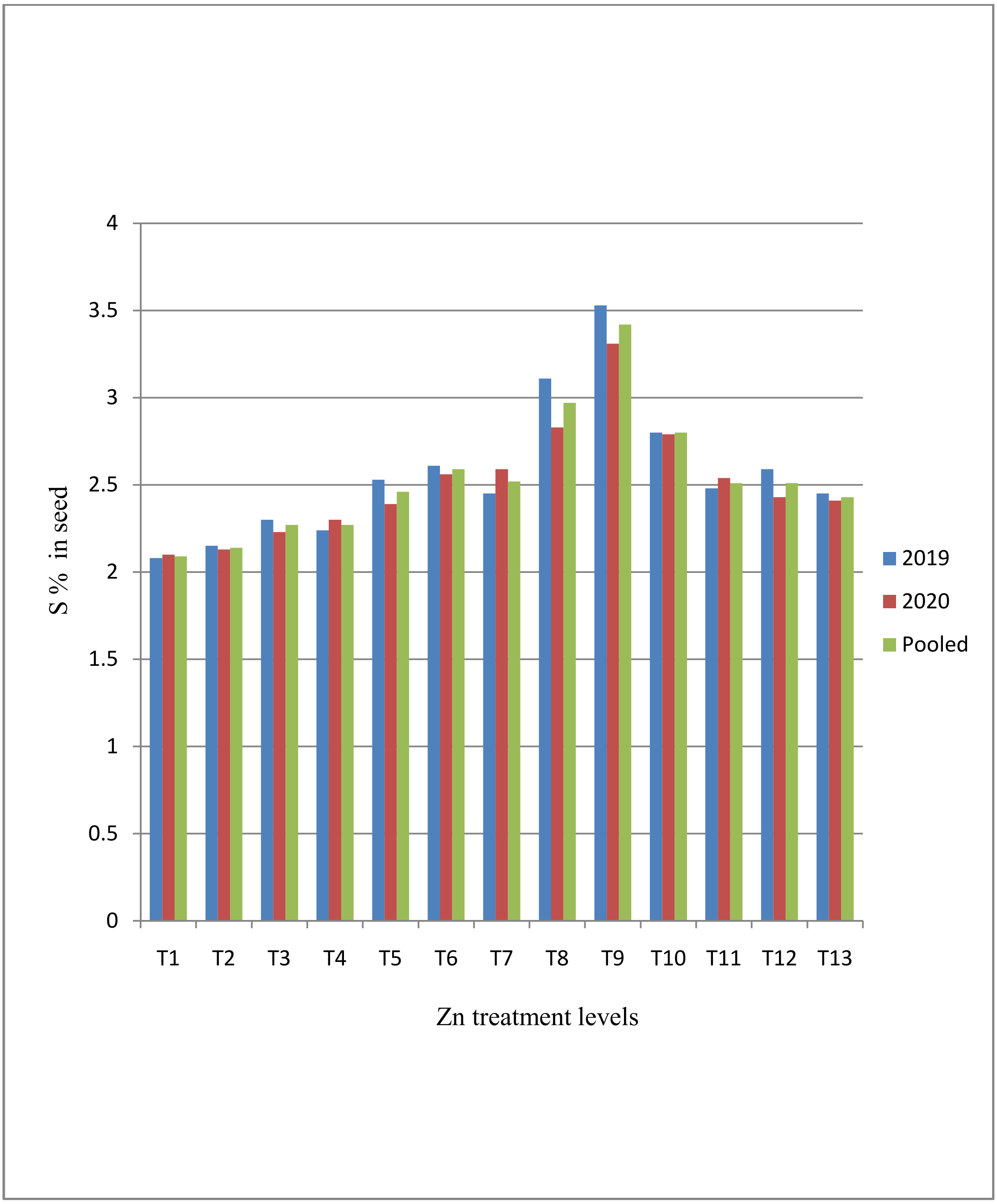

Fig 29: Effect of the sources and levels of Zn on S content in seed

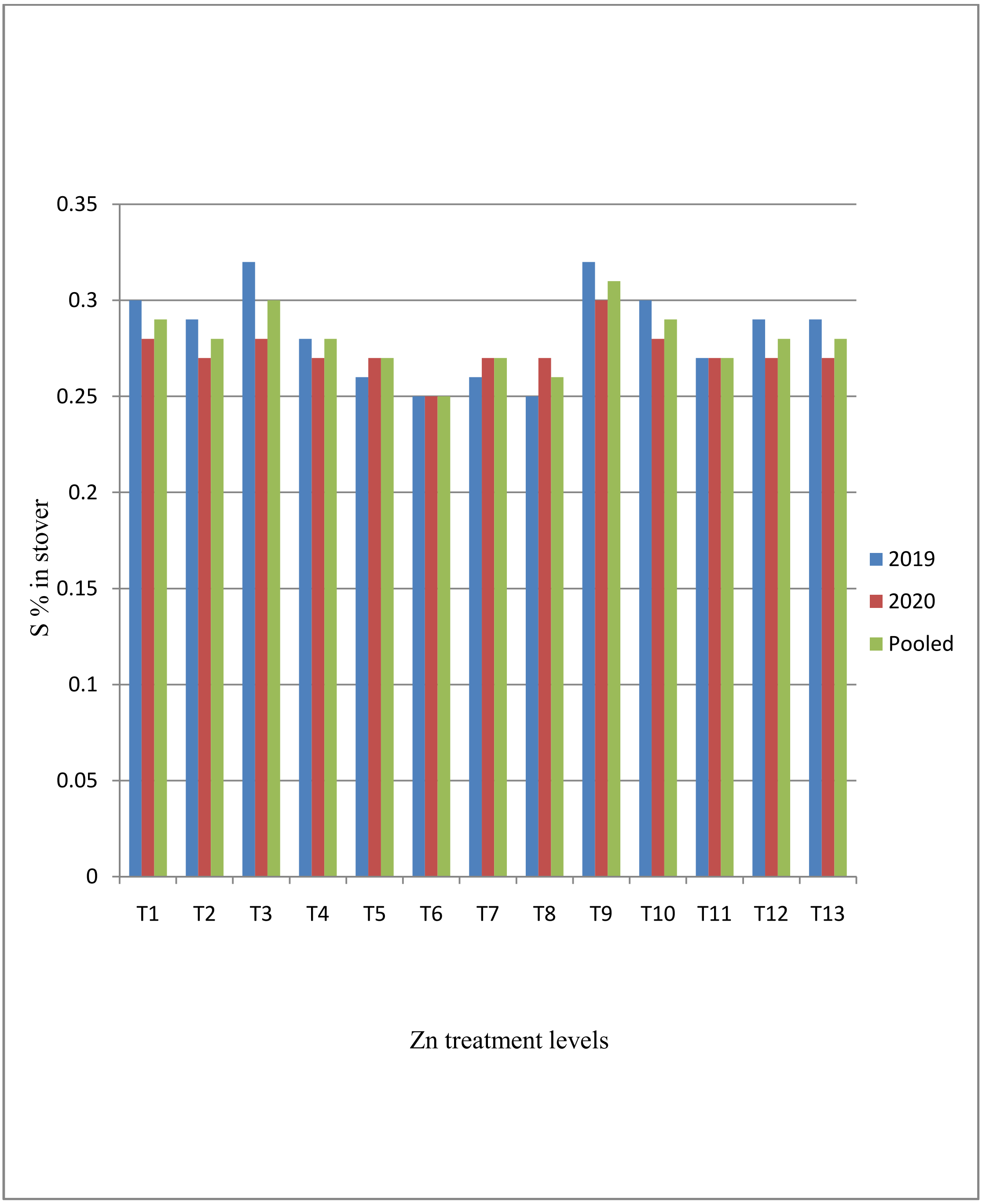

Fig 30: Effect of the sources and levels of Zn on S content in stover

Table 4.19: Effect of the sources and levels of Zn on S uptake in seed and stover

Treatments	S uptake in seed (kg ha^{-1})			S uptake in stover (kg ha^{-1})		
	2019	2020	Pooled	2019	2020	Pooled
T_1	2.08	2.10	2.09	5.09	4.62	4.86
T_2	2.15	2.13	2.14	5.13	4.82	4.98
T_3	2.30	2.23	2.27	5.24	5.08	5.16
T_4	2.24	2.30	2.27	5.38	5.43	5.41
T_5	2.53	2.39	2.46	5.29	5.61	5.45
T_6	2.61	2.56	2.59	5.19	5.39	5.29
T_7	2.45	2.59	2.52	5.27	5.74	5.51
T_8	3.11	2.83	2.97	5.29	6.01	5.65
T_9	3.53	3.31	3.42	6.98	6.59	6.79
T_{10}	2.80	2.79	2.80	6.03	5.78	5.91
T_{11}	2.48	2.54	2.51	5.35	5.23	5.29
T12	2.59	2.43	2.51	5.25	5.02	5.14
T_{13}	2.45	2.41	2.43	5.39	5.08	5.24
SEm±	0.37	0.32	0.24	0.80	0.64	0.51
C.D at 5%	NS	NS	NS	NS	NS	NS

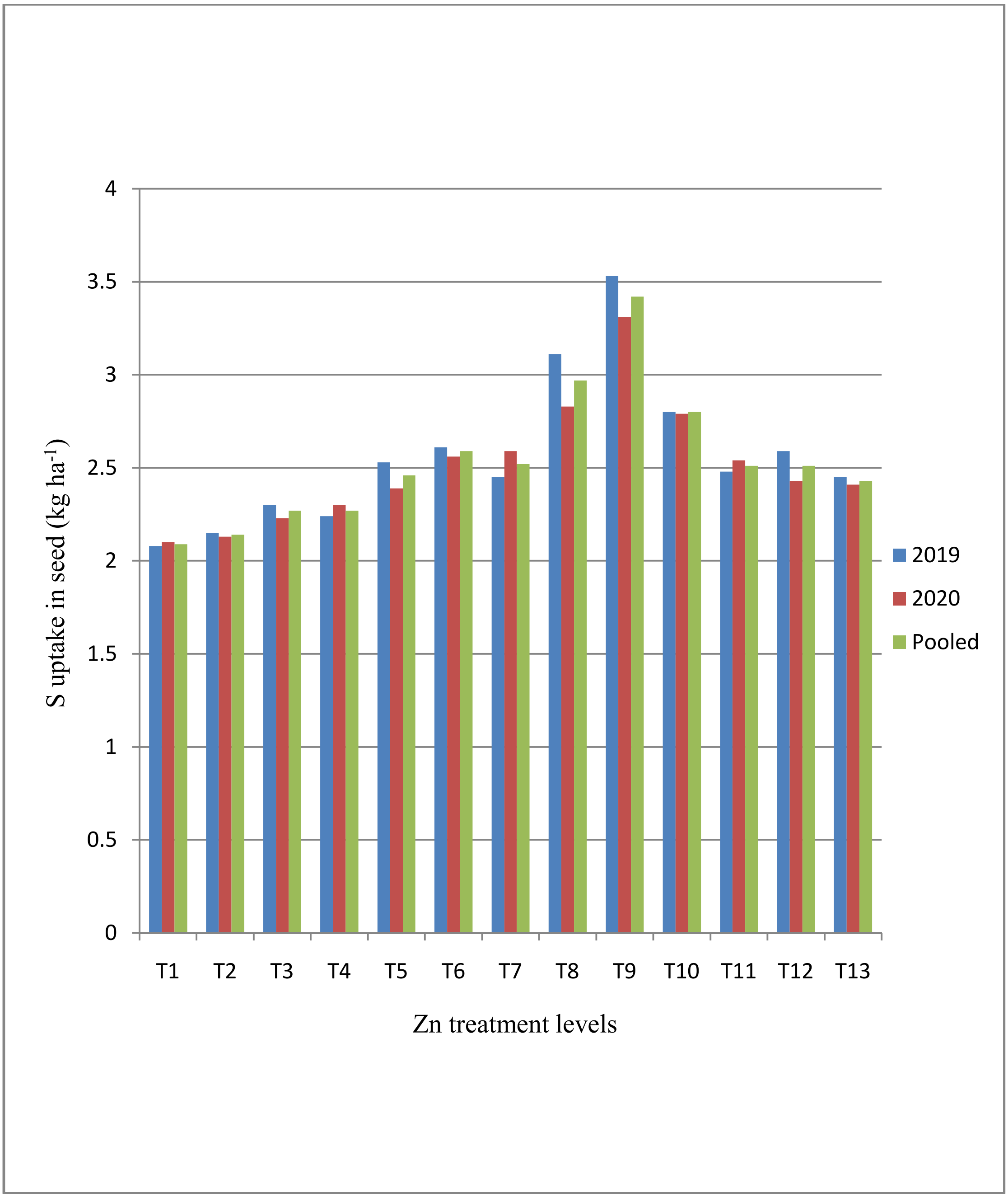

Fig 31: Effect of the sources and levels of Zn on S uptake in seed

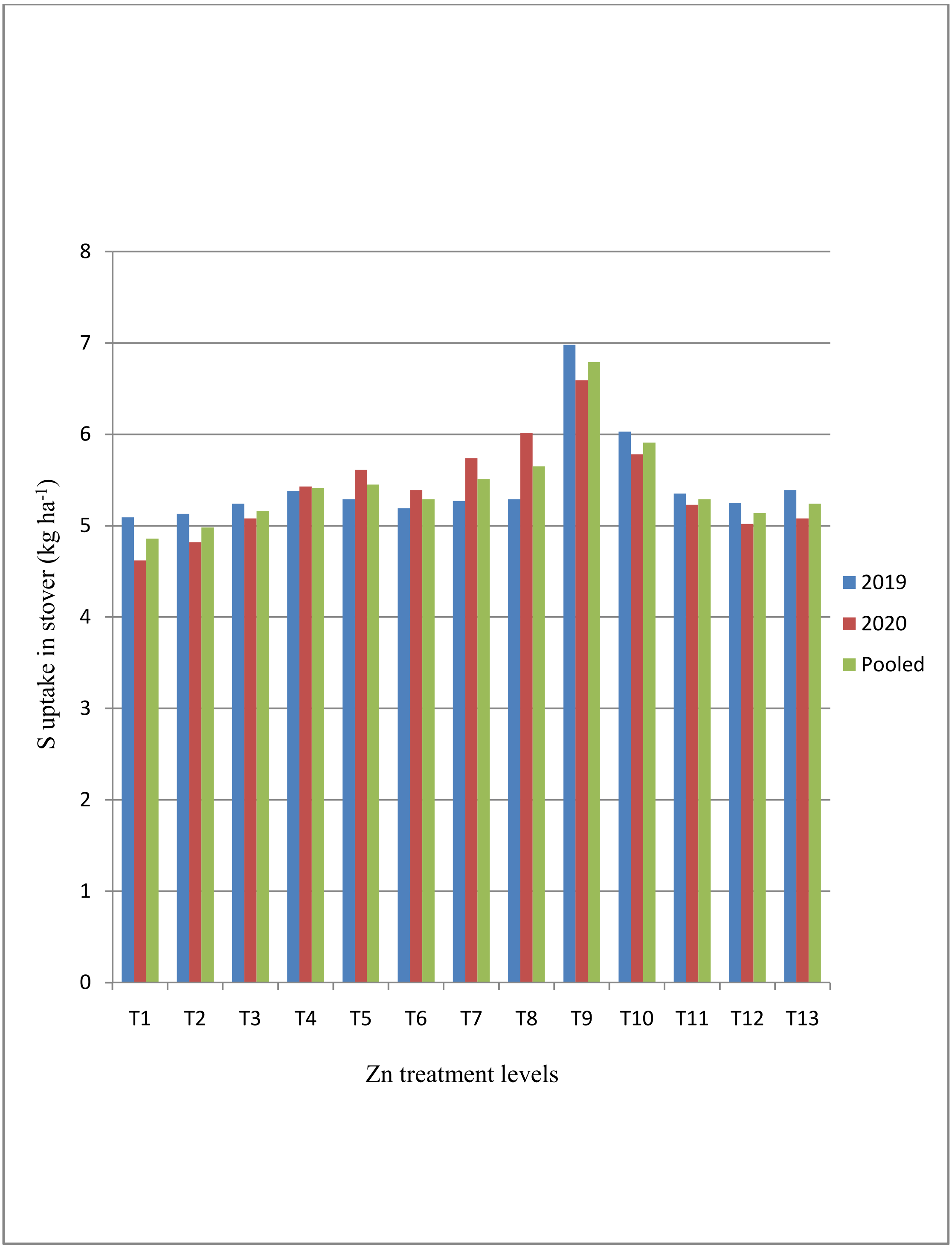

Fig 32: Effect of the sources and levels of Zn on S uptake in stover

Table 4.20: Effect of the sources and levels of zinc on Zn content in seed and stover

Treatments	Zn content in seed (mg kg^{-1})			Zn content in stover (mg kg^{-1})		
	2019	2020	Pooled	2019	2020	Pooled
T_1	36.20	32.14	34.17	20.12	21.48	20.80
T_2	37.25	36.34	36.80	22.32	23.32	22.82
T_3	33.29	39.78	36.54	24.45	23.23	23.84
T_4	40.99	43.81	42.40	21.26	24.20	22.73
T_5	33.90	52.20	43.05	23.14	22.50	22.82
T_6	45.40	51.28	48.34	24.03	23.96	24.00
T_7	43.63	49.64	46.64	24.10	24.23	24.17
T_8	50.84	54.56	52.70	26.21	26.47	26.34
T_9	53.69	63.65	58.67	28.33	28.65	28.49
T_{10}	47.83	50.85	49.34	24.67	25.65	25.16
T_{11}	30.35	30.32	30.34	22.12	21.32	21.72
T_{12}	32.13	28.68	30.41	23.16	22.11	22.64
T_{13}	30.34	28.97	29.66	23.64	21.21	22.43
SEm±	4.35	1.31	2.27	0.47	0.72	0.43
C.D at 5%	12.45	3.76	6.40	1.35	2.07	1.21

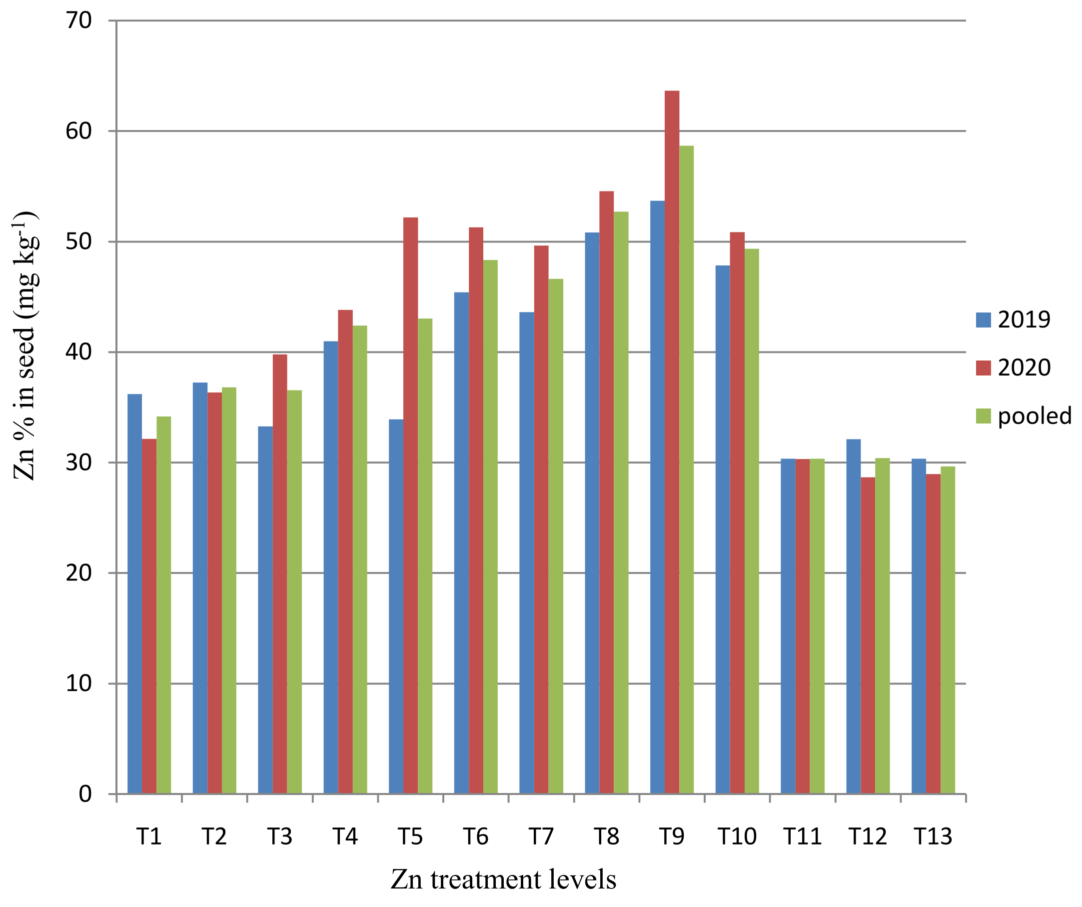

Fig 33: Effect of the sources and levels of Zn on Zn content in seed

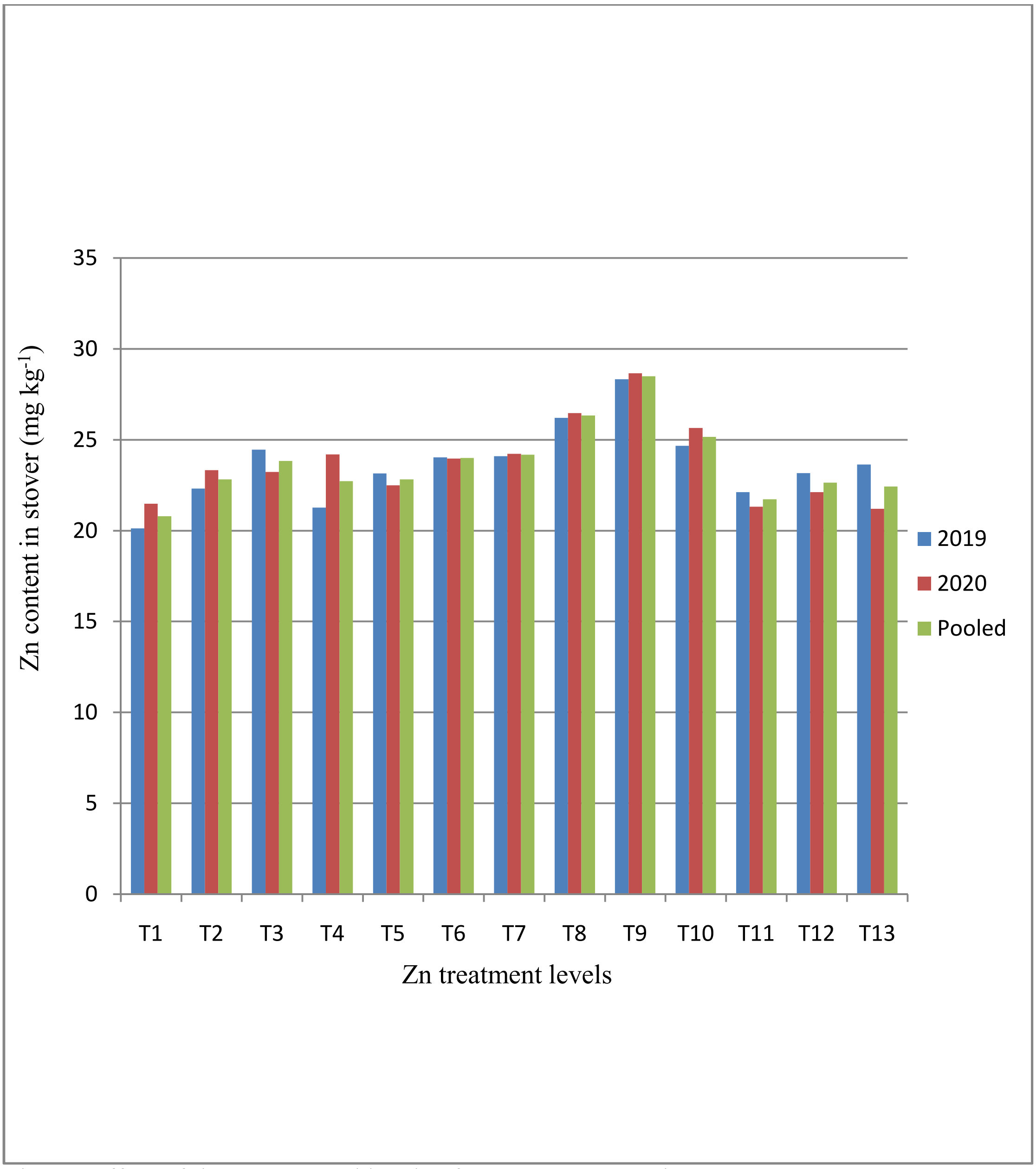

Fig 34: Effect of the sources and levels of Zn on Zn content in stover

Table 4.21: Effect of the sources and levels of Zn on Zn uptake in seed and stover

Treatments	Zn uptake in seed (g ha^{-1})			Zn uptake in stover (g ha^{-1})		
	2019	2020	Pooled	2019	2020	Pooled
T_1	50.91	45.77	48.34	33.95	35.74	34.85
T_2	55.75	54.28	55.02	39.71	40.90	40.31
T_3	50.93	61.33	56.13	43.86	41.80	42.83
T_4	65.03	70.06	67.55	41.04	48.14	44.59
T_5	54.82	85.11	69.97	46.24	47.56	46.90
T_6	77.47	89.20	83.34	48.98	48.03	48.51
T_7	73.88	85.33	79.61	48.67	52.45	50.56
T_8	89.87	95.45	92.66	55.95	56.18	56.07
T_9	97.42	116.98	107.20	62.27	63.78	63.03
T_{10}	78.91	86.77	82.84	50.95	54.31	52.63
T_{11}	48.28	48.08	48.18	43.72	41.80	42.76
T12	49.32	44.46	46.89	42.06	40.77	41.42
T_{13}	47.28	44.23	45.76	44.19	38.79	41.49
SEm±	0.01	0.01	0.01	0.01	0.07	0.04
C.D at 5%	0.03	0.03	0.02	0.03	0.21	0.10

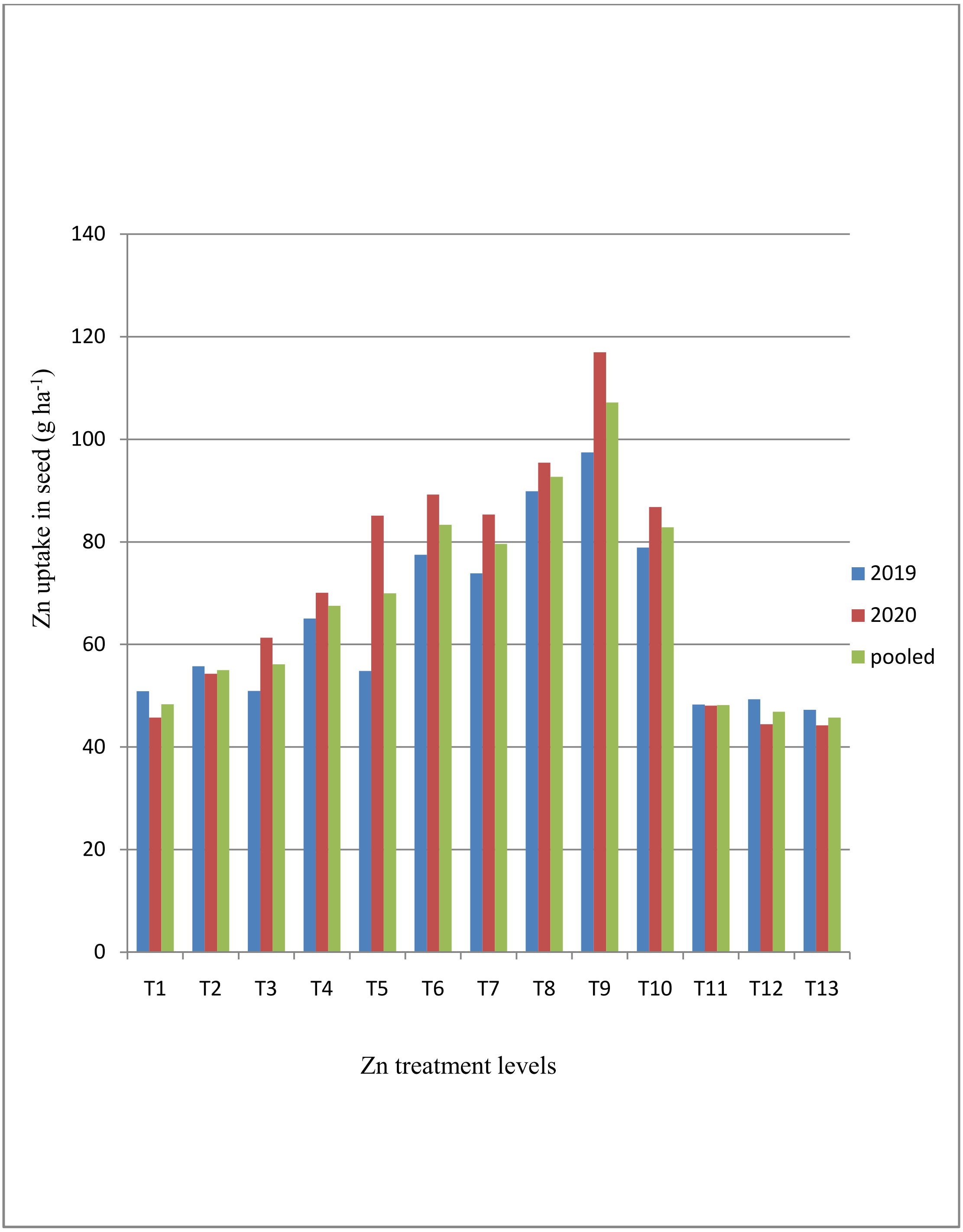

Fig 35: Effect of the sources and levels of Zn on Zn uptake in seed

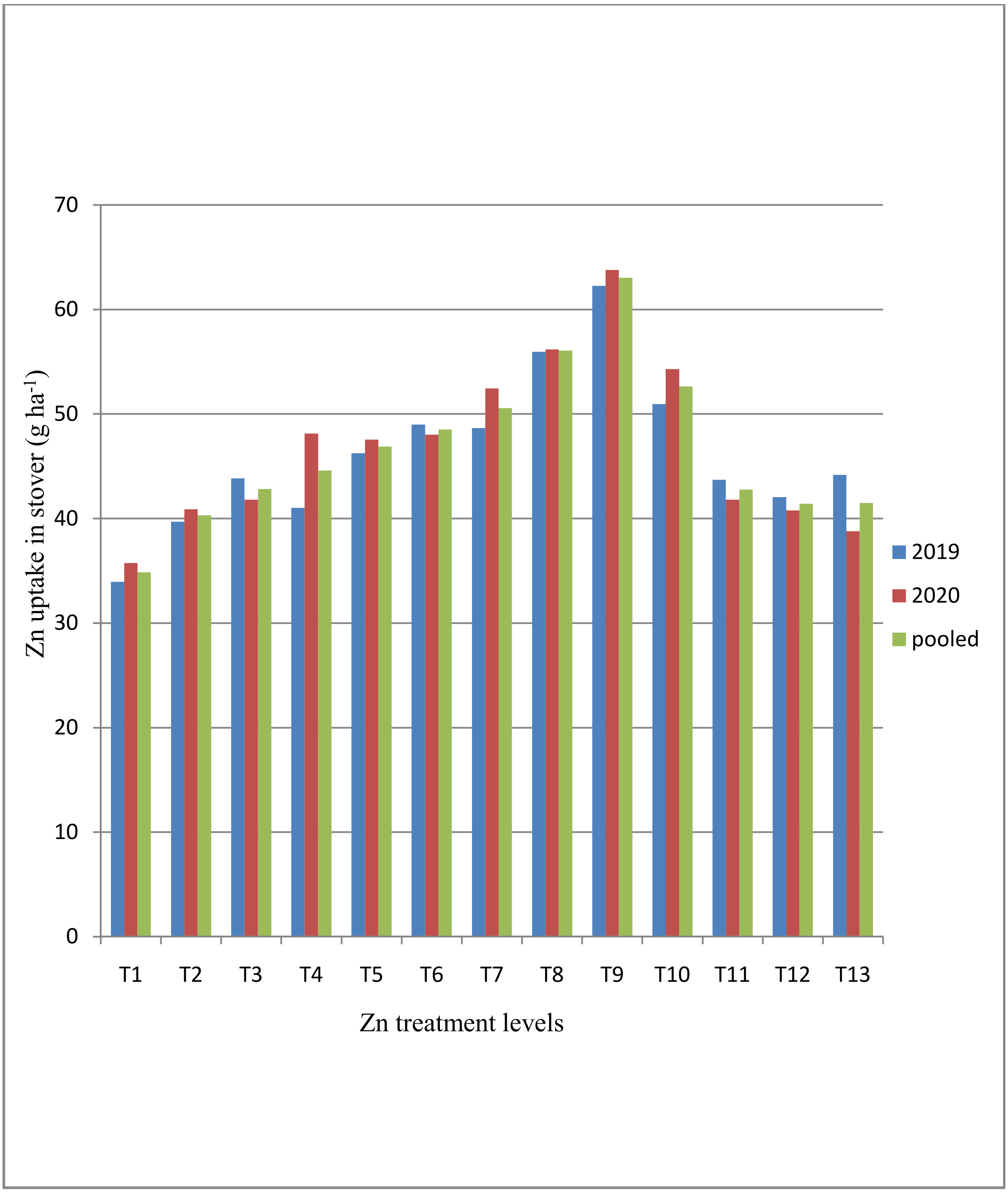

Fig 36: Effect of the sources and levels of Zn on Zn uptake in stover

4.3. To study the effect of sources and levels of Zn on physical chemical properties of soil.

4.3.1. Effect on soil pH

The pH of the post-harvest soil could not be affected significantly with the application of various levels of Zn sources during both the years and pooled respectively as shown in the table 4.22 and fig 37 below. During 2019 and 2020, it was observed from the data that the maximum soil pH recorded were 5.85 and 5.79 at treatment T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) as compared to the rest of the treatment. In the pooled data, it was also observed that soil pH was found to be maximum at Zn treatment T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) with the value of 5.82. The lowest soil pH was recorded at treatment T_{11} (300 ml ha^{-1} Liquid ZnO). The non-significant effect of the soil pH at various Zn levels was reported by Sharma *et al*. (2021) in wheat. Gupta *et al*. (2018) also reported that the pH of the postharvest soil did not produced significant result with the application of different levels of Zn and P fertilization in maize crop. While Ranpariya*et al*. (2017) observed that in summer green gram, the postharvest soil pH did not significantly increased by Zn application, Tiwari *et al*. (2006) also opined that the application of Zn did not positively affect the soil pH and was found non-significant after the wheat harvest. Gupta *et al*. (2018) found that the pH of the post-harvest soil was found non-significantwith the maximum pH being recorded atT_4 @ 40 kg ha^{-1} P + 0 kg ha^{-1} Zn.Keram*et al*. (2012) also observed that the soil pH in the post-harvest soil was found to be non- significant with various Zn treatments in wheat crop.

4.3.2. Effect on Electrical Conductivity (EC)

The response of various levels of Zn sources on soil electrical conductivity (EC) is shown in the table 4.23 and fig 38. From the data recorded, it was observed that the EC in the soil was not increased significantly with Zn application during 2019, 2020 and as well as in pooled respectively. There was a less variation among the various Zn sources. The maximum EC was recorded at T_7 (RDF + 2.5 kg Zn-EDTA) *i.e.*0.23, 0.22 and 0.23ds m^{-1}. The lowest was recorded at T_{10} (RDF + 5 kg Zn-EDTA) i.e., 0.18, 0.17 and 0.18ds m^{-1}. Sharma *et al.* (2021) found that the application of various levels of Zn had a non-significant effect on EC in wheat crop. The soil EC of the postharvest soil was also found non-significant by Gupta *et al.* (2018) with the application of different levels of Zn and P fertilizers in maize crop. It was also observed in summer green gram that the EC of the post-harvest soil did not increased significantly with Zn application (Ranpariya*et al.* 2017). Tiwari *et al.* (2006) also revealed that the application of Zn did not affect the soil EC and was found non-significant after the wheat harvest. Keram*et al.* (2012) reported that the soil EC in the postharvest soil was found to be non- significant with various Zn treatments in wheat crop. According to Sharma *et al.* (2021), the EC of the post-harvest soil was not increased significantly at varying levels of Zn in wheat crop. Varalakshmi *et al.* (2021) also found that the application of Zn at increasing rates decreased the soil EC under the rice-wheat cropping system.

4.3.3. Effect on soil OC

The response of soil OC to Zn sources are shown below in the table 4.24 and fig 39. It was observed from the data recorded that the OC of the post-harvest soil were not found to be significantly increased with application of varying Zn sources during both the years. The maximum soil OC of 0.63 and 0.60% was recorded at treatment T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) and the lowest was recorded at T_{12} (600 ml ha^{-1} Liquid ZnO). The pooled data also indicated non-significant effect on soil OC. The maximum soil OC was 0.62 % observed at treatment T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) and the lowest was recorded at T_{12} (600 ml ha^{-1} Liquid ZnO). Similar finding was reported by Sharma *et al.* (2021) who observed non-significant effect of various Zn levels on soil OC in wheat. Singh *et al.* (2017) also reported non-significant increase in the soil OC at various sources and levels of Zn after the harvest of maize crop.Gupta *et al.* (2018) observed that the post-harvest soil OC was found to be non-significant with the application of various levels of Zn and P fertilizers in maize crop.

Ranpariya*et al*. (2017) also reported that in summer green gram, the OC of the postharvest soil did not produced significant results through Zn application. Keram*et al*. (2012) observed that the OC of the postharvest soil was found to be non-significant with various Zn treatments in wheat crop.

4.3.4. Effect on CEC

The response of soil CEC to varying levels of Zn sources are shown in the table 4.25 and fig 40 below. As per the research data recorded, it was observed that there was a less variation among the various Zn sources and the CEC of the postharvest soil thereby it did not produced significant results with Zn application during the years 2019 and 2020. Even the pooled data showed non-significant effect of Zn on postharvest soil CEC. The maximum postharvest soil CEC recorded was 12.35 and 13.14 cmol (p+) kg^{-1} at treatment T_7 (RDF + 2.5 kg Zn-EDTA) and the lowest soil CEC of 11.97 and 12.24 cmol (p+) kg^{-1} was recorded at T_1 (control). From the pooled data, the maximum soil CEC of 12.75 cmol (p+) kg^{-1} was recorded at treatment T_7 (RDF + 2.5 kg Zn-EDTA) and the lowest observed was 12.11cmol (p+) kg^{-1} at T_1 (control). Meena *et al*. (2018) observed that the application of Zn with enriched FYM did not influence positively on CEC of the soil after harvest of the mung bean crop.

4.3.5. Effect on particle density (PD)

The soil particle density (PD) of the postharvest soil with response to Zn sources are shown in the table 4.26 and fig 41 below. From the research data observed, it was found that the particle density of the postharvest soil of soybean was not increased significantly with Zn application during 2019 and 2020 respectively. The maximum particle density of the postharvest soil recorded was 2.35 and 2.38 g cm^{-3} at T_9 (RDF + 5kg $ZnSO_4$ H_2O ha^{-1}) and the lowest soil particle density was recorded at T_1 (control). The pooled data also showed that it did not produce significant result and the maximum soil particle density observed was 2.25 g cm^{-3} at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}). Meena *et al*. (2018) showed similar findings where the soil particle density was not increased significantly with the application of $ZnSO_4$ fertilizer after the harvest of mustard crop. Arun *et al*. (2014) observed that the soil particle density was found to be non-significant in the post-harvest soil with the various levels of N, P, K, Zn and Rhizobium application in pea crop. Chethan*et al*. (2018) observed that the particle density of the postharvest soil in pea crop was also found to be non-significant with the application of NPK + Zn fertilizer.Singh *et al*. (2021) observed that the decreased in the soil particle density could be due to the non-significant effect of the various nutrient sources and levels on particle density in one cropping season.

4.3.6. Effect on bulk density (BD)

The effect of various levels of Zn sources on soil bulk density is shown in the table 4.27 and fig 42 below. From the given data, it was observed that the soil bulk density was not increased significantly with Zn application during 2019, 2020 and pooled respectively. The maximum bulk density recorded was 1.22, 1.21 and 1.22 g cm^{-3} at treatment T_8 (RDF + 5 kg $ZnSO_4$ $7H_2O$) and the lowest was recorded at T_1 (control). The application of Zn along with FYM resulted in non-significant effect of soil bulk density after harvest of mung bean crop (Meena *et al*. 2018). Arun *et al*. (2014) and Chethan*et al*. (2018) reported similar findings on the soil bulk density of the postharvest soil with Zn application in pea crop. Upadhyay *et al*. (2016) and Varalakshmi *et al*. (2021) also observed non-significant effect on soil bulk density with the application of Zn at increasing rates in mustard and rice-wheat cropping system.

4.3.7. Effect on porosity

The response of soil porosity (%) in postharvest soil of soybean to varying levels of Zn sources is shown in the table 4.28 and fig 43 below. From the research data recorded, it was observed that the pore space in the soil were not increased significantly with Zn application during both the years and pooled respectively. The maximum pore space of 48.51 % and 50.63 % were recorded at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) and T_{10} (RDF + 5 kg Zn-EDTA) during

2019 and 2020. In pooled, the maximum porosity recorded was 49.26 % at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) in 2020. Meena *et al*. (2018) observed that porosity of the postharvest soil was not increased significantly with the application of $ZnSO_4$ in mustard crop.The non-significant effect of porosity in the postharvest soil was also reported byChethan*et al*. (2018).

Table 4.22: Effect of the sources and levels of Zn on soil pH

Treatments	pH		
	2019	2020	Pooled
T_1	5.69	5.65	5.67
T_2	5.33	5.56	5.45
T_3	5.42	5.48	5.45
T_4	5.61	5.35	5.48
T_5	5.69	5.53	5.61
T_6	5.83	5.41	5.62
T_7	5.51	5.52	5.52
T_8	5.34	5.54	5.44
T_9	5.85	5.79	5.82
T_{10}	5.49	5.66	5.58
T_{11}	5.18	5.29	5.24
T_{12}	5.23	5.44	5.34
T_{13}	5.53	5.52	5.53
SEm±	0.23	0.40	0.23
C.D at 5%	NS	NS	NS

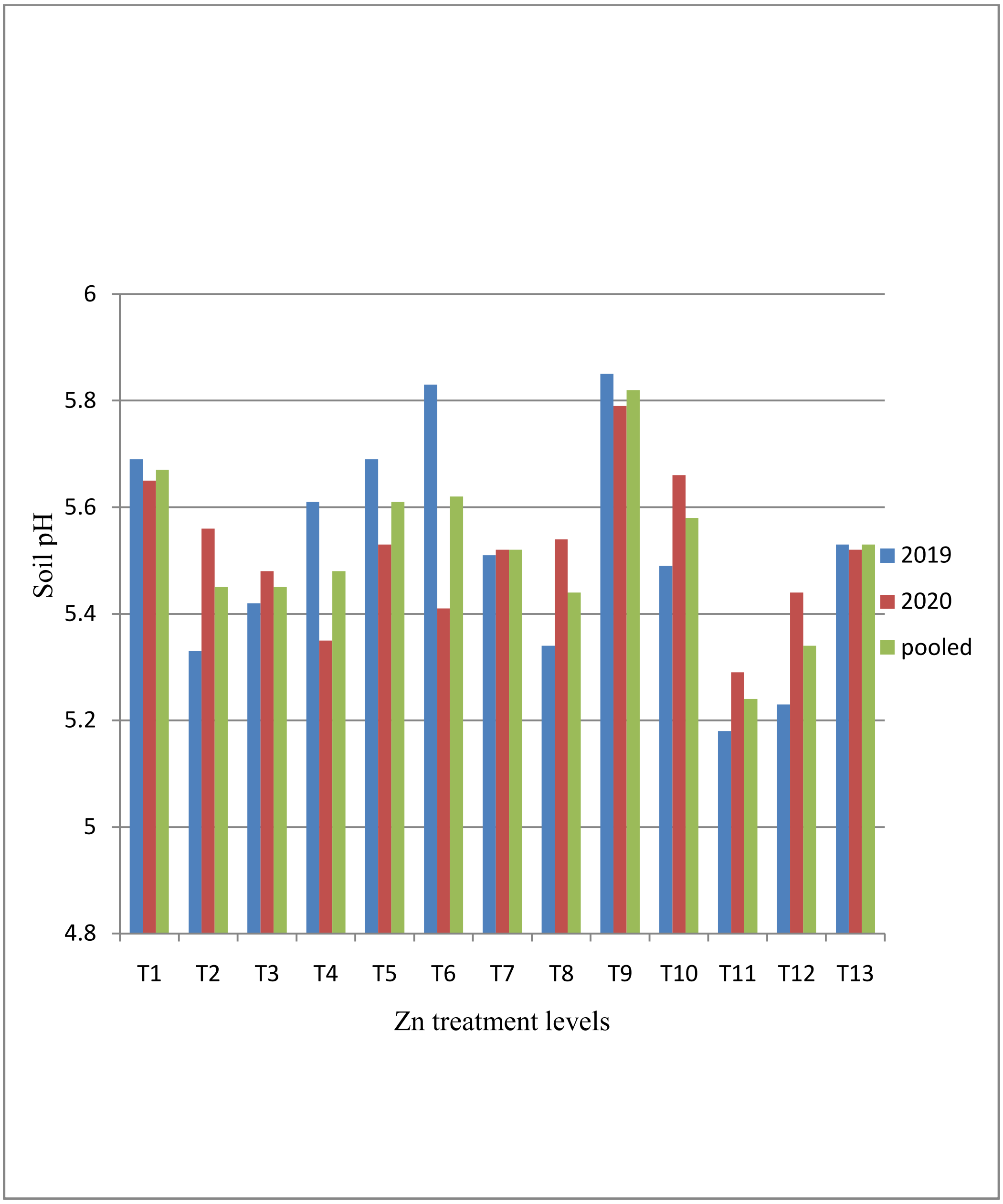

Fig 37: Effect of the sources and levels of Zn on soil pH

Table 4.23: Effect of the sources and levels of Zn on EC

Treatments	EC (ds m^{-1})		
	2019	2020	Pooled
T_1	0.20	0.19	0.20
T_2	0.20	0.19	0.20
T_3	0.20	0.21	0.21
T_4	0.20	0.20	0.20
T_5	0.20	0.20	0.20
T_6	0.20	0.21	0.21
T_7	0.23	0.22	0.23
T_8	0.20	0.21	0.20
T_9	0.20	0.21	0.21
T_{10}	0.18	0.17	0.18
T_{11}	0.20	0.20	0.20
T_{12}	0.19	0.20	0.20
T_{13}	0.20	0.19	0.20
SEm±	0.01	0.01	0.01
C.D at 5%	NS	NS	NS

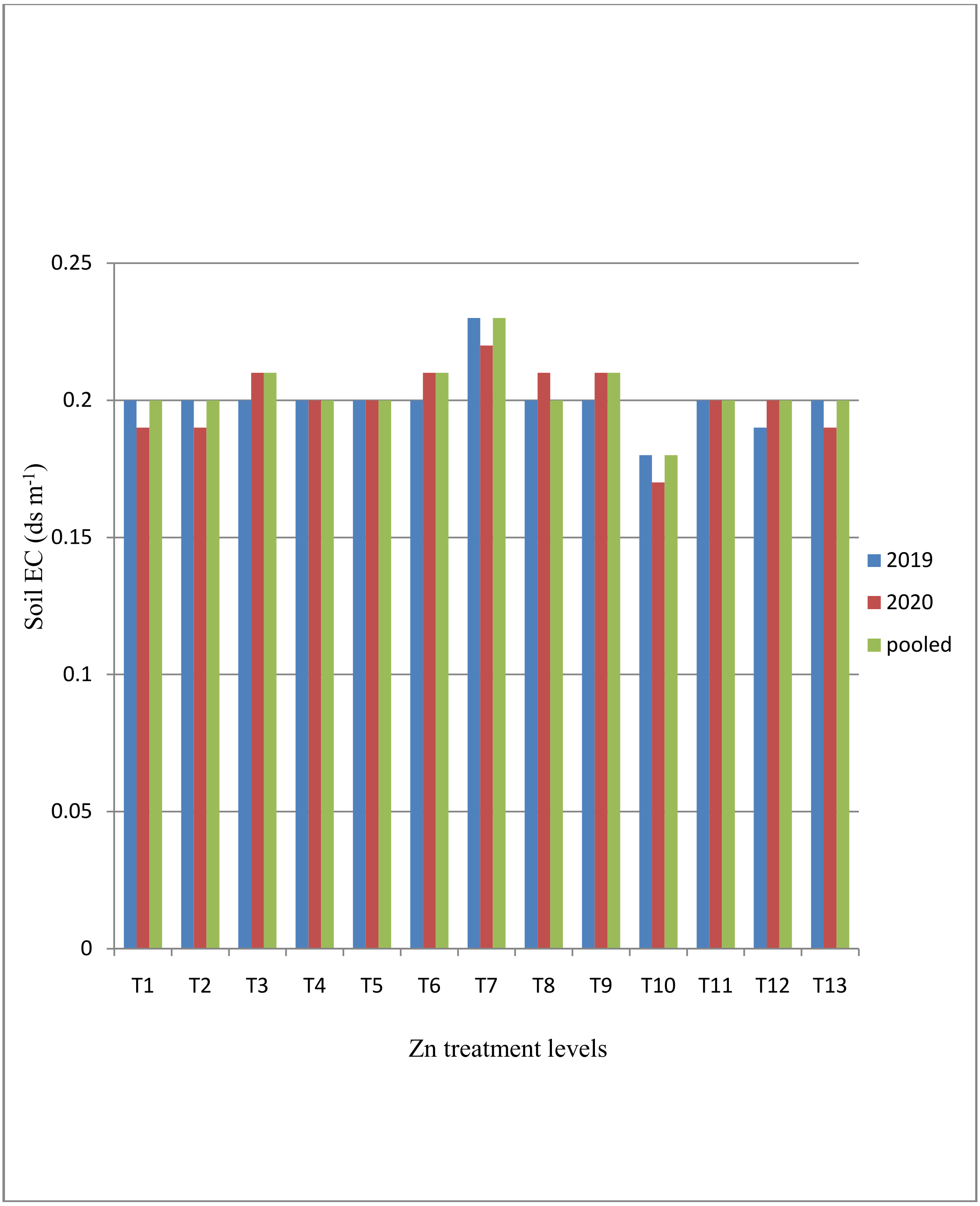

Fig 38: Effect of the sources and levels of Zn on soil EC

Table 4.24: Effect of the sources and levels of Zn on soil organic carbon

Treatments	OC (%)		
	2019	2020	Pooled
T_1	0.61	0.58	0.60
T_2	0.61	0.57	0.59
T_3	0.60	0.59	0.60
T_4	0.62	0.60	0.61
T_5	0.60	0.59	0.60
T_6	0.60	0.58	0.59
T_7	0.61	0.58	0.60
T_8	0.61	0.57	0.59
T_9	0.63	0.60	0.62
T_{10}	0.61	0.57	0.59
T_{11}	0.59	0.56	0.58
T_{12}	0.58	0.53	0.56
T_{13}	0.60	0.54	0.57
SEm±	0.01	0.02	0.01
C.D at 5%	NS	NS	NS

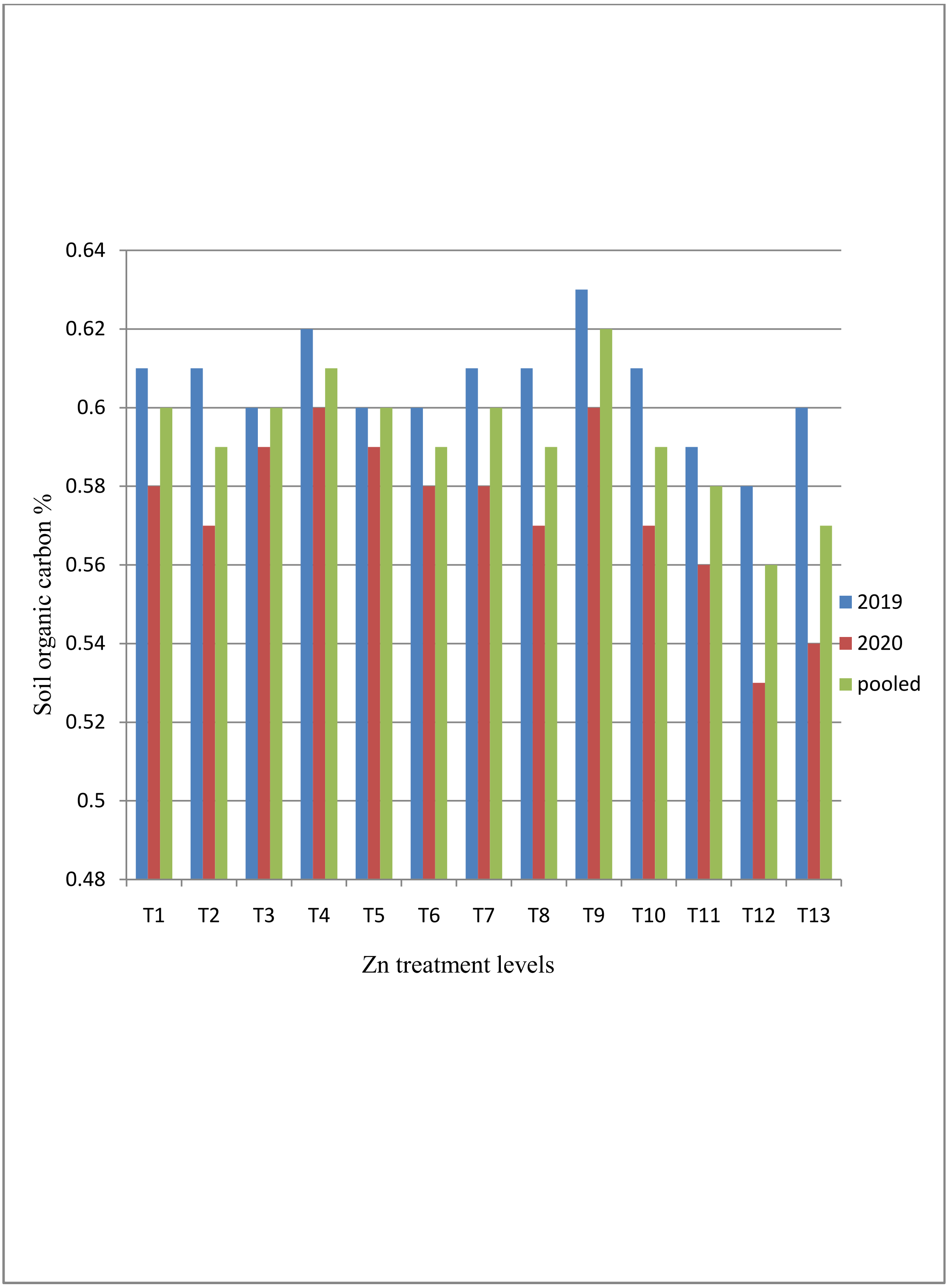

Fig 39: Effect of the sources and levels of Zn on soil organic carbon

Table 4.25: Effect of the sources and levels of Zn on soil CEC

Treatments	CEC {cmol (p+) kg^{-1}}		
	2019	2020	Pooled
T_1	11.97	12.24	12.11
T_2	12.25	13.09	12.67
T_3	12.02	13.00	12.51
T_4	12.08	13.00	12.54
T_5	12.23	12.38 .	12.31
T_6	11.99	13.07	12.53
T_7	12.35	13.14	12.75
T_8	12.33	13.03	12.68
T_9	12.29	13.11	12.70
T_{10}	12.21	12.67	12.44
T_{11}	12.00	12.85	12.43
T_{12}	12.09	12.61	12.35
T_{13}	12.62	12.92	12.77
SEm±	0.19	0.23	0.15
C.D at 5%	NS	NS	NS

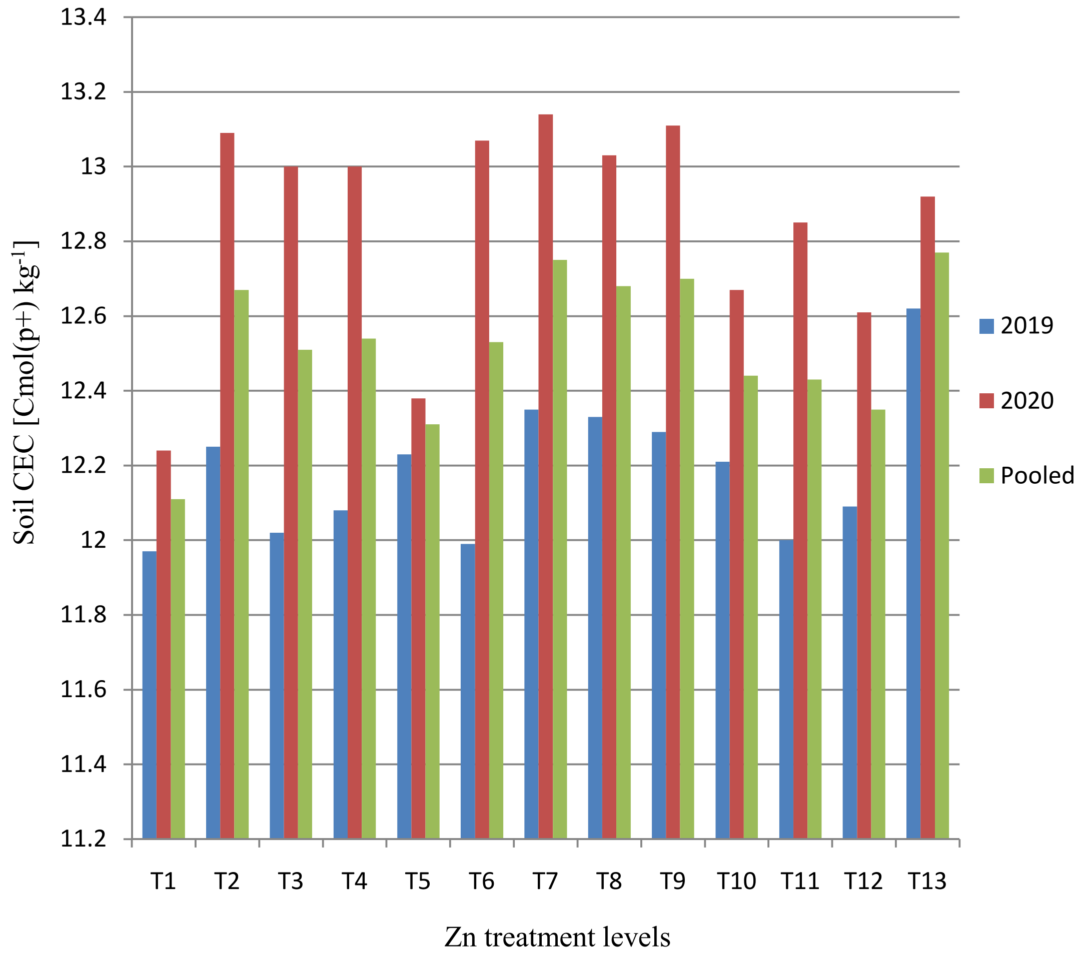

Fig 40: Effect of the sources and levels of Zn on soil CEC

Table 4.26: Effect of the sources and levels of Zn on soil particle density

Treatments	Particle density (g cm^{-3})		
	2019	2020	Pooled
T_1	2.24	2.26	2.26
T_2	2.27	2.29	2.25
T_3	2.29	2.31	2.23
T_4	2.25	2.31	2.22
T_5	2.31	2.27	2.23
T_6	2.33	2.30	2.20
T_7	2.30	2.33	2.24
T_8	2.31	2.35	2.25
T_9	2.35	2.38	2.25
T_{10}	2.30	2.37	2.23
T_{11}	2.28	2.32	2.23
T_{12}	2.26	2.29	2.21
T_{13}	2.30	2.31	2.24
SEm±	0.03	0.01	0.02
C.D at 5%	NS	NS	NS

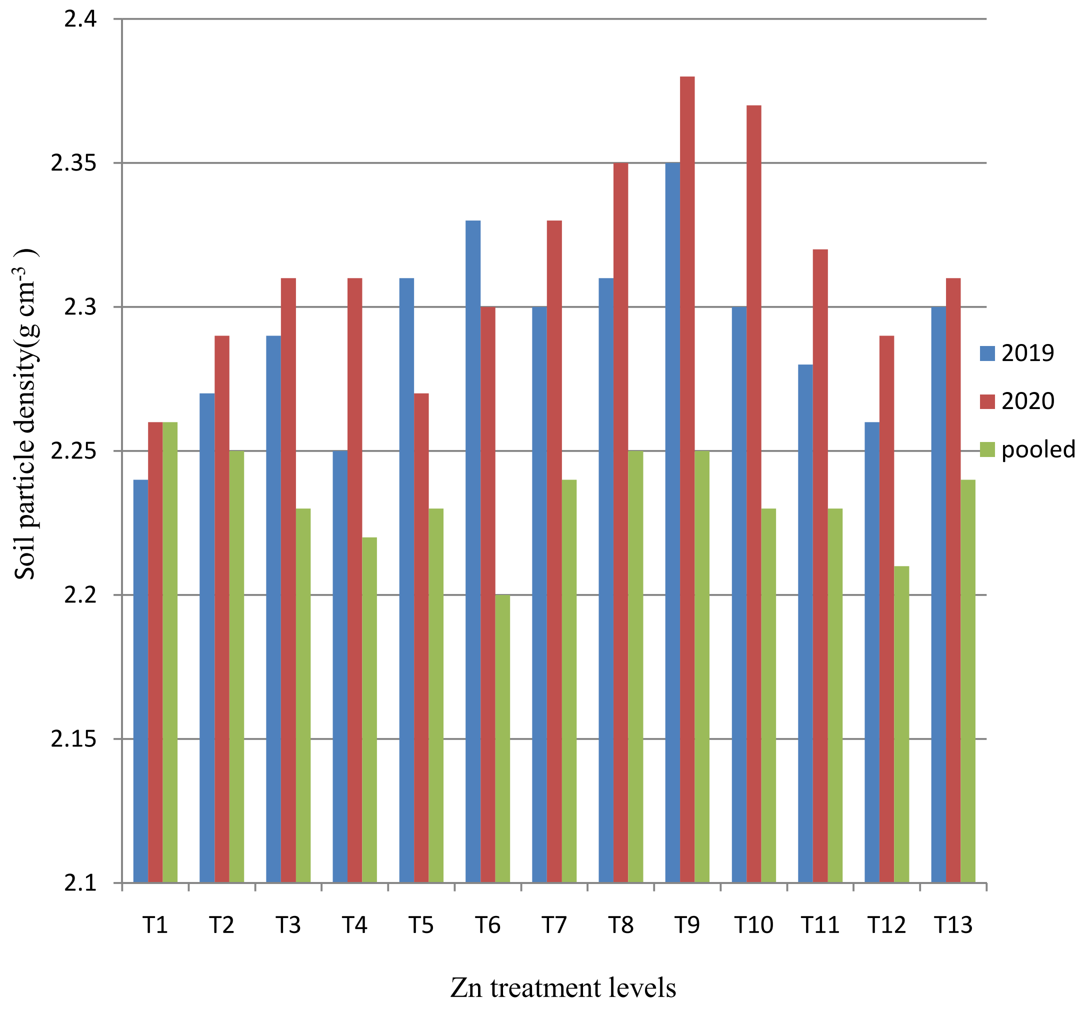

Fig 41: Effect of the sources and levels of Zn on soil particle density

Table 4.27: Effect of the sources and levels of Zn on soil bulk density

Treatments	Bulk density (g cm^{-3})		
	2019	2020	Pooled
T_1	1.18	1.15	1.17
T_2	1.21	1.18	1.19
T_3	1.19	1.19	1.19
T_4	1.21	1.16	1.19
T_5	1.20	1.19	1.20
T_6	1.20	1.16	1.18
T_7	1.20	1.16	1.18
T_8	1.22	1.21	1.22
T_9	1.21	1.19	1.20
T_{10}	1.20	1.17	1.19
T_{11}	1.19	1.19	1.19
T_{12}	1.20	1.18	1.19
T_{13}	1.20	1.16	1.18
SEm±	0.01	0.02	0.01
C.D at 5%	NS	NS	NS

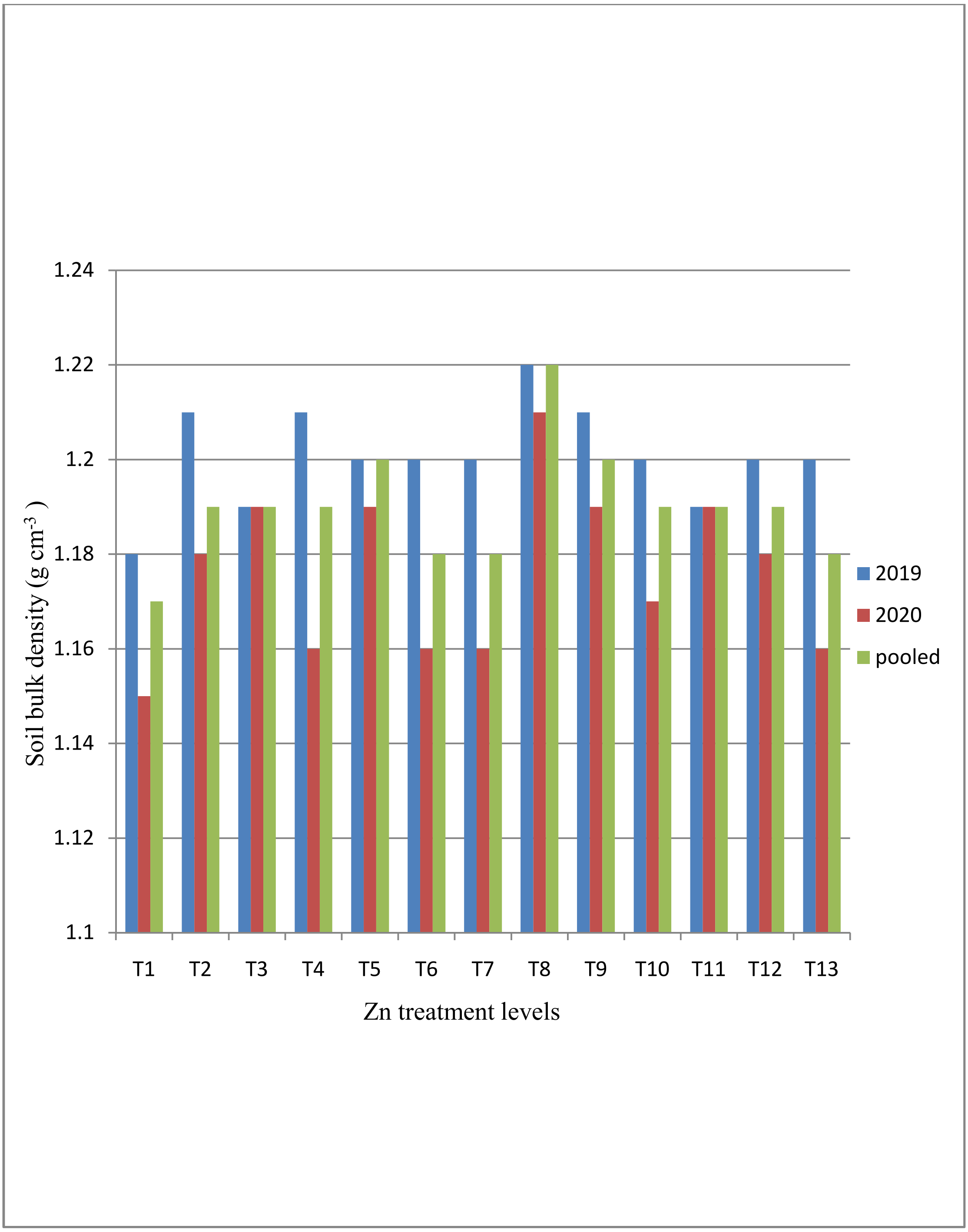

Fig 42: Effect of the sources and levels of Zn on soil bulk density

Table 4.28: Effect of the sources and levels of Zn on soil pore space

Treatments	Pore space (%)		
	2019	2020	Pooled
T_1	47.32	49.12	48.22
T_2	46.70	48.47	47.59
T_3	48.03	48.48	48.26
T_4	46.22	49.78	48.00
T_5	48.05	47.58	47.82
T_6	48.50	49.57	49.04
T_7	47.83	50.21	49.02
T_8	47.19	48.51	47.85
T_9	48.51	50.00	49.26
T_{10}	47.83	50.63	49.23
T_{11}	47.81	48.71	48.26
T_{12}	46.90	48.47	47.69
T_{13}	47.83	49.78	48.81
SEm±	0.55	1.21	0.66
C.D at 5%	NS	NS	NS

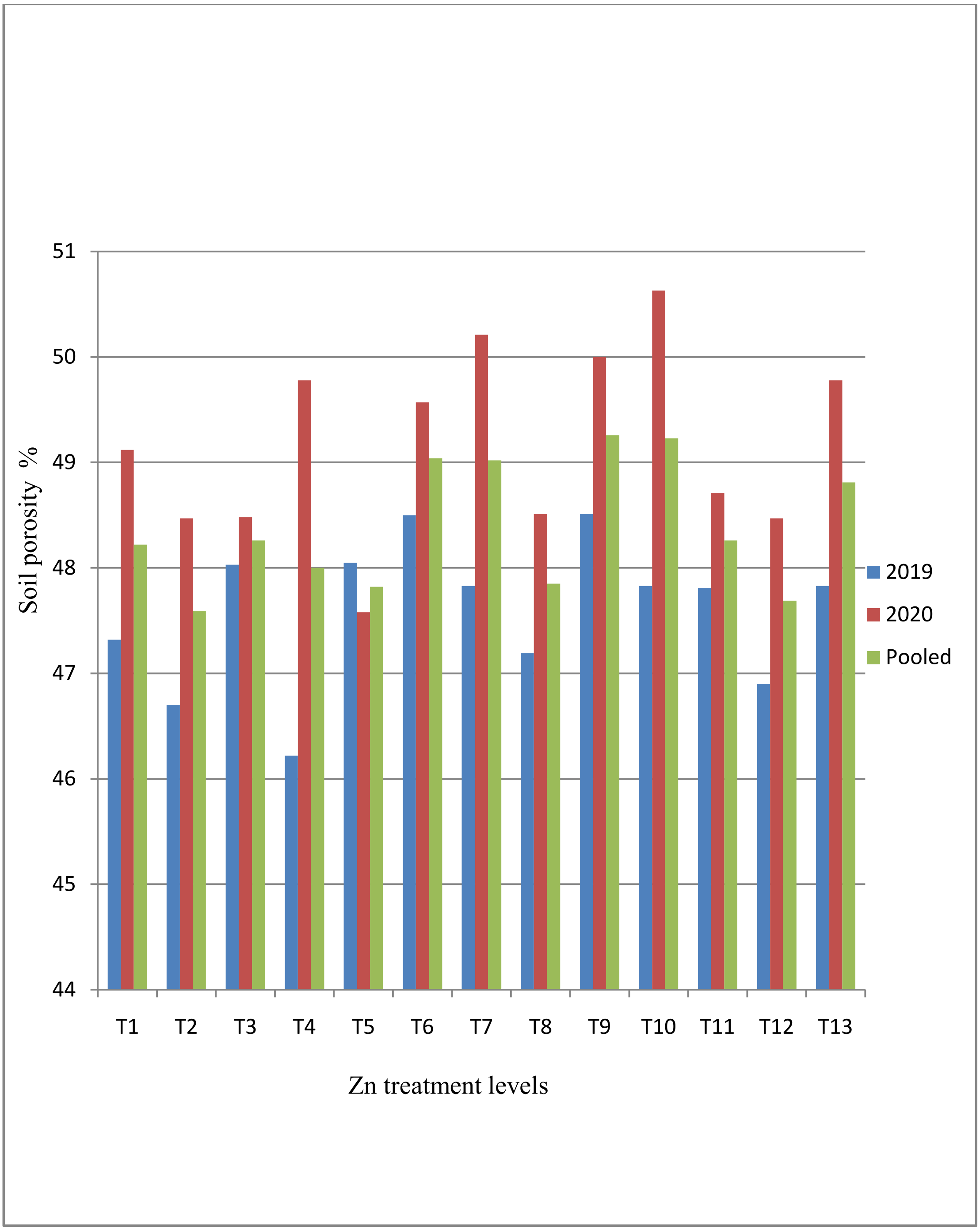

Fig 43: Effect of the sources and levels of Zn on soil porosity

4.4. To study the response of soybean to sources and levels of Zn on soil fertility.

4.4.1. Effect on available N (kg ha^{-1})

The effect of Zn sources on available N in soil is shown in the table 4.29 and fig 44. It was observed from the data recorded that the available N in the soil was increased significantly with Zn application during 2019 and 2020 respectively. The highest soil available N recorded was 345.00 and 357.90 kg ha^{-1} at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) as compared to the rest of the treatment. The lowest recorded was 219.10 and 231.70 kg ha^{-1} in the control plot (T_1). The available N of the postharvest soil from the pooled data showed significant increased with Zn sources and levels. The maximum available soil N from the pooled data was 351.45 kg ha^{-1} at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) and the lowest recorded was 225.40 kg ha^{-1} at T_1 (control). Balai*et al*. (2017) observed significant increase in soil available N with Zn application @ 6 kg Zn ha^{-1} in chickpea. Thus increasing the soil available N by about 16.55% over control (6.44%).Gupta*et al*. (2018) also observed that the treatment combination of T_8 @ 80 kg ha^{-1} P and 25 kg ha^{-1} Zn significantly increased the soil available N after harvest of maize crop.The application of Zn significantly increased the available N of the postharvest soil which might be due to the synergistic interaction between Zn and soil N. This increased in soil Zn could also be due to enhancement of the incorporation of inorganic Zn into solubilisation, diffusivity and mobilization(Jat*et al*. 2012).

4.4.2 Effect on available P (kg ha^{-1})

The application of various levels of Zn sources on available P in soil is shown in the table 4.30 and fig 45. As per the data recorded, it was concluded that the available P in the postharvest soil were found to be non-significant with Zn application during 2019 and 2020 respectively. The maximum soil available P of 14.34 and 14.44 kg ha^{-1} was recorded at T_1 (control). According to the pooled data, maximum soil available P recorded was 14.39 kg ha^{-1} at T1 (control). Tiwari *et al*. (2006) reported that increasing levels of Zn doses @ 5 and 10 kg ha^{-1} lowered the soil available P non-significantly after the wheat harvest. Karan *et al*. (2014) revealed that the available P in the soil showed decreasing trend with the increasing levels of Zn in Lentil. Balai*et al*. (2017) reported that the Zn fertilization decreased the soil available P after harvest of chickpea crop due to the antagonistic effect between Zn and P. Singh *et al*. (2017) observed that the available soil P was not significantly increased with the sources and levels of Zn in maize. Similar observation was also reported by Meena *et al*. (2018) and Kumawat (2012) in mustard-pearl millet cropping system and fennel crop. It might also be due to the increased in the concentration of insoluble Zinc phosphate thereby decreasing the P availability in the soil.

4.4.3. Effect on available K (kg ha^{-1})

The response of Zn sources on available K of the postharvest soil is shown in the table 4.31 and fig 46. As per the data recorded, it was observed that the available K in the soil was increased significantly with Zn application during 2019 and 2020 respectively. The highest soil available K was recorded at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) *i.e*. 251.10 and 258.15 kg ha^{-1} which was followed by treatment T_8. The lowest was recorded in the control plot (T_1). According to the pooled data, the soil available K was increased significantly with Zn fertilization. The maximum soil K recorded was 254.63 kg ha^{-1} at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) and the lowest was recorded at T_1 (control). Application of different levels of Zn also significantly increased the K availability in the soil after harvest of chick pea crop. The highest available K in the soil was observed @ 6 kg Zn ha^{-1} over control (Balai*et al*., 2017).Gupta *et al*. (2018) observed that the treatment combination of T_7 @ 80 kg P ha^{-1} + 12.5 Kg ha^{-1} Zn) significantly increased the soil available K after harvest of maize crop.Zn has a positive interaction with soil nutrients such as K which leads to increase in soil available K and increased crop yield (Prasad *et al*., 2016).Ranade-Malvi. (2011) opined that micronutrient Zn has a synergistic effect on macronutrient K so the increase in Zn availability optimizes the uptake of soil K.

4.4.4. Effect on available S (kg ha^{-1})

The effect of Zn sources on soil available S is shown in the table 4.32 and fig 47. From the data recorded, it was observed that the available S in the soil was not increased significantly with Zn application during 2019 and 2020. The highest soil available S was recorded at T_7 (RDF + 2.5 kg Zn-EDTA) i.e., 11.98 and 11.97 kg ha^{-1}. The lowest was recorded in the treatment T1 (control plot). Even from the pooled data it was observed that the available soil S was not effected significantly. The maximum soil available S was 11.98 kg ha^{-1} at T_7 (RDF + 2.5 kg Zn-EDTA) and the minimum was recorded at T_1 (control). Similar findings were also observed by Pandey *et al*. (2016) in wheat crop where the available S in the postharvest soil found to be non-significant with Zn fertilization and Thenua*et al*. (2014) in soybean crop where the available S status from the postharvest soil was found to be non-significant with Zn treatments.

4.4.5. Effect on available Zn (mg kg^{-1})

The response of various levels of Zn sources on of available Zn in soil is shown in the table 4.33 and fig 48. From the data recorded, it was observed that the available Zn in the soil were increased significantly with Zn application during 2019, 2020 and pooled respectively. The highest soil available Zn was recorded at T_9 (RDF + 5kg $ZnSO_4$ H_2O ha^{-1}) *i.e.* 0.39, 0.35 and 0.35 mg kg^{-1} which was followed by T_8. The lowest was recorded in T_{11} (300 ml ha^{-1} Liquid ZnO). Raghuwanshi*et al*. (2006) also reported that the available Zn in the soil after soybean harvest was significantly increased @10 kg Zn ha^{-1} over control. Balai*et al*. (2017) also reported significant increase in the Zn content in the soil with increasing levels of Zn application after harvest of chick pea.This significant increase in the soil available Zn might be due to chelation of Zn which effectively maintain the Zn status in the soil solution (Meena *et al*., 2006).

Table 4.29: Effect of the sources and levels of Zn on soil available N after harvest

Treatments	Available N (kg ha^{-1})		
	2019	2020	Pooled
T_1	219.10	231.70	225.40
T_2	251.30	274.00	262.65
T_3	274.70	269.10	271.90
T_4	293.00	288.30	290.65
T_5	289.90	293.80	291.85
T_6	313.20	330.60	321.90
T_7	337.00	345.50	341.25
T_8	342.80	351.20	347.00
T_9	345.00	357.90	351.45
T_{10}	328.20	348.80	338.50
T_{11}	319.30	316.10	317.70
T_{12}	320.60	314.40	317.50
T_{13}	309.40	313.00	311.20
SEm±	0.12	0.17	0.10
C.D at 5%	0.36	0.48	0.29

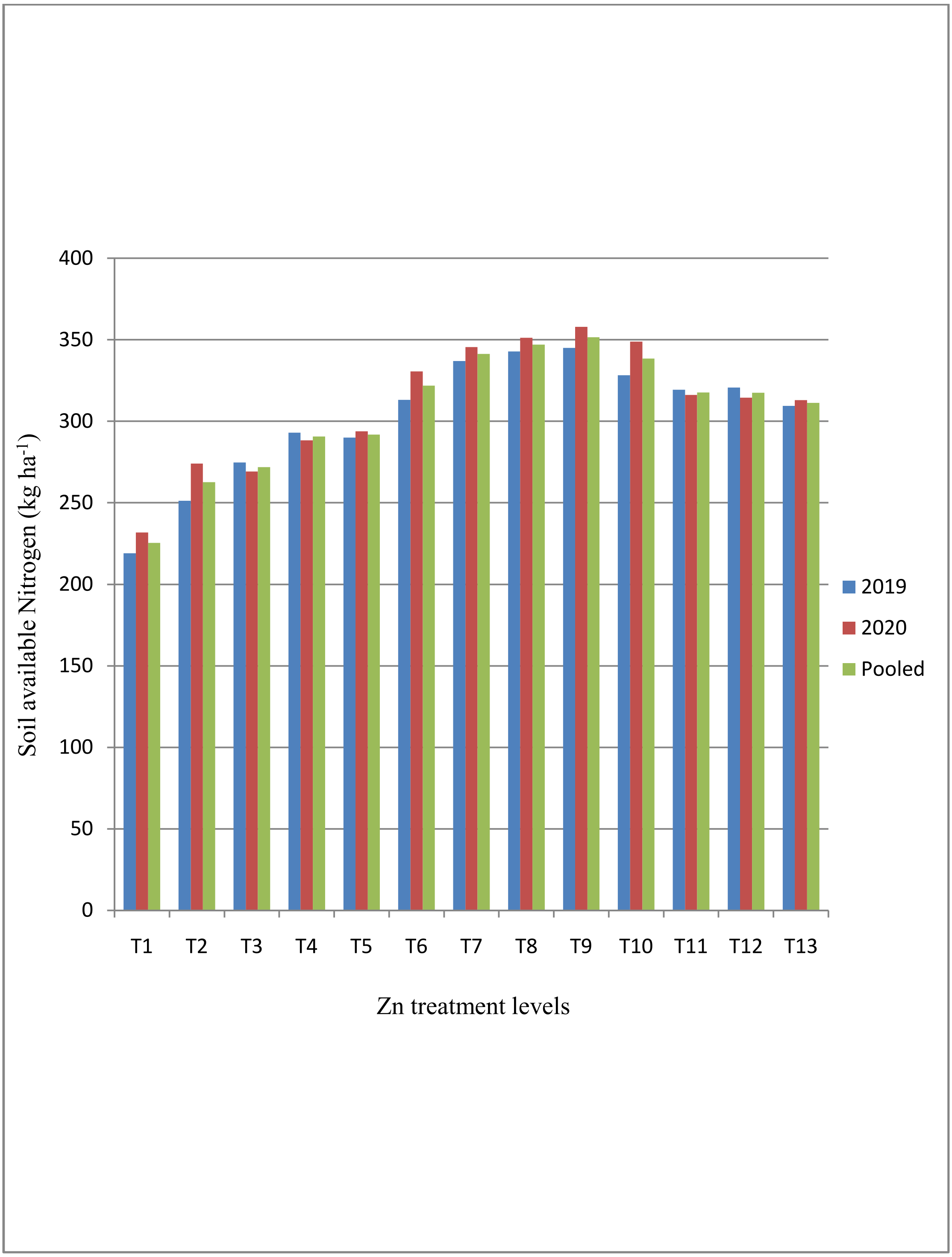

Fig 44: Effect of the sources and levels of Zn on soil available N

Table 4.30: Effect of the sources and levels of Zn on soil available P after harvest

Treatments	Available P (kg ha^{-1})		
	2019	2020	Pooled
T_1	14.34	14.44	14.39
T_2	13.10	13.62	13.36
T_3	11.01	12.91	11.96
T_4	12.17	11.40	11.79
T_5	12.97	12.38	12.67
T_6	10.24	12.83	11.54
T_7	12.30	11.47	11.88
T_8	11.48	12.46	11.97
T_9	12.73	11.22	11.98
T_{10}	13.39	12.24	12.82
T_{11}	11.68	11.72	11.70
T_{12}	12.08	11.15	11.62
T_{13}	11.72	12.06	11.89
SEm±	0.74	0.80	0.55
C.D at 5%	NS	NS	NS

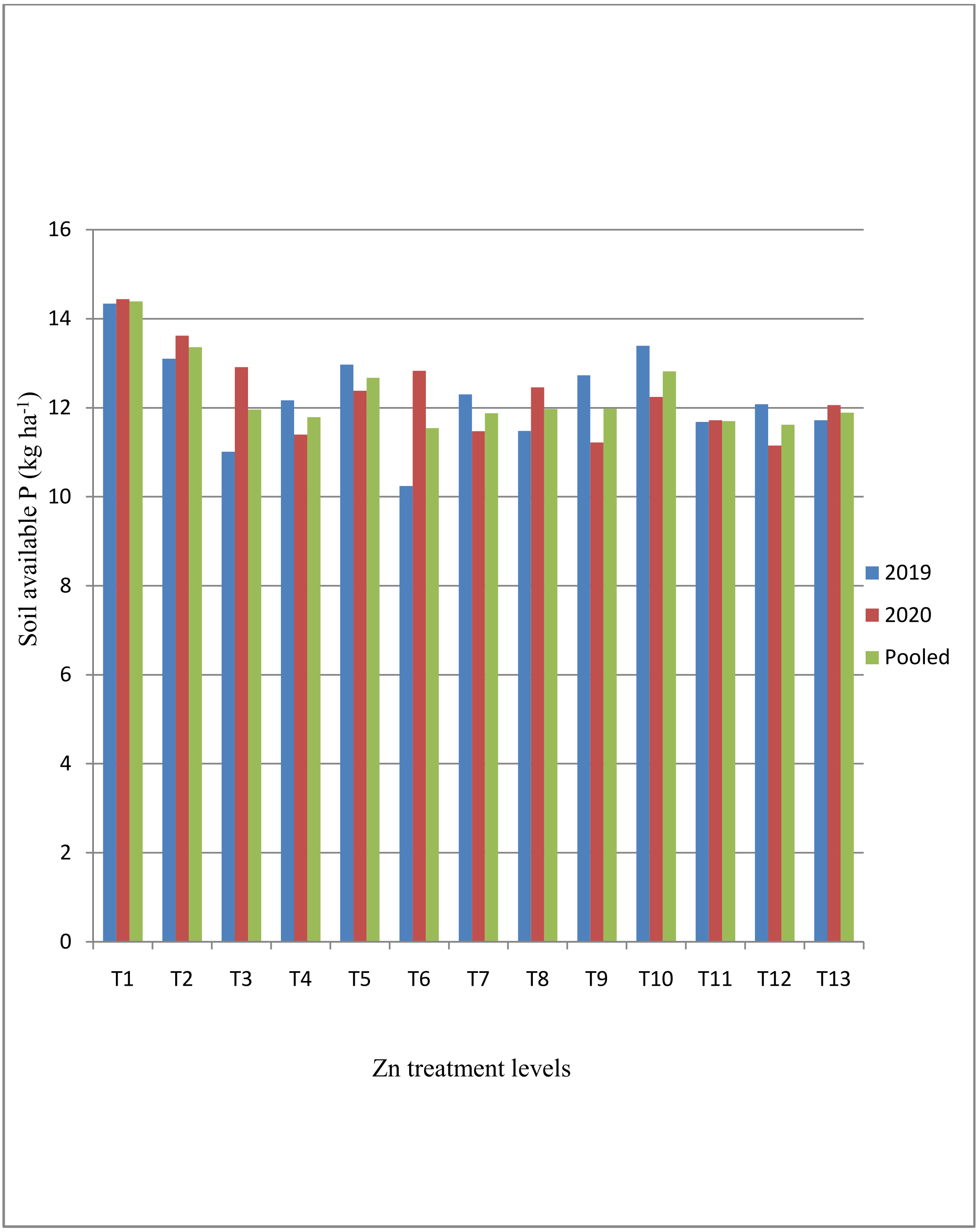

Fig 45: Effect of the sources and levels of Zn on soil available P

Table 4.31: Effect of the sources and levels of Zn on soil available K after harvest

Treatments	Available K (kg ha^{-1})		
	2019	2020	Pooled
T_1	115.70	129.00	122.38
T_2	134.20	154.06	144.13
T_3	149.80	135.12	142.46
T_4	163.20	214.29	188.75
T_5	189.90	219.09	204.50
T_6	190.20	225.21	207.71
T_7	194.60	226.17	210.39
T_8	240.40	248.24	244.32
T_9	251.10	258.15	254.63
T_{10}	228.40	223.36	225.88
T_{11}	213.10	201.29	207.20
T_{12}	211.20	201.51	206.36
T_{13}	216.10	190.40	203.25
SEm±	0.02	0.01	0.01
C.D at 5%	0.05	0.02	0.03

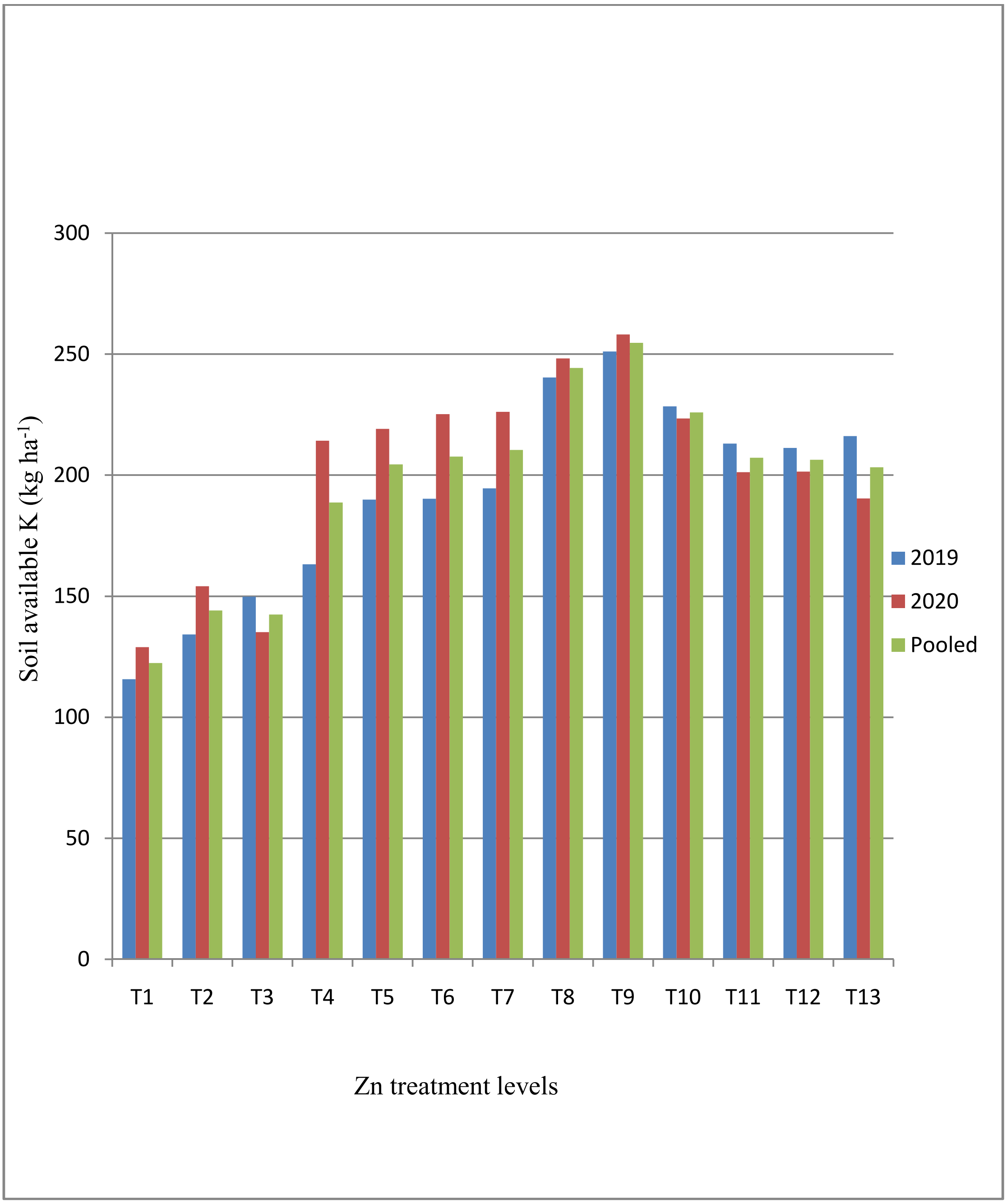

Fig 46: Effect of the sources and levels of zinc on soil available K

Table 4.32: Effect of the sources and levels of Zn on soil available S after harvest

Treatments	Available Sulphur (kg ha^{-1})		
	2019	2020	Pooled
T_1	9.63	9.83	9.73
T_2	9.97	10.12	10.05
T_3	10.23	10.37	10.30
T_4	10.43	10.53	10.48
T_5	10.74	11.23	10.99
T_6	11.12	10.67	10.89
T_7	11.98	11.97	11.98
T_8	11.56	10.89	11.23
T_9	10.93	11.15	11.04
T_{10}	10.76	10.93	10.85
T_{11}	10.67	11.25	10.96
T_{12}	10.11	10.99	10.55
T_{13}	10.32	10.87	10.60
SEm±	2.10	2.10	1.49
C.D at 5%	NS	NS	NS

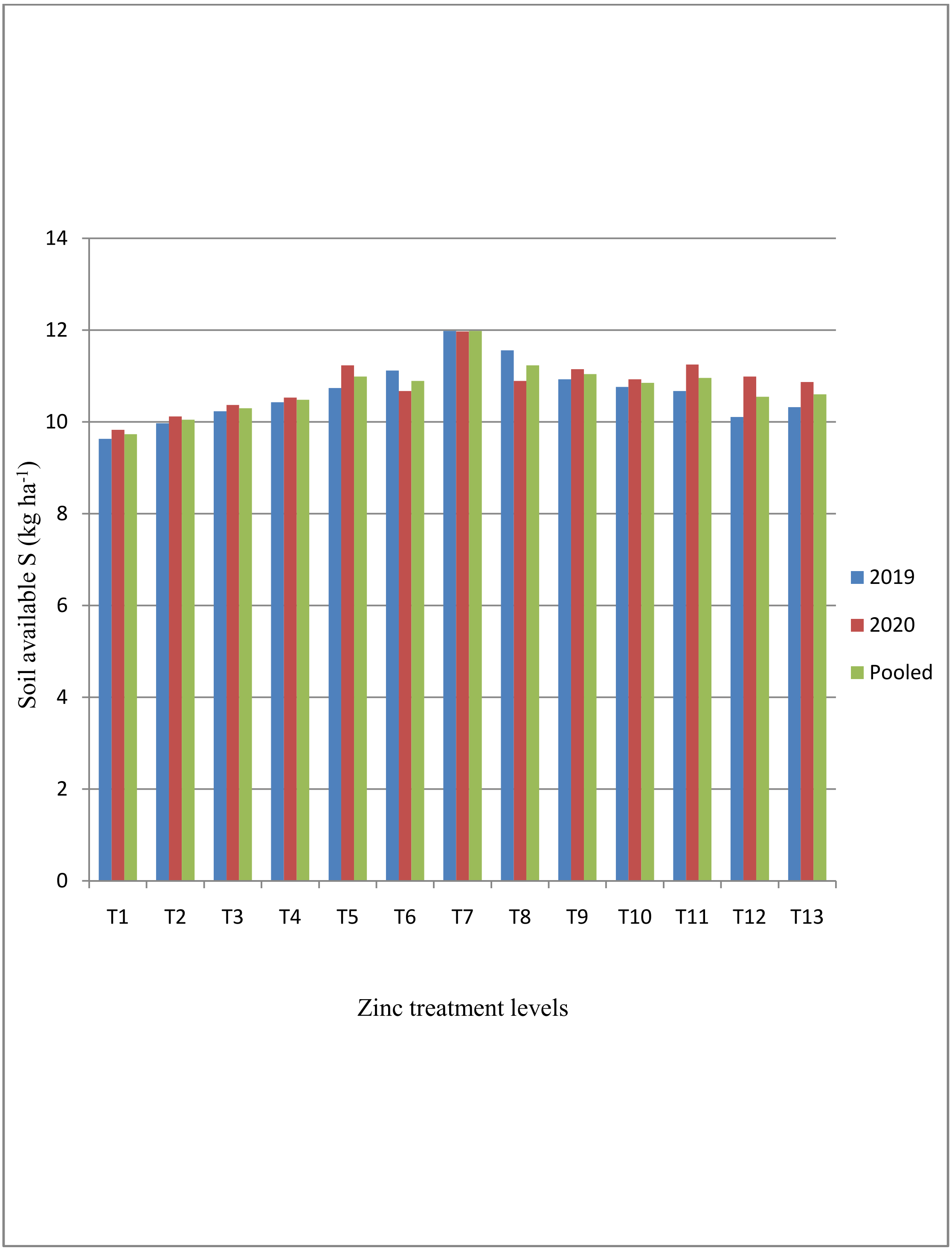

Fig 47: Effect of the sources and levels of Zn on soil available S

Table 4.33: Effect of the sources and levels of Zn on soil available Zn after harvest

Treatments	Available Zn (mg kg^{-1})		
	2019	2020	Pooled
T_1	0.24	0.23	0.24
T_2	0.23	0.24	0.24
T_3	0.32	0.21	0.27
T_4	0.29	0.25	0.27
T_5	0.26	0.30	0.28
T_6	0.39	0.33	0.36
T_7	0.30	0.29	0.30
T_8	0.36	0.34	0.35
T_9	0.39	0.35	0.37
T_{10}	0.32	0.33	0.33
T_{11}	0.20	0.21	0.21
T_{12}	0.24	0.20	0.22
T_{13}	0.21	0.21	0.21
SEm±	0.01	0.01	0.01
C.D at 5%	0.03	0.03	0.02

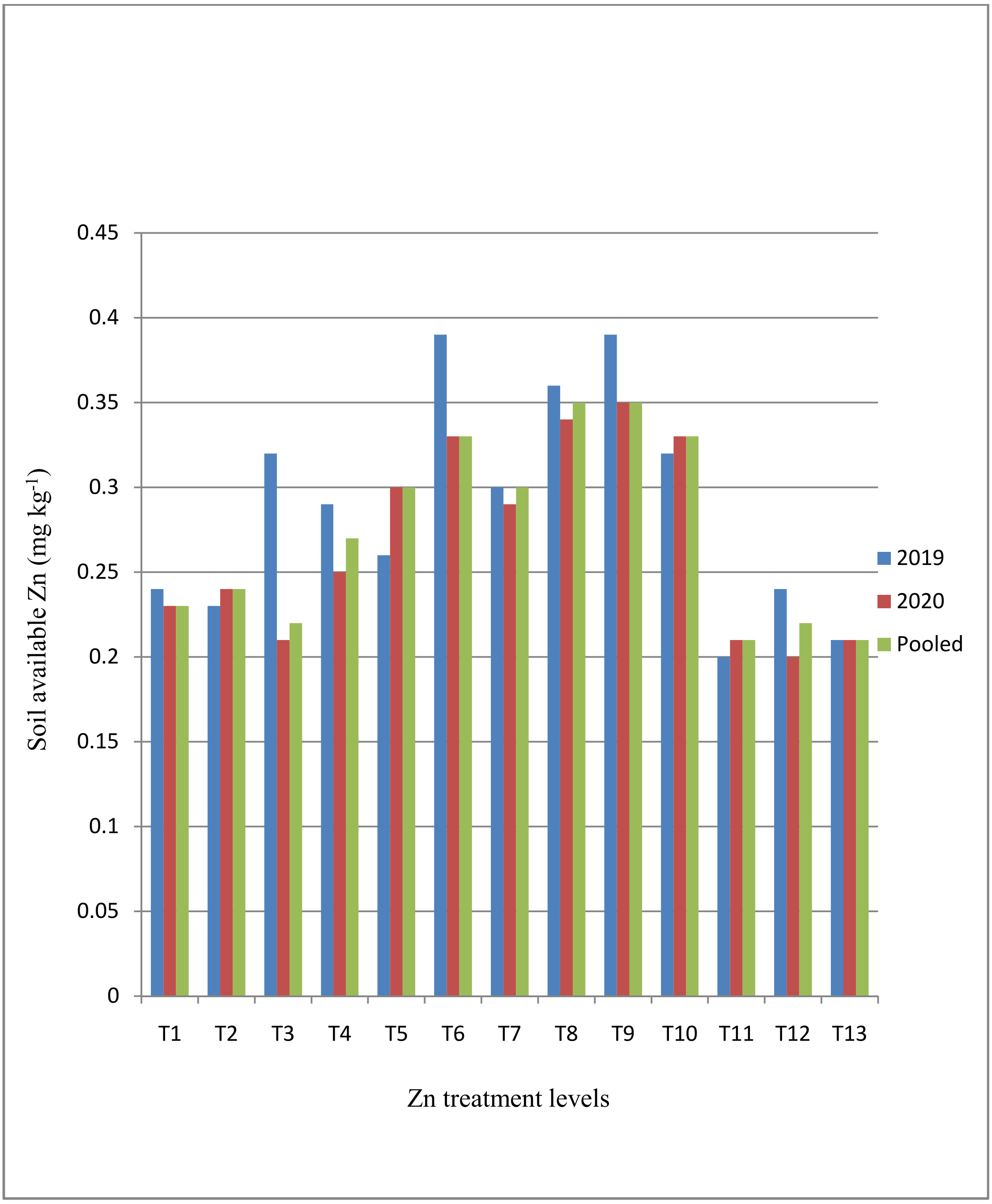

Fig 48: Effect of the sources and levels of Zn on soil available Zn

CHAPTER V

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

Field experiments were conducted in the Department of Agricultural Chemistry and Soil Science, School of Agricultural Sciences and Rural Development (SASRD), Nagaland University, Medziphema during the Kharif season of 2019 and at the State Horticulture Nursery, Green Park, Dimapur during the kharif season of 2020 to carry out the investigation entitled, “Response of Soybean (*Glycine max* L. Merril) to Sources and Levels of Zinc”. The main findings from the investigations are summarized below”

To study the response of soybean to sources and levels of Zn on growth, yield and quality

1. There was a significant increase in plant height at all the growth stages of soybean *i.e.* 30 and 60 DAS except at 90 DAS where it failed to give the significant result during 2019, 2020 and pooled respectively. The highest plant heights were observed at treatment T_9 (RDF + 5kg $ZnSO_4$ H_2O ha^{-1}) *i.e.* 31.63, 31.90, 31.77 cm at 30 DAS, 36.87, 36.91, 36.89 cm at 60 DAS and 38.24, 38.11, 38.18 cm at 90 DAS during 2019, 2020 as well as in pooled. Zn treatments such as T_8 (RDF + 5kg $ZnSO_4$ $7H_2O$ ha^{-1}) and T_{10} (RDF + 5 kg Zn-EDTA ha^{-1}) were found to closely follow T_9 treatment. The lowest data were recorded in the control plot (T_1) *i.e.*26.12, 27.31, 26.72 cm at 30 DAS, 33.23, 33.56, 33.40 cm at 60 DAS and 35.12, 35.80, 35.46 cm at 90 DAS during 2019, 2020 and pooled respectively.

2.The no. of nodules at flowering stage was increased significantly with the application of various Zn sources and levels. The maximum increased in the no. of nodules at flowering stage was found at treatment T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) *i.e.* 46.70, 45.10 and 45.90 which was closely followed by T_8 (RDF + 5 kg $ZnSO_4$ $7H_2O$ ha^{-1}) and T_{10} (RDF + 5 kg Zn-EDTA ha^{-1}) during

2019, 2020 and pooled respectively. The lowest was recorded in the control plot *i.e.* 32.30, 29.60 and 30.95.

3.The nodules fresh weight was significantly increased at the time of flowering with the application of Zn sources at 2019, 2020 and pooled respectively. The maximum fresh weight of nodules was recorded at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) treatment *i.e.*0.36, 0.37 and 0.37 g which was followed by T_8 (RDF + 5 kg $ZnSO_4$ $7H_2O$ ha^{-1}) and T_{10} (RDF + 5kg Zn-EDTA ha^{-1}). The lowest fresh weight of nodules in both the years and pooled were recorded at control plot (T_1) *i.e.*0.18, 0.18 and 0.18 g.

4.The dry weight of nodule was significantly influenced at the time of flowering in 2019 and 2020 respectively. Pooled data also show significant increase in the dry weight of nodules. The maximum nodule dry weight was observed in treatment T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) *i.e.* 0.13, 0.12 and 0.13 gwhich was closely followed by T_8 (RDF + 5 kg $ZnSO_4$ $7H_2O$ ha^{-1}) and T_{10} (RDF + 5 kg Zn-EDTA ha^{-1})in both the years and pooled. The lowest dry weight of noduleswere observed at control (T_1) *i.e.* 0.06, 0.05 and 0.05 g.

5.There was a significant increased on the seed yield of soybean with the application of various levels of Zn sources during 2019, 2020 and pooled respectively. The highest seed yield was observed at treatment T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) *i.e.* 1814.50, 1837.90 and 1826.20 kg ha^{-1}which was followed by T_8 (RDF + 5 kg $ZnSO_4$ $7H_2O$ ha^{-1}) during the consecutive years and pooled. The lowest seed yield was recorded in the control plot (T_1) *i.e.*1406.40, 1424.20 and 1415.30 kg ha^{-1}.

6. The stover yield of soybean was increased significantly during 2019, 2020 and pooled. The highest stover yield was recorded in treatment T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1})*i.e.*2198.10, 2226.30 and 2212.20 kg ha^{-1}which was found at par with T_8 (RDF + 5kg $ZnSO_4$ $7H_2O$ ha^{-1}). Zn treatment with increasing levels was found to be effective in increasing the stover yield. The lowest stover yield was recorded in the control (T_1)*i.e.* 1687.60 and 1663.80 and 1675.70 kg ha^{-1}.

7.The no. of pods plant^{-1}was showed to have positive influence with Zn application during 2019, 2020 and pooled respectively. The highest no. of pods plant^{-1} was recorded at Zn treatment T_9 (RDF + 5kg $ZnSO_4$ H_2O ha^{-1}) *i.e.* 104.30, 107.20 and 105.75 which was closely followed by T_8 (RDF + 5 kg $ZnSO_4$ $7H_2O$ ha^{-1}) and T_{10} (RDF + 5 kg Zn-EDTA ha^{-1}). The lowest no. of pods plant^{-1}was recorded in the control plot (T_1)*i.e.* 76.30, 63.30 and 68.80.

8.Effect of various Zn sources in soybean significantly increased the no. of seeds pod^{-1} during 2019, 2020 and pooled respectively. The maximum no. of seeds pod^{-1} was recorded at treatment T_9 (RDF + 5 kg $ZnSO_4H_2O$ ha^{-1}) *i.e.* 3.93 and 3.63 and 3.78 which enhance the yield attributes better than the rest of the other treatments. It was closely followed by treatments T_8 (RDF + 5 kg $ZnSO_4$ $7H_2O$ ha^{-1}) and T_{10} (RDF + 5 kg Zn-EDTA ha^{-1}). Treatment T_1 recorded the lowest no. of seeds pod^{-1} in both the years and pooled*i.e.*2.03, 2.00 and 2.02.

9. The test weight of soybean was showed to benon-significant with various Zn treatments during 2019, 2020 and pooled respectively. The maximum test weight was observed at treatment T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) *i.e.*72.54, 73.67 and 73.11 g and the lowest were observed at T_1 (control)*i.e.*68.40, 70.13 and 69.27 g.

10.The response of Zn sources on protein content in soybean was recorded to be significant during both the years and pooled. Among the various Zn sources, application of treatment T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) gave the highest protein content of 39.38, 38.69 and 39.04 %which was closely followed by T_8 (RDF + 5 kg $ZnSO_4$ $7H_2O$ ha^{-1}) and T_{10} (RDF + 5kg Zn-EDTA ha^{-1}) treatments. The lowest protein content was recorded in T_1 (control) i.e.33.50, 34.38 and 33.94 %.

11.The response of Zn sources on oil content in soybean was recorded to be significant. It was observed that during 2019, 2020 and pooled, the maximum oil content was recorded at treatment T_9 (RDF + 5 kg $ZnSO_4H_2O$ ha^{-1}) *i.e.*

23.96, 23.79 and 23.88 % where it produced higher response to the Zn treatment. It was closely followed by treatment T_8 (RDF + 5 kg $ZnSO_4$ $7H_2O$ ha^{-1}). The lowest oil content was recorded at control (T_1)*i.e.*19.24, 19.02 and 19.13 %.

To study the nutrient (NPKS& Zn) content and uptake by soybean aseffected by Zn

1. The effect of Zn sources on N content and uptake in seed and stover of soybean was found to be significant with its increasing levels. It was observed that the N content in seed and stover of soybean increased significantly with Zn application in 2019, 2020 and in pooled respectively. The highest N content in seed and stover was recorded at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) *i.e.* 6.30, 6.19 and 6.25 % in seed and 1.71, 1.69 and 1.70 % in stover which were followed by treatments - T_8 and T_{10}. The lowest was recorded in the treatment T_1(control)*i.e.*5.36, 5.50 and 5.43 % in seed and 1.53, 1.48 % and 1.51% in stover. The highest N uptake in seed and stover was recorded significantly at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) *i.e.*114.31, 113.77 and 114.04 kg ha^{-1} in seed and 37.59, 37.62 and 37.61 kg ha^{-1}in stover which was followed by T_8 and T_{10} treatment. The lowest was recorded in T_1*i.e.*79.75, 79.47 and 79.61 kg ha^{-1} in seed and at T_{11} (300 ml ha^{-1}Liquid ZnO) *i.e.*25.89, 30.47 and 28.18kg ha^{-1}in stover.

2.The various levels of Zn sources on P content and uptake in seed and stover of soybean was found to be non-significant. From the observations recorded, it was revealed that the P content and uptake in seed and stover of soybean did not increase significantly with Zn fertilization during the years 2019, 2020 and pooled respectively. The maximum P content in seed and stover was recorded at T_1 (control)*i.e.*0.22, 0.21, 0.21 % in seed and 0.20, 0.18, 0.19% in stover. The maximum P uptake in seed was recorded at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) *i.e.*3.63, 3.49 and 3.56kg ha^{-1}in seed and in stover it was recorded at T_1 (control) *i.e.*3.38, 2.99 and 3.19kg ha^{-1}as compared to the rest of the treatment applied.

3.The K content and uptake in seed and stover of soybean was found to be increased significantly with various sources and levels of Zn in both 2019 and 2020. Pooled data also indicate significant increase with increasing levels of Zn treatments. The highest K content in seed and stover was recorded at T_9 (RDF + 5 kg $ZnSO_4H_2O$ ha^{-1})*i.e.*1.69, 1.63 and 1.66 % in seed and 2.62, 2.42 and 2.52 % in stover and the lowest at control (T_1)*i.e.*1.12, 1.13 and 1.13 % in seed and 2.03, 2.16 and 2.10 % in stover. For K uptake in seed and stover, the highest value was reported at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) *i.e.*30.67, 29.96 and 30.32kg ha^{-1} in seed and 57.59, 53.88 and 55.74kg ha^{-1}in stover. The lowest was recorded at control (T_1)*i.e.*15.75, 16.39 and 16.07kg ha^{-1}in seed and 34.26, 35.94 and 35.10kg ha^{-1}in stover.

4.The Zn fertilization on S content and uptake in seed and stover of soybean was found to be non-significant. As per the observations, it was found that the S content and uptake in seed and stover of soybean did not increase significantly during the years 2019, 2020 and pooled respectively. The maximum S content in seed and stover was recorded at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) *i.e.*0.19, 0.18 and 0.19 % in seed and 0.32, 0.30 and 0.31 % in stover.The maximum nutrient uptake was also recorded at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) *i.e.* 3.53, 3.31 and 3.42 kg ha^{-1} in seed and 6.98, 6.59 and 6.79 kg ha^{-1} in stover as compared to the rest of the treatment applied.

5.On the basis of recorded value, it was revealed that the Zn content in seed and stover of soybean was increased significantly with Zn application in both 2019 and 2020. Pooled data also revealed significant increase in Zn content in seed and stover respectively. The highest Zn content in seed and stover was recorded at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) *i.e.*53.69, 63.65 and 58.67mg kg^{-1} in seed and 28.33, 28.65 and 28.49mg kg^{-1} in stover. The lowest was recorded at T_{13} (900 ml ha^{-1} Liquid ZnO) *i.e.*30.34, 28.97 and 29.66mg kg^{-1} in seed and T_1(control) *i.e.*20.12, 21.48 and 20.80mg kg^{-1} in stover. The highest K uptake in seed and stover was recorded at T_9 (RDF + 5kg $ZnSO_4H_2O$ ha^{-1}) *i.e.*97.42, 116.98 and 107.20g ha^{-1}inseed and 62.27, 63.78 and 63.03g ha^{-1}in stover which were followed by T_8 and T_{10} treatment. The lowest was recorded at T_{13} (900 ml ha^{-1} Liquid ZnO)*i.e.*47.28, 44.23 and 45.76g ha^{-1}in seed and T_1 (control) in stover *i.e.*33.95, 35.74 and 34.85g ha^{-1}as compared to the rest of the treatments.

To study the effect of sources and levels of Zn on Physicochemical properties of soil

1.The soil pH did not show much variation among the treatments with the applications of various levels of Zn treatments. From the data recorded, it showed that the pH in the soil was non- significant during 2019, 2020 and in pooled respectively. The maximum soil pH was recorded at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) *i.e.*5.85, 5.79 and 5.82over the rest of the treatment. The lowest was recorded at treatment T_{11} (300 ml ha^{-1} Liquid ZnO)*i.e.*5.18, 5.29 and 5.24.

2.The effect of various levels of Zn sources on soil electrical conductivity (EC) is found to be non-significant. From the observations made, it was observed that there was only a little variation among the Zn sources and the EC of the soil was not influence positively during 2019, 2020 and in pooled respectively. The maximum EC was recorded at T_7 (RDF + 2.5 kg Zn-EDTA)*i.e.*0.23, 0.22 and 0.23ds m^{-1}. The lowest was recorded at T_{10} (RDF + 5 kg Zn-EDTA)*i.e.*0.18, 0.17 and 0.18ds m^{-1}.

3.The response of Zn sources on postharvest soil OCwas not found to be positively influenced. According to the data recorded, it was observed that the OC in the soil was not significantly increased with Zn application during 2019, 2020 and pooled respectively. The maximum soil OC was recorded at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1})*i.e.*0.63, 0.60 and 0.62 %. The lowest was recorded at T_{12} (600 ml ha^{-1} Liquid ZnO)*i.e.*0.58, 0.53 and 0.56 %.

4.It was observed that the CEC in the postharvest soil were not increased significantly with various Zn treatmentsduring 2019, 2020 and in pooled. There was a very little variation among the various Zn sources. The maximum soil

CEC was recorded at T_7 (RDF + 2.5 kg Zn-EDTA)*i.e.*12.35, 13.14 and 12.75{cmol (p+) kg^{-1}}and the lowest was recorded at T_1 (control)*i.e.*11.97, 12.24 and 12.11{cmol (p+) kg^{-1}}.

5.The effect of Zn sources on soil particle density (PD) showed that it was not increased significantly with Zn application during both the years. The soil particle density (PD) was also found non-significant in the pooled data observed. The variation among the various Zn sources was also very less. The maximum particle density was recorded at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) *i.e.*2.35, 2.38 and 2.25g $cm^{-3}$and the lowest were recorded at T_1 (control)*i.e.*2.24, 2.26 and 2.26g cm^{-3}.

6.The response of Zn sources on soil bulk density (BD) was noticed to be non-significant. From the data recorded, it was observed that the BD in the soil were not increased positively with Zn during 2019, 2020 and pooled respectively. The maximum bulk density was recorded at T_8 (RDF + 5 kg $ZnSO_4$ $7H_2O$) *i.e.*1.22, 1.21 and 1.22g $cm^{-3}$and the lowest was recorded at T_1 (control)*i.e.*1.18, 1.15 and 1.17g cm^{-3}.

7.The application of various Zn treatmentsdid not show positive influence on the soil pore space (%). It was observed that the pore space in the soil were not increased significantly with Zn application during both the years and pooled respectively. The maximum pore space were recorded at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) *i.e.*48.51 and 49.26 % in 2019 and pooled and T_{10} (RDF + 5 kg Zn-EDTA) *i.e.* 50.63 % in 2020. There was a little variation among the various Zn sources.

To study the response of soybean to sources and levels of Zn on soil fertility

1. There was significant effect of various levels of Zn sources on available N in soil. As per the observations recorded, it was found that the highest available N in the soil was recorded at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1}) *i.e.*345.00, 357.90 and 351.45kg ha^{-1}as compared to the rest of the treatment during 2019, 2020

and pooled respectively. The lowest was recorded in the control plot (T_1) *i.e.*219.10, 231.70 and 225.40kg ha^{-1}.

2.The effect of various levels of Zn sources on soil available P was observed to be non-significant. From the data recorded, it was observed that the maximum available P in the soil was recorded at T_1 (control)*i.e.*14.34, 14.44 and 14.39kgha^{-1}as compared to the rest of the treatment.

3.It was observed that the available K in the soil was increased significantly with application of various Zn sources in both the years 2019 and 2020. It was also found to be significant in pooled. The highest soil available K was recorded at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1})*i.e.*251.10, 258.15 and 254.63kg ha^{-1}. It was found at par with T_8. The lowest was recorded in the control plot (T_1)*i.e.*115.70, 129.00 and 122.38kg ha^{-1}.

4.It was observed that the available S in the soil was not increased significantly with Zn sources during 2019, 2020 and pooled respectively. The maximum soil available S was recorded at T_7 (RDF + 2.5 kg Zn-EDTA)*i.e.*11.98, 11.97 and 11.98kg ha^{-1}. The lowest was recorded in the control treatment (T_1)*i.e.*9.63, 9.83 and 9.73kg ha^{-1}.

5.There was a significant increase insoil available Zn with application of Zn sources during 2019, 2020 and pooled respectively. It was observed that the maximum soil available Zn was recorded at T_9 (RDF + 5 kg $ZnSO_4$ H_2O ha^{-1})*i.e.*0.39, 0.35 and 0.35mg kg^{-1} and it was followed by T_8. The lowest was recorded in treatment T_{11} (300 ml ha^{-1} Liquid ZnO)*i.e.*0.20, 0.21 and 0.21mg kg^{-1}.

CONCLUSION

From the given summary, it can be concluded that:

1. The growth, yield, yield attributes and quality parameters were all significantly increased with the application of Zn fertilization along with RDF. Application of 5 kg $ZnSO_4$ H_2O ha^{-1} + RDF was found to be optimum to get desired yield of soybean crop.

2. Application of Zn @ 5 kg $ZnSO_4$ H_2O ha^{-1} + RDF was observed to significantly increase the nutrient content and uptake of N, K and Zn in seed and stover of soybean crop. Thus this treatment was found to give positive response.

3. The soil fertility status of N, K and Zn were increased significantly with the application of 5 kg $ZnSO_4$ H_2O ha^{-1} + RDF as compared to the rest of the treatments. This treatment proved to be optimum to give good performance and results in soybean crop.

4. As per the observations done from the experiments conducted, it was concluded that soybean responded well to Zn fertilization along with RDF. Application of 5 kg $ZnSO_4$ H_2O ha^{-1} + RDF had been found to be optimum for soil application under the acidic foothill condition of Nagaland.

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APPENDICES

Appendix I: Effect of the sources and levels of Zn on plant height of soybean at 30 DAS

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MS S	F cal	DF	SS	MSS	Fcal	
Years								1	9.09	4.55	5189.73 *	3.11
Replicatio	2	0.00	0.00	0.86	0.01	0.00	0.00	5	0.01	0.00	2.81*	2.22
Treatment	12	86.1	6.62	7737.7	60.4	4.65	5189.	12	146.5	5.64	6434.43	1.64
Error	24	0.03	0.00		0.03	0.00		60	0.07	0.00		

* Significant at 5% level

Appendix II: Effect of the sources and levels of Zn on plant height of soybean at 60 DAS

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	0.62	0.31	644.96	3.11
Replication	2	0.00	0.00	0.10	0.00	0.00	0.00	5	0.00	0.00	0.70	2.22
Treatment	12	33.5	2.58	4861.34	26.2	2.02	4710.13	12	59.8	2.30	4793.7	1.64
Error	24	0.02	0.00		0.02	0.00		60	0.04	0.00		

* Significant at 5% level

Appendix III: Effect of the sources and levels of Zn on plant height of soybean at 90 DAS

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	0.93	0.47	0.01	3.11
Replication	2	187.85	62.62	1.08	200.77	0.00	0.00	5	388.62	64.77	1.08	2.22
Treatment	12	24.48	1.88	0.03	12.41	0.95	0.02	12	36.89	1.42	0.02	1.64
Error	24	2261.66	57.99		2405.6	61.6		60	4667.35	59.84		

* Significant at 5%level

Appendix IV: Effect of the sources and levels of Zn on the number of nodules at flowering stage

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF				
Years								1	41.96	20.98	30.82	3.11
Replication	2	6.20	2.07	1.76	0.79	0.00	0.00	5	7.00	1.17	1.71	2.22
Treatment	12	1780.	136.9	116.5	1070	82.3	442.9	12	2851.	109.6	161.0	1.64
Error	24	45.85	1.18		7.25	0.19		60	53.10	0.68		

* Significant at 5%level

Appendix V: Effect of the sources and levels of Zn on fresh weight of nodules at flowering stage

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	0.00	0.00	1.97	3.11
Replication	2	0.02	0.01	19.03*	0.00	0.00	0.00	5	0.02	0.00	8.01*	2.22
Treatment	12	0.11	0.01	28.86*	0.10	0.01	17.90*	12	0.21	0.01	22.44*	1.64
Error	24	0.01	0.00		0.02	0.00		60	0.03	0.00		

* Significant at 5%level

Appendix VI: Effect of the sources and levels of Zn on dry weight of nodules at flowering stage

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	0.00	0.00	7.19*	3.11
Replication	2	0.00	0.00	0.31	0.00	0.00	0.00	5	0.00	0.00	0.51	2.22
Treatment	12	0.02	0.00	4.05*	0.02	0.00	13.02*	12	0.05	0.00	6.35*	1.64
Error	24	0.02	0.00		0.01	0.00		60	0.02	0.00		

* Significant at 5%level

Appendix VII: Effect of the sources and levels of Zn on seed yield

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MS	F	DF	SS	MSS	F cal	
Years								1	262	1313.	50267.64*	3.11
Replicatio	2	0.06	0.02	0.36	0.03	0.00	0.00	5	0.09	0.01	0.55	2.22
Treatment	12	46333 4.62	35641 .12	69340 1.77*	514 057.	395 42.8	455 641	12	977 392.	37592 .01	1438426.2 5*	1.64
Error	24	2.00	0.05		0.03	0.00		60	2.04	0.03		

* Significant at 5%level

Appendix VIII: Effect of the sources and levels of Zn on stover yield

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MS	F	DF	SS	MSS	F cal	
Years								1	20093 .00	10046. 50	194.2 6*	3.11
Replicatio n	2	0.03	0.01	11.97	332. 12	0.00	0.00	5	332.1 5	55.36	1.07	2.22
Treatment	12	82853 7.21	63733 .63	73438 426.1	121 955	938 12.1	906. 99*	12	20480 95.56	78772. 91	1523. 17*	1.64
Error	24	0.03	0.00		403 3.85	103. 43		60	4033. 88	51.72		

* Significant at 5%level

Appendix IX: Effect of the sources and levels of Zn on the number of pods plant^{-1}

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MS	F	DF	SS	MSS	F cal	
Years								1	1.25	0.63	0.56	3.11
Replication	2	87.92	29.31	17.57*	22.15	0.00	0.00	5	110.07	18.35	16.47*	2.22
Treatment	12	5350.67	411.59	246.76*	4835.03	371.93	663.97*	12	10185.70	391.76	351.64*	1.64
Error	24	65.05	1.67		21.8	0.56		60	86.90	1.11		

* Significant at 5%level

Appendix X: Effect of the sources and levels of Zn on the number of seeds plant^{-1}

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	0.09	0.09	0.29	4.04
Replication	2	0.02	0.01	0.03	0.53	0.27	1.00	4	0.56	0.14	0.45	2.57
Treatment	12	10.02	0.83	2.36*	9.43	0.79	2.95*	24	19.45	0.81	2.62*	1.75
Error	24	8.49	0.35		6.38	0.27		48	14.87	0.31		

* Significant at 5%level

Appendix XI: Effect of the sources and levels of Zn on the test weight

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	14.17	14.1	3.31	4.00
Replication	2	26.032	8.77	1.90	39.73	0.00	0.00	5	66.05	13.2	3.08	2.37
Treatment	12	49.60	3.82	0.83	25.52	1.96	0.99	12	75.12	6.26	1.46	1.92
Error	24	179.68	4.61		77.27	1.98		60	256.9	4.28		

* Significant at 5%level

Appendix XII: Effect of the sources and levels of Zn on the protein content

SOV	DF	2019			2020			Pooled				F tab
		SS	M	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	5.53	5.53	8095.00*	4.00
Replicatio	2	0.00	0.0	3.02	0.00	0.00	0.00	5	0.01	0.00	1.48	2.37
Treatment	12	75.61	6.30	7631.70*	46.95	3.91	4441.89*	12	122.56	10.21	14963.16**	1.92
Error	24	0.02	0.00		0.02	0.00		60	0.04	0.00		

* Significant at 5%level

Appendix XIII: Effect of the sources and levels of Zn on the oil content

	DF	2019			2020			Pooled				F tab
		SS	MSS	F	SS	MSS	F	DF	SS	MSS	F	
Years								1	7.03	3.51	46.8	3.11
Replication	2	0.18	0.06	0.41	0.00	0.00	0.24	5	0.18	0.03	0.41	2.22
Treatment	12	34.5	2.66	17.8	11.5	0.89	983.	12	46.1	1.78	23.6	1.64
Error	24	5.82	0.15		0.04	0.00		60	5.86	0.08		

* Significant at 5%level

Appendix XIV: Effect of the sources and levels of Zn on N content in seed

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	0.15	0.15	82.09	4.00
Replication	2	0.00	0.00	0.30	0.01	0.00	0.00	5	0.01	0.00	1.01	2.37
Treatment	12	1.94	0.16	57.99	1.20	0.10	58.0	12	3.14	0.26	145.0	1.92
Error	24	0.07	0.00		0.04	0.00		60	0.11	0.00		

* Significant at 5%level

Appendix XV: Effect of the sources and levels of Zn on N content in stover

SOV	DF	2019			2020			Pooled				F tab
		SS	MS	F cal	SS	MS	F	DF	SS	MS	F	
Years								1	0.05	0.05	2.77	4.00
Replication	2	0.03	0.01	18.74	0.10	0.00	0.00	5	0.12	0.02	1.33	2.37
Treatment	12	0.48	0.04	56.22	1.59	0.13	2.94	12	2.07	0.17	9.39	1.92
Error	24	0.02	0.00		1.08	0.05		60	1.10	0.02		

* Significant at 5%level

Appendix XVI: Effect of the sources and levels of Zn on N uptake in seed

SOV	DF	2019			2020			Pooled				F tab
		SS	MS	F cal	SS	MS	F cal	DF	SS	MSS	F cal	
Years								1	19.04	9.52	23031.1	3.11
Replication	2	0.00	0.00	0.04	0.00	0.00	0.00	5	0.00	0.00	0.25	2.22
Treatment	12	3421.74	263.21	434967.56*	3115.82	239.68	1081112.6	12	6537.57	251.44	608218.29*	1.64
Error	24	0.02	0.00		0.01	0.00		60	0.03	0.00		

* Significant at 5%level

Appendix XVII: Effect of the sources and levels of Zn on N uptake in stover

SOV	DF	2019			2020			Pooled				F tab
		SS	MS	F	SS	MS	F cal	DF	SS	MSS	F cal	
Years								1	32.95	16.48	61336.95	3.11
Replication	2	0.00	0.00	0.23	0.00	0.00	2.25	5	0.00	0.00	1.27	2.22
Treatment	12	359.87	27.68	105683.	277.68	21.36	77574.75*	12	637.54	24.52	91278.28*	1.64
Error	24	0.01	0.00		0.01	0.00		60	0.02	0.00		

* Significant at 5%level

Appendix XVIII: Effect of the sources and levels of Zn on P content in seed

SOV	DF	2019			2020			Pooled				F tab
		SS	MS	F	SS	MS	F cal	DF	SS	MSS	F cal	
Years								1	0.00	0.00	1.17	3.11
Replication	2	0.04	0.01	8.28	0.03	0.00	0.00	5	0.07	0.01	7.49*	2.22
Treatment	12	0.03	0.00	1.52	0.01	0.00	0.75	12	0.05	0.00	1.14	1.64
Error	24	0.06	0.00		0.06	0.00		60	0.12	0.00		

* Significant at 5%level

Appendix XIX: Effect of the sources and levels of Zn on P content in stover

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	0.00	0.00	0.13	3.11
Replication	2	0.01	0.00	1.06	0.01	0.00	0.00	5	0.02	0.00	1.25	2.22
Treatment	12	0.03	0.00	0.61	0.02	0.00	0.51	12	0.05	0.00	0.57	1.64
Error	24	0.15	0.00		0.09	0.00		60	0.24	0.00		

* Significant at 5%level

Appendix XX: Effect of the sources and levels of Zn on P uptake in seed

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	1.02	1.02	1.30	4.00
Replication	2	1.37	0.68	0.81	7.82	0.00	0.00	5	9.19	1.84	2.34	2.37
Treatment	12	9.73	0.81	0.96	5.19	0.43	0.39	12	14.9	1.24	1.58	1.92
Error	24	20.2	0.85		26.8	1.12		60	47.0	0.78		

* Significant at 5%level

Appendix XXI: Effect of the sources and levels of Zn on P uptake in stover

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	0.00	0.00	0.00	4.00
Replication	2	0.15	0.08	0.07	7.	0.00	0.00	5	7.69	1.54	2.08	2.37
Treatment	12	5.74	0.48	0.44	3.	0.31	0.40	12	9.44	0.79	1.07	1.92
Error	24	25.8	1.08		18	0.77		60	44.3	0.74		

* Significant at 5%level

Appendix XXII: Effect of the sources and levels of Zn on K content in seed

SOV	DF	2019			2020			Pooled				F tab
		SS	MS	F cal	SS	MS	F cal	DF	SS	MSS	F cal	
Years								1	0.08	0.08	232.39 *	4.00
Replication	2	0.00	0.00	0.06	0.00	0.00	0.00	5	0.00	0.00	1.33	2.37
Treatment	12	1.11	0.09	185.9	1.23	0.10	286.3	12	2.34	0.19	569.90	1.92
Error	24	0.01	0.00		0.01	0.00		60	0.02	0.00		

* Significant at 5%level

Appendix XXIII: Effect of the sources and levels of Zn on K content in stover

SOV	DF	2019			2020			Pooled				F tab
		SS	MS	F cal	SS	MS	F cal	D	SS	MS	F cal	
Years								1	0.2	0.2	419.60	4.00
Replication	2	0.0	0.0	0.59	0.0	0.0	0.00	5	0.0	0.0	0.21	2.37
Treatment	12	0.8	0.0	166.8	0.3	0.0	28.86	12	1.1	0.0	175.40	1.92
Error	24	0.0	0.0		0.0	0.0		60	0.0	0.0		

* Significant at 5%level

Appendix XXIV: Effect of the sources and levels of Zn on K uptake in seed

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	16.74	16.74	295.87*	4.00
Replication	2	0.00	0.00	1.53	0.08	0.00	0.00	5	0.08	0.02	0.28	2.37
Treatment	12	664.05	55.34	136162.43	667.75	55.65	394.65*	12	1331.81	110.98	1962.11*	1.92
Error	24	0.01	0.00		3.38	0.14		60	3.39	0.06		

* Significant at 5%level

Appendix XXV: Effect of the sources and levels of Zn on K uptake in stover

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	31.07	31.07	49461.08	4.00
Replication	2	0.00	0.00	2.22	0.00	0.00	0.00	5	0.00	0.00	1.18	2.37
Treatment	12	1392.	116.05*	148634.16	1062.84	88.57	112150.08*	12	2455.43	204.62	325719.70*	1.92
Error	24	0.02	0.00		0.02	0.00		60	0.04	0.00		

* Significant at 5%level

Appendix XXVI: Effect of the sources and levels of Zn on S content in seed

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	0.00	0.00	0.94	4.04
Replication	2	0.00	0.00	0.62	0.00	0.00	0.02	4	0.00	0.00	0.38	2.57
Treatment	12	0.01	0.00	1.40	0.00	0.00	1.05	24	0.01	0.00	1.26	1.75
Error	24	0.01	0.00		0.01	0.00		48	0.02	0.00		

* Significant at 5%level

Appendix XXVII: Effect of the sources and levels of Zn on S content in stover

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	0.00	0.00	1.57	1
Replication	2	0.02	0.01	8.07	0.00	0.00	0.37	4	0.02	0.01	4.77*	4
Treatment	12	0.02	0.00	1.24	0.00	0.00	0.37	24	0.02	0.00	0.86	24
Error	24	0.03	0.00		0.02	0.00		48	0.06	0.00		48

* Significant at 5%level

Appendix XXVIII: Effect of the sources and levels of Zn on S uptake in seed

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	0.06	0.06	0.16	4.04
Replication	2	2.65	1.32	3.16	0.74	0.37	1.23	4	3.39	0.85	2.35	2.57
Treatment	12	5.71	0.48	1.13	3.89	0.32	1.08	24	9.60	0.40	1.11	1.75
Error	24	10.07	0.42		7.20	0.30		48	17.27	0.36		

* Significant at 5%level

Appendix XXIX: Effect of the sources and levels of Zn on S uptake in stover

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	0.03	0.03	0.02	4.04
Replication	2	3.89	1.95	1.01	2.50	1.25	1.01	4	6.39	1.60	1.01	2.57
Treatment	12	9.49	0.79	0.41	10.24	0.85	0.69	24	19.7	0.82	0.52	1.75
Error	24	46.3	1.93		29.67	1.24		48	76.0	1.58		

* Significant at 5%level

Appendix XXX: Effect of the sources and levels of Zn on Zn content in seed

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	248.20	248.20	515.91*	4.00
Replication	2	2.5	1.26	1.41	18.62	0.00	0.00	5	21.14	4.23	8.79*	2.37
Treatment	12	2282.4	190.21	212.51*	4662.52	388.54	1262.77*	12	6945.01	578.75	1202.97*	1.92
Error	24	21.48	0.90		7.38	0.31		60	28.87	0.48		

* Significant at 5%level

Appendix XXXI: Effect of the sources and levels of Zn on Zn content in stover

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	0.07	0.07	0.05	4.00
Replicatio	2	1.38	0.69	0.64	0.21	0.00	0.00	5	1.59	0.32	0.22	2.37
Treatment	12	159.8	13.3	12.32	173.	14.43	5.66	12	332.	27.75	19.12	1.92
Error	24	25.95	1.08		61.1	2.55		60	87.0	1.45		

* Significant at 5%level

Appendix XXXII: Effect of the sources and levels of Zn on Zn uptake in seed

SOV	DF	2019			2020			Pooled				F tab
		SS	MS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	876.96	876.96	1221.49*	4.00
Replication	2	1.38	0.69	0.67	7.54	0.00	0.00	5	8.92	1.78	2.49*	2.37
Treatment	12	10561.50	880.13	858.12*	19955.73	1662.98	2161.87*	12	30517.23	2543.10	3542.18*	1.92
Error	24	24.62	1.03		18.46	0.77		60	43.08	0.72		

* Significant at 5%leve

Appendix XXXIII: Effect of the sources and levels of Zn on Zn uptake in stover

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	8.65	8.65	818.34*	4.00
Replication	2	0.00	0.00	0.28	0.05	0.00	0.00	5	0.05	0.01	0.96	2.37
Treatment	12	1923.91	160.33	230727.39	2327.71	193.98	7541.69*	12	4251.63	354.30	33531.80	1.92
Error	24	0.02	0.00		0.62	0.03		60	0.63	0.01		

* Significant at 5%level

Appendix XXXIV: Effect of the sources and levels of Zn on soil pH

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MS	F	
Years								1	0.03	0.02	0.04	3.11
Replication	2	0.19	0.06	0.41	0.27	0.00	0.00	5	0.33	0.05	0.14	2.22
Treatment	12	1.66	0.13	0.83	0.64	0.05	0.09	12	4.30	0.17	0.42	1.64
Error	24	6.00	0.15		21.87	0.56		60	30.48	0.39		

* Significant at 5%level

Appendix XXXV: Effect of the sources and levels of Zn on soil EC

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	0.00	0.00	0.00	4.00
Replication	2	0.00	0.00	0.58	0.00	0.00	0.00	5	0.00	0.00	0.75	2.37
Treatment	12	0.00	0.00	0.73	0.01	0.00	0.69	12	0.01	0.00	1.77	1.92
Error	24	0.01	0.00		0.02	0.00		60	0.03	0.00		

* Significant at 5%level

Appendix XXXVI: Effect of the sources and levels of Zn on soil OC

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MS	F	
Years								1	0.01	0.01	0.16	4.00
Replication	2	0.04	0.02	0.28	0.90	0.00	0.00	5	0.94	0.19	2.78	2.37
Treatment	12	0.01	0.00	0.01	0.06	0.00	0.05	12	0.06	0.01	0.08	1.92
Error	24	1.73	0.07		2.33	0.10		60	4.06	0.07		

* Significant at 5%level

Appendix XXXVII: Effect of the sources and levels of Zn on CEC

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	8.69	8.69	6.10	4.00
Replication	2	0.00	0.00	0.00	2.46	0.00	0.00	5	2.46	0.49	0.35	2.37
Treatment	12	1.26	0.11	0.06	3.07	0.26	0.15	12	4.33	0.36	0.25	1.92
Error	24	44.0	1.83		41.5	1.73		60	85.5	1.43		

* Significant at 5%level

Appendix XXXVIII: Effect of the sources and levels of Zn on soil particle density

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	M	F cal	DF	SS	MSS	F cal	
Years								1	0.00	0.00	0.41	3.11
Replication	2	0.06	0.02	5.51*	0.15	0.05	84.60*	5	0.20	0.03	16.80*	2.22
Treatment	12	0.05	0.00	1.03	0.01	0.00	1.38	12	0.06	0.00	1.08	1.64
Error	24	0.13	0.00		0.02	0.00		60	0.16	0.00		

* Significant at 5%level

Appendix XXXIX: Effect of the sources and levels of Zn on soil bulk density

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	0.01	0.01	9.53*	4.00
Replication	2	0.00	0.00	1.47	0.01	0.00	0.00	5	0.01	0.00	1.20	2.37
Treatment	12	0.00	0.00	2.06	0.01	0.00	0.32	12	0.02	0.00	1.03	1.92
Error	24	0.00	0.00		0.07	0.00		60	0.07	0.00		

* Significant at 5%level

Appendix XXXX: Effect of the sources and levels of Zn on soil porosity

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	48.92	48.92	2.54	4.00
Replication	2	3.85	1.92	2.08	81.38	0.00	0.00	5	85.23	17.05	0.89	2.37
Treatment	12	17.04	1.42	1.54	28.32	2.36	0.05	12	45.35	3.78	0.20	1.92
Error	24	22.15	0.92		1132.62	47.19		60	1154.77	19.25		

* Significant at 5%level

Appendix XXXXI: Effect of the sources and levels of Zn on available N

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								2	951.30	475.65	7298.73*	3.11
Replication	3	0.20	0.07	1.46	0.73	0.24	2.90*	6	0.93	0.16	2.39*	2.22
Treatment	13	49947.94	3842.15	82991.20*	49341.03	3795.46	45161.19*	26	99288.97	3818.81	58598.31*	1.64
Error	39	1.81	0.05		3.28	0.08		78	5.08	0.07		

* Significant at 5%level

Appendix XXXXII: Effect of the sources and levels of Zn on available P

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	0.01	0.01	0.00	4.00
Replication	2	0.62	0.31	0.10	8.67	0.00	0.00	5	9.28	1.86	0.55	2.37
Treatment	12	41.86	3.49	1.17	33.26	2.77	0.51	12	75.12	6.26	1.87	1.92
Error	24	71.38	2.97		130.00	5.42		60	201.38	3.36		

* Significant at 5%level

Appendix XXXXIII: Effect of the sources and levels of Zn on available K

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	M	F cal	DF	SS	MSS	F cal	
Years								1	613568.06	306784.03	579506351.5*1	3.11
Replication	2	0.35	0.12	132.95	0.00	0.00	0.97	5	0.35	0.06	109.15*	2.22
Treatment	12	59873.80	4605.68	5306695.67*	13.59	1.05	5473.90*	12	59887.038	2303.36	4350983.54*	1.64
Error	24	0.03	0.00		0.01	0.00		60	0.04	0.00		

* Significant at 5%level

Appendix XXXXIV: Effect of the sources and levels of Zn on available S

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	0.64	0.64	0.04	4.00
Replication	2	43.13	21.56	1.00	43.09	0.00	0.00	5	86.21	17.24	1.00	2.37
Treatment	12	15.13	1.26	0.06	10.90	0.91	0.04	12	26.04	2.17	0.13	1.92
Error	24	517.56	21.56		517.60	21.57		60	1035.16	17.25		

* Significant at 5%level

Appendix XXXXV: Effect of the sources and levels of Zn on available Zn

SOV	DF	2019			2020			Pooled				F tab
		SS	MSS	F cal	SS	MSS	F cal	DF	SS	MSS	F cal	
Years								1	0.01	0.01	28.81*	4.00
Replication	2	0.00	0.00	3.60*	0.00	0.00	0.00	5	0.01	0.00	4.55*	2.37
Treatment	12	0.15	0.01	41.25*	0.12	0.01	25.98*	12	0.27	0.02	82.30*	1.92
Error	24	0.01	0.00		0.01	0.00		60	0.02	0.00		

* Significant at 5%level