BIOFORTIFICATION OF ZINC AND IRON IN SOYBEAN (*Glycine max* (L.) Merrill) UNDER FOOTHILL OF NAGALAND

Thesis

submitted to

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in partial fulfilment of requirements for the Degree of

Doctor of Philosophy

in

Agronomy

by

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2022

Dedicated

To my beloved Mother

(L) Smt. Trialscene

Makdoh

DECLARATION

I, Badapmain Makdoh, 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 **"Biofortification of zinc and iron in soybean (*Glycine max* (L.) Merrill) under foothill of Nagaland"** submitted to Nagaland University in partial fulfilment of the requirements for the award of degree of Doctor of Philosophy (Agriculture) in Agronomy is the record of research work carried out by Mr. Badapmain Makdoh, Registration No. Ph.D/AGR/00113 under my personal supervision and guidance.

The result of the investigation reported in the thesis has 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 AGRONOMY

This is to certify that the thesis **"Biofortification of zinc and iron in soybean (*Glycine max* (L.) Merrill) under foothill of Nagaland"** submitted by Badapmain Makdoh, Admission No. Ph-240/17, Registration No. Ph.D/AGR/00113 to the NAGALAND UNIVERSITY in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy (Agriculture) in Agronomy has been examined by the Advisory Board on …………………...........

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Place: Medziphema

Date : .... *(Badapmain Makdoh)*

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LIST OF ABBREVIATIONS

@	: At the rate of
AAS	: Atomic absorption spectrophotometer
AE	: Agronomic efficiency
B:C	: Benefit-to-cost ratio
^oC	: Degree Celsius
cm	: Centimeter (s)
cv.	: Cultivar or variety
DAS	: Days after sowing
dS	: desi Siemens
DTPA	: Diethylene-triamine-penta-acetic acid
EDTA	: Ethylene-diamine-tetra-acetic acid
et al.	: And others
FDA	: Fluorescience diacetate hydrolytic activity
Fe	: Iron
$FeSO_4$. $7H_2O$	: Ferrous sulphate heptahydrate
Fig.	: Figure
ha	: Hectare
hrs	: Hours
HI	: Harvest index
i.e.,	: That is
K or K_2O	: Potassium
kharif/rabi	: Indian agricultural crop seasons
kg	: Kilogram
$KMnO_4$	: Potassium permanganate
KOH	: Potassium hydroxide
K_2SO_4	: Potassium sulphate
µL	: Microlitre
Mini.	: Minimum
mg	: Miligram
mM	: Millimolar
M	: Molar

MOP	: Muriate of potash
N	: Nitrogen
N	: Normal
NaOH	: Sodium hydroxide
No.	: Number
NS	: Non-significant
OC	: Organic carbon
O. D.	: Optical Density
P or P_2O_5	: Phosphorus
PE	: Physiological efficiency
PFP	: Partial factor productivity
pH	: Puissance de hydrogen
q	: quintal
%	: Per cent
$^{-1}$	: Per
RE	: Recovery efficiency
RH	: Relative humidity
Rs	: Rupee
S	: Sulphur
SDS	: Sodium Dodecyl Sulphate
SEm±	: Standard error of mean
Sl. No.	: Serial number
SSP	: Single super phosphate
t	: tone
t ha^{-1}	: Tonne per hactare
TPF	: Triphenyl formazan
Viz.,	: Namely or they are
Zn	: Zinc
ZnHI	: Zinc harvest index
ZnMEI	: Zinc mobilization efficiency index
ZnO	: Zinc oxide
$ZnSO_4.H_2O$	: Zinc sulphate heptahydrate

ABSTRACT

The present study entitled "Biofortification of zinc and iron in Soybean (*Glycine max* (L.) Merrill) under foothill of Nagaland" was conducted in two experiments. The Experiment I was conducted during 2018 and 2019 at the Research farm of SASRD, Nagaland University, Medziphema. The field experiment was laid out in factorial RBD in three replications consisted of three (3) varieties *viz*., JS-335, JS-97-52 and local cultivar with seven (7) zinc treatments *viz*., Z_0 (control), Z_1 (Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$), Z_2 (Soil application of Zn @ 5 kg ha^{-1} through ZnO), Z_3 (Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$ + Two foliar spray application of $ZnSO_4$ @ 0.25%), Z_4 (Soil application of Zn @ 5 kg ha^{-1} through ZnO + Two foliar spray application ZnO @ 0.25%), Z_5 (Three foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5%) and Z_6 (Three foliar spray applications of ZnO @ 0.5 %). The results of the experiment revealed that varieties differed significantly in some of the important growth and yield parameters, where JS 97-52 was found superior in almost all aspects. Seed yield was recorded significantly higher in JS 97-52 (1.88, 1.69 t ha^{-1}) than JS-335 (1.49, 1.52 t ha^{-1}) and local cultivar (1.29, 1.24 t ha^{-1}).

Among the zinc fertilization treatments, Z_5 was found most effective and was at par with Z_3 in many parameters in enhancing growth, yield, nutrient uptake and grain quality of soybean. Zinc sulphate ($ZnSO_4.7H_2O$) was found more effective and convenient zinc fertilizer source when compared to ZnO. Seed yield was found to increase (19.70, 20.88%) from (1.38, 1.32 t ha^{-1}) in control to (1.65 ,1.59 t ha^{-1}) under Z_3 treatment which was effective as Z_5 (1.62, 1.55 t ha^{-1}). With respect to biofortification and zinc content in grain, it was observed that JS-335 and local cultivar was slightly higher over JS-97-52 (9% and 8% higher zinc content). However, significantly higher phytic acid content was observed in grain of local cultivar which is an antinutritional factor having a negative effect on zinc bioavailability. Phytic acid content in local cultivar (718.71 mg/100 g) was 24.53% and 16.64 % higher than JS-335 (577.12 mg/100 g) and JS 97-52 (616.18 mg/100g) and this implies that zinc bioavailability in local cultivar was much lower. However, desirable parameters like agronomic use efficiency and biofortification recovery efficiency were higher in JS-335 and JS 97-52. Considering the comparatively higher grain quality like protein, oil with lower phytic acid content alongside with it significantly higher seed yield, JS 97-

52 can be considered a better option among the varieties. Among zinc treatments, Z_5 (Three foliar applications of zinc sulphate @ 0.5%) found to have the highest value of biofortification recovery efficiency, partial factor productivity and agronomic use efficiency with the maximum BC ratio. With respect to zinc content in grain, Z_5 and Z_3 were the two most effective zinc application treatments with the highest zinc density enhancement of 29.20% and 24.60%, respectively. These are the suitable factors for considering the choice for effective recommendation of zinc agronomic biofortification programmes.

The Experiment II was conducted as pot experiment to study the biofortification of iron in soybean with same varieties and with six iron fertilization treatments laid out in Factorial CRD, simultaneously with the experiment I. Six (6) iron treatments *viz*., Fe_0 as Control, Fe_1 (Foliar spray application of $FeSO_4.7H_2O$ @ 0.5%), Fe_2 (Foliar spray application of $FeSO_4.7H_2O$ @ 1%), Fe_3 (Foliar spray application of $FeSO_4.7H_2O$ @ 1.5%), Fe_4 (Foliar spray application of $FeSO_4.7H_2O$ @ 2%), Fe_5 (Soil application of $FeSO_4.7H_2O$ @ 10 kg ha^{-1}). Two foliar applications of each foliar treatments were applied at pre-flowering stage of the crop. Many growth parameters were significantly affected by varieties and Fe fertilization. Fe_3 (Foliar spray application of $FeSO_4.7H_2O$ @ 1.5%) was found most effective treatment for enhancing growth, yield and quality of soybean in both the years. With foliar application of 1.5% iron sulphate (Fe_3) it was found to enhance seed yield by 27.60%, protein content by 8.50%, oil content by 6.20% and most importantly the Fe content in grain by 18.51% over the control. One of the important observations with this Fe treatment (Fe_3) was that phytic acid and phytic acid: Fe molar ratio was found to reduce by 13.43% and 27.41%, respectively over the control. Hence, it is concluded that foliar application of 1.5% iron sulphate can be recommended as an effective biofortification strategy for enhancing iron content of soybean seed and simultaneously improving its grain yield and quality as well.

Key words: Biofortification, Soybean, Zinc, Iron, Yield, Quality

CHAPTER I

INTRODUCTION

INTRODUCTION

Soybean (*Glycine max* L.) is considered to be the miracle crop of the 21st century due to its high content in protein (42-45%), oil (22%) and starch content (21%), good source of vitamin B complex, particularly thiamine and riboflavin. Soybean's protein, being rich in valuable amino acids like lysine (5%), low saturated fat content with no cholesterol; omega-3 fats along with minerals including calcium, magnesium, ferrous and selenium. Soybean is considered the world's most important seed legume crop and it shares 25% of the global edible oil and contributes almost two-thirds of protein concentrate required for livestock feed production globally. Being a crop with sustainable yield, higher economic return, and its contribution towards maintaining soil health has further increase its importance agriculture widely.

In India the area, production and productivity were reported to be 11.40 m ha, of 10.90 mt and 1049 kg ha^{-1}, respectively (Anon., 2020). India is also the 4th largest producer of soybean in the world. Soybean is also considered to be an important crop in the North-Eastern states of India. This crop has been part and parcel of the farming communities. Although, soybean being categorized as an oilseed crop, however cultivated as a pulse crop and a major source of vegetable protein. The crop has always been an integral part in the culture and farming systems of different ethnic groups and farming communities of North-Eastern India in general and Nagaland in particular. Soybean has been traditionally known be an invaluable item of different cuisines and local delicacies of almost all communities of the region. It is consumed roasted, fermented, fresh pods as vegetable and local preparations by almost all the tribal communities of this region. In the state of Nagaland many tribes have been using soybean as an important ingredient for many local delicacies especially in fermented forms. Akhoni, a local fermented soybean of Sema tribe of Nagaland is a favoured preparations liked by many tribes of the Northeast. It is also well recommended owing to its high nutritious value and good sources of quality protein, minerals and vitamins. The area, production and productivity of soybean in Nagaland was reported to be 2424 ha, 2510 mt and 1032 kg ha^{-1}, respectively (Anon., 2010). In recent decades many efforts have been taken to popularize soybean crop through various governmental programmes and intensive varietal trials under varied cropping systems and climatic situations with an aim to expand the area of the crop and improve its productivity in the state.

Currently, one of the major concerns on public health and socio-economic issue particularly developing countries is zinc and iron deficiency (Welch & Graham, 2004). Through recent reports, around 5000 children below the age of 5 years die every year (Black *et al.*, 2010). According to an estimate that of the world's total population, it was found that 60-70% has iron deficiency and more than 30% has zinc deficiency. India accounts for more than 27% of the world's undernourished population which is 230 million people under the category (Chakraborti *et al.*, 2011). According to Stoltzfus and Dreyfuss (1998), iron deficiency is one of the most prevalent micronutrient deficiencies in the world, affecting an estimated two billion people. According to WHO (2002), iron deficiency is ranked 6^{th} among the risk factors for death and disability in developing countries. The recommended daily allowance of iron is 13 mg per day for children, 17 mg per day for adult and that of zinc is 7 mg per day for children, 12 mg per day for adult. Unfortunately, in India, due to lack of nutritional diversity deficiency in micronutrients, iron and zinc are prevalent (Anon., 2009). Zinc deficiency is also estimated to affect billions of people, affecting growth and development, and most importantly their immune systems.

Zinc is a structural constituent of proteins or a catalysing co-factor which involved for the functioning of many enzymes such as the RNA polymerase, cellular signalling proteins, superoxide dismutase, having important role in multiple biological functions (Johnson & Giulivi, 2005; Oteiza & Mackenzie, 2005). In most case zinc deficiency is associated with poor diets which are highly dependent on cereal-based food products which often have low zinc content and bio-availability as well (Wessells & Brown, 2012; Clemens, 2014).

Approximately 50% of the cereal-growing areas in the world are often confined to soils with low plant available Zn (Cakmak, 2002). Indian soil as a whole is known to be deficient in zinc, which according to Sharma (2008) is estimated to be 49% which will likely to increase to 63% by 2025. Soil analysis reports demonstrated that approximately 12% of Indian soils are Fe deficient. Almost 70% of the total geographical area of North-Eastern region has acidic soils. Zinc deficiency of acidic soils of NE region was also explained by Sarkar and Singh (2003), who reported that zinc deficiency is predominant with the highest rate of 57% in acid soils of Kerala and Meghalaya. The available DTPA-extractable zinc and iron in Dimapur, Nagaland was reported to be 1.20 and 107.10 mg kg^{-1} soil respectively (Anon., 2017). Bandyopadhay *et al*. (2014) reported that available Zn in Dimapur area mostly in the sufficient zone covering 74.40% (in the range of 0.6-1.2 and above 1.2 mg kg^{-1}) of the TGA of the district. Similarly, the available Fe was in sufficient concentration in 98% of TGA.

Among micronutrients, zinc and iron is known to play a crucial role in their health and well beings. Zinc is an exceptional micronutrient regarding its relevance in biological systems because it is the only metal represented in all classes of enzyme (Broadley *et al*., 2007). Zinc is involved in several physiological processes of the plant growth and metabolism like enzyme activation, protein synthesis, carbohydrates metabolism, auxins, lipids, nucleic acids, reproductive development, gene expression and regulation etc. (Cakmak, 2000). It is found to involve in the activity of more than hundred enzymes that are part of the major metabolic pathways that is vital in many biochemical, immunological and clinical functions (Hotz & Brown, 2004). Iron is a structural component of porphyrin molecules, cytochromes, hematin, ferrichrome and leghaemoglobin involved in oxidation reduction reactions in respiration. Iron is an important constituent element for the nitrogenase enzyme which plays an important role in N-fixation through the N-fixing bacteria and also in the chloroplast for photosynthetic reduction processes. Human requirement of zinc or iron is derived from his food which in turn derives from the soil-plant system and in case if deficiency is observed in that system, it will be reflected in human health as zinc or iron malnutrition.

In the past 30 years there has been a serious issue to address dietary micronutrient deficiency in a more preventive and holistic approach through agriculture aiming at combating food and human micronutrient deficiency concurrently (Rouse & Davis, 2004; Burchi *et al*., 2011). For alleviating the problem of zinc and iron deficiency in humans, strategies comprising of zinc and iron supplementation, fortification, dietary diversification/ modification and biofortification can be deployed. The approach through 'biofortification' gradually has gained global attention (Graham *et al*., 2001). Biofortification is defined as 'the process of increasing the bioavailable concentrations of essential elements in edible portions of crop plants through genetic selection or agronomic intervention' (White & Broadley, 2005).

Biofortification of food crops has been considered to be the most cost-effective approach to addressing micronutrient malnutrition (Qaim *et al*., 2007; Stein *et al*., 2007). Among those, agronomic bio-fortification is considered most sustainable, easy and cost-effective approach. Agronomic bio-fortification is defined as the process of increasing the bioavailable concentrations of an element in edible portions of crop plants through agronomic intervention by application of nutrients through various external approaches (White & Broadley, 2005). In the recent past many agronomic biofortification programmes have been mainly emphasized on major cereals or staple food crops like wheat, maize and rice which indeed gave encouraging results for enhancing zinc and iron density in grain. Hence, the concept has since been gradually extended to different crops based on preferences or location specific. So, the idea of ferti-fortification of zinc and iron on soybean crop being a commonly cultivated crop in the state of Nagaland has been considered in this research programme. Although soybean is a pulse crop it is also known to be a good source of many essential minerals and vitamins, but unfortunately their bioavailability is relatively very low due to the presence of anti-nutrient factors. Agronomic biofortification could be an alternative tool to improve bioavailability of these micronutrients in such crops. This approach could possibly be a practicable means of reaching a wider population in rural areas or financially weaker sections with a goal to deliver naturally-fortified foods who have limited access to costly fortified foods without compromising crop yield or change their dietary preference.

Hence, a study that will take into account a crop like soybean which has not only been traditionally-cultivated but also has shown its vital importance in the state of Nagaland with the objective to enhance its grain quality *viz*., zinc and iron content and simultaneously improve its yield as well. Apart from that, very limited number of studies and information available related to this aspect in the region which could benefit for future researches. Keeping in view of the above points, the present experiment entitled "Biofortification of zinc and iron in Soybean (*Glycine max* (L.) Merrill) under foothill of Nagaland" was proposed with the following objectives:

1. To study the effect of zinc and iron application on growth and yield of soybean
2. To assess the zinc and iron application on biofortification of soybean cultivars
3. To work out the economics of zinc and iron treatment under study

CHAPTER II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

2.1 Genotypic response to Zn and iron application and their efficiency

Graham *et al.* (1992) reported that there were differences in varieties and strains of crops in their efficiency to take up zinc from their environment where it was found out that zinc efficient ones able to take more zinc even under low zinc availability and accumulate more dry matter compared to zinc inefficient ones, but may not always produce high zinc concentration.

Graham *et al*. (1997) also observed that there was large variation in iron and zinc content in grains of rice varieties. The aromatic cultivars have consistently higher concentration of iron and zinc in grain than the non-aromatic types Zn-efficient varieties with Zn-dense seeds are higher yielding in Zn-deficient soils.

Khoshgoftarmanesh *et al.* (2004) studied the Zn efficiency of five wheat cultivars on saline calcareous soil at Iran and reported that variation among wheat cultivars was found in relation to grain yield and Zn use efficiency. They found that the most efficient cultivar was Cross and the most inefficient one was Dur-3 whereas cultivars Kavir, Falat and Rushan were intermediate in Zn use efficiency.

Joshi *et al.* (2010) studied the effect of genotype x environment interaction in Eastern Gangetic plains for variation in Fe and Zn concentrations of wheat grains and reported that micronutrient density in grain is highly variable for different genotypes sown at different locations. Hussain *et al*. (2010) elaborated that there are differences in endurance among crop genotypes towards zinc levels in soils, despite optimum zinc amount applied as accumulation in grains is higher than the plants growth requires.

Hossain *et al*. (2011) reported that in his experiment on maize responsiveness to zinc addition found that varieties were not equally responsive hybrids as well as composites and suggests that BARI Hybrid Maize-3 and BARI Maize-6 were the most Zn responsive (Zn efficient) varieties.

2.2 Crop growth

2.2.1 Effect of zinc nutrition on crop growth

Shukla and Warsi (2000) recorded significantly more leaf area index, crop growth rate, net assimilation rate, relative growth rate, dry matter accumulation, grain yield, and harvest index as compared to control treatment with soil application of 25 kg $ZnSO_4$ ha^{-1}.

Sangwan and Raj (2004) also reported a similar kind of finding with respect to branching in chickpea, clusterbean, mungbean and pigeonpea with the application of zinc at a magnitude of 15 kg Zn ha^{-1}, 5 kg Zn ha^{-1}, 10 kg Zn ha^{-1} and 5 mg kg^{-1}.

Ghatak *et al.* (2005) reported that Zn fertilizer application ($ZnSO_4.H_2O$ or ZnO) significantly increased the plant height and effective tillers of rice plants. Similarly, Sharma *et al*. (2009) in their work in Karnataka, recorded significantly higher plant height (184.09 cm) of pigeonpea under combined application of $ZnSO_4$ @ 15 kg ha^{-1} and FYM @ 5t ha^{-1}.

Naik and Das (2007) reported that the performance of split applications of $ZnSO_4$ was found to be significantly better than the corresponding basal application and no Zn application, in terms of growth characteristics Zn fertilizer application significantly increased maize (*Zea mays* L.) dry matter yield compared with the control treatment.

Khan *et al*. (2008) conducted experiment on wheat with 0 (Control), 5, 10, 15, 20, 25 and 30 kg zinc sulphate ha^{-1}. Result revealed that leaf area index increased with each of the zinc applications. Maximum LAI's obtained were in the range 2.0 to 2.5 at ear emergence with the application of 30 kg zinc sulphate ha^{-1}.

Sharma *et al*. (2009) also reported that the application of FYM @ 5 t ha^{-1} + $ZnSO_4$ @ 15 kg ha^{-1} to pigeonpea showed significantly higher primary branches (12.34) and secondary branches (7.86 $plant^{-1}$) as compared to the treatment without FYM.

Shivay *et al*. (2010) in his experiment on rice observed that Zn fertilization significantly increased the plant height and other growth parameters of rice over no Zn application.

Kulhare *et al*. (2014) in their investigation at Jawaharlal Nehru Krishi, Vishwa, Vidyalaya during 2007-2009, observed that with the application of Zn @ 5 kg ha^{-1} incubated with 200 kg of cow dung significantly increased plant height of soybean over control at all the growth stages.

Shivay *et al*. (2016) in the experiment conducted in New Delhi to compare the effect of zinc sulphate heptahydrate and Zn–EDTA on growth, yield and zinc concentration of rice, it was reported that foliar spray does not have much significant difference when compared with soil application especially on single foliar spray. When it comes to zinc concentration and uptake by rice, three foliar applications of 0.5% solution of ZnSHH (Zinc sulphate hepta hydrate) recorded significantly much higher Zn concentration in grain and straw than soil applied treatment.

Tayyeba *et al*. (2017) in the investigation in Pakistan on mungbeans with various concentrations of Zn they found that the application of Zn @ 2μM significantly improved the plant height.

2.2.2 Effect of iron nutrition on crop growth

Bhanavase *et al*. (1994) reported that soil application of ferrous sulphate at 25 kg ha^{-1} in soybean crop increased nodule number, nodule dry weight and dry matter accumulation when compared to control. Also, Mundra and Bhati (1991) in their experiment on cowpea found that soil application of ferrous sulphate at 10 kg ha^{-1} increased the number of branches $plant^{-1}$, dry matter accumulation and nodulation.

Farhan and Al-Dulaemi (2011) conducted a pot experiment on wheat to study the effect of foliar application of microelements (Cu, Zn and Fe) on growth and productivity. They reported the results revealed that all microelement treatments showed significant increase in height of plant, leaf number, leaf area, branch number, total dry weight for shoots and roots, chlorophyll content, concentrations of N, P, K, Fe, Zn, Cu, starch, protein in grains, 1000-grain weight and grain yield. Also results showed that application of Fe gave increases in grain yield, protein and starch in grains by 29, 30 and 6%, respectively compared to the control treatment.

Trivedi *et al*. (2011) conducted investigation on the effect of iron and sulphur application on growth and yield of soybean where two levels of iron (15 and 20 mg kg^{-1} soil) and sulphur (40 and 80 mg kg^{-1} soil) were applied on soybean individually and in combination. It was reported that positive effect of iron and sulphur application was observed on different parameters *viz,* plant height, number of leaves $plant^{-1}$, root length, chlorophyll content, nitrogen content of leaf, number of pods $plant^{-1}$, pod length, growth parameters, 100 seed weight and protein content.

Abbas *et al*. (2012) reported that applications of Fe affected the yield and growth parameter of wheat and NPK uptake. Application rate of doses 12 kg Fe ha^{-1} improved the number of tillers per square meter, straw yield, spike length, 1000-grain weight and grain yield of wheat in first year, whilst in second year it increased the spikelets per spike, spike length, 1000-grain weight and grain yield on recommended NPK.

Rawashdeh and Sala (2014) in their field experiment which was carried out to evaluate the influence of foliar application of Fe-chelate on growth and physiological parameters of wheat at various growth stages. Results showed that using foliar application of Fe at different growth stages significantly increased and improved the plant height, number of plants per square meter, flag leaf area and flag leaf chlorophyll content as compared to without Fe application.

2.3 Yield and yield attributes

2.3.1 Effect of Zinc on yield and yield attributes

Saxena and Chandel (1997) in their study in highly Zn-deficient soils of Pantnagar, reported that application of 10 kg Zn ha^{-1} increased soybean yield by more than 50%. Soybean (JS-335) seed yield was significantly high (2.59 t ha^{-1}) at high levels of Zn while it was lower (2.10 t ha^{-1}) in control.

Brennan *et al*. (2001) in their investigation on zinc fertilization chickpea which reported that there were significant differences in pods $plant^{-1}$ and 1,000-seed weight and significant differences in yield between Zn treatments. The smallest number of pods $plant^{-1}$ (5.90 pods $plant^{-1}$) but the highest 1,000-seed weight (374.80 g) was obtained in ZnO treatment. The lowest yield (2.65 g $plant^{-1}$) was obtained when no Zn was applied.

Dube *et al*. (2001) in the investigation onPigeonpea (*Cajanus cajan* L. Millsp.) in Western UP. The increase in height, branching, production of pods and harvest index of pigeonpea was highest at 5 mg kg^{-1} Zn added soil which raised DTPA extractable soil Zn from 0.41 to 1.23 mg kg^{-1}.

Nayyar *et al.* (2001) reported that ZnO was inferior to Zn sulphate with respect to grain yield of rice. Hence, due to better solubility, Zn sulphate-enriched urea produced more grain yield than Zn oxide-enriched urea at the same level of Zn enrichment.

Rattan and Sharma (2004) reported that the Zn oxide was inferior to Zn sulphate both in grain yield and N uptake. However, the degree of influence varied depending upon the soil type, weather condition, and duration of the crop, method of rice culture and application of Zn fertilizers.

Kanase *et al*. (2008) conducted a field experiment during *Kharif* 2001-02 to study response of soybean to application of Zn in an Inceptisol. The results revealed that the application of Zn 7.5 kg ha^{-1} through zinc sulphate recorded the highest grain yield (3958 kg ha^{-1}) and on par with 5 and 10 kg ha^{-1} (3955 kg ha^{-1}). The results also specified that the application of Zn increased the uptake of the NPK and micronutrient at harvest and zinc sulphate was superior to zinc oxide.

Shivay *et al.* (2008b) reported that the highest grain and straw yields were recorded with 2.0% Zn-coated urea irrespective of the Zn sources *i.e*., $ZnSO_4$ or ZnO. It was concluded that $ZnSO_4$ showed superiority over ZnO.

Valenciano *et al*. (2009) in the pot experiment on chickpea in Spain reported that plants fertilized with Zn resulted in greater value of total dry matter production mainly due to increments in pods weight. The lowest yield (2.65 g $plant^{-1}$) was obtained from 0 mg Zn pot^{-1}, while the highest yield (3.52 g $plant^{-1}$) was recorded at 4 mg Zn pot^{-1}. The increased yields in Zn applied plants were the result of increased number of pods $plant^{-1}$.

Sharma *et al*. (2010) revealed that the seed yield was significantly higher with RDF + $ZnSO_4$ @ 15 kg ha^{-1} (13.73 q ha^{-1}) followed by RDF + $ZnSO_4$ @ 25 kg ha^{-1} (13.53 q ha^{-1}). All the yield contributing characters *viz*., number of pods $plant^{-1}$, number of seeds pod^{-1}, 100-seed weight and protein content were increased significantly over control.

Nasri *et al.* (2011) conducted an experiment on *Phaseolus vulgaris* to determine the effect of Zn foliar application under different levels of N and K fertlizers in Iran. Data showed that N, K and Zn-foliar application significantly affected Zn in pod, nitrate in pod, carbohydrate percentage, carbohydrate yield, protein percentage, protein yield, chlorophyll of leaf, number of pods in plant, number of pods in m^2, number of seeds pod^{-1}, 100 seed weight, fresh pod yield, seed yield, biological yield, harvest index and plant height.

Nadergoli *et al*. (2011) conducted a field experiment on the effect of zinc and Mn on common bean in Iran under different stages of crop as foliar application. Results showed that the highest plant height, number of seeds pod^{-1}, number of pods plant^{-1}, shilling percentage, yield and harvest index were obtained by foliar application at shooting, flowering and podding stages, respectively. The highest 100 kernel weight was obtained by foliar application at shooting, flowering and podding stages with manganese sulphate.

Pable and Patil (2011) conducted an experiment to study the effect of sulphur and zinc on nutrient uptake and yield of soybean crop *var*. JS-335 on vertisol during 2009. Results revealed that application of 30 kg ha^{-1} of sulphur and 2.5 kg ha^{-1} of zinc with fertilizer dose of 30:75:0 kg NPK ha^{-1} recorded higher seed and straw yield.

Singh *et al*. (2012) found that application of $ZnSO_4$ @ 25 kg ha^{-1} combined with 5t ha^{-1} FYM increased number of pods plant^{-1} in chickpea. Foliar application of 0.2% $ZnSO_4$ at seed filling stage in chickpea showed significantly higher number of seeds plant^{-1} (83.92) in chickpea as compared to no foliar application (Habbasha *et al*., 2013).

Kumar *et al*. (2016) stated that deficiency of zinc, boron, molybdenum is one of the major factors constraining crop production on acidic soils of Northeast India. To assess the criticality of micronutrients' application on these soils, a greenhouse experiment on an acid Alfisol where French bean (*Phaseolus vulgaris* L.), a micronutrient-sensitive crop, was grown with seven combinations of macro and micronutrients. The results suggested that on acidic soils, micronutrients application is indispensable for improving growth and yield of crops, particularly pulses, which are more sensitive to micronutrients.

2.3.2 Effect of iron on yield and yield attributes

Ziaeian and Malakouti (2001) found that Fe, Mn, Zn and Cu fertilization significantly increased grain yield, straw yield, 1000 grain weight, and the number of grains per spikelet in calcareous soil. Also, they reported that grain yield increases 20.80% with rate of Fe application 20 kg ha^{-1} compared to without Fe. Also showed that application of Fe significantly increased the concentration and total uptake of Fe in grain, flag leaves grain protein contents as well.

Gupta *et al*. (2003) in the experiment at Kota (Rajasthan) on mungbean found that application of Fe either through soil (2.20 and 5.00 mg kg^{-1}) or foliar application of 0.5% $FeSO_4$ increased the grain yield when compared to the control.

Kumar *et al*. (2009) in his experiment in Kanpur, India on chickpea found that the number of branches $plant^{-1}$, number of pods $plant^{-1}$, number of grains pod^{-1} and test weight were found to be significantly increased with levels of Fe up to 10 kg ha^{-1} over control.

Farhan and Al-Dulaemi (2011) conducted a pot experiment on wheat to study the effect of foliar application of microelements (Cu, Zn and Fe) on growth and productivity. It was reported that that all microelement treatments showed significant improved growth parameters, protein in grains, 1000-grain weight and grain yield. Also results showed that application of Fe increased grain yield, protein and starch in grains by 29, 30 and 60%, respectively compared to the control treatment.

Habib (2012) in the field experiment which was conducted on clay-loam soil at Parsabad Moghan region, Iran to investigate the effect of foliar application of zinc, iron and urea on wheat yield and quality at filling stage. It was found that that foliar application of Zn and Fe increased seed yield and its quality when compared with the control. Foliar feeding with urea increased seed yield and yield component, but Fe, Zn and Cu concentration reduced them, as compared to other foliar feeding methods.

Kumar *et al*. (2015) in their field experiment which was conducted to study iron fertilization on aerobic rice (*Oryza sativa* L.) varieties during the rainy (*kharif*) seasons of 2011 and 2012 at the research farm of the IARI, New Delhi. Their results revealed that the highest dry-matter accumulation and number of effective tillers/m^2 and grain yield were recorded with 3 foliar sprays of 2.0% iron sulphate followed by 3 foliar sprays of 0.5% iron chelate. They reported that the highest grain yield was recorded from the 3 foliar sprays of 2.0% iron sulphate followed by three foliar sprays of 0.5% iron chelate, two foliar sprays of 2.0% iron sulphate and two foliar sprays of 0.5% iron chelate, whereas the lowest grain yield was recorded in the control plot.

2.3.3 Cumulative effect of zinc and iron nutrition on crop growth, yield and quality

Anitha *et al*. (2005) has indicated that foliar application of micronutrients like iron and zinc has significant influence on the yield of cowpea. It was also found that the combined spraying of 0.5% $FeSO_4$ and 0.5% $ZnSO_4$ at 45 DAS confirmed most effective and increased the seed yield by 43.09%.

Patel *et al.* (2009) reported that foliar spraying of 0.5% $ZnSO_4$ at 25 and 45 DAS gave significantly higher grain and straw yield of cowpea (1451 and 2011 kg ha^{-1}) over control. They also reported that spraying of 0.5% $FeSO_4$ spray at 25 and 45 DAS gave significantly higher seed and straw yields of cowpea (1377 and 1918 kg ha^{-1}) over control.

Ghasemian *et al*. (2010) reported that yield and yield attributes of soybean is affected by application of iron, zinc and manganese. It was stated that those applications improved yield and yield components like number of pods, pod weight $plant^{-1}$, biological yield and seed yield kg ha^{-1}.

Heidarian *et al*. (2011) reported that application of Zn + Fe as combined treatment on soybean had significant effect on grain yield, number of pods $plant^{-1}$ ($p<0.01$). The timing of foliar application on number of pods per plant

(<0.05) and 1000 grain weight ($p<0.01$) was found to be significant. Also, with foliar application of zinc higher values of crop growth rate (CGR) and net assimilation rate (NAR) were recorded.

Kobraee *et al.* (2011a) conducted an experiment at Research Farm, Islamic Azad University of Kermanshah during 2010. Three levels of Zn (0, 20, 40 kg), Fe (0, 25, 50 kg) and Mn (0, 20, 40 kg) having source of $ZnSO_4$, $FeSO_4$ and $MnSO_4$ respectively, were tested. Results indicated that applying zinc to soybean resulted in increase in plant height, number of pods plant^{-1}, biological yield, harvest index and grain yield.

Mostafavi (2012) indicated that combined application of Zn + Fe on soybean registered maximum yield which was 15.75 t ha^{-1}. Zn treatment and Fe treatment separately yielded 25 and 11.41 % higher than control treatment in soybean, respectively.

Naz *et al.* (2015) conducted a pot experiment to assess the biofortification potential of wheat crop by exogenously applied Fe and Zn. Soil and foliar application with two levels of Fe and Zn (2 ppm and 4 ppm) were applied at milking stage of wheat. Results showed that soil application at level 4 ppm of Fe and Zn is significant effect on plant available nutrients and nutrient concentration in wheat straw and grain. Application of Fe and Zn also increased and improved growth parameters.

Pal *et al.* (2019) in the experiment biofortification of Zn and Fe on chickpea at Punjab, India found that soil application of $ZnSO_4$ @ 25 kg ha^{-1} + foliar spray of $ZnSO_4$ @ 0.5% at flowering and pod formation stages resulted in the highest Zn (45.06 & 44.69 mg Zn kg^{-1} grain). It was also reported that grain yield with the application of $ZnSO_4$ @ 25 kg ha^{-1} at sowing combined with foliar spray of Zn at flowering and pod formation stages, which was 14.20% and 10.60% higher than control treatment.

Soni and Kushwaha (2020) in the field trial on mungbean with foliar spray of zinc and iron found that plant height, number of nodules plant^{-1} and branches plant^{-1} were not influenced significantly by foliar spray of zinc and iron. Yield attributes *viz*., pods plant^{-1} was significantly improved with 0.5% $FeSO_4$ spray at flower initiation. Application of 0.5% $ZnSO_4$ spray at flower initiation and pod initiation stage resulted in maximum seed yield of mung (571 kg ha^{-1}) and pod length (6.30 cm).

Hafeez *et al*. (2021) conducted field-based experiments to study the impact of agronomic biofortification of two wheat cultivars with zinc and iron. Two spring-planted bread wheat cultivars Zincol-16 (Zn-efficient) and Anaj-17 (Zn-inefficient with high-yield potential) were treated with either zinc (10 kg ha^{-1}), iron (12 kg ha^{-1}), or their combination. Maximum proteins were recorded in Anaj-17 under control treatments. Zincol-16 produced maximum ionic concentration, starch contents, and wet gluten as compared to Anaj-17. Combined application of Zn and Fe resulted in significant enhancement of yield and growth attributes as compared to the sole application of Zn or Fe.

2.4 Effect on nodulation, chlorophyll content and phenology

2.4.1 Effect on Nodulation

Balachander *et al*. (2003) reported that the application of Fe at 2 kg ha^{-1} through ferrous sulphate significantly increases the number and weight of nodules, biomass production, plant height and grain yield of black gram over control.

Goudar *et al*. (2008) reported that there was a significant increase in the nodule number, nodule dry weight and nodule N content in soybean due to seed treatment with *Bradirhizobium japonicum* strains along with the combination of zinc and molybdenum.

Kobraee *et al.* (2011b) reported that there were significant differences in the number, fresh and dry weight of nodules plant^{-1} due to different levels of zinc, iron and manganese application. The maximum number of nodules plant^{-1} was obtained from 4, 8 and 30 mg Zn, Fe and Mn kg^{-1} soil, respectively.

Pooladvand *et al.* (2012) in their investigation suggested that $FeSO_4$ increased seed production, nodule formation and the number of pods and leaves. But there is negative impact of excessive application of ferrous sulphate as with higher concentrations of $FeSO_4$ reduced nodules and leaf numbers.

Ismail and Tariq (2018) on the experiment on mungbean in Pakistan found that application of various levels of both iron and zinc significantly increased the nodules number as well as nodules weight. With Fe application of 5 kg ha^{-1} has resulted for a maximum number of nodules plant^{-1}, similarly Zn application also improved the no of nodules plant^{-1} linearly from 24 at 0 kg ha^{-1} to 30 at 10 kg ha^{-1}.

2.4.2 Effect on Chlorophyll

Ebrahim and Aly (2004) conducted a pot experiment on wheat plants, grown in sandy soil and two times applied with Zn at concentrations of 25 and 50 mg L^{-1}. This treatment significantly increased the photosynthetic criteria (Chlorophyll “a” and “b” "concentration and PS II activity) as well as the metabolite (Soluble sugars, polysaccharides and total-soluble proteins) accumulation in shoots.

Janakiraman *et al.* (2005) reported that in Zn-deficient soils, application of Zn increased the nodulation, chlorophyll content and pod yield of groundnut.

Ahmed *et al.* (2022) in his experiment on rice to find out the effect of zinc deficiency on chlorophyll content. It was reported that the highest level of Zn significantly enhanced chlorophyll a (134 and 65%), chlorophyll b (143 and 43%), total chlorophyll (142 and 60%), in both Super Basmati (SB) and KSK-434 rice varieties.

2.4.3 Effect on Phenology

Adams *et al*. (2000) reported that in zinc, iron and manganese deficiency conditions, leaf chlorophyll concentration also found to be reduced. Metal such as Zn, Fe and Mn are required in the biosynthetic pathway and essential for the synthesis of chlorophyll (Pushnik & Miller., 1989).

Jalivand *et al*. (2014) reported that balanced fertilization of Fe and Zn promotes early tillering, early booting and early anthesis. Hafeez *et al*. (2013) also reported early anthesis with Zn application. Vigorous crop growth rate and their effect on the earliness of anthesis might be attributed to physiological role of Zn in pollen formation and carbohydrate metabolism (Reddy, 2004).

Keram *et al*. (2014) reduction in days to 50% flowering with the increasing Zn level could be due to the role of Zn in regulating the synthesis of auxin that promotes flowering. They elaborated that early flowering in wheat crop might also be due to the fact that Zn which helps in the activation of enzymes that are involved in maintenance of cellular membrane integrity, synthesis of auxin and protein.

Tayade *et al*. (2018) in the experiment to study the effect of foliar application of zinc and iron on flowering and quality of tuberose found that foliar application of 0.4% $ZnSO_4$ recorded significantly minimum days to initiation of first spike (95.38 days), days to opening of first pair of florets (13.60 days), days to 50% flowering (106.32 days) and days to first harvesting (104.45 days) when compared to the control.

Narahari *et al*. (2018) reported that application of (0.8% Zinc + 0.8% Boron) in Gooseberry, resulted in early flowering and fruiting. This early flowering might be due to rapid initial plant growth because of favourable environment and due to proper and appropriate concentrations of micronutrients. Earliness (Flowering and fruiting) might be because of better absorption of the nutrients which involved in the metabolic activity and also activated the hormone which influence the earliness.

Ali *et al*. (2021) on their agronomic biofortification study with zinc and iron for the improvement of wheat phenology, revealed that there was significant effect of foliar Zn and Fe application on the days to anthesis. Control plots showed delayed anthesis (121 and 119 days), while earlier anthesis (118 and 119 days). It was also observed that the anthesis in wheat was delayed by about three days in unsprayed check plots (120 days) over the rest treatments (117 days). Similarly, higher doze of foliar Fe spray also delayed the anthesis across the experimental period. Application of 6 kg ha^{-1} Fe resulted in inducing earlier anthesis (116 days) while plots treated with water spray only delayed the anthesis (118 days).

2.5 Effect on Zinc and Iron concentration and uptake (Biofortification)

2.5.1 Zinc biofortification and uptake

Cakmak (2008) in Turkey reported that the soil and foliar application of zinc fertilizers were the most effective method for increasing Zn in grain that resulted in about 3.5 folds increases in the grain Zn concentration.

Sahrawat *et al.* (2008) reported that the grain and straw quality of maize crop improved with the application of zinc to maize crop as compared to control treatment. Zinc concentration in maize grain also increased significantly due to applied zinc in maize crop.

Shivay *et al.* (2008) conducted field experiments at the IARI, New Delhi and reported that application of Zn in the form of 0.5 to 2% of Zn enriched urea significantly increased yield attributes, grain and straw yield, Zn concentrations in the grain and straw and Zn uptake in spring wheat. It was found that $ZnSO_4$ and ZnO were equally effective in increasing the grain yield of wheat. Zn enrichment of urea with $ZnSO_4$ gave significantly higher agronomic efficiency than ZnO.

Dhaliwal *et al*. (2009) on his experiment of biofortification of zinc and iron in wheat in Punjab found that foliar spray application of Zn and Fe significantly increased the Zn density of the grain by 17.3-38.8% and 13.1-30.3% with Fe through inorganic sources of Zn ($ZnSO_4.2H_2O$) and Fe ($FeSO_4.2H_2O$), respectively.

Habib (2009) reported that foliar application of Fe and Zn at tillering and heading stage increased Fe and Zn concentration from 84.93 to 139.60 and 12.17 to 20.27 mg kg^{-1} respectively, compared with control and consequently increased grain yield.

Kumar *et al*. (2011) reported that N and Zn content of grain and straw increased significantly with the application of increasing levels of Zn and the highest contents were observed with the application of 30 kg ha^{-1} $ZnSO_4$, it was at par with the application of 20 kg ha^{-1} $ZnSO_4$.

Lu *et al.* (2011) conducted a field experiment in China to study the effect of combined P and Zn fertilization on the Zn nutritional quality of wheat grown on potentially Zn-deficient calcareous soil. It was reported that Zn fertilization increased grain Zn concentrations by 13% and 15% in two years experiment. It was also found that with the application of 200 kg P_2O_5 ha^{-1} combined with Zn fertilizer has reduced grain Zn concentrations by 38% and 17% in both the years compared with the control.

Ram *et al*. (2011) reported that application of zinc either through soil or foliar or both have significant effect on increasing zinc concentration in wheat grain. The grain Zn significantly increased (from 29.36 to 224% higher) with Zn application (Soil + foliar) over no Zn application.

Wen *et al*. (2011) concluded from his experiments at China that foliar Zn application at the early grain development stage increased grain Zn concentration and decreased the phytic acid concentration and the phytic acid to

Zn molar ratio thereby improving the bioavailability in wheat grown on potentially Zn-deficient calcareous soil.

Zhang *et al*. (2011) studied the effect of Zn biofortification of wheat through fertilizer application on different locations of China and results showed that foliar Zn application was much more effective than soil Zn application in enrichment of wheat grain with Zn as compared to no foliar Zn application. Foliar application of 0.4% $ZnSO_4.7H_2O$ application resulted in grain Zn with 58% increase in whole grain Zn, 76% increase in wheat flour Zn and up to 50% decrease in the molar ratio of phytic acid to Zn in flour.

2.5.2 Iron biofortification and uptake

Dhaliwal *et al*. (2013) in the experiment conducted on maize at fertifortification of maize cultivars with iron found that increased the concentration of Fe at knee high, pre-tasseling, post-tasseling and maturity stages. The results further reported that foliar application of Fe ($FeSO_4.7H_2O$) @ 1.0% significantly increased the plant height, SPAD value and grain yield of maize compared with unsprayed control. Among different maize cultivars, per cent increase in Fe concentration was higher in PMH-1 (62%) cultivar which was followed by Prabhat (40%) and Navjot (39%) cultivars. On the other hand, JH-3459 and Navjot cultivars reported almost equivalent concentrations of Fe as 39.90 and 39.57 mg kg^{-1} respectively.

Yadav *et al*. (2013) in the field experiment at New Delhi to study the Fe density and uptake in aerobic rice as influenced by mulching and iron nutrition. It was reported that mulching improved the iron concentration and uptake in grain and straw in paddy rice where the application of 2.0% $FeSO_4$ (Three foliar sprays) recorded higher Fe concentration at the same time enhanced the Fe uptake by grain as well as in straw. There was also improvement of Fe concentration in grain and straw from 5.40 to 19.90% in grain and 5.80 to 13.30% straw of aerobic rice. It was also reported that application of Fe fertilizer increased the grain and straw yield 4.00 to 8.20% and 2.70 to 6.70% over control, respectively.

Hanumanthappa *et al.* (2018) in the study which was conducted to evaluate the effect of micronutrient fertilization on increasing iron and zinc content of pigeonpea genotypes at Karnataka, India Fe and Zn content of pigeonpea through foliar spray of Fe @ 0.5 per cent and Zn @ 0.5 per cent at pod setting stage. It was reported that when compared to control that, foliar application of Fe @ 0.5 per cent and Zn @ 0.5 per cent at the time of pod setting stage significantly increased Fe concentration of pigeonpea by 71.29% and Zn by 26.52%.

Dhaliwal *et al*. (2022) in the three-year experiment at Ludhiana, Punjab on biofortification of soybean with $FeSO_4$ to observe the application rate and number of sprays application reported that due to the enhanced enzymatic activity of Fe-containing enzymes has resulted to beneficial impacts on number of parameters. It was reported that, among various treatments, application of 0.5% $FeSO_4$ application at 30, 60 and 90 DAS resulted in the maximum grain and straw yield (3064 and 9341 kg ha^{-1}, respectively) over the control (2397 and 6894 kg ha^{-1}, respectively). Similar results were attained for grain Fe concentration (69.9 mg kg^{-1}) and Fe uptake in grain and straw (214 and 9088 g ha^{-1}, respectively).

2.5.3 Zn and Fe biofortification and uptake

Kumar *et al.* (1999) noticed a significant increase in Zn uptake with every increase in the level of Zn application. Zn removal by rice ranged from 0.04 to 0.06 kg Zn $tonne^{-1}$ of grain yield, with an average of 0.05 kg Zn $tonne^{-1}$. A rice crop yielding of 6 tonnes ha^{-1} takes up about 0.3 kg Zn ha^{-1}, of which 60% remain in the straw at maturity (IRRI, 2000).

Habib (2009) investigated the effect of foliar application of Zn and Fe on wheat yield and quality which he found that foliar application of (Fe + Zn) at tillering and heading stage increased Zn concentration up to 20.27 from 12.17 mg kg^{-1}. Iron concentration increased by using (Fe + Zn) compared with control (from 84.93 to 139.6 mg kg^{-1}).

Dhaliwal *et al*. (2010) in an experiment at Punjab, India on ferti-fortification of Zn and Fe on rice reported that 0.5% foliar application of Zn and Fe resulted in 7.00 and 8.60% increase in rice yield respectively. Also, it was observed that 0.5% Fe foliar application increased rice yield from 6.90-10.30%. Irrespective of cultivars, foliar application of $ZnSO_4.7H_2O$ and $FeSO_4.7H_2O$ resulted in 30.80-44.80% increase in Zn concentration and 22.30-38.20% of Fe concentration respectively. It was also observed the cultivars differed in their response to foliar Zn application; the increase was 44.80% in PR 116, 42.40% in PR 115, 40.60% in PR 114, 39.30% in PASU 201 and 30.80% in PR 113. The Zn concentration in rice grain was 47% in Zn fertilized crop as against 33.80% in no Zn control.

Darwesh (2011) conducted a pot experiment to investigate the influence of two different Fe sources (Fe-EDTA and FeEDDHA) were sprayed on to the leaves and applied to the soil in levels were involved 0, 10, 20 and 30 ppm, both fertilizers were applied to leaves at two times on lentil plant (*Lens esculenta* L.). The results indicated that there was significant effect of the combination among two types, concentration, and method of Fe application on total dry matter and on the concentration of N, P, Ca, Mg, K and Fe in plant.

Kobraee *et al*. (2011 c) reported that the application of micro-nutrient such as Zn, Fe and Mn increased the Zn content in different plant part. Zn application of 0, 20 and 40 kg ha^{-1} increased Zn content in seed by 21.70, 32.60 and 40.30 mg kg^{-1}, respectively in soybean in silty clay soil.

Yadav *et al*. (2013) in the field experiment at New Delhi to study the Fe density and uptake in aerobic rice as influenced by mulching and iron nutrition reported that mulching improved the iron concentration and uptake in grain and straw in paddy rice where the application of 2.0% $FeSO_4$ (Three foliar sprays) recorded higher Fe concentration at the same time enhanced the Fe uptake by grain as well as in straw. There was also improvement of Fe concentration in grain and straw from 5.40 to 19.90% in grain and 5.80 to 13.30% straw of aerobic rice. It was also reported that application of Fe fertilizer increased the grain and straw yield 4.00 to 8.20% and 2.70 to 6.70% over control, respectively.

Ali *et al.* (2014) reported increased Fe concentration (46%) in mungbeans upon foliar application of Fe. Similarly, foliar application of Fe and Zn significantly increased the concentration of these minerals along with agronomic efficiency in seeds of cowpeas (Salih, 2013).

Shivay *et al.* (2014) reported that there were differences in the effect of chickpea varieties and zinc levels on yield, zinc uptake and grain zinc concentration. It was found that variety Pusa 372 showed the highest zinc concentration in grain with increased level of zinc from 2.5 kg ha^{-1} to 7.5 kg ha^{-1}. It was also found that the highest zinc grain density was recorded in case of zinc application at 7.5 kg ha^{-1}.

Sunder *et al.* (2017) in their experiment on the effect of $ZnSO_4$ and $FeSO_4$ separately or in combination as foliar spray application on gerbera leaf nutrient content. They have reported that the combined application of $ZnSO_4$ and $FeSO_4$ 0.2% each has registered the highest range of nutrient content in leaves of Fe, Zn, N and K.

Pal *et al.* (2019) in the experiment biofortification of Zn and Fe on chickpea at Punjab, India found that soil application of $ZnSO_4$ @ 25 kg ha^{-1} + foliar spray of $ZnSO_4$ @ 0.5% at flowering and pod formation stages resulted in the highest Zn (45.06 and 44.69 mg Zn kg^{-1} grain).

2.6 Effect of zinc and iron fertilization on NPK Uptake

Mundra and Bhati (1991) conducted a field experiment at Jobner (Rajasthan), revealed that the application of 10 and 20 kg $FeSO_4$ ha^{-1} significantly reduces P and Mn concentration in seed and its uptake but increased the uptake of N and Fe compared to control.

Singh and Tiwari (1992) reported that the concentration and plant uptake of Zn were increased by Zn application while plant concentration of P, Fe and Cu were generally decreased due to Zn application in chickpea crop. Pande *et al*. (1993) revealed that the foliar spray of 3% $FeSO_4$ to groundnut increased uptake of N, K and Fe as compared to foliar sprays of 0.5, 1.0 and 2.0% and soil applied $FeSO_4$ @ 25 and 50 kg ha^{-1}.

Khan *et al.* (2003) reported that the uptake of nutrients by a crop depends upon the total biomass production and nutrient concentrations in plant parts which in turn are influenced by soil, climate, and cultural practices, level of nutrients applied and age of the plant. N concentration in paddy straw and roots increased significantly with the application of Zn over control). Nayyar *et al.* (2001) from Punjab showed that ZnO was inferior to Zn sulphate in relation to N uptake by rice grain and straw.

Abbas *et al*. (2012) in their experiment to study the influence of effects of Iron on take up of phosphorus, potassium and nitrogen on wheat yield. Results of the different studies conducted showed that application of Fe increased NPK uptake and their concentration in soil significantly over control. Soil application of 50 kg $FeSO_4$ ha^{-1} significantly increased content and uptake of Fe, P and N by chickpea over control (Singh *et al*., 2004).

Fageria (2001) reported that the application of 30 kg $ZnSO_4$ ha^{-1} resulted into highest value of uptake of N and K by rice plants as compared to other treatments. Swami and Shekhawat (2009) found that the uptake of N, P and K by rice increased significantly with application of $ZnSO_4$ over control (No Zn application).

Pooniya and Shivay (2011) reported that the application of 2.0% Zn-enriched urea with $ZnSO_4.H_2O$ recorded significantly higher N uptake by *Basmati* rice as compared to 2.0% Zn-enriched urea with ZnO, soil application of 5 kg Zn ha^{-1} of $ZnSO_4.H_2O$ or ZnO, ZnO slurry and control (No Zn application) treatments.

2.7 Quality parameters

2.7.1 Effect on protein content and oil content

Majumdar *et al.* (2001) studied in their experiment at Umiam, Meghalaya, on the individual and interactive effect of phosphorus and zinc on groundnut in phosphorus and zinc deficient Ustic Haplustalf. It was reported that phosphorus and Zn application significantly increased the protein and oil content of groundnut and their interaction effect was also impressive. They also found that the yield, number of pods $plant^{-1}$ and shelling percentage increased significantly with increasing doses of phosphorus and zinc.

Janakiraman *et al.* (2005) reported that in Zn-deficient soils, application of Zn increased the nodulation, chlorophyll content and pod yield of groundnut. With The application of $ZnSO_4$ at 5 kg ha^{-1} + $FeSO_4$ at 10 kg ha^{-1} + boron (B) at 1 kg ha^{-1} with the recommended dose of NPK (Nitrogen, phosphorus, potassium) showed significantly highest pod yield, oil content and seed quality.

Sharma *et al*. (2010) in his experiment on zinc application on soybean he reported that soil application of RDF + $ZnSO_4$ @ 5 kg ha^{-1} and RDF + $ZnSO_4$ @ 25 kg ha^{-1} gave significantly higher protein content in pigeon pea seed over control and RDF.

Trivedi *et al*. (2011) conducted investigation on the effect of iron and sulphur application on growth and yield of soybean where two levels of iron (15 and 20 mg kg^{-1} soil) and sulphur (40 and 80 mg kg^{-1} soil) were applied on soybean individually and in combination. It was reported that positive effect of iron and sulphur application was observed on different parameters *viz.*, shoot height, root length, number of leaves plant^{-1}, chlorophyll content, leaf nitrogen content, seed protein content.

Yasari and Vahedi (2012) reported micronutrient zinc has many effects on soybean (*Glycine max*. Merrill) with respect to qualitative and quantitative traits. Their findings were that foliar application of zinc (0.2%) has increased pod plant^{-1} (56.64-68.33) as compared to absolute control. The effects of foliar application of zinc increased oil percentage (25.03%) and oil yield (366.18 kg ha^{-1}) by spraying zinc (0.2%) on the crop.

Kumar (2013) carried out an experiment on effect of zinc, iron and manganese levels on growth, yield and quality of rice (*Oryza sativa* L.) which was therefore carried out at the Institute of Agricultural Sciences, Banaras Hindu University, Varanasi. It was reported that iron and zinc have a synergistic interactive effect in increasing the Zn, Fe and Mn content of grain, while zinc 10 kg ha^{-1} and manganese @ 5 kg ha^{-1} combinedly increased the Fe content of grain.

Abdel *et al.* (2014) reported that combined foliar application treatment of micronutrients Fe + Zn in soybean produced the highest values of plant height at harvest, number of branches plant^{-1}, number of pods plant^{-1}, 100-seed weight, seed yield plant^{-1}, seed yield (kg ha^{-1}), oil content, oil yield, protein content and protein yield compared with control treatment.

Khattak *et al.* (2015) reported that the following zinc sulphate treatment receiving $ZnSO_4$ as 5 kg ha^{-1} soil + 1.0% foliar, 15 kg ha^{-1} soil + 1.0% foliar and 5 kg ha^{-1} soil + 0.5% foliar application recorded 29.50, 29.00 and 27.50% higher protein contents, respectively over the control.

Pal *et al*. (2019) in the experiment biofortification of Zn and Fe on chickpea at Punjab, India found that the highest protein content which was found in the treatment of soil application of $ZnSO_4$ @ 25 kg ha^{-1} + foliar spray of $ZnSO_4$ @ 0.5% at flowering and pod formation stages (21.80% and 22.20%

in grain and 10.10% and 10.30% in straw) though it was found to be statistically similar with $ZnSO_4$ @ 25 kg ha^{-1} + foliar spray of $ZnSO_4$ @ 0.5% at flowering stage alone.

2.7.2 Phytic acid content and molar ratio

Oberleas *et al.* (1961) explained the presence of inhibitory effect of phytate on the estimated bioavailability of zinc was determined by measuring their molar ratios. Due to high phytate content it may affect the bioavailability of the minerals in the body. Phytic acid is an essential food component that has crucial negative impact on the absorption of Zn and Zn concentration in grains increased linearly with increasing Zn application rate in the soil and P concentration as phytate decreased directly with increased zinc levels.

Graham (1984) has explained on the importance of Phytate: zinc or phytate: Fe ratio on their bioavailability to human system for considering their quality. He concluded that Phytate: zinc ratio of < 5:1, 5-15 and > 15:1 is considered an index of bioavailability high, medium and low, respectively. If phytate is more than >15:1 the absorption in human system is considered to be low.

Chitra *et al.* (1995) in the study on variability in phytic acid content, protein and total phosphorus in different genotypes of legumes *viz.*, chickpea, pigeonpea, urd bean, mung bean and soybean. It was found that phytic acid (mg g^{-1}) varied significantly among and within these species. It was observed that the phytic acid content was highest in soybean (36.40) followed by urd bean (13.70), pigeon pea (12.70), mungbean (12.00) and chickpea (9.60). According to the findings it was revealed that soybean genotypes differed significantly in phytic acid content ranging from 13.9-23.0 mg g^{-1}.

Cakmak *et al.* (1999) in his trials in Central Anatolia, he reported that zinc application through soil and foliar application significantly decreased phytate to zinc molar ratios in grain in both durum and bread wheat.

Erdal *et al.* (2002) conducted a field experiment of wheat cultivars under zinc deficient soil in Turkey with zinc applied and no zinc added treatments. The findings were that with zinc fertilization there was reduction of seed concentration of P and phytic acid in all the cultivars. With zinc fertilization, there was reduction of phytic acid from 3.90 to 3.50 mg g^{-1} for P and from 10.70 to 9.10 mg g^{-1}. With concurrent decrease in phytic acid in grain and increasing zinc concentration, the phytic acid to molar ratio reduced proportionately. On average for all cultivars, phytic acid to Zn molar ratios decreased from 126 to 56 with Zn fertilization.

Kumar *et al*. (2005) studied the phytic acid of 80 cultivars /strains of Indian soybean as to identify the genotypes with lower level of phytic acid. It was found that the variations of phytic acid were from 28.60-46.40 mg g^{-1}. As per the results accumulation of phytic acid found in soybean not only affected by the genetic make-up of the genotype but also soil characteristics and soil environment too play a big factor on the phytic acid concentration in soybean grain.

Oberleas and Harland (2005) explained that determination of the phytate: Zn molar ratio is commonly used to estimate zinc bioavailability in food. The same can be applied in case of iron bioavailability.

Mirvat *et al*. (2006) and Cakmak (2008) indicated that applying zinc to plants under potentially zinc deficient soils is effective in reducing uptake and accumulation of phosphorus and thus phytate. This agronomic side effect of zinc fertilization resulted in better bioavailability of zinc in human digestive system.

2.8 Zinc use Efficiency indices

Prasad *et al.* (2000) revealed that the Partial factor productivity value of Zn is comparatively very high when compared to that of nitrogen. They reported that partial factor productivity of Zn (Soil applied) was high and varied from 984-3,367 kg grain kg^{-1} Zn whereas that of N were about 82-84 kg grain kg^{-1} N. Similar was the case of agronomic efficiency (AE) of Zn which varied from 212-311 kg grain kg^{-1} N as against 13-22 reported for N.

Prasad (2005) reported that the apparent recovery efficiencyof soil applied Zn varied from 9-20% as against 33-40% reported for N in rice. The main cause of low RE for Zn is due to its rapid adsorption over soil organic matter and clay minerals (Hazra & Mandal, 1995) and its subsequent slow desorption (Mandal *et al.*, 2000).

Shivay *et al.* (2007) and Shivay *et al.* (2008a) reported that the partial factor productivity, agronomic efficiency, apparent recovery efficiency and physiological efficiency of applied Zn in a rice-wheat cropping system decreased significantly with each successive increase in the level of Zn-enrichment of urea. They also reported that the Zn sulphate was a superior coating material for urea to supply Zn compared to Zn oxide with respect to nutrient use efficiencies.

Shivay *et al.* (2010) also reported that physiological efficiency (PE) of Zn was also high (6,384-17,077 kg grain kg^{-1} Zn) as against a value of 37 to 44 reported for N (Prasad *et al.*, 2000). These high values of PFP, AE and PE and Zn-harvest index were due to very small amount of Zn needed for rice growth and grain production as compared to N.

Jat *et al.* (2011) reported the highest agronomic efficiency (AE) of applied Zn in aromatic rice was obtained with the application of 2% Zn-enriched urea with $ZnSO_4.H_2O$ over all other treatments

Shivay *et al*. (2016) in the experiment on various levels, sources and methods of application of zinc on rice crop, zinc use efficiency indices was computed to compare among the treatments. As per the results it was found that soil or foliar applications of $ZnSO_4$ or Zn-EDTA has no significant influence on the Zinc harvest index (ZnHI) and Zinc mobilization index (ZnMEI) but Zinc

Agronomic efficiency (Zn AE) revealed that Zn–EDTA was significantly higher than $ZnSO_4$ for both soil and foliar applications. The value of Zn AE was 4-27 folds of that obtained with soil application. With respect to Zinc crop recovery efficiency (Zn CRE) value was much higher when applied to foliage (10-20 folds) than the treatment applied on soil.

2.9 Soil Properties

2.9.1 Post-harvest soil chemical properties

Chitdeshwari and Krishnaswami (1998) conducted an investigation in a greenhouse experiment in two Zn deficient soil Typic Ustorthent and Vertic Aguic Ustropep. They observed that the application of zinc increased the DTPA-Zn (Diethylene triamine penta acetic acid) in the soil, application of 54 mg Zn kg^{-1} soil, increased the DTPA-Zn content in all stages. The higher solubility, diffusion and mobility of the applied inorganic Zn fertilizer might be reason for increasing Zn status,

Shivay *et al.* (2008b) reported that the DTPA extractable Zn was significantly higher with the application of ZnO over $ZnSO_4.H_2O$ to soil and control (No Zn applied) after 6 weeks of incubation. They also observed that $ZnSO_4.H_2O$ resulted to significantly higher amount of DTPA extractable Zn after 8 weeks of incubation over ZnO and control. It was also observed that the DTPA-Zn after rice harvest increased from original value of 0.60 mg kg^{-1} to 0.87, 1.70 and 2.59 mg kg^{-1}, respectively with the application of 5.60, 11.20 and 16.80 kg Zn ha^{-1}.

Thenua *et al.* (2014) conducted a field experiment during *kharif* season at Agronomical Research Farm of Amar Singh College Lakhaoti, Bulandshahr (CCS University, Meerut) with four levels of zinc (0, 10, 20 and 30 kg Zn ha^{-1}) to study the availability status in the soil. The highest yield of soybean was recorded under application of Zinc @ 30 kg ha^{-1} as compared to its lower levels. The availability status of Zn in soil after harvest of soybean crop was found non-significant.

Ghoneim (2016) conducted a field experiment on rice in Egypt to evaluate the effects of different methods of Zn application on rice growth, yield, nutrients dynamics in soil and plant. Among the different of Zn application, soil application of 15 kg ha^{-1} as $ZnSO_4.H_2O$ caused highest increase in total N, K and available Zn content in both grain and straw, however, the percentage of total P decreased significantly. Zinc content in soil after harvesting was significantly affected by Zn application. Different methods of Zn tend to increase the total N and total K contents of soil but decreased P concentration significantly.

Goverdhan *et al*. (2017) in the field experiment conducted during 2015-16 at Rajendranagar, India revealed that application of recommended NPK + basal application of $FeSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} fb foliar spray of 0.5% $FeSO_4$ and 0.2% $ZnSO_4$ at 20, 40 and 60 DAS and 0.2% $ZnSO_4$ at 20, 40 and 60 DAS resulted in significant increase in DTPA-Available zinc over the other treatments. But available NPK after harvest did not cause significant changes from the initial values upon imposition of those treatments.

2.9.2 Soil biological properties

Dhull *et al*. (2004) in their experiment on the effect of chemical fertilizers and organic amendments on soil chemical and microbiological properties. It was reported that microbial biomass C increased significantly with the combined application of chemical fertilizers and organic amendments, in comparison to soils receiving chemical fertilizers alone. Dehydrogenase and alkaline phosphatase activities also increased with the application of farmyard manure and *Sesbania aculeata* green manure. The results indicated that there is improvement in soil organic matter, microbial activities and crop yields due to the use of chemical fertilizers along with organic manures.

Pooniya and Shivay (2012) found that with application of application of 2.0% Zn-enriched urea (ZEU) as $ZnSO_4.H_2O$ was found to be best with respect to soil biological properties, especially enhanced alkaline phosphatase, dehydrogenase, fluorescein diacetate activities and microbial biomass-C compared to Zn-enriched urea with ZnO, dipping of rice seedlings in ZnO slurry or control.

2.10 Effects of zinc and iron nutrition on economics

Ghatak *et al*. (2005) revealed that net return was maximum (₹4,832 ha^{-1}) when recommended doses of NPK fertilizers were applied with 30 kg $ZnSO_4$ ha^{-1} application in transplanted rice. It was observed that successive increase in grain yield was seen with each incremental dose of Zn reaching the threshold level of $ZnSO_4$ at 22.5 kg ha^{-1}.

Jain and Dahama (2006) conducted a field experiment and reported that there was significant increase in net return and benefit: cost ratio with the application of zinc up to 6 kg ZnSO4 ha^{-1}. Net return increased up to magnitude of 33.50% over control.

Pooniya and Shivay (2012) reported that application of 2.0% Zn-enriched urea with ZnSO4.H_2O to Basmati rice resulted in significantly higher B:C ratio over other Zn sources control (No Zn enrichment to urea). Similar findings were also reported by Jat *et al*. (2011)

Durgude *et al.* (2014) in the experimental results effect soil and foliar application of Fe_2SO_4 and $ZnSO_4$ on Bt cotton at the Micronutrient Research Farm, MPKV, Rahuri, revealed that treatment of soil application of Fe_2SO_4 @ 25 kg ha^{-1} + $ZnSO_4$ @ 20 kg ha^{-1} + Recommended Dose as per STCR recorded the highest gross return (₹ 1,66,297/-), net monetary return (₹ 96,037/-) and B: C ratios (2.37). B:C ratio value was also found to be high (2.27) in the case of foliar spray of Fe_2SO_4 @ 0.25% + $ZnSO_4$ @ 0.25%.

Kumar *et al*. (2015) in their field experiment which was conducted to study iron fertilization on aerobic rice (*Oryza sativa* L.) varieties during the rainy (*kharif*) seasons of 2011 and 2012 at the research farm of the IARI, New Delhi. The benefit: cost ratio was recorded the highest with three foliar sprays of 2.0% iron sulphate followed by two foliar sprays of 2.0% iron sulphate and found significantly higher over all other treatments.

Baishya *et al.* (2019) conducted a field experiment at Jharnapani, Nagaland, during *kharif* season to study the effect of Zn and Fe content on productivity and profitability of rice. The result revealed that foliar application of 2% $ZnSO_4$ (0.5%) at tillering + 0.5% at stem elongation + 0.5% at booting + 0.5% at grain filling) enhanced the economics of rice production (Return/rupee invested up to 2.32), crop profitability up to Rs.123.54 $ha^{-1}day^{-1}$ over the control (No foliar spray). On the other hand, foliar application of 1.5% $FeSO_4$ (0.5% tillering + 0.5% at booting + 0.5% at grain filling) also enhanced the economics of rice production (Return/rupees invested upto 2.24) and crop profitability up to ₹ 91.09 $haday^{-1}$.

Shivay *et al*. (2019) conducted three field trials on aromatic rice to test boron-coated urea (BCU), sulphur-coated urea (SCU), and zinc-coated urea (ZnCU) in 2013 and 2014. The findings of this study suggested that 0.5% boron, 5.0% sulphur, or 2.5% zinc-coated urea show improvement in returns and benefit-cost ratio in aromatic rice of western Indo-Gangetic Plains.

Sai *et al*. (2021) in their field experiment on foliar application of iron and zinc on yield and economics finger millets reported that higher gross returns (₹ 87,573.33/-), net return (₹ 56639.80/-) and benefit cost ratio (B:C 1.83) wasobtained with foliar application of 0.6% Zinc sulphate + 0.5% Ferrous sulphate, which was significantly superior over rest of the treatments.

CHAPTER III

MATERIALS AND METHODS

MATERIALS AND METHODS

The experiment entitled "Biofortification of zinc and iron in Soybean (*Glycine max* (L.) Merrill) under foothill of Nagaland" were conducted during the *kharif* seasons of 2018 and 2019 in the Agronomy experimental farm of School of Agricultural Sciences and Rural Development (SASRD), Nagaland University, Medziphema Campus, Nagaland. The details of the materials used and methods adopted during the course of investigation have been discussed in this chapter.

3.1 General information

3.1.1 Location

The experiment was conducted at the experimental farm located at Medziphema, in foot hill situation of Nagaland at an altitude of 310 meters above mean sea level (MSL) with the geographical location at $25^{0}45^{/}\,43^{//}$ North latitude and $95^{0}53^{/}\,4^{//}$ East longitude.

3.1.2 Climatic condition

Annexure I and Figure 3.1 & 3.2 showed the monthly average atmospheric temperature, rainfall, relative humidity and sunshine hour during the period of field experiments.

3.1.2.1 Rainfall

From the recorded meteorological data, it has been found that the crop received total rainfall of 785.30 mm and 1017.70 mm in the year of 2018 and 2019, respectively during the period of experimentation. However, highest rainfall occurred in August (302.80 mm) during 2018 and in August (274.30 mm) in the year of 2019 respectively. Minimum rainfall received in the month of November (13.30 mm) during 2018 and December (0.90 mm) during 2019.

3.1.2.2 Temperature

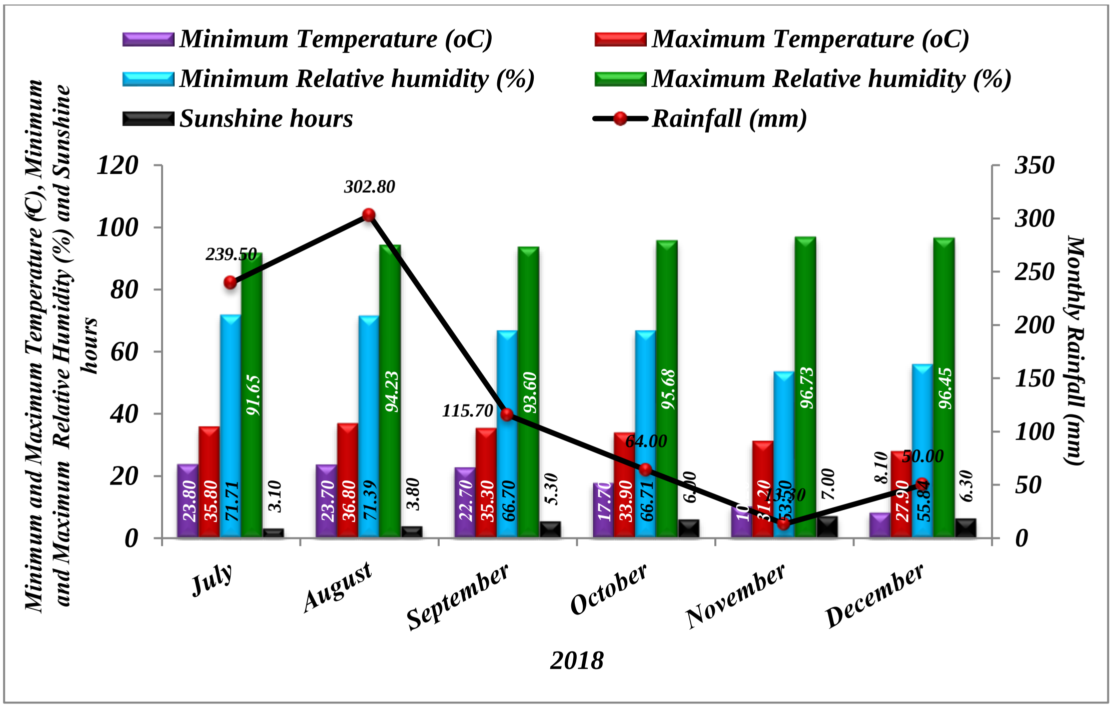


Fig 3.1 Graphical presentation of meteorological data during the period of investigation (July 2018 to December 2018)

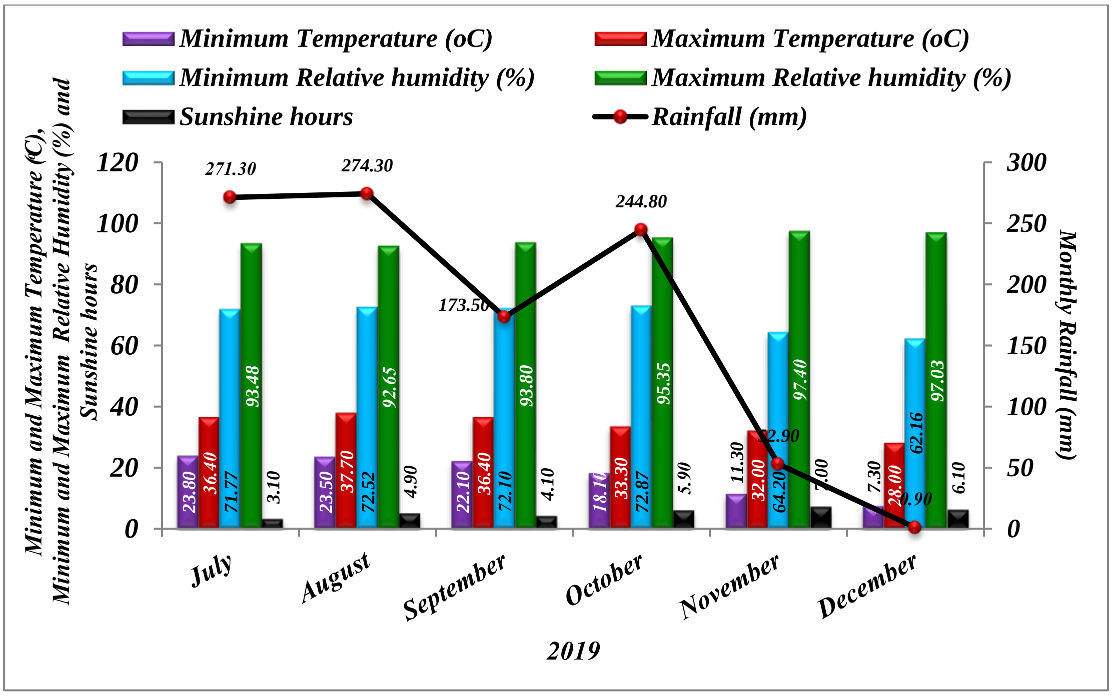


Fig 3.2 Graphical presentation of meteorological data during the period of investigation (July 2019 to December 2019)

During the period of field experiment, highest monthly average maximum temperature was recorded in the month of April (35.80˚C) and lowest maximum temperature (36.80˚C) was in August during the first experimentation year (2018). In 2019, highest average maximum temperature was recorded in the month of August (37.70˚C) and lowest monthly mean minimum temperature (7.30˚C) was observed in December. The maximum monthly average temperature ranged between 27.90˚C-37.70˚C and minimum monthly average temperature ranged between 7.30˚C-23.8˚C during study period.

3.1.2.3 Relative Humidity

Regarding relative humidity (RH) it was found that the highest monthly relative humidity was recorded in November, 2018 (96.73%) while, the lowest monthly mean minimum relative humidity was in November, 2018 (53.50%) during the first study year. However, during second year, the highest monthly mean maximum relative humidity was in November (97.40%) and the lowest monthly mean minimum relative humidity was in December (62.16%).

3.1.3 Previous cropping history of the experimental field:

The crops grown in the experimental field (Table 3.1.) were as follows:

Table 3.1 Previous cropping history of the experimental field

Year	***Crops grown***		
	Pre-kharif	***Kharif***	***Rabi***
2014-2015	Fallow	Pigeon pea	-
2015-2016	-	Pigeon pea	-
2016-2017	-	Fallow	Fallow
2017-2018	Fallow	Fallow	Fallow

3.1.4 Soil condition

The soil of the experimental plot was categorized as sandy loam and well drained. To ascertain the fertility status of the soil, respective samples of soils from a depth of 0-15 cm were taken from different locations with the help of soil auger, which was processed and analysed by methods of mechanical and chemical analysis.

Table 3.2 Initial physico-chemical properties of experimental soil

A. Physical properties	***Value***		***Method followed***	
1. Bulk density (g cc^{-1})	1.52		Core sampler method (Dastane, 1972)	
2. Soil textural class	Sandy clay loam		Bouyoucos Hydrometer method (Piper,1966)	
B. Chemical properties	***2018***	***2019***	***Method followed***	
1. Soil pH	4.85	4.90	Strong acidity	Blackman's pH meter method (Jackson,1967)
2. Organic carbon (%)	1.48	1.51	High	Walkley and Black method (Walkley & Black, 1934)
3. Available nitrogen (kg ha^{-1})	531.28	526.70	Medium	Modified Macro-Kjeldhal distillation method (Jackson, 1967)
4. Available phosphorus (kg ha^{-1})	36.81	32.80	High	Brays and Kurtz method (1945).
5. Available potassium (kg ha^{-1})	286.64	264.82	High	Flame photometric method (Jackson, 1967)

3.2 Details of the experiment

The research programme was divided into two main experiments *viz*., Experiment I was conducted at the field as "Biofortification of zinc in Soybean (*Glycine max* (L.) Merrill) under foothill of Nagaland" and experiment II "Biofortification of iron in Soybean (*Glycine max* (L.) Merrill) under foothill of Nagaland" was conducted in pot experiment in the both years 2018 and 2019. Under the experiment I, three varieties of soybean *viz*., JS-335, JS-97-52 and local check was selected under different zinc application doses with $ZnSO_4.7H_2O$ and ZnO used as sources. Similarly, in the pot experiment II, three same varieties of soybean which was used in field experiment were used under different concentrate of iron as foliar applications. The source of Fe was $FeSO_4.7H_2O$.

3.2.1 Experiment I

The field experiment was conducted for two years during *kharif* 2018 and 2019 at Agronomy farm of SASRD, Nagaland University, Medziphema, Nagaland, where three selected varieties of soybean was sown according to the recommended package of practices. Sowing of the crop was carried out on 2nd week of July, 2018 and repeated in the subsequent year. Recommended dose of NPK (RDF) of 20-60-40 kg ha^{-1} NPK (in the form of Urea, SSP and MOP) was imposed along with FYM @ 10 t ha^{-1} as general dose for all plots irrespective of treatments. The source of zinc as zinc sulphate ($ZnSO_4.7H_2O$) with 21% zinc and zinc oxide (80% zinc) in the experiment I was used.

3.3 Experimental details of field experiment (Experiment I)

▪ Variety of soybean	:	3
▪ Zinc levels	:	7
▪ Treatment combinations	:	21
▪ Number of replications	:	3
▪ No. of plots	:	63
▪ Experimental design	:	Factorial Randomized Block Design (FRBD)
▪ Plot size	:	4.5 m X 3 m
▪ Spacing	:	45 cm X 10 cm

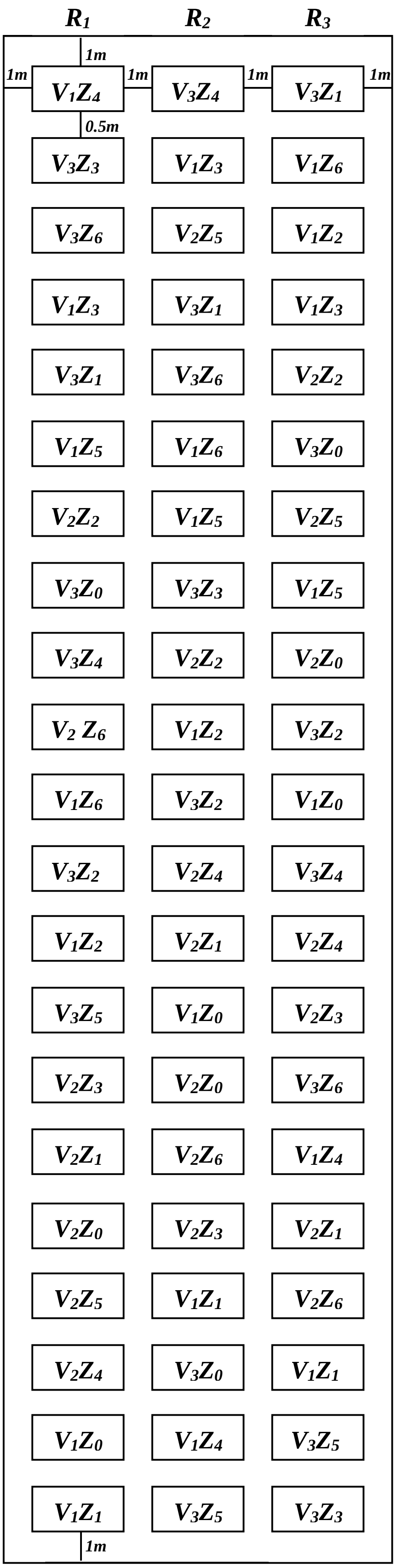
Table 3.4 Treatment details of the Experiment I

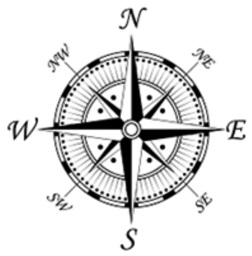
Treatment No.	
I. Varieties	***Treatments***
V_1	JS-335
V_2	JS-97-52
V_3	Local cultivar
II. Levels of Zinc	***Treatments***
Z_0	Control
Z_1	Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$
*Z_2	Soil application of Zn @ 5 kg ha^{-1} through ZnO
Z_3	Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$ + Two foliar spray application of $ZnSO_4$@ 0.25% at pre-flowering and pod formation stages
*Z_4	Soil application of Zn @ 5 kg ha^{-1} through ZnO + Two foliar spray application ZnO @ 0.25% at pre-flowering and pod formation stages
Z_5	Three (3) foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5% at maximum vegetative stage, pre-flowering and pod formation stage.
*Z_6	Three (3) foliar spray applications of ZnO @ 0.5% at maximum vegetative stage, pre-flowering and pod formation stage.

*****In these treatments additional sulphur will be applied.

3.2.2 Experimental details of pot experiment (Experiment II)

Pot experiments were conducted to study the biofortification effect of iron and varieties on soybean for consecutive years 2018 and 2019 at the farm premises. Sowing of the crop was carried out on 16th July, 2018 and repeated in the subsequent year. Recommended dose of NPK (RDF) of 20-60-40 kg ha^{-1} (in the form of Urea, SSP and MOP) was given along with FYM @ 10 t ha^{-1} as general dose for all plots irrespective of treatments. Fertilizer as well as FYM calculation on weight basis of soil in the pot was done. Iron sulphate ($FeSO_4.7H_2O$) was used as iron source in the experiment.





Treatments details:

Factor A (Varieties)

V_1: JS-335

V_2: JS-97-52

V_3: Local cultivar

Factor B (Zinc treatments)

Z_0: Control

Z_1: Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$

Z_2: Soil application of Zn @ 5 kg ha^{-1} through ZnO

Z_3: Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$ + Two foliar spray application of $ZnSO_4$ @ 0.25% at pre-flowering and pod formation stages

Z_4: Soil application of Zn @ 5 kg ha^{-1} through ZnO + Two foliar spray application ZnO @ 0.25% at pre-flowering and pod formation stages

Z_5: Three (3) foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5% at maximum vegetative stage, pre-flowering and pod formation stage.

Z_6: Three (3) foliar spray applications of ZnO @ 0.5% at maximum vegetative stage, pre-flowering and pod formation stage.

Fig. 3.1: Field layout of the experiment in Factorial Randomized Block Design (FRBD)

▪ Varieties of soybean	:	3
▪ Levels of Fe	:	6
▪ Number of replications	:	3
▪ Number of treatments	:	18
▪ Experimental design	:	Factorial Completely Randomized Design (FCRD)
▪ Number of pots	:	54

Table 3.5 Treatment details of the Experiment II (Pot culture experiment)

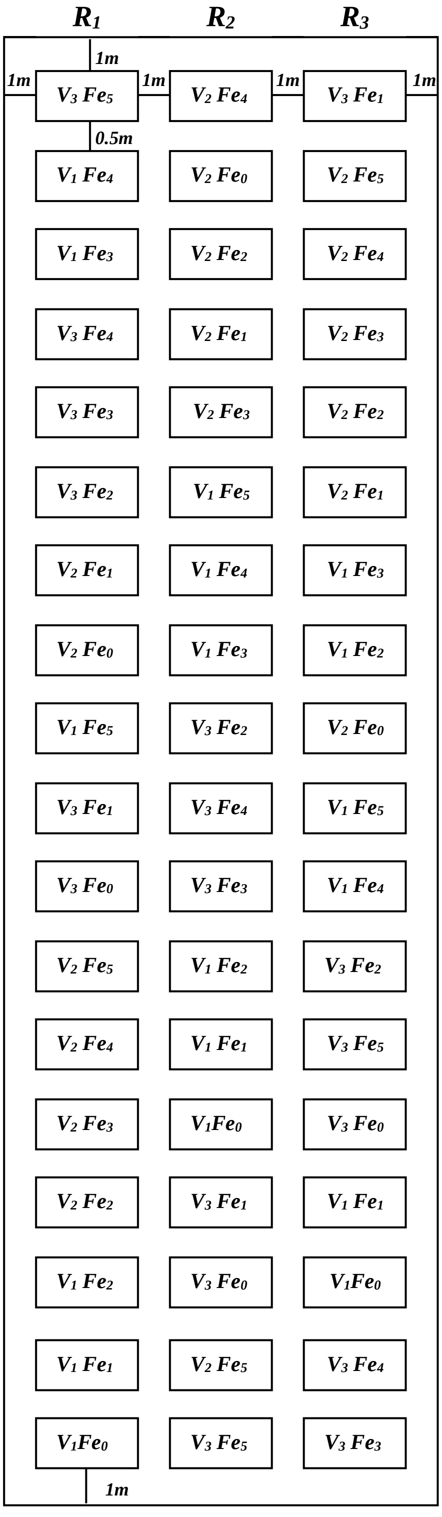
Treatment No.	
I. Varieties	***Treatments***
V_1	JS-335
V_2	JS-97-52
V_3	Local cultivar
II. Levels of Fe	***Treatments***
Fe_0	Control
Fe_1	Foliar application of $FeSO_4.7H_2O$ @ 0.5% at pre-flowering stage
Fe_2	Foliar application of $FeSO_4.7H_2O$ @ 1% at pre-flowering stage
Fe_3	Foliar application of $FeSO_4.7H_2O$ @ 1.5% at pre-flowering stage
Fe_4	Foliar application of $FeSO_4.7H_2O$ @ 2% at pre-flowering stage
Fe_5	Soil application of $FeSO_4.7H_2O$ @ 10 kg ha^{-1}

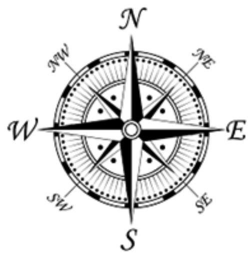
3.3 Cultivation details

3.3.1 Selection of variety

Agronomic characters of crop variety

JS 97-52: The variety JS 97-52 has been evolved during 2008 from the selection of a cross between PK 327 x LI 29 at Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur. It is a high yielding variety with 3-4 seeds per pod. The plants are 60-80 cm tall with tawny colour pubescence on the stem. Growth habit of the variety is semi determinate. Flowers are white and initiates in 45 days after sowing and ceases in about 75 days. The variety matures within 98-





Treatments details:

Factor A (Varieties)

V_1: JS-335

V_2: JS-97-52

V_3: Local cultivar

Factor B (Fe treatments)

Fe_0: Control

Fe_1: Two (2) foliar spray applications of $FeSO_4.7H_2O$@ 0.5% at pre-flowering stage

Fe_2: Two (2) foliar spray applications of $FeSO_4.7H_2O$ @ 1.0% at pre-flowering stage

Fe_3: Two (2) foliar spray applications of $FeSO_4.7H_2O$@ 1.5% at pre-flowering stage

Fe_4: Two (2) foliar spray applications of $FeSO_4.7H_2O$ @ 2.0% at pre-flowering stage

Fe_5: Soil application of $FeSO_4.7H_2O$@ 10 kg ha^{-1}

Fig. 3.2: Field layout of the experiment in Factorial Completely Randomized Design (FCRD)

102 days. Seeds are greenish yellow, lustrous with blackish hilum. The seed size is medium with 100 seed weight of nearly 10-12 g. The variety is resistant to major diseases and abiotic stress. The yield potential of the variety is 2.5-3.0 tha^{-1}.

JS-335: It was developed from JNKVV. Till 2002, JS 335 alone was a ruling variety among farmers of low rainfall and upland areas. The soybean cultivation reached to its height with the release of this early duration and very high yielding variety. It possesses wide adaptability, good germinability, semi dwarf habit, non-lodging, and non-shattering characteristics. It has resistance against girdle beetle and stem fly and tolerance to moisture stress conditions. This has occupied most of the soybean growing areas created mono-culturing. However, it has become susceptible to several diseases and insect pests. The yield potential of the variety is 2.7-3.0 t ha^{-1}.

Local cultivar: The local cultivar was collected from Mon District, Nagaland. It is long duration landrace which usually takes 130-140 days to mature. It is a tall statured and bushy cultivar proned to lodging. It is a small seeded variety with approximate yield of 1.5-1.8 t ha^{-1}.

3.3.2 Preparation and properties of Zn sources

Zinc sulfate: Zinc sulfate ($ZnSO_4$) monohydrate is produced by adding sulfuric acid to ZnO (Zn oxide), followed by dehydration to form $ZnSO_4.H_2O$. Most sources contain about 33% total Zn and 98% water-soluble Zn.

Zinc oxide: Zinc oxide (ZnO) is a common inorganic salt of Zn derived from many industrial processes. ZnO can range from 70 to 80% total Zn but is less soluble than $ZnSO_4$.

3.3.3 Application of Zinc treatments in Experiment I

Since two sources of zinc fertilizers was used *viz*., $ZnSO_4.7H_2O$ and ZnO which has 21% and 80% zinc content respectively and accordingly applied in different treatments and the calculation of quantity is shown in table 3.6. As

$ZnSO_4.7H_2O$ contains 10% sulphur so extra sulphur must be compensated by external application of sulphur. In this experiment we have accordingly added bentonite (90% S) in ZnO treatments.

Table 3.6 Calculation of Zinc fertilizers and zinc nutrient applied under different treatments

	Treatment	***Calculation of fertilizer use per ha***	***Quantity of Zinc nutrient (only) applied***
Z_0	Control	0	0 kg ha^{-1}
Z_1	Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$	23.80 kg ha^{-1} $ZnSO_4.7H_2O$	5 kg ha^{-1}
*Z_2	Soil application of Zn @ 5 kg ha^{-1} through ZnO	6.25 kg ha^{-1}ZnO	5 kg ha^{-1}
Z_3	Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$ + Two foliar spray application of $ZnSO_4$ @ 0.25% at pre-flowering and pod formation stages	Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$= 23.80kg ha^{-1} 2 foliar sprays of $ZnSO_4.7H_2O$ =1.5 kg x 2 sprays= 3 kg ha^{-1} Total = 26.80kg ha^{-1}	5.63 kg ha^{-1}
*Z_4	Soil application of Zn @ 5 kg ha^{-1} through ZnO + Two foliar spray application ZnO @ 0.25% at pre-flowering and pod formation stages	Soil application of Zn @ 5 kg ha^{-1} through ZnO = 6.25 kg ha^{-1} * 2 foliar sprays of ZnO @ 0.25%= =1.5 kg x 2 sprays= 3 kg ha^{-1}ZnO Total ZnO = 6.25 + 3 kg= 9.25 kg ha^{-1}	7.40 kg ha^{-1}
Z_5	Three (3) foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5% at maximum vegetative stage, pre-flowering and pod formation stage.	3 foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5%=3 kg ha^{-1} Total $ZnSO_4.7H_2O$ used is 3 kg x 3 foliar sprays= 9 kg $ha^{-1}$$ZnSO_4.7H_2O$	1.89 kg ha^{-1}
*Z_6	Three (3) foliar spray applications of ZnO @ 0.5% at maximum vegetative stage, pre-flowering and pod formation stage.	3 foliar spray applications of ZnO @ 0.5 %= 3 kg ha^{-1}ZnO (for 1 foliar spray) Total ZnO used is 3 kg x 3 foliar sprays= 9 kg ha^{-1}ZnO	7.20 kg ha^{-1}

3.4 Selection and preparation of the field

The field experiment was carried out in the experimental field in Agronomy block at SASRD farm, Medziphema. The experimental field was ploughed with tractor drawn disc plough in the last week of April followed by harrowing in the first week of May and levelled properly. All the stubbles were removed and then the field was laid out to the plan and design of the experimental field.

3.4.1 Preparation of pots

Soil from the top 15 cm was collected randomly from same field in which field experiment was conducted. The soil was mixed thoroughly to make a uniform medium in all respects and shade dried. 12 kg of soil was filled in pots of 20 L capacity each. Each treatment was given to the pots in triplicate and the experiment was laid out in Factorial Completely Randomized Design (FCRD). The pots were given small quantity of water daily to avoid leaching of nutrients. The N, P and K fertilizer was given to each pot as the recommended dose fertilizers on soil weight basis.

3.5 Manures and fertilizers

3.5.1 Seed and Sowing

Healthy and clean seeds were sown in the open furrows in lines by dibbling 2 seeds per hill with a spacing of 45 cm x 10 cm at the depth of 3-5 cm.

3.5.2 Intercultural operations

Gap filling was done at 10 DAS to maintain the optimum plant population in the field. Similarly, thinning was carried out at 15 DAS keeping one plant with a view to obtain optimum plant population. Hand weeding was done with the help of *khurpi* whenever required. Earthing up was done at 30 DAS.

Table 3.7 Details of field operation carried out during the period of experimentation

Sl. No.	*Field oprations*	*Date*	
		2018	***2019***
1	Land preparation	29-06-2018	20-06-2019
a.	Primary tillage harrowing with cultivator	18-07-2018	28-06-2019
b.	Secondary tillage harrowing with rotovators	20-07-2018	10-07-2019
c.	Layout of the experiment	25-07-2018	15-07-2019
2.	Application of fertilizers	27-07-2018	18-07-2019
3	Seed treatment and sowing	27-07-2018	18-07-2019
4	Weeding	25-08-2018	20-08-2019
5	Zn foliar application	16-09-2018 onwards	20-09-2019
6	Harvesting	30/10/2018 till 8/12/2018	02/11/2019 10 /12/2018
7	Threshing	10/11/2018 till 20/12/2018	1/11/2019 till 24/12/2019

3.5.3 Insect pests and disease management

Furadan @ 2-3 granules were applied on the top leaf whorl to control shoot borer at 20-30 DAS supplemented by two chlorpyriphos spray application at 40 and 50 DAS.

3.5.4 Harvesting

Harvesting was done manually treatment wise when the pods turned golden brown and when leaves dried completely. Manually threshed and sundried to safe moisture content.

3.6 Biometrical observation (For field experiment)

3.6.1 Growth attributes

For recording the growth attributes, five plants were selected randomly

from each plot.

3.6.2 Plant height (cm)

Plant height from the five randomly selected plants from the middle rows was recorded at 30,60 and 90 days after sowing (DAS) and at harvest. Plant height was measured by linear scale from the ground level to the terminal apex. The mean height from the selected plants was taken as the score for each plot.

3.6.3 Number of branches plant^{-1}

Number of branches per plant of five (5) randomly selected and tagged plants was counted at 30,60 and 90 days after sowing (DAS) and at harvest. The average number of branches of five plants was worked out.

3.6.4 Number of green leaves plant^{-1}

The number of leaves per plant was determined by counting the leaves of the five tagged plants from the middle row at 30, 60, 90 DAS and at harvest and average values were taken to compute the score.

3.6.5 Dry matter accumulation

The randomly five (5) plants from each plot were carefully uprooted. The uprooted samples were kept separately in paper bags and oven dried at 60 $^{\circ}$C for 48 hours. After 48 hours each sample attains a constant dry weight. Each sample was weighed and dry matter accumulation was recorded at 30, 60, 90 DAS and at harvest stage.

3.6.6 Leaf Area

It is calculated by conventional length-width method with a factor is derived using graph paper. Leaf area of each individual leaf of plant was added up to determine leaf area plant^{-1}. Area of each individual leaf was determined in cm^2. The measured factor is different for the three varieties. Leaf area of five (5) plants samples which is used for dry matter accumulation is washed properly with clean water. The mean of leaf area of the five (5) plants is expressed as cm^2 plant^{-1}.

3.6.7 Leaf Area Index (LAI)

The LAI was worked out using the formula (Watson, 1947). The LAI of the five (5) tagged plants were taken at 30, 60 and 90 DAS.

$$\text{LAI} = \frac{\text{Leaf area (cm}^2)}{\text{Unit ground area (cm}^2)}$$

3.6.8 Crop growth rate (CGR)

It is the rate of growth in an interval of time. Leopold and Kridemann (1975) suggested the following formula to calculate the value of CGR. CGR is expressed as g plant^{-1} day^{-1}. The crop growth rate was calculated by the dry matter accumulated at 0-30 DAS, 30-60 DAS, 60-90 DAS, and 90-harvest stage.

$$\text{CGR} = \frac{W_2 - W_1}{t_2 - t_1}$$

Where, CGR= Crop growth rate

W_2-W_1= Dry matter accumulation at definite time intervals

t_2-t_1= Time intervals in days

3.6.9 Relative growth rate (RGR)

This parameter indicates rate of growth per unit dry matter. The unit of RGR is g g^{-1} plant^{-1} day^{-1}. The relative growth rate was computed at 30-60 DAS, 60-90 DAS and 90-harvest

$$\text{RGR} = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1}$$

Where, RGR= Relative growth rate

W_2-W_1=Dry matter accumulation at definite time intervals

t_2-t_1= Time intervals in days

3.6.10 Nodulation studies

Randomly selected five (5) plants were removed along with the soil from each plot with the help of fork and *khurpi* and then dipped in water for separation of nodules from soil and washed gently with the help of sieve to avoid washing over of nodules. Number of nodules was recorded at most active stage at 45 DAS and 60 DAS. The nodules collected is then taken for fresh weight and later shade dry and further dried in an oven for nodules dry weight.

3.6.11 Chlorophyll content

The procedure developed by Witham *et al.* (1971) was followed for estimation of chlorophyll content of leaves.

3.6.12 Days to 50% flowering

Number of days taken from the date of sowing to 50% of plants plot^{-1} recorded flowering. The average of three replicates was calculated and expressed as days to 50% flowering.

3.6.13 Days to maturity

The stage when most of the leaves turned yellow, desiccated and 95% of the pods last green colour and attained mature pod colour, was designated as full maturity. The number of days taken for full maturity in each treatment was recorded and days were calculated from the date of sowing. The average days to maturity over three replications was calculated and expressed as days to full maturity.

3.7 Biometrical observation (For pot experiment)

3.7.1 Growth attributes

Initially five (5) plants were strictly allowed to maintain plant population per pot. Therefore, non-destructive parameters like plant height, number of branches plant^{-1}, number of leaves plant^{-1} were taking from the two (2) tagged plants till harvest of the crop. Whereas, parameters like leaf area, dry matter yield, nodulation and chlorophyll content were taken from each plant pot^{-1} per replication at different crop stages following the same procedure as in the field experiment.

3.8 Yield attributes

3.8.1 Number of pods plant^{-1}

The number of pods per plant was counted from the tagged plants in each plot and the average was recorded as the numbers of pods plant^{-1}.

3.8.2 Number of seeds pod^{-1}

The number of seeds per pod was counted from five (5) tagged plants from each plot and mean was calculated for statistical analysis.

3.8.3 Seed index (g)

The hundred seeds were randomly taken from the finally cleaned produce of each plot for recording test weight. Then weight of 100-seeds of each plot was recorded separately on an electrical balance.

3.8.4 Biological yield (t ha^{-1})

1 m^2 quadrate is used to harvest soybean from each treatment and the harvest is sun dried properly. The whole weight is measured using digital hanging balance and converted in tonnes ha^{-1} basis.

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

The seed yield per sq. meter area was recorded after winnowing the seed with the help of digital balance. Finally, seed yield of each plot was converted into seed yield per hectare by multiplying it with appropriate conversion factor.

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

The stover yield per sq. meter area was determined by subtracting seed yield (Economical yield) of each plot from biological yield (Bundle weight) of the same plot. This was later on converted into stover yield per hectare by multiplying with the same conversion factor which was used in case of seed yield per hectare.

3.8.7 Harvest index

It is the ratio of economic yield to the biological yield. It was determined with the help of following formula and expressed in percentage as follows:

$$\text{Harvest index} = \frac{\text{Economic yield (seed yield)}}{\text{Biological yield (seed and stover yields)}} \times 100$$

3.9 Chemical analysis of soil samples

3.9.1 Collection and preparation of soil samples

After the harvest of crop, the soil samples were collected from all the treatments (0-15 cm) and brought to the laboratory in polythene bags. The soil samples were dried under shade and ground with wooden pestle and mortar and sieved through 2 mm sieve. The processed soil samples were analyzed for pH, EC, available N, P, K, Zn and Fe. The powdered soil samples were again powdered in an agate mortar and passed through 0.2 mm sieve for organic carbon analysis**.** The procedure of analysis carried out for various characteristics in initial soil and post-harvest soil samples are same and given below:

3.9.2 Soil pH

The soil pH was determined in 1:2:5 water suspensions and analyzed using glass electrode pH meter (Richards, 1954).

3.9.3 Electrical conductivity (EC)

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

3.9.4 Organic carbon

Organic carbon in soil was determined using alkaline potassium permanganate method outlined by Walkey and Black (1934) and expressed in percentage as described by Jackson (1973).

3.9.5 Available Nitrogen

Available nitrogen in the soil was estimated by alkaline potassium permanganate method (Subbiah & Asija, 1956). The soil was treated with alkaline $KMnO_4$ and distilled. The organic matter present in the soil was oxidized by the nascent oxygen liberated by $KMnO_4$ in the presence of NaOH and thus, the ammonia released was distilled and absorbed in a known volume of boric acid and stannous mixed indicator and titrated with a standard acid.

3.9.6 Available Phosphorus

Available phosphorus was extracted with 0.03N NH_4F in 0.025N HCl Solution. The procedure is primarily mean for soils which are moderate to strongly acidic pH and determined by Brays and Kurtz method (1945).

3.9.7 Available potassium

The available potassium content in soil was extracted wih neutral normal ammonium acetate (pH 7.0). The potassium content in the extract was determined by flame photometer (Jackson, 1973).

3.10 Soil microbial activity

3.10.1 Soil microbial biomass carbon

Soil microbial biomass-C was determined by fumigation-extraction method (Vance *et al.*, 1987). Microbial biomass-C was expressed as µg C g^{-1} soil.

3.10.2 Dehydrogenase Activity

Dehydrogenase activity was determined bythe procedure given Casida *et al.*, 1964 expressed as ug TPFg^{-1}soil hr^{-1}.

3.10.3 Fluorescein diacetate

It was determined by the procedure given Adam and Duncan (2001) expressed as µg fluorescein/g dry soil/0.5 hr.

3.11 Chemical analysis of plant samples

The grain and stover samples were oven dried at a temperature of 60 ℃ ± 2 ℃ for 6 h to attain a constant weight. The dried seed and stover samples were then ground and sieve by passing through 40 mesh sieve and kept in polythene bags for chemical analysis. The powdered seed and stover samples were analysed for N, P, K, Zn and Fe content.

3.11.1 Digestion of plant samples for nutrients

Half a gram powdered sample was pre-digested with concentrated HNO_3 overnight. Further pre-digested sample was treated with di-acid (HNO_3: $HClO_4$ in the ratio 10:4) mixture and kept on hot plate for digestion till colourless thread like structures was obtained. After complete digestion precipitate was dissolved in 6N HCL and transferred to the 100 ml volumetric flask through Whatman No. 42 filter paper and finally the volume of extract was made to 100 ml with double distilled water and preserved for further analysis.

3.11.2 Nitrogen

Half a gram 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 distilled water to know 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 as per the procedure given by Black (1965)

3.11.3 Nitrogen content and uptake

Nitrogen content was estimated by digesting 0.50 g sample with 10 ml concentrated sulphuric acid and digestion mixture. Total nitrogen was determined by modified Kjeldahl method. N uptake was calculated by multiplying grain and straw yields with corresponding values of N concentration and expressed in as kg ha^{-1}. N uptake in grain and straw was added to compute the total N uptake in respective treatments.

The nutrient uptake by soybean at harvest was worked out using the following equations:

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

Micronutrient uptake (kg ha^{-1}) = $\frac{\text{Nutrient content (mg kg}^{-1}\text{) x Dry matter yield (kg ha}^{-1}\text{)}}{1000}$

3.11.4 Phosphorus content and uptake

Phosphorus content of ground samples of rice and was determined by "Vanado-Molybdo-phosphoric acid yellow colour method" using systronics spectrophotometer after digestion in tri acid mixture (HNO_3: $HClO_4$: H_2SO_4 at the rate of 10:4:1). Subsequently phosphorus uptake was calculated by multiplying grain and straw yields with corresponding values of P concentration and expressed in as kg ha^{-1}. P uptake in grain and straw was added to compute the total P uptake in respective treatments

3.11.5 Potassium content and uptake

K content (%) in the plant sample was determined by flame photometer (Jackson, 1973). K uptake was calculated by multiplying grain and straw yields with corresponding values of K concentration and expressed in as kg ha^{-1}. K uptake in grain and straw was added to compute the total K uptake in respective treatments.

3.11.6 Zinc/iron concentration and uptake

The Zn and Fe content in dry matter of soybean grains and straw were determined as per the procedure described by Prasad (2006) using Atomic Absorption Spectrophotometer (AAS). The Zn, content was expressed as mg kg^{-1}. The Zn uptake was calculated by multiplying the grain and straw yields with their respective Zn concentration and expressed in g ha^{-1}. The total Zn uptake was determined by adding Zn uptake in grain and straw for the individual treatment.

3.11.7 Protein content

The protein content in seeds was calculated for each treatment by multiplying the seed N by a factor of 6.25.

3.11.8 Oil content

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:

$$\text{Per cent oil} = \frac{(W_2 - W_1) \times 100}{X}$$

Where, W_2= Weight of the empty flask (g)

W_1= Weight of empty flask + weight of oil (g)

X = Weight of sample taken for extraction (g)

3.11.9 Phytic acid

Phytic acid is determined by procedure given by Sadasivam and Manickam (1996).

3.11.10 Phytic: Zinc/Iron molar ratio

$$\frac{\text{g/kg phytate}}{\text{660 (Molecular weight of phytate)}} : \frac{\text{g/kg phytate}}{\text{65.4 (atomic weight of Zinc)}}$$

3.12 Zinc use indices

The estimated values of partial factor productivity (PFP), agronomic efficiency (AE), crop recovery efficiency (CRE), physiological efficiency (PE), zinc harvest index (ZHI) and zinc mobilization efficiency index (ZMEI) of applied Zn were computed using the following expressions as suggested by Fageria and Baligar (2003), Dobermann (2005) and Shivay and Prasad (2012).

3.12.1 Partial factor productivity (PFP)

The Partial factor productivity (PFP) of applied Zn was calculated as the equation given below:

$$PFP = \frac{Y_t}{Zn_a}$$

Where, Y_t = Yield under treatment (kg ha^{-1})

Zn_a = Amount of nutrient (Zn) added (kg ha^{-1})

3.12.2 Agronomic use-efficiency (AE)

The Agronomic use-efficiency (AE) is expressed as kg grain increase per kg a particular nutrient applied and was calculated as the equation given below:

$$AE = \frac{Y_t - Y_o}{A_t}$$

Where, Y_t = Yield under test treatment (kg ha^{-1})

Y_o = Yield under control (kg ha^{-1})

At = Units of nutrient (Zn) applied in the test treatment (kg ha^{-1})

3.12.3 Physiological efficiency (PE)

The Physiological efficiency (PE) of applied Zn/Fe will be calculated as the equation given below:

$$PE = \frac{Y_t - Y_o}{U_t - U_o}$$

Where, Y_t = Yield under test treatment (kg ha^{-1})

Y_o = Yield under control (kg ha^{-1})

U_t = Uptake of nutrient (Zn) in test treatment (kg ha^{-1})

U_o = Uptake of nutrient (Zn) in control (kg ha^{-1})

3.12.4 Crop recovery efficiency (CRE)

The Crop recovery efficiency (CRE) of applied Zn will be calculated as the equation given below and was expressed in percentage terms.

$$CRE = \frac{N_t - N_o}{N_a} \times 100$$

Where,

N_t = Amount of nutrient taken (Zn) from test treatment plot (kg ha^{-1})

N_o = Amount of nutrient taken (Zn) from the control plot (kg ha^{-1})

N_a = Amount of nutrient (Zn) added (kg ha^{-1})

3.12.5 Zinc harvest index (ZnHI)

The zinc harvest index (ZnHI) will be calculated as the equation given below and was expressed in percentage terms.

$$ZnHI = \frac{Zn_s}{Zn_t} \times 100$$

Where, Zn_s = Zn uptake by grain at harvest

Zn_t = Zn uptake by whole crop (grain + straw) at harvest

3.12.6 Zinc mobilization efficiency index (ZnMEI)

The zinc mobilization efficiency index (ZnMEI) will be calculated as the equation given below:

$$ZMEI = \frac{\text{Zn concentration in grain (mg kg}^{-1}\text{ grain)}}{\text{Zn concentration in straw (mg kg}^{-1}\text{ straw)}}$$

3.13 Economics of the Treatments

The economic analysis of the treatments is very important to assess the practical utility of treatments for farmers' point of view. Therefore, economics of different treatments were worked out in terms of cost of cultivation, gross monetary returns (GMR), net monetary returns (NMR) and benefit-cost ratio (B:C) on per hectare area basis to ascertain the economic viability of the treatments. The details for determination of economics are given in *Appendix II-III* for reference.

3.13.1 Cost of cultivation

The cost of cultivation for each treatment is determined on the basis of different inputs used for raising the crop under different treatments on one hectare area basis.

3.13.2 Gross monetary returns (GMR)

The values realized from the produce obtained under each treatment was computed on the basis of existing market price of the produce (both seed and stover) as the gross monetary returns (GMR) per hectare under different treatments.

Gross monetary returns = Value of seed + Value of stover

3.13.3 Net monetary returns (NMR)

The net monetary returns (NMR) per hectare under each treatment were determined by subtracting the cost of cultivation of a particular treatment from the GMR of the same treatment.

Net monetary returns = Gross monetary returns -Total cost of cultivation

3.13.4 Benefit-cost ratio (B: C)

To estimate the benefits obtained under different treatments for each rupee of expenditure incurred, B: C ratio of each treatment was calculated as below: -

$$\text{B: C ratio} = \frac{\text{Gross monetary returns}}{\text{Total cost of cultivation}}$$

3.14 Statistical analysis

The collected data was processed, classified, tabulated systematically and statistically analysedby using two-way analysis of variance (ANOVA). Further, differences between treatments were analysed by using ANOVA at a significance level of 0.05 and the significant of different source of variations was tested by '*F*' test to find out the significant differences between mean values (Gomez & Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

4.1 Experiment I: "Biofortification of zinc in Soybean (*Glycine max* (L.) Merrill) under foothill of Nagaland"

The results obtained during the experimental studies have been presented in this chapter under appropriate headings through data, Tables and illustrations wherever necessary.

4.1.1 Growth parameters

4.1.1.1 Plant height

Data pertaining to plant height at different crop stages as influenced by varieties and zinc fertilization is presented in Table 4.1.1 and illustrated in Fig 4.1.1 & Fig 4.1.2.

The data indicated that plant height at early crop stages at 30 days after sowing (DAS) did not show any significant differences among varieties in both the years. However, at 60 DAS significant difference among varieties was observed where local cultivar (V_3) recorded the highest value (65.18, 51.19 cm), followed by JS-97-52 (45.93, 47.34 cm) and least in JS-335 (35.62, 36.44 cm). The same trend was observed in plant height among the varieties at 90 DAS and harvest. At harvest, the local recorded the highest value (66.76, 65.67 cm) followed by JS 97-52 (53.30, 48.64 cm) and least in JS-335 (40.58, 40.47 cm). The difference among varieties in plant height was solely due to genetic makeup and morphological difference of each cultivar. In most cases, improved varieties are shorter in stature compared to local cultivars.

Zinc fertilization failed to show any significant variations in plant height at early crop stages (30 and 60 DAS). At 90 DAS three foliar applications of $ZnSO_4.7H_2O$ @ 0.5% (Z_5) recorded the maximum plant height (57.19, 57.55 cm) and least was recorded in control (49.63, 48.71 cm). Similar trend was also observed at harvest with respect to zinc applications. The significant increase in

Table 4.1.1 Effect of varieties and zinc fertilization on plant height (cm) in soybean

Treatments	***30 DAS***			***60 DAS***			***90 DAS***			***At harvest***		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
Varieties												
V_1	27.06	25.16	26.11	35.62	36.44	36.03	40.80	41.87	41.33	40.36	40.58	40.47
V_2	28.42	25.22	26.82	45.93	47.34	46.63	50.86	51.77	51.32	53.30	48.64	50.97
V_3	27.09	26.03	26.56	65.18	51.19	58.19	65.60	62.95	64.28	66.76	65.67	66.21
SEm±	***0.69***	***0.56***	***0.44***	***1.05***	***0.75***	***0.65***	***0.94***	***1.08***	***0.72***	***1.29***	***1.08***	***0.84***
CD at 5%	***NS***	***NS***	***NS***	***3.00***	***2.15***	***1.96***	***2.70***	***3.10***	***2.19***	***3.68***	***3.09***	***2.56***
Zinc fertilization												
Z_0	27.27	25.59	26.43	46.04	43.68	44.86	49.63	48.71	49.17	49.50	48.57	49.03
Z_1	26.84	24.10	25.47	49.02	44.05	46.54	53.70	50.81	52.25	52.65	52.08	52.36
Z_2	27.39	24.81	26.10	48.55	43.03	45.79	50.00	50.57	50.29	50.24	49.37	49.80
Z_3	26.87	26.03	26.45	49.90	46.89	48.39	52.34	53.32	52.83	56.73	53.42	55.08
Z_4	27.51	25.95	26.73	48.97	44.97	46.97	49.76	52.06	50.91	53.17	50.14	51.66
Z_5	28.15	25.53	26.84	51.21	47.81	49.51	57.19	57.55	57.37	58.08	57.37	57.72
Z_6	28.61	26.28	27.45	48.69	44.50	46.60	54.34	52.34	53.34	53.95	50.48	52.21
SEm±	***1.05***	***0.86***	***0.68***	***1.60***	***1.15***	***0.99***	***1.44***	***1.66***	***1.10***	***1.97***	***1.65***	***1.29***
CD at 5%	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***4.13***	***4.73***	***3.09***	***5.63***	***4.73***	***3.62***

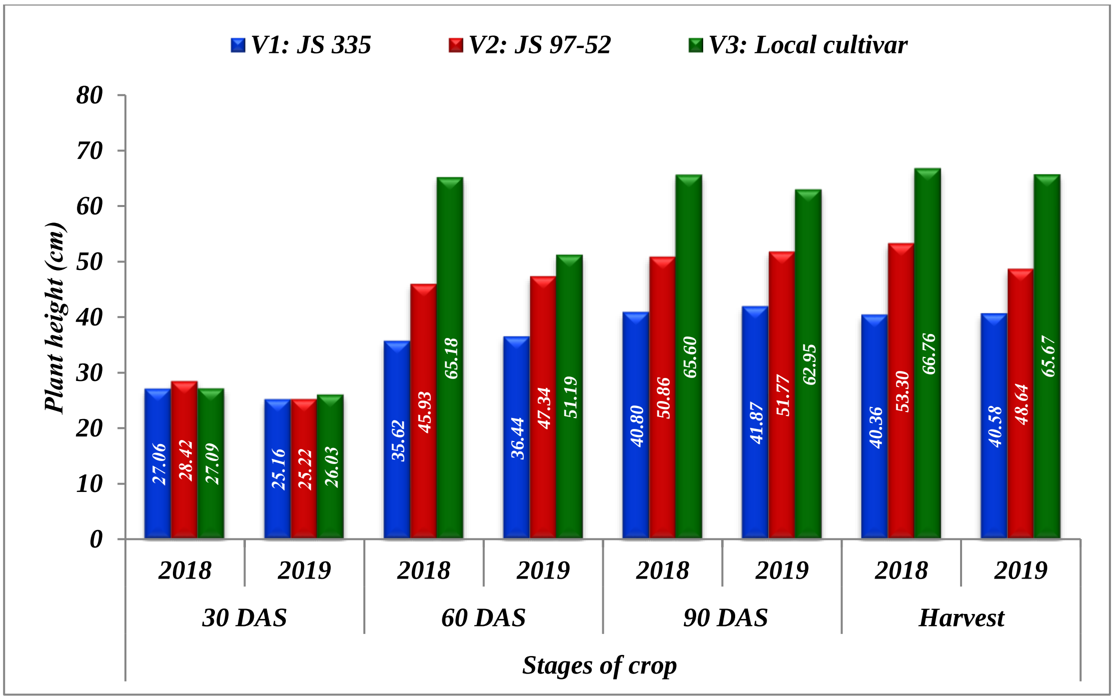


Fig 4.1.1 Effect of varieties on plant height of soybean at different stages of crop during 2018 and 2019

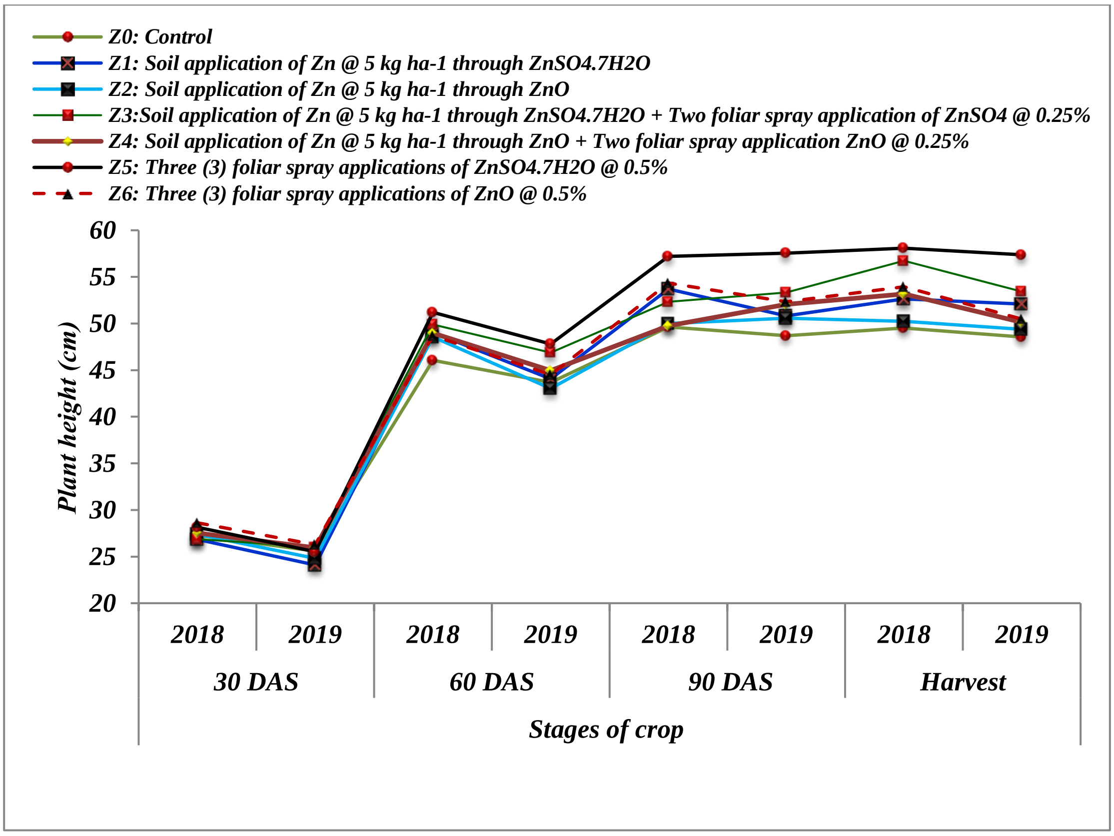


Fig 4.1.2 Effect of zinc application on plant height of soybean at different stages of crop during 2018 and 2019

plant height with zinc application irrespective of the sources might be due to more availability and absorption of Zn from soil solution which caused more auxin metabolism, faster cell division and cell elongation and root and shoot development ultimately increased plant height of soybean. Zinc might have stimulated the enzymatic and hormonal activity resulting in vegetative and meristematic growth that might have enhanced more cell elongation. The results were in close conformity with the findings of many other reports in India and abroad where significant response of zinc fertilization on plant height reported by Ghatak *et al*. (2005), Shivay *et al*. (2010) and Kulhare *et al*. (2014), Tayyeba *et al*. (2017). Zinc is known to involve in the hormone synthesis, hence indirectly related to translocation and metabolism of carbohydrate finally contributing to additional growth compared to control (Deotale *et al*., 1998). Habbasha *et al.* (2013) had earlier indicated in their work on chickpea that foliar application of 0.2% $ZnSO_4$ at seed filling stage increased plant growth which supports present findings.

4.1.1.2 Number of leaves per plant

The perusal of data in the number of leaves plant^{-1} is presented in Table 4.1.2. The number of leaves plant^{-1} varied significantly among varieties at different crop stages. It reached the maximum value at 60 DAS in JS 97-52 (24.77, 20.51 cm) and JS-335 (17.26, 17.32 cm) and declined at 90 DAS. Whereas, in the case of local cultivar it was observed have the highest number of leaves at 90 DAS (29.86, 25.69 cm). The variation among varieties in number of leaves was mainly due to their genetic and morphological differences. The two improved varieties *viz*., JS 97-52 and JS-335 which are short duration tend to reach physiological maturity early thereby we observed early leaf senescence while local cultivar is a long duration cultivar had their maximum number of leaves at 90 DAS.

Significant variations in number of leaves plant^{-1} upon zinc fertilization was observed only at 60 DAS stage where the maximum value was observed at

Table 4.1.2 Effect of varieties and zinc application on number of leaves in soybean

Treatments	***30 DAS***			***60 DAS***			***90 DAS***		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
Varieties									
V_1	7.86	7.72	7.79	17.26	17.32	17.29	9.61	11.29	10.45
V_2	10.09	9.36	9.72	24.77	20.51	22.64	16.39	15.71	16.05
V_3	8.50	9.42	8.96	19.45	19.80	19.62	29.86	25.69	27.77
SEm±	***0.24***	***0.18***	***0.15***	***0.51***	***0.41***	***0.33***	***0.53***	***0.61***	***0.41***
CD at 5%	***0.70***	***0.51***	***0.46***	***1.47***	***1.16***	***1.00***	***1.52***	***1.75***	***1.23***
Zinc fertilization									
Z_0	8.78	8.62	8.70	18.84	16.87	17.86	17.27	18.29	17.78
Z_1	9.04	8.62	8.83	20.82	19.58	20.20	18.84	21.29	20.07
Z_2	8.38	8.42	8.40	19.47	17.42	18.44	18.64	18.73	18.69
Z_3	9.29	8.91	9.10	21.60	20.27	20.93	18.44	20.58	19.51
Z_4	9.00	8.80	8.90	21.04	18.38	19.71	18.64	18.91	18.78
Z_5	8.87	9.22	9.04	22.62	21.71	22.17	19.58	21.33	20.46
Z_6	8.33	9.43	8.88	19.04	18.49	18.77	18.91	19.60	19.26
SEm±	***0.37***	***0.27***	***0.23***	***0.78***	***0.62***	***0.50***	***0.81***	***0.93***	***0.62***
CD at 5%	***NS***	***NS***	***NS***	***2.24***	***1.78***	***1.41***	***NS***	***NS***	***NS***

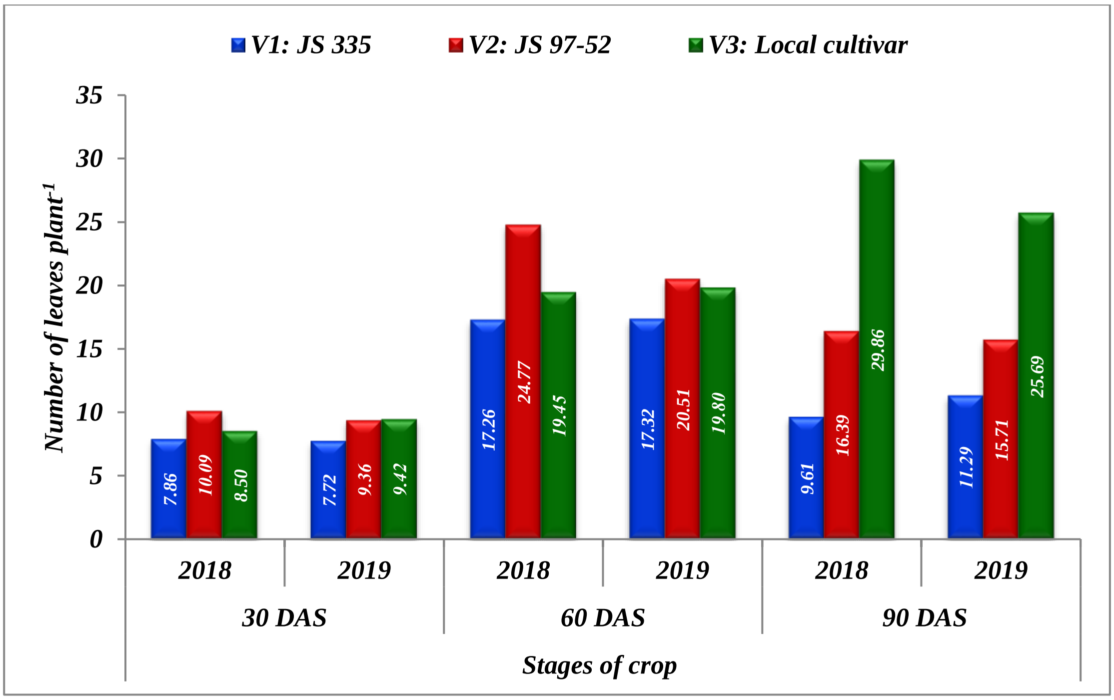


Fig 4.13 Effect of varieties on number of leaves plant^{-1} of soybean at different stages of crop during 2018 and 2019

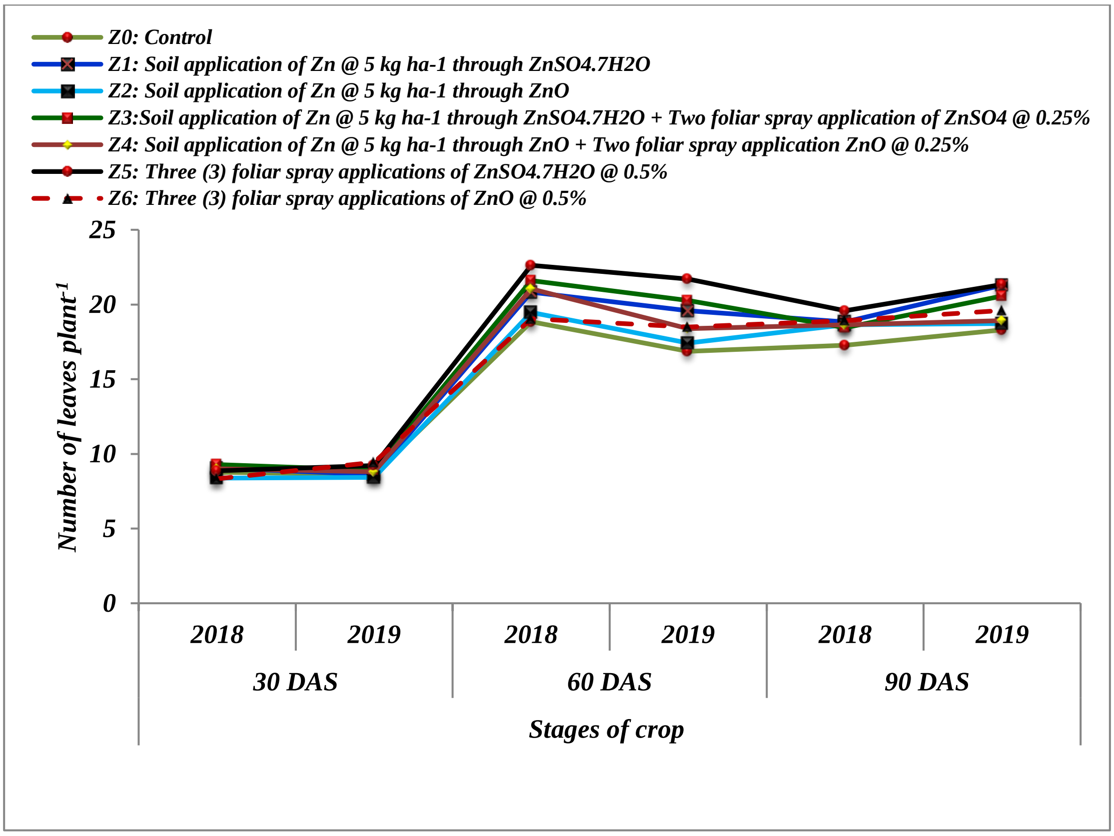


Fig 4.1.4 Effect of zinc application on number of leaves plant^{-1} of soybean at different stages of crop during 2018 and 2019

Z_5 (Three foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5%) (22.62, 21.71) which was statistically significant over control and at par with Z_1 (19.58, 20.20), Z_3 (21.60, 20.27) and Z_4 (21.04, 18.38). Zinc nutrition in plant might have stimulated the enzymatic and hormonal activities which indirectly led to more translocation and metabolism of carbohydrate contributed for more leaf area of crops which was supported by the findings reported by Deotale *et al*. (1998).

The interaction effect of cultivar and zinc application was found non-significant in both the years of experimentation.

4.1.1.3 Number of branches

The data pertaining to the number of branches plant^{-1} as influenced by varieties and zinc fertilization is presented in Table 4.1.3a. As revealed by the results there were no significant effect of cultivar on the number of branches at early crop stage (30 DAS). The number of branches plant^{-1} varied significantly among varieties from 60 DAS onwards. At 60 DAS the maximum value was observed in JS 97-52 (4.46, 3.39) which was statistically at par with local cultivar (3.42, 3.88) and the lowest value was observed in JS-335 (2.45, 2.93). At harvest of the crop the highest number of branches was recorded in local cultivar (4.50, 3.61) which was statistically at par with JS 97-52 (4.43, 3.42) and least branch was recorded in JS-335 (2.51, 2.93). The significant variations in the number of branches among varieties were due to genetic and morphological differences among them.

Zinc fertilization significantly influenced the number of branches irrespective of varieties. At early crop stage (30 DAS) no significant difference was observed with zinc application. Significant variation was observed in the second year of the experiment at 60 DAS and 90 DAS. At 60 DAS the highest value was observed in Z_5 and Z_3 and the least value in control. At harvest stage the maximum branching was recorded in Z_5 (4.16, 3.76). The other zinc treatments were significantly higher over control plots. The reason for more

Table 4.1.3 Effect of varieties and zinc fertilization on number of branches in soybean

Treatments	*30 DAS*			*60 DAS*			*90 DAS*			*At harvest*		
	2018	*2019*	*Pooled*	*2018*	*2019*	*Pooled*	*2018*	*2019*	*Pooled*	*2018*	*2019*	*Pooled*
Varieties												
V_1	1.19	1.16	1.17	2.45	2.93	2.69	2.51	2.93	2.72	2.51	2.93	2.72
V_2	1.28	1.27	1.27	4.46	3.39	3.92	4.43	3.42	3.93	4.43	3.42	3.93
V_3	1.15	1.17	1.16	4.34	3.42	3.88	4.41	3.53	3.97	4.50	3.61	4.06
SEm±	***0.04***	***0.04***	***0.03***	***0.08***	***0.09***	***0.06***	***0.07***	***0.08***	***0.06***	***0.06***	***0.08***	***0.05***
CD at 5%	***NS***	***NS***	***NS***	***0.23***	***0.26***	***0.18***	***0.20***	***0.24***	***0.17***	***0.16***	***0.23***	***0.15***
Zinc fertilization												
Z_0	1.13	1.13	1.13	3.64	2.80	3.22	3.71	2.98	3.34	3.69	3.02	3.36
Z_1	1.22	1.24	1.23	3.69	3.09	3.39	3.78	3.13	3.46	3.82	3.18	3.50
Z_2	1.24	1.24	1.24	3.67	3.02	3.34	3.69	3.07	3.38	3.78	3.09	3.43
Z_3	1.18	1.20	1.19	3.67	3.67	3.67	3.62	3.69	3.66	3.64	3.71	3.68
Z_4	1.27	1.20	1.23	3.73	3.58	3.66	3.82	3.60	3.71	3.84	3.62	3.73
Z_5	1.16	1.13	1.14	4.11	3.67	3.89	4.11	3.71	3.91	4.16	3.76	3.96
Z_6	1.24	1.27	1.26	3.73	3.20	3.47	3.76	3.27	3.51	3.78	3.31	3.54
SEm±	***0.06***	***0.06***	***0.04***	***0.12***	***0.14***	***0.09***	***0.11***	***0.13***	***0.08***	***0.09***	***0.12***	***0.08***
CD at 5%	***NS***	***NS***	***NS***	***NS***	***0.39***	***0.26***	***NS***	***0.37***	***0.24***	***0.25***	***0.36***	***0.21***

branches on zinc fertilization might be due to improved uptake of nutrients from the soil or foliar applied which might have enhanced the overall crop growth and metabolic processes which leads to increased cell division thereby resulting to higher number of branches (Hugar & Kurdikeri, 2000). With foliar application of zinc there is enhancement in branching in pulses which is mainly attributed to the promotion of bud and branch development by the auxins and upon Zn application resulted upon in increase availability of other nutrients and accelerated the translocation of photo assimilates (Guhey, 1999). However, application of foliar spray solely or combined with soil application resulted in significantly more branching which is supported by the findings reported by Sangwan and Raj (2004), Khorgamy and Farmia (2009) and Singh *et al*. (2012) on chickpea, cluster bean, mungbean and pigeonpea.

At 90 DAS the maximum number of branches was recorded in the combination of local cultivar and Z_5 (Table 4.1.3b). The same combination was observed to be superior at harvest of the crop.

4.1.1.4 Dry matter accumulation

The data on dry matter accumulation (DMA) of soybean as influenced by varieties and zinc fertilization are presented in Table 4.1.4a and illustrated in Fig 4.1.5 & Fig 4.1.6. Dry matter accumulation is the total accumulation of photosynthates and total nutrient uptake by the plant up to stimulated growth period. It indicates the photosynthetic efficiency of crop. Among soybean varieties there were significant differences on dry matter accumulation at all crop stages except at the second year of the 30 DAS. Local cultivar was found dominant in dry matter accumulation at all crop stages. At harvest, the local cultivar registered the highest dry matter weight per plant in both the years (29.34, 19.69 g plant^{-1}) which proceeded JS 97-52 (26.17, 17.76 g plant^{-1}) and JS-335 (18.67, 14.55 g plant^{-1}). This was mainly due to varietal difference.

Zinc fertilization significantly influenced on the dry matter accumulation in all the crop stages except 30 DAS. It was observed that Z_5 and Z_3 were significantly superior over the others treatments and both remained at par with each other in all the stages. At harvest the dry matter accumulation was maximum in Z_5 (26.68, 18.62 g plant^{-1}) and Z_3 (26.46, 18.85 g plant^{-1}) with the least value in control (21.00, 15.93 g plant^{-1}). The improvement in dry matter of soybean with zinc fertilization might be due to enhanced value of crop growth rate and net assimilation rate. This might have attributed to significant increase in leaf expansion due to better growth of plants as affected by Zn application at early growth stages of crop which finally increased the dry matter of plant. Zn is required for the biosynthesis of plant growth regulator (IAA) and auxin is known to maintain the higher rate of photosynthesis which contributed to higher dry matter which was an indicator of current photosynthesis (Upadhyay, 2002). The results on the improvement of DMA upon zinc application were corroborated by the findings of many workers in the past (Obrador *et al.*, 2003; Arif *et al*., 2006; Kobraee *et al*., 2011). Positive dry matter production response to Zn application was also reported by Slaton *et al*. (2005a) and Obrador *et al*. (2003). Brennan *et al*. (2001) explained that dry matter production at higher Zn supply increased mostly due to greater pod bearing. Z_5 (Three foliar spray of $ZnSO_4.7H_2O$ @ 0.5%) and Z_3 (Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$ + Two foliar spray of $ZnSO_4$ @ 0.25%) resulted in numerical superiority in dry matter accumulation. This could be due to the effectiveness of foliar application over soil application. Foliar application of zinc led to better crop response as the applied zinc was readily absorbed by the crop through leaves. Similar results have been reported by Pandey and Gupta (2012).

The interaction effect of varieties and zinc applications did not show any significant effect at 30 DAS in both the years (Table 4.1.4b). However, the interaction effect showed significant effect from 60 DAS onwards particularly

Table 4.1.4a Effect of varieties and zinc fertilization on dry matter accumulation (g) in soybean

Treatments	***30 DAS***			***60 DAS***			***90 DAS***			***At harvest***		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
Varieties												
V_1	1.64	1.57	1.61	13.72	8.93	11.33	17.52	13.63	15.58	18.67	14.55	16.61
V_2	1.90	1.55	1.72	22.48	15.97	19.23	25.23	18.71	21.97	26.17	17.76	21.96
V_3	2.05	1.51	1.78	24.53	16.21	20.37	27.60	21.27	24.44	29.25	19.69	24.47
SEm±	***0.03***	***0.04***	***0.03***	***0.41***	***0.29***	***0.25***	***0.41***	***0.29***	***0.25***	***0.44***	***0.17***	***0.24***
CD at 5%	***0.09***	***NS***	***0.08***	***1.17***	***0.82***	***0.76***	***1.18***	***0.84***	***0.77***	***1.26***	***0.49***	***0.72***
Zinc fertilization												
Z_0	1.72	1.44	1.58	17.72	11.74	14.73	20.63	15.46	18.05	21.00	15.93	18.46
Z_1	1.82	1.44	1.63	19.73	13.16	16.44	23.07	17.92	20.49	24.48	17.60	21.04
Z_2	1.94	1.51	1.73	19.44	12.51	15.98	23.20	16.72	19.96	24.69	17.08	20.89
Z_3	1.87	1.58	1.73	22.13	14.36	18.24	25.18	18.21	21.69	26.46	18.85	22.65
Z_4	1.93	1.56	1.75	19.08	14.10	16.59	22.58	17.99	20.28	24.08	16.13	20.11
Z_5	1.88	1.66	1.77	23.31	15.76	19.54	25.54	20.20	22.87	26.68	18.62	22.65
Z_6	1.90	1.58	1.74	20.30	14.29	17.30	23.95	18.58	21.27	25.48	17.14	21.31
SEm±	***0.05***	***0.06***	***0.04***	***0.62***	***0.44***	***0.38***	***0.63***	***0.45***	***0.39***	***0.68***	***0.26***	***0.36***
CD at 5%	***NS***	***NS***	***NS***	***1.78***	***1.26***	***1.08***	***1.80***	***1.28***	***1.09***	***1.93***	***0.75***	***1.02***

Table 4.1.4b Interaction effect of varieties and zinc fertilization on dry matter accumulation (g) in soybean

V x Zn Interaction	**60 DAS**			**90 DAS**			**at harvest**		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
V_1Z_0	12.34	7.64	9.99	15.82	11.88	13.85	14.20	13.20	13.70
V_1Z_1	13.25	8.33	10.79	16.70	13.50	15.10	17.05	14.18	15.62
V_1Z_2	12.28	7.70	9.99	16.50	12.86	14.68	17.92	13.77	15.84
V_1Z_3	14.50	8.92	11.71	18.48	13.22	15.85	20.60	16.38	18.49
V_1Z_4	13.22	9.75	11.49	17.31	13.74	15.53	19.52	13.04	16.28
V_1Z_5	16.56	10.36	13.46	20.15	16.02	18.09	22.03	16.75	19.39
V_1Z_6	13.92	9.80	11.86	17.68	14.18	15.93	19.40	14.56	16.98
V_2Z_0	17.68	14.15	15.92	20.14	16.70	18.42	20.54	16.55	18.55
V_2Z_1	21.32	15.73	18.53	24.27	18.55	21.41	26.98	18.47	22.73
V_2Z_2	22.96	15.05	19.01	27.52	17.67	22.60	28.62	18.32	23.47
V_2Z_3	26.24	16.15	21.19	29.43	18.60	24.02	29.70	19.56	24.63
V_2Z_4	20.92	15.56	18.24	23.97	18.55	21.26	25.17	16.60	20.88
V_2Z_5	25.70	18.19	21.95	26.19	21.12	23.65	27.08	17.52	22.30
V_2Z_6	22.55	16.96	19.76	25.07	19.80	22.44	25.07	17.32	21.20
V_3Z_0	23.15	13.44	18.30	25.95	17.81	21.88	28.24	18.05	23.15
V_3Z_1	24.60	15.43	20.02	28.23	21.70	24.97	29.42	20.14	24.78
V_3Z_2	23.07	14.79	18.93	25.57	19.64	22.61	27.53	19.17	23.35
V_3Z_3	25.65	18.00	21.83	27.61	22.82	25.21	29.07	20.60	24.84
V_3Z_4	23.10	16.99	20.04	26.45	21.68	24.07	28.23	18.76	23.49
V_3Z_5	27.68	18.72	23.20	30.28	23.46	26.87	30.94	21.58	26.26
V_3Z_6	24.44	16.12	20.28	29.12	21.77	25.44	31.95	19.56	25.76
SEm±	***1.08***	***0.76***	***0.66***	***1.09***	***0.78***	***0.67***	***1.20***	***0.46***	***0.64***
CD at 5%	***3.09***	***NS***	***1.86***	***3.11***	***NS***	***NS***	***3.42***	***1.30***	***1.80***

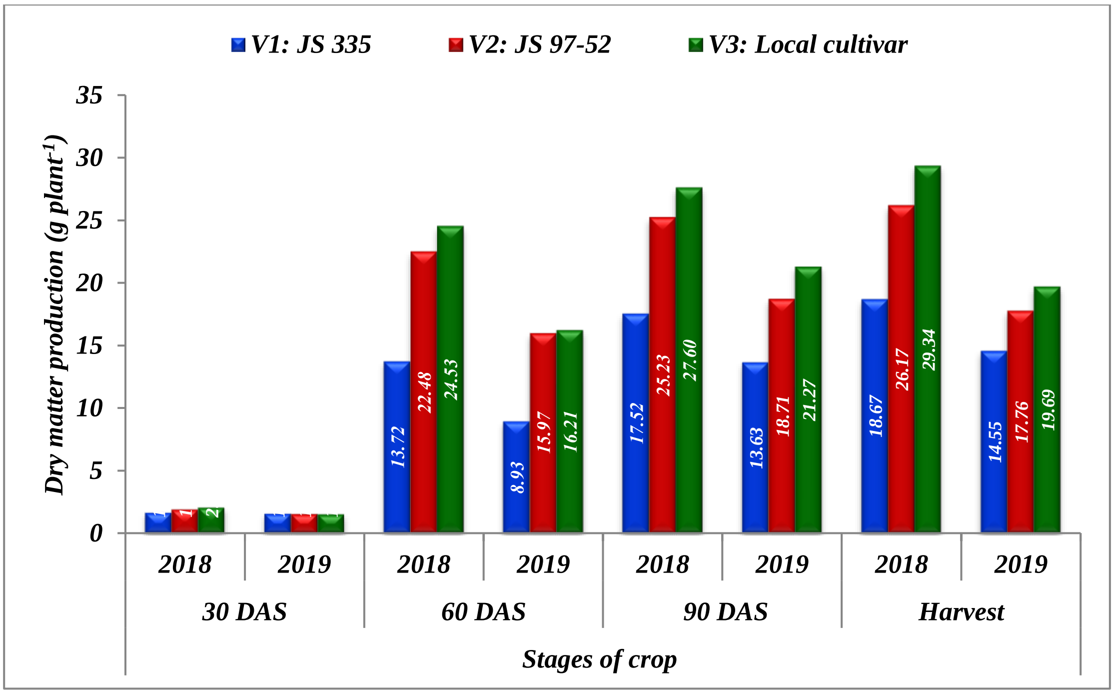


Fig 4.1.5 Effect of varieties on dry matter production of soybean at different stages of crop during 2018 and 2019

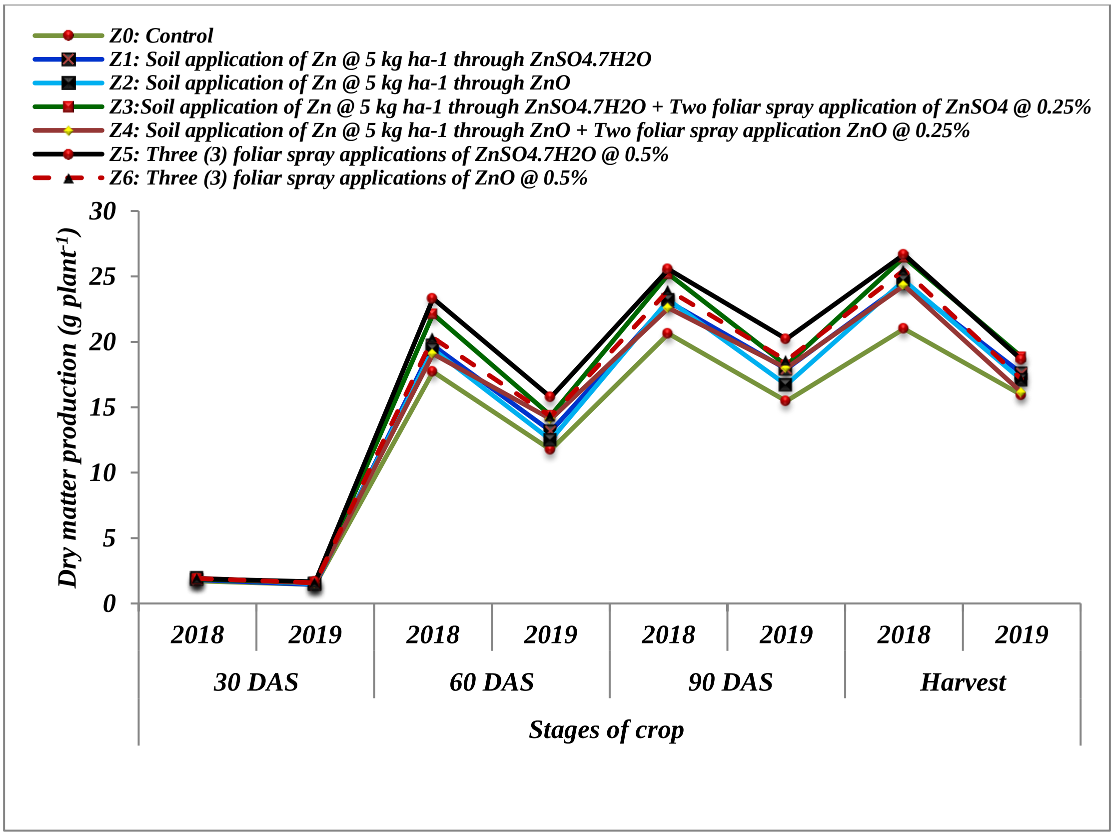


Fig 4.1.6 Effect of zinc on dry matter production of soybean at different stages of crop during 2018 and 2019

in the first year. At 60 DAS the interaction effect V_3Z_5 (27.68 g plant^{-1}) was the highest value.

4.1.1.5 Leaf area

Data on leaf area at different growth stages of soybean as influenced by cultivar and Zn fertilizer application are presented in Table 4.1.5a and illustrated in Fig 4.1.7. & Fig 4.1.8 Among the varieties, local cultivar recorded the highest leaf area which was statistically superior over the other varieties in both the years and in all crop stages. At 30 DAS, local cultivar had leaf area of (499.59, 336.18 cm^2 plant^{-1}), JS-97-52 (378.13, 307.64 cm^2 plant^{-1}) followed by JS-335 with value of (279.95, 275.37 cm^2 plant^{-1}). Similarly, the same trend followed at 60 DAS and 90 DAS stage. At 60 DAS stage, local cultivar registered the highest leaf area (1815.94, 1835.94 cm^2 plant^{-1}) followed by JS-97-52 (1448.51, 1169.21 cm^2 plant^{-1}). There was a drastic decline in leaf area JS-335 and JS-97-52 at 90 DAS stage. The local cultivar was at its peak of vegetative stage at 90 DAS. At 90 DAS maximum leaf area was recorded by local cultivar (2576.49, 2526.89 cm^2 plant^{-1}). This difference was mainly due to typical varietal characteristics and genetic makeup of each cultivar. Usually, local landraces are long duration and have more vegetative growth with lesser economic yield.

Zinc fertilization significantly influenced the leaf area of soybean after 60 DAS onwards. Maximum leaf area plant^{-1} was observed in Z_5 which was at par with Z_1, Z_2, Z_3 and Z_4 in the first year but significantly higher than the rest in the seond year. Similar trend was also observed at 90 DAS where three foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5% (Z_5) registered the highest leaf area. Higher value of leaf area and LAI was observed in zinc treatments particularly in folair application of zinc sulphate was due to better absorption and translocation of foliar applied nutrients leading to delayed senescence and abscission. Foliar application increases enzymes activities which lead to higher crop production and leaf area (LA) expansion (Zayed *et al.*,

Table 4.1.5a Effect of varieties and zinc fertilization on leaf area (cm^2) in soybean

Treatments	***30 DAS***			***60 DAS***			***90 DAS***		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
Varieties									
V_1	279.95	275.37	277.66	994.90	1077.41	1036.15	572.95	553.78	563.37
V_2	378.12	307.64	342.88	1448.51	1169.21	1308.86	1090.84	1133.72	1112.28
V_3	501.97	336.18	419.08	1815.94	1835.94	1825.94	2576.49	2526.89	2551.69
SEm±	***9.96***	***6.40***	***5.92***	***29.98***	***37.89***	***24.16***	***27.14***	***30.78***	***20.52***
CD at 5%	***28.47***	***18.29***	***18.00***	***85.69***	***108.31***	***73.44***	***77.57***	***87.96***	***62.37***
Zinc fertilization									
Z_0	367.75	297.15	332.45	1297.33	1175.99	1236.66	1281.00	1302.98	1291.99
Z_1	366.24	296.39	331.31	1437.12	1368.78	1402.95	1403.18	1380.18	1391.68
Z_2	406.16	296.81	351.49	1467.13	1302.32	1384.73	1341.34	1360.84	1351.09
Z_3	402.13	328.32	365.22	1468.54	1317.98	1393.26	1469.35	1397.83	1433.59
Z_4	378.59	304.30	341.44	1360.06	1386.50	1373.28	1373.91	1416.11	1395.01
Z_5	406.96	322.65	364.80	1501.51	1572.96	1537.24	1626.66	1549.62	1588.14
Z_6	378.95	299.16	339.06	1406.80	1401.44	1404.12	1398.55	1426.01	1412.28
SEm±	***15.22***	***9.77***	***9.04***	***45.80***	***57.88***	***36.90***	***41.46***	***47.01***	***31.34***
CD at 5%	***NS***	***NS***	***NS***	***130.90***	***165.44***	***103.86***	***118.49***	***134.37***	***88.20***

Table 4.1.5b Interaction effect of varieties and zinc fertilization on leaf area (cm^2) in soybean

V x Zn Interaction	*60 DAS*			*90 DAS*		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
V_1Z_0	881.86	986.90	934.38	564.29	587.12	575.70
V_1Z_1	1039.90	1083.47	1061.68	565.45	569.01	567.23
V_1Z_2	1031.27	993.00	1012.13	541.17	513.05	527.11
V_1Z_3	1108.40	1081.98	1095.19	639.95	560.65	600.30
V_1Z_4	946.05	1094.15	1020.10	559.70	478.60	519.15
V_1Z_5	1072.80	1281.54	1177.17	650.15	568.07	609.11
V_1Z_6	884.02	1020.82	952.42	489.97	599.96	544.96
V_2Z_0	1378.10	1113.70	1245.90	1004.50	1081.77	1043.13
V_2Z_1	1604.07	1051.15	1327.61	969.05	1108.03	1038.54
V_2Z_2	1512.38	1231.26	1371.82	1209.72	1142.50	1176.11
V_2Z_3	1531.26	1181.45	1356.35	1035.30	1122.58	1078.94
V_2Z_4	1218.44	1158.92	1188.68	971.72	1138.40	1055.06
V_2Z_5	1449.82	1262.75	1356.28	1310.00	1244.62	1277.31
V_2Z_6	1445.50	1185.22	1315.36	1135.57	1098.15	1116.86
V_3Z_0	1632.03	1427.37	1529.70	2274.20	2240.05	2257.12
V_3Z_1	1667.40	1971.71	1819.56	2675.03	2463.50	2569.27
V_3Z_2	1857.75	1682.70	1770.23	2273.12	2426.98	2350.05
V_3Z_3	1765.96	1690.52	1728.24	2732.80	2510.27	2621.53
V_3Z_4	1915.70	1906.42	1911.06	2590.32	2631.32	2610.82
V_3Z_5	1981.92	2174.60	2078.26	2919.84	2836.17	2878.01
V_3Z_6	1890.86	1998.28	1944.57	2570.12	2579.92	2575.02
SEm±	***79.32***	***100.25***	***63.92***	***71.81***	***81.42***	***54.28***
CD at 5%	***226.72***	***NS***	***179.89***	***NS***	***232.73***	***152.77***

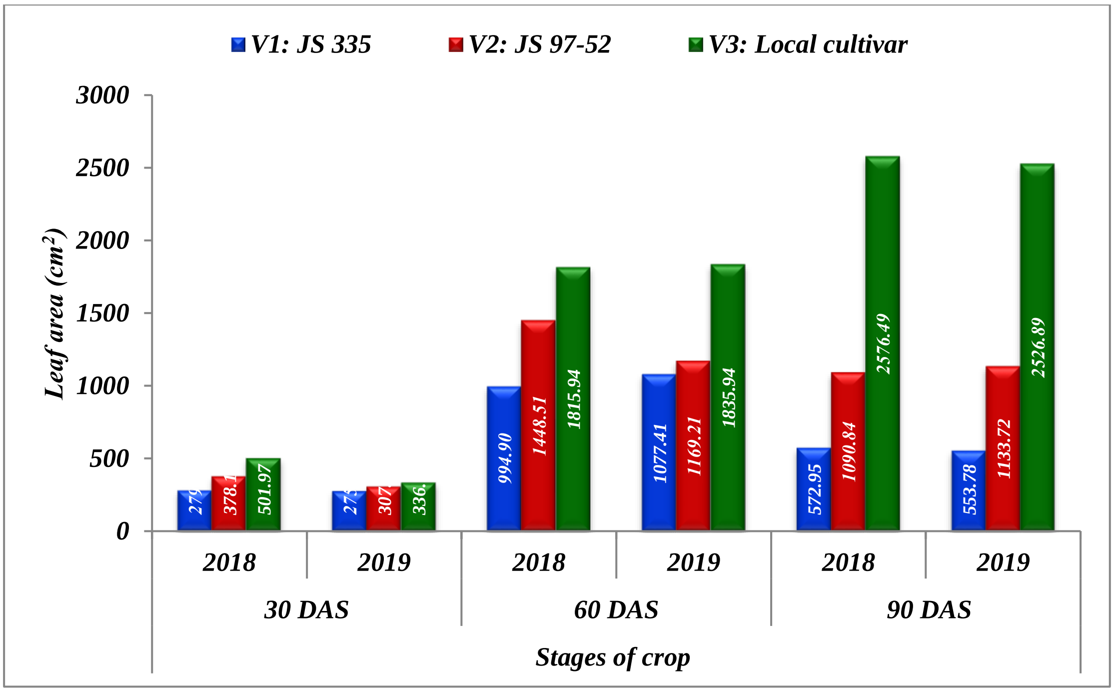


Fig 4.1.7 Effect of varieties on leaf area of soybean at different stages of crop during 2018 and 2019

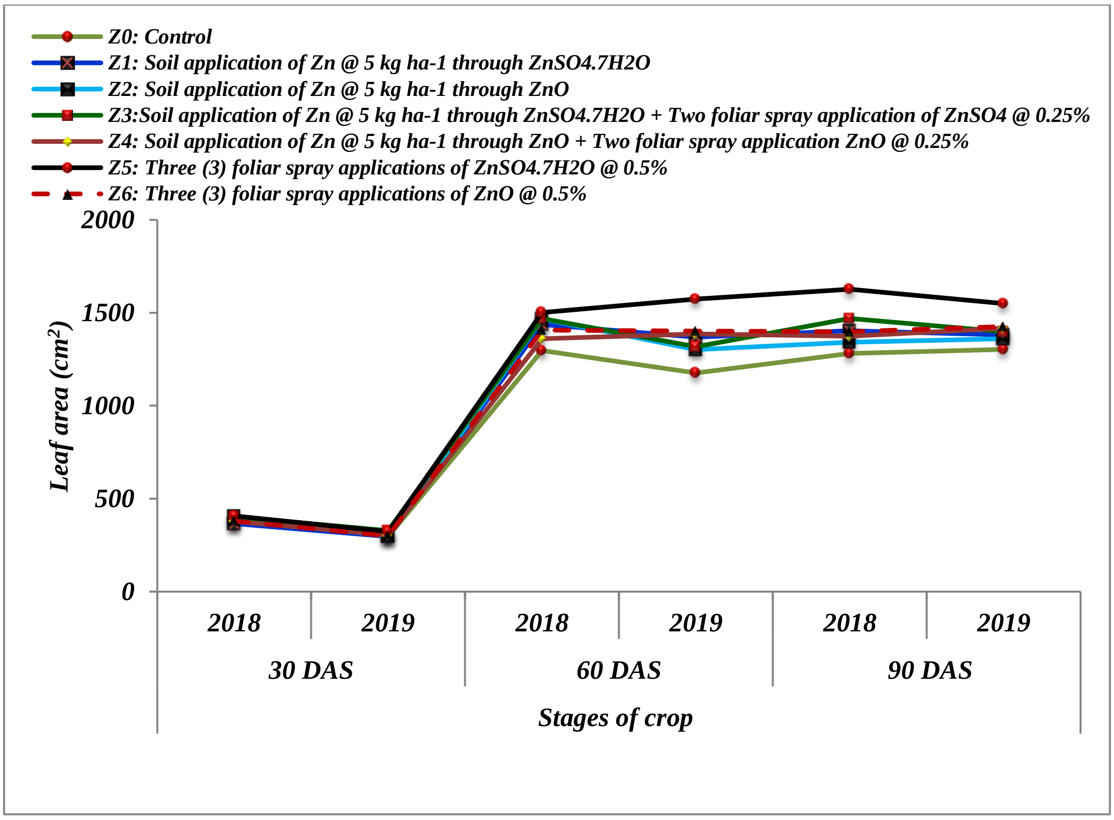


Fig 4.1.8 Effect of zinc application on leaf area of soybean at different stages of crop during 2018 and 2019

2011). Also, an increased leaf area index by Zn application might be due to increase in tryptophan amino acid and indole acetic acid hormone which are two main factors in leaf area expansion (Seifi-Nadergholi *et al*., 2011).

The interaction effect between varieties and zinc application was found significant effect at 60 DAS (Table 4.1.5b). In the first year there was significant effect and the combination of local cultivar and three foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5% registered the highest value of leaf area.

4.1.1.6 Leaf area Index

As leaf area index (LAI) is derivative of the leaf area, therefore the same trend seen in the above parameter will also be seen in the LAI (Table 4.1.6a). Higher the LAI, higher will be the PAR interception which is the source of energy for the process of photosynthesis, which accumulates more photosynthates for translocation to grains resulting in higher yield. The LAI value was significantly higher in local cultivar as compared to JS-335 and JS 97-52 at all crop stages and the lowest LAI was recorded in JS 335. At 60 DAS the maximum LAI was recorded in local cultivar (4.04, 4.08) and lowest was recorded in JS-335 (2.21, 2.39). The same trend was observed at 90 DAS where the highest LAI was recorded in local cultivar (5.73, 5.62).

Zinc fertilization failed to show any significant difference in LAI at 30 DAS. However, with progress of crop stage the effect on LAI was apparent where maximum value at 60 DAS was recorded in Z_5 (3.34, 3.50). The rest of zinc treatments remained at par with each other. The same trend was also observed at 90 DAS with the same treatment Z_5 being superior (3.61, 3.44). The present observations on the significant increase in leaf area index was in accordance with Khan *et al*. (2008), Abdoli *et al*. (2014) and Zayed *et al*., 2011) who also reported an increase in leaf area index through zinc application.

Table 4.1.6a Effect of varieties and zinc fertilization on leaf area index in soybean

Treatments	*30 DAS*			*60 DAS*			*90 DAS*		
	2018	*2019*	*Pooled*	*2018*	*2019*	*Pooled*	*2018*	*2019*	*Pooled*
Varieties									
V_1	0.62	0.61	0.62	2.21	2.39	2.30	1.27	1.23	1.25
V_2	0.84	0.68	0.76	3.22	2.60	2.91	2.42	2.52	2.47
V_3	1.12	0.75	0.93	4.04	4.08	4.06	5.73	5.62	5.67
SEm±	***0.02***	***0.01***	***0.01***	***0.07***	***0.08***	***0.05***	***0.06***	***0.07***	***0.05***
CD at 5%	***0.06***	***0.04***	***0.04***	***0.19***	***0.24***	***0.16***	***0.17***	***0.20***	***0.14***
Zinc fertilization									
Z_0	0.82	0.66	0.74	2.88	2.61	2.75	2.85	2.90	2.87
Z_1	0.81	0.66	0.74	3.19	3.04	3.12	3.12	3.07	3.09
Z_2	0.90	0.66	0.78	3.26	2.89	3.08	2.98	3.02	3.00
Z_3	0.89	0.73	0.81	3.26	2.93	3.10	3.27	3.11	3.19
Z_4	0.84	0.68	0.76	3.02	3.08	3.05	3.05	3.15	3.10
Z_5	0.90	0.72	0.81	3.34	3.50	3.42	3.61	3.44	3.53
Z_6	0.84	0.66	0.75	3.13	3.11	3.12	3.11	3.17	3.14
SEm±	***0.03***	***0.02***	***0.02***	***0.10***	***0.13***	***0.08***	***0.09***	***0.10***	***0.07***
CD at 5%	***NS***	***NS***	***NS***	***0.29***	***0.37***	***0.23***	***0.26***	***0.30***	***0.20***

Table 4.1.6b Interaction effect of varieties and zinc fertilization on LAI at 30, 60 and 90 DAS in soybean

V x Zn Interaction	***60 DAS***			***90 DAS***		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
V_1Z_0	1.96	2.19	2.08	1.25	1.30	1.28
V_1Z_1	2.31	2.41	2.36	1.26	1.26	1.26
V_1Z_2	2.29	2.21	2.25	1.20	1.14	1.17
V_1Z_3	2.46	2.40	2.43	1.42	1.25	1.33
V_1Z_4	2.10	2.43	2.27	1.24	1.06	1.15
V_1Z_5	2.38	2.85	2.62	1.44	1.26	1.35
V_1Z_6	1.97	2.27	2.12	1.09	1.33	1.21
V_2Z_0	3.06	2.47	2.77	2.23	2.40	2.32
V_2Z_1	3.56	2.34	2.95	2.15	2.46	2.31
V_2Z_2	3.36	2.74	3.05	2.69	2.54	2.61
V_2Z_3	3.40	2.63	3.01	2.30	2.49	2.40
V_2Z_4	2.71	2.58	2.64	2.16	2.53	2.34
V_2Z_5	3.22	2.81	3.01	2.91	2.77	2.84
V_2Z_6	3.21	2.63	2.92	2.52	2.44	2.48
V_3Z_0	3.63	3.17	3.40	5.05	4.98	5.02
V_3Z_1	3.71	4.38	4.04	5.94	5.47	5.71
V_3Z_2	4.13	3.74	3.93	5.05	5.39	5.22
V_3Z_3	3.92	3.76	3.84	6.07	5.58	5.83
V_3Z_4	4.26	4.24	4.25	5.76	5.85	5.80
V_3Z_5	4.40	4.83	4.62	6.49	6.30	6.40
V_3Z_6	4.20	4.44	4.32	5.71	5.73	5.72
SEm±	***0.18***	***0.22***	***0.14***	***0.16***	***0.18***	***0.12***
CD at 5%	***0.50***	***NS***	***0.40***	***0.46***	***NS***	***0.34***

The interaction effect was observed the first-year experiment at 60 DAS and 90 DAS (Table 4.1.6b). The highest value of LAI at 60 DAS was observed V_3Z_5 (4.40) and the least was observed in V_1Z_0 (1.96). The same treatment combinations also displayed significant result at 90 DAS. The local cultivar at 90 DAS was at its peak growing stage with maximum vegetative growth which thereby possessed the maximum leaf area or LAI. With the foliar application of three foliar sprays of $ZnSO_4.7H_2O$ @ 0.5% might have attributed and enhanced the overall performance of the crop at this stage.

4.1.1.7 Crop Growth Rate

The data on Crop Growth Rate (CGR) at 30-60 DAS and at 60-90 DAS as influenced by varieties and zinc fertilization are presented in Table 4.1.7a and illustrated in Fig 4.1.9. It revealed that crop growth rate (CGR) at 30-60 DAS was significantly higher in local cultivar (1.647, 1.125 mg day^{-1} cm^{-2}) when compared to JS 97-52 (1.54, 1.07 mg day^{-1} cm^{-2}) and JS-335 (0.89, 0.56 mg day^{-1} cm^{-2}) in both the years of experimentation. With progress in crop stages the CGR value started to decline drastically as observed at 60-90 DAS. The CGR was found significantly higher in JS-335 (0.281, 0.319 mg day^{-1} cm^{-2}) over JS 97-52 with the least value (0.204, 0.203 mg day^{-1} cm^{-2}). The higher value of CGR at 30-60 DAS in local cultivar and JS 97-52 was due to exponential increase in crop growth or increase in dry matter accumulation from 30 DAS to 60 DAS in these two varieties when compared to JS-335. The main reason for higher CGR at 60-90 DAS in JS-335 over the other two varieties was mainly due to the significant increase in dry matter yield from 60 DAS to 90 DAS or the difference in DMA.Varieties have differences in their growing nature which is purely the variability in their genetic makeup.

Plate 3 Soybean crop under different varieties and zinc treatments (Experiment I)

Zinc fertilization resulted to significant variation in CGR during both the periods of 30-60 DAS and at 60-90 DAS in the two years of experimentation. Foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5% (Z_5) recorded the highest CGR at 30-60 DAS (1.52, 1.04 mg day^{-1} cm^{-2}) which was statistically at par with Z_3 (1.48, 0.95 mg $day^{-1}cm^{-2}$). The value of CGR in the first year was observed higher compared to the second year owing to congenial environment for better crop performance which was depicted in the dry matter accumulation. As depicted in the Table 4.1.7a the highest CGR at 60-90 DAS was observed in (Z_5) (0.255, 0.329 mg $day^{-1}cm^{-2}$). The result on the effect of zinc nutrition on increase in CGR was supported by the finding reported by Heidarian *et al*. (2011). Safyan *et al*. (2012) reported increase in leaf area index (LAI) of maize with foliar applied Zn. Further, enhanced value of crop growth rate and net assimilation rate might have attributed to significant increase in leaf expansion due to better growth of plants as affected by Zn application at early growth stages of crop which finally increased the dry matter of plant.

4.1.1.8 Relative Growth Rate

The data pertaining to relative growth rate (RGR) at 30-60 DAS and 60-90 DAS are given in Table 4.1.7a and illustrated in Fig 4.1.10.

The relative growth rate was found significantly influenced among varieties in both the years and stages. RGR at 30-60 DAS was significantly higher in local cultivar (35.79, 34.88 mg g^{-1}) and JS 97-52 (35.82, 33.83 mg g^{-1}) which remained at par with each other. It was observed to have significant in the first year and non-significant in the second year of experimentation. The RGR value at 60-90 DAS was much lesser compared to the previous crop stage. Highest value of RGR was observed in JS-335 (3.57, 5.62 mg g^{-1}) which was significantly higher than JS 97-52 (1.68, 2.31mg g^{-1}) and local cultivar (1.63, 3.18 mg g^{-1}).

Zinc fertilization did not significantly influence the RGR value of 30-60

Table 4.1.7a Effect of varieties and zinc fertilization on CGR, RGR and NAR in soybean

Treatments	Crop growth rate (mg $day^{-1}cm^{-2}$)						Relative growth rate (mg g^{-1})						Net assimilation rate (mg cm^{-2})		
	30-60 DAS			*60-90 DAS*			*30-60 DAS*			*60-90 DAS*			*30-60 DAS*		
	2018	*2019*	*Pooled*	*2018*	*2019*	*Pooled*	*2018*	*2019*	*Pooled*	*2018*	*2019*	*Pooled*	*2018*	*2019*	*Pooled*
Varieties															
V_1	0.89	0.56	0.73	0.281	0.319	0.300	30.70	25.37	28.04	3.57	5.62	4.59	1.73	0.97	1.35
V_2	1.54	1.07	1.30	0.204	0.203	0.203	35.82	33.83	34.82	1.68	2.31	1.99	2.09	1.73	1.91
V_3	1.65	1.12	1.39	0.214	0.303	0.258	35.79	34.88	35.33	1.63	3.18	2.40	1.86	1.14	1.50
SEm±	***0.02***	***0.02***	***0.02***	***0.009***	***0.012***	***0.008***	***0.36***	***0.47***	***0.30***	***0.08***	***0.16***	***0.09***	***0.06***	***0.04***	***0.04***
CD at 5%	***0.07***	***0.06***	***0.05***	***0.027***	***0.034***	***0.023***	***1.04***	***1.36***	***0.91***	***0.24***	***0.46***	***0.28***	***0.18***	***0.13***	***0.12***
Zinc fertilization															
Z_0	1.19	0.81	1.00	0.216	0.242	0.229	33.39	30.61	32.00	2.38	3.66	3.02	1.81	1.28	1.55
Z_1	1.33	0.88	1.10	0.223	0.262	0.243	34.13	31.64	32.88	2.24	3.73	2.99	1.75	1.26	1.51
Z_2	1.32	0.87	1.10	0.246	0.241	0.243	33.08	30.83	31.95	2.55	3.53	3.04	1.76	1.20	1.48
Z_3	1.48	0.95	1.22	0.225	0.269	0.247	35.18	31.30	33.24	2.10	3.60	2.85	1.97	1.35	1.66
Z_4	1.32	0.93	1.12	0.243	0.288	0.265	33.25	31.53	32.39	2.45	3.71	3.08	1.98	1.26	1.62
Z_5	1.52	1.04	1.28	0.255	0.329	0.292	35.64	32.13	33.88	2.14	3.92	3.03	2.02	1.27	1.64
Z_6	1.36	0.94	1.15	0.221	0.293	0.257	34.06	31.49	32.77	2.17	3.76	2.97	1.98	1.31	1.65
SEm±	***0.04***	***0.03***	***0.02***	***0.014***	***0.018***	***0.012***	***0.55***	***0.72***	***0.46***	***0.13***	***0.24***	***0.14***	***0.10***	***0.07***	***0.06***
CD at 5%	***0.10***	***0.09***	***0.07***	***NS***	***0.052***	***0.033***	***1.59***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***

Table 4.1.7b Interaction effect varieties and zinc fertilizationon CGR, RGR and NAR in soybean

V x Zn Interaction	Crop growth rate (mg day^{-1} cm^{-2})						Relative growth rate (mg g^{-1})						Net assimilation rate(mgcm^{-2})		
	30-60 DAS			*60-90 DAS*			*30-60 DAS*			*60-90 DAS*			*30-60 DAS*		
	2018	*2019*	*Pooled*	*2018*	*2019*	*Pooled*	*2018*	*2019*	*Pooled*	*2018*	*2019*	*Pooled*	*2018*	*2019*	*Pooled*
V_1Z_0	0.81	0.49	0.65	0.26	0.28	0.27	31.01	24.85	27.93	3.60	5.51	4.56	1.79	0.92	1.35
V_1Z_1	0.86	0.51	0.69	0.26	0.30	0.28	30.36	24.81	27.59	3.37	5.72	4.54	1.53	0.86	1.20
V_1Z_2	0.79	0.49	0.64	0.31	0.29	0.30	28.93	23.76	26.34	4.29	5.68	4.98	1.44	0.89	1.17
V_1Z_3	0.94	0.54	0.74	0.29	0.32	0.31	30.43	24.70	27.56	3.51	5.70	4.61	1.60	1.00	1.30
V_1Z_4	0.85	0.60	0.73	0.30	0.30	0.30	29.48	25.83	27.66	3.92	5.02	4.47	1.73	1.00	1.37
V_1Z_5	1.10	0.65	0.88	0.27	0.42	0.34	32.75	27.30	30.03	2.84	6.33	4.58	1.95	0.94	1.45
V_1Z_6	0.92	0.61	0.76	0.28	0.32	0.30	31.93	26.35	29.14	3.46	5.35	4.40	2.07	1.13	1.60
V_2Z_0	1.17	0.94	1.06	0.18	0.19	0.19	32.90	33.42	33.16	1.89	2.41	2.15	1.68	1.61	1.65
V_2Z_1	1.45	1.06	1.26	0.22	0.21	0.21	36.19	35.59	35.89	1.88	2.42	2.15	1.68	1.96	1.82
V_2Z_2	1.63	1.01	1.32	0.21	0.19	0.20	36.15	33.95	35.05	1.66	2.33	2.00	2.07	1.52	1.80
V_2Z_3	1.80	1.07	1.44	0.19	0.18	0.18	38.09	32.66	35.38	1.33	2.05	1.69	2.29	1.70	2.00
V_2Z_4	1.55	1.03	1.29	0.20	0.22	0.21	35.67	32.51	34.09	1.63	2.55	2.09	2.56	1.66	2.11
V_2Z_5	1.64	1.22	1.43	0.23	0.22	0.23	37.01	33.75	35.38	1.79	2.16	1.98	2.23	1.82	2.02
V_2Z_6	1.52	1.14	1.33	0.19	0.21	0.20	34.72	34.90	34.81	1.55	2.25	1.90	2.15	1.82	1.98
V_3Z_0	1.58	0.98	1.28	0.21	0.26	0.23	36.25	33.56	34.91	1.65	3.07	2.36	1.97	1.30	1.64
V_3Z_1	1.67	1.07	1.37	0.19	0.28	0.24	35.82	34.53	35.18	1.48	3.05	2.26	2.04	0.96	1.50
V_3Z_2	1.55	1.11	1.33	0.21	0.24	0.22	34.16	34.78	34.47	1.68	2.56	2.12	1.77	1.20	1.48
V_3Z_3	1.71	1.23	1.47	0.19	0.31	0.25	37.01	36.53	36.77	1.46	3.04	2.25	2.02	1.34	1.68
V_3Z_4	1.55	1.15	1.35	0.22	0.35	0.29	34.59	36.25	35.42	1.79	3.55	2.67	1.64	1.12	1.38
V_3Z_5	1.82	1.26	1.54	0.27	0.35	0.31	37.15	35.33	36.24	1.81	3.28	2.54	1.87	1.06	1.46
V_3Z_6	1.65	1.07	1.36	0.20	0.34	0.27	35.53	33.21	34.37	1.51	3.69	2.60	1.73	0.98	1.35
SEm±	***0.06***	***0.06***	***0.04***	***0.02***	***0.03***	***0.02***	***0.96***	***1.25***	***0.79***	***0.22***	***0.42***	***0.24***	***0.16***	***0.12***	***0.10***
CD at 5%	***0.18***	***NS***	***0.12***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***0.47***	***NS***	***0.28***

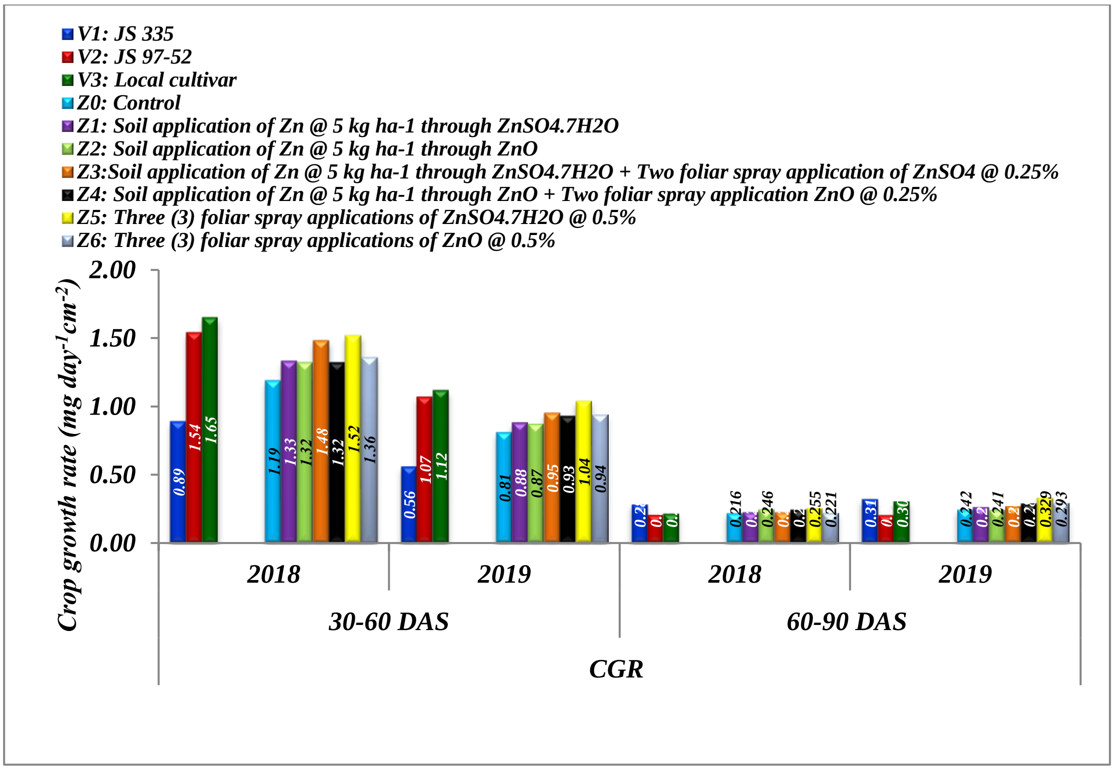


Fig 4.1.9 Effect of varieties and zinc application on crop growth rate (CGR) of soybean at different stages of crop during 2018 and 2019

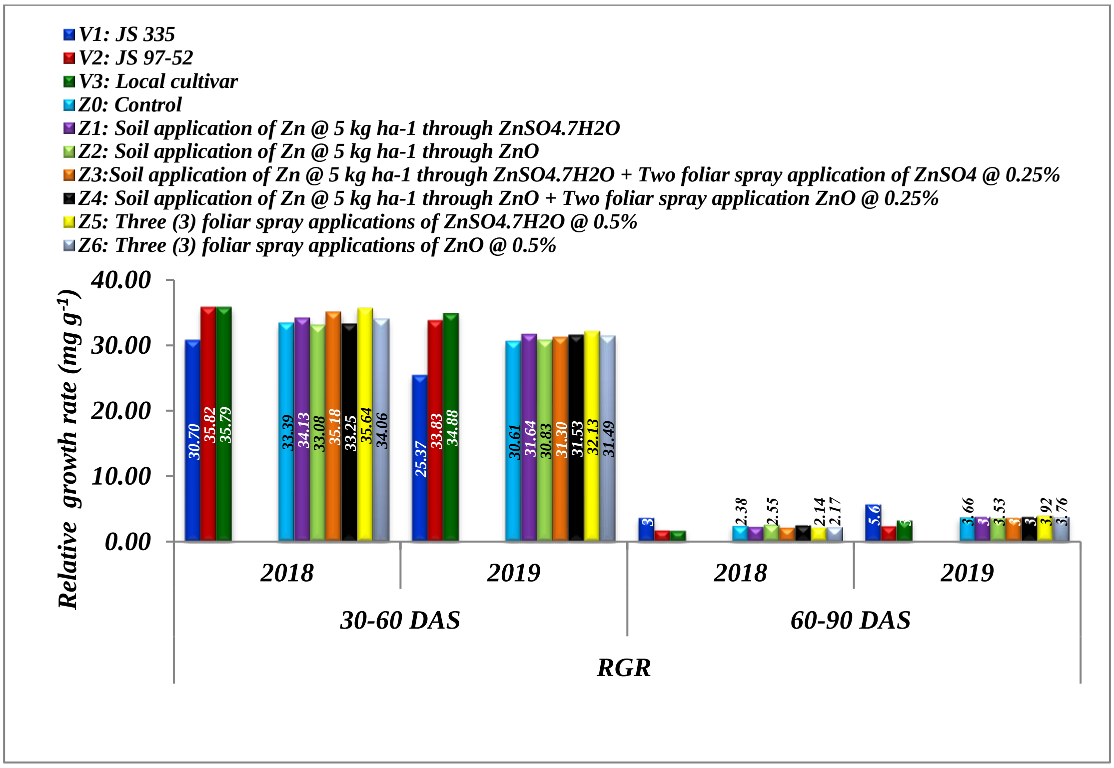


Fig 4.1.10 Effect of varieties and zinc application on relative growth rate (RGR) of soybean at different stages of crop during 2018 and 2019

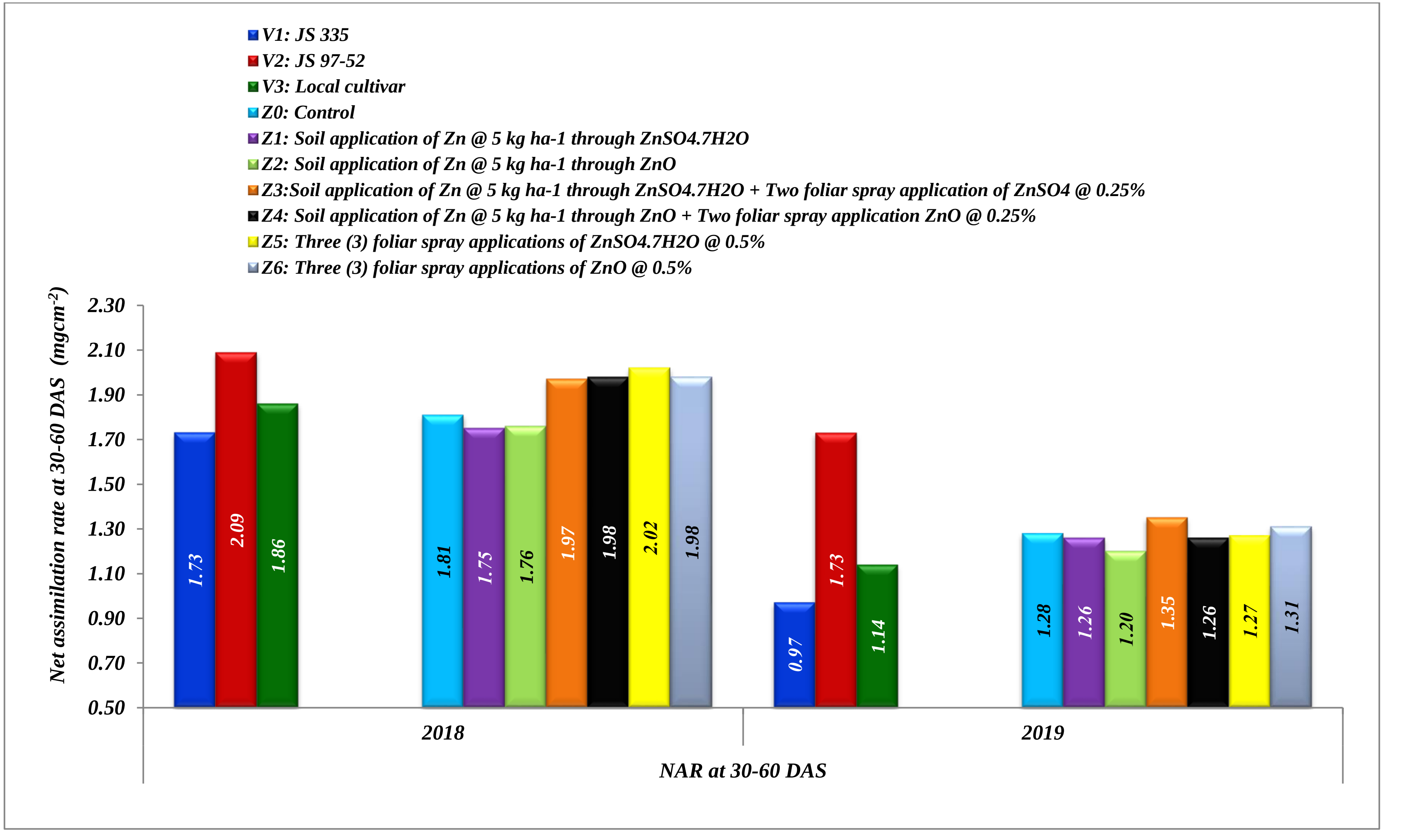


Fig 4.1.11 Effect of varieties and zinc application on net assimilation rate of soybean at 30-60 DAS during 2018 and 2019

DAS and 60-90 DAS although significant effect was observed in the first-year experiment of 30-60 DAS.

The interaction effect of varieties and zinc fertilization was non-significant in both the years of study.

4.1.1.9 Net Assimilation Rate 30-60 DAS (mg cm^{-2})

The data on net assimilation rate (NAR) at 30-60 DAS is presented in Table 4.1.7a and Fig 4.1.11. The data revealed that varieties have significant effect on NAR value. The highest NAR was observed in JS 97-52 (2.09, 1.73 mg cm^{-2}) which was significantly higher than local cultivar (1.86, 1.14 mg cm^{-2}) and least in JS-335 (1.73, 0.97 mg cm^{-2}). The higher value of NAR in JS 97-52 might be due to much higher increase in dry matter accumulation as well as leaf area from 30 DAS to 60 DAS stage. The difference in these parameters which is purely morphological characteristics of varieties depend on the genetic make of the cultivar.

NAR was found to remain non-significant upon zinc fertilization in both the years of experimentation although slight improvement in the value was observed in zinc treated plots when compared to control.

4.1.1.10 Chlorophyll content at 30 and 60 DAS

The data pertaining to the chlorophyll content (Chlorophyll a, b and total chlorophyll) at 30 DAS and 60 DAS are presented in Table 4.1.8a. and Fig 4.1.12 which revealed that there were significant differences among varieties with respect to chlorophyll content at 30 and 60 DAS in both the years of experimentation. Cultivar JS 97-52 (0.87 mg g^{-1}) was statistically at par with JS-335 (0.86, 0.88 mg g^{-1}) in chlorophyll “a” content at 30 DAS stage. Similarly, the two varieties were at par with each other in chlorophyll “b” at 30 DAS stage where JS-335 and JS 97-52 recorded (0.53, 0.56) and (0.54, 0.53 mg g^{-1}) respectively. The highest total chlorophyll at 30 DAS was recorded by JS-335 (1.39, 1.44 mg g^{-1}) which was statistically at par with JS

97-52 (1.41, 1.36 mg g^{-1}). Similar trend was also observed at 60 DAS where the total chlorophyll was recorded highest in JS 97-52 (1.66, 1.70 mg g^{-1}) which was at par with JS-335 (1.64, 1.67 mg g^{-1}). Local cultivar recorded the lowest total chlorophyll content (1.41, 1.37 mg g^{-1}) in both the years of study. The difference in chlorophyll content among varieties is mainly attributed by the genetic difference which is the characteristics of particular cultivar.

Zinc fertilization resulted in significant difference at 60 DAS but remained non significant at 30 DAS. At 60 DAS all the zinc treated plots recorded significantly higher chlorophyll "a" and chlorophyll "b" content over control plots. The highest total chlorophyll content at 60 DAS was observed in Z_3 (1.71, 1.73 mg g^{-1}). The rest of zinc treated plots were statistically at par with each other but significant over the control plot.

Zinc is a metal which acts as a structural and catalytic component of proteins, enzymes and as co-factor for normal development of pigment biosynthesis like chlorophyll in plant systems. Micronutrients such as Zn, Fe and Mn are required in the biosynthetic pathway and essential for the synthesis of chlorophyll. At low level of zinc or at zero zinc application there is reduction of photosynthesis observed in zinc deficient plants might have been, in part, due to decrease in chlorophyll content and the abnormal structure of chloroplasts. The reduction of photosynthesis observed in zinc deficient plants might due to decrease in chlorophyll content and the abnormal structure of chloroplasts. With increasing level and quantity of zinc plants show progressing increase in photosynthetic criteria (Chlorophyll a and chlorophyll b concentration) which was also reported by Ebrahim and Aly (2004) and Maurya *et al*. (2010) in their pot experiment on wheat. Ahmed *et al*. (2022) intheir experiment on rice found that the higher level of zinc application enhanced the chlorophyll content differently based on the different varieties of the same crop which is in confirmation of the results in this experiment.

Table 4.1.8a Effect of varieties and zinc fertilization on chlorophyll content (mg g^{-1}) in soybean

Treatments	*at 30 DAS*									*at 60 DAS*								
	Chlorophyll ‘a’			**Chlorophyll ‘b’**			**Total chlorophyll**			**Chlorophyll ‘a’**			**Chlorophyll ‘b’**			**Total chlorophyll**		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
Varieties																		
V_1	0.86	0.88	0.87	0.53	0.56	0.54	1.39	1.44	1.41	1.03	1.05	1.04	0.61	0.62	0.62	1.64	1.67	1.65
V_2	0.87	0.83	0.85	0.54	0.53	0.54	1.41	1.36	1.39	1.01	1.04	1.03	0.65	0.66	0.65	1.66	1.70	1.68
V_3	0.77	0.83	0.80	0.46	0.53	0.50	1.23	1.36	1.29	0.88	0.85	0.86	0.54	0.53	0.53	1.41	1.37	1.39
SEm±	***0.01***	***0.01***	***0.01***	***0.01***	***0.01***	***0.01***	***0.02***	***0.02***	***0.01***	***0.02***	***0.02***	***0.01***	***0.01***	***0.01***	***0.01***	***0.02***	***0.02***	***0.01***
CD at 5%	***0.04***	***0.04***	***0.03***	***0.02***	***NS***	***0.02***	***0.05***	***0.05***	***0.04***	***0.05***	***0.05***	***0.04***	***0.02***	***0.02***	***0.02***	***0.06***	***0.06***	***0.04***
Zinc fertilization																		
Z_0	0.80	0.82	0.81	0.49	0.53	0.51	1.29	1.35	1.32	0.90	0.90	0.90	0.57	0.57	0.57	1.47	1.47	1.47
Z_1	0.83	0.87	0.85	0.51	0.55	0.53	1.35	1.42	1.38	0.98	0.97	0.98	0.60	0.60	0.60	1.59	1.57	1.58
Z_2	0.84	0.82	0.83	0.52	0.55	0.53	1.36	1.37	1.37	0.97	1.00	0.98	0.60	0.61	0.61	1.57	1.61	1.59
Z_3	0.86	0.88	0.87	0.53	0.55	0.54	1.39	1.43	1.41	1.05	1.07	1.06	0.66	0.66	0.66	1.71	1.73	1.72
Z_4	0.83	0.83	0.83	0.51	0.53	0.52	1.34	1.36	1.35	0.98	0.99	0.98	0.60	0.60	0.60	1.58	1.59	1.58
Z_5	0.86	0.88	0.87	0.53	0.55	0.54	1.39	1.43	1.41	0.97	1.01	0.99	0.58	0.60	0.59	1.56	1.61	1.58
Z_6	0.80	0.82	0.81	0.49	0.51	0.50	1.30	1.33	1.31	0.94	0.92	0.93	0.58	0.59	0.58	1.51	1.50	1.51
SEm±	***0.02***	***0.02***	***0.02***	***0.01***	***0.01***	***0.01***	***0.02***	***0.03***	***0.02***	***0.03***	***0.03***	***0.02***	***0.01***	***0.01***	***0.01***	***0.03***	***0.03***	***0.02***
CD at 5%	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***0.07***	***NS***	***0.05***	***0.07***	***0.08***	***0.05***	***0.03***	***0.03***	***0.02***	***0.09***	***0.09***	***0.06***

Table 4.1.8b Interaction effect of varieties and zinc application on chlorophyll content ($mg\ g^{-1}$) in soybean

V x Zn Interaction	*at 60 DAS*								
	Chlorophyll 'a'			**Chlorophyll 'b'**			**Total chlorophyll**		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
V_1Z_0	0.98	1.00	0.99	0.60	0.61	0.61	1.58	1.61	1.59
V_1Z_1	1.05	1.00	1.02	0.60	0.62	0.61	1.65	1.62	1.63
V_1Z_2	0.98	1.05	1.02	0.58	0.60	0.59	1.56	1.65	1.60
V_1Z_3	1.09	1.15	1.12	0.64	0.66	0.65	1.74	1.81	1.77
V_1Z_4	1.06	1.08	1.07	0.64	0.65	0.65	1.69	1.73	1.71
V_1Z_5	1.07	1.09	1.08	0.61	0.62	0.61	1.68	1.71	1.69
V_1Z_6	0.96	0.98	0.97	0.59	0.61	0.60	1.56	1.59	1.57
V_2Z_0	0.97	0.96	0.96	0.62	0.63	0.62	1.58	1.59	1.58
V_2Z_1	0.98	1.07	1.03	0.65	0.66	0.65	1.63	1.73	1.68
V_2Z_2	1.02	1.06	1.04	0.68	0.69	0.69	1.70	1.75	1.72
V_2Z_3	1.08	1.09	1.08	0.71	0.72	0.72	1.78	1.82	1.80
V_2Z_4	1.01	1.05	1.03	0.61	0.62	0.62	1.62	1.67	1.65
V_2Z_5	1.04	1.09	1.07	0.66	0.67	0.67	1.70	1.77	1.73
V_2Z_6	0.97	0.97	0.97	0.60	0.61	0.60	1.57	1.58	1.58
V_3Z_0	0.77	0.74	0.75	0.48	0.46	0.47	1.25	1.20	1.22
V_3Z_1	0.92	0.85	0.88	0.56	0.52	0.54	1.49	1.37	1.43
V_3Z_2	0.90	0.90	0.90	0.55	0.54	0.54	1.45	1.44	1.44
V_3Z_3	0.99	0.96	0.98	0.61	0.60	0.61	1.60	1.56	1.58
V_3Z_4	0.88	0.83	0.86	0.55	0.52	0.54	1.43	1.36	1.39
V_3Z_5	0.80	0.85	0.83	0.49	0.50	0.49	1.29	1.35	1.32
V_3Z_6	0.87	0.81	0.84	0.54	0.54	0.54	1.41	1.34	1.38
SEm±	***0.04***	***0.05***	***0.03***	***0.02***	***0.02***	***0.01***	***0.05***	***0.05***	***0.04***
CD at 5%	***NS***	***NS***	***NS***	***0.06***	***0.05***	***0.04***	***NS***	***NS***	***NS***

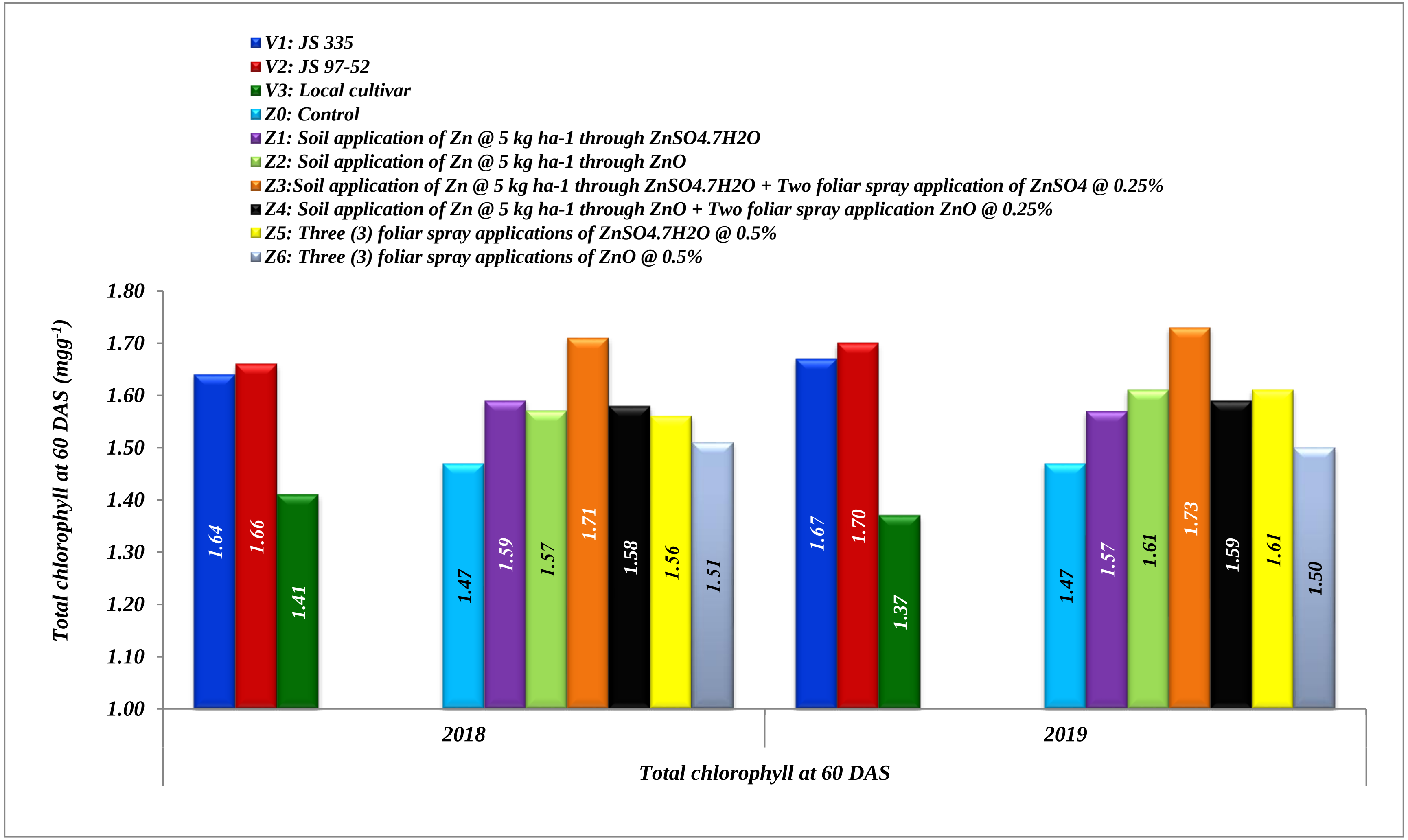


Fig 4.1.12 Effect of varieties and zinc application on total chlorophyll of soybean at 60 DAS during 2018 and 2019

The interaction effect of varieties and zinc fertilization was significant only in chlorophyll "b" content at 60 DAS. The treatment combinations, V_2Z_3 (0.71, 0.72) and V_2Z_2 (0.68, 0.69) were found highly significant over other treatments while they remained statistically at par with each other.

4.1.1.11 Days to 50% flowering and days to maturity

The data pertaining to days to 50% flowering and days to maturity are presented in Table 4.1.9 and Fig 4.1.13. It was revealed that among the varieties local cultivar recorded the longest number of days to attain 50% flowering (68.40, 74.10 days) which was statistically higher value when compared to JS-335 (41.70, 41.00 days) and JS 97-52 (45.00, 46.80 days) in both the years. Similar trend was also observed among varieties towards attaining maturity period. JS-335 (97.50, 107.00 days) took the least number of days to reach maturity which was statistically at par with JS 97-52 (99.10, 109.00 days) and superior as compared to local cultivar (126.90, 137.50 days). It is a common characteristic that local landrace to take much longer time to flower and mature compared to improved varieties. Our results were corroborated by the findings of Muhammad *et al.* (2003) and Bhatia *et al.* (1999). This is mainly due to varietal difference and genetic characteristics of the variety or cultivar.

Zinc fertilization significantly influenced the number of days to 50% flowering as well as days to maturity irrespective of varieties in both the years of experimentation. Zinc application significantly reduced the number of days to achieve 50% flowering. Control treatment took the longest time to achieve flowering (52.60, 55.10 days) while zinc treatments, Z_2, Z_3, Z_4 and Z_5 recorded lesser number of days to 50% flowering. Similar was the case in days to maturity where Z_3 (117.30, 112.10 days) took the least number of days to maturity compared to control (119.60, 114.70 days). Zinc application treatments have no significant effect on the days to 50% flowering in both the years, although there was slight delay in flowering in control treatments as compared to the zinc treated plots. Similarly, many other workers have reported that zinc could significantly affect the crop duration for achieving maturity time who have reiterated the fact that zinc application either foliar or soil (Masoud *et al*., 2012; Hafeez *et al*., 2013; Ali *et al*. 2021). The reason for early flowering in case of zinc application to crops might be due to rapid initial plant growth because of favourable environment and due to proper and appropriate concentrations of micronutrients. Upon zinc application, the crop might have experienced better absorption of the nutrients which involved in the metabolic activity and activated the hormone which influences the earliness. The foliar application of zinc enhanced the metabolic activities of the plant which increased cell enlargement and cell elongation due to which the rate of photosynthesis increased and plant produced early flowering. Days to 50% flowering was reduced with the increasing Zn level could be due to the role of Zn in regulating the synthesis of auxin that promotes flowering (Keram *et al*., 2014). A minor reduction in flowering time with application of zinc nutrition supported a comparative lengthier grain filling duration. These findings were in agreement to the one reported by Abdoli *et al*. (2014) as they also related increase in yield components and grain zinc components with reduced days to flowering. This led to lengthier grain filling duration which finally influenced the reproductive attributes of the crop. Similar results on zinc effect on 50% flowering were obtained by researchers in different crops (Narahari *et al.*, 2018; Hussain *et al*., 2020; Ali *et al*., 2021; Keram *et al*., 2014).

4.1.1.12 Number of nodules

The data on the effect of varieties and zinc application on the number of nodules plant^{-1} have been presented in Table 4.1.10a and Table 4.1.10b. At 45 DAS varieties significantly differed with respect to the number of nodules plant^{-1}. Local cultivar (V_3) recorded the highest number of nodules plant^{-1} (21.55, 21.76) at 45 DAS which was significantly higher when compared to JS-97-52 (16.19, 17.14) and JS-335 (15.59, 16.45) in both the years. The same trend was

Table 4.1.9 Effect of varieties and zinc application on 50% flowering and days to maturity of soybean

Treatments	***Days to 50% flowering***			***Days to maturity***		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
Varieties						
V_1	41.70	41.00	41.30	97.50	107.00	102.30
V_2	45.00	47.00	46.00	99.10	109.00	104.10
V_3	68.40	74.10	71.20	126.90	137.50	132.20
SEm±	***0.26***	***0.28***	***0.19***	***0.48***	***0.39***	***0.31***
CD at 5%	***0.74***	***0.81***	***0.58***	***1.37***	***1.11***	***0.94***
Zinc fertilization						
Z_0	52.60	55.10	53.80	109.80	119.60	114.70
Z_1	51.70	53.70	52.70	107.90	117.60	112.70
Z_2	51.90	53.20	52.60	108.70	117.90	113.30
Z_3	51.00	54.10	52.60	106.80	117.30	112.10
Z_4	51.20	53.90	52.60	107.80	118.10	112.90
Z_5	51.10	54.30	52.70	106.90	116.80	111.80
Z_6	52.20	53.80	53.00	106.90	117.90	112.40
SEm±	***0.39***	***0.43***	***0.29***	***0.73***	***0.60***	***0.47***
CD at 5%	***NS***	***NS***	***0.82***	***NS***	***NS***	***1.33***

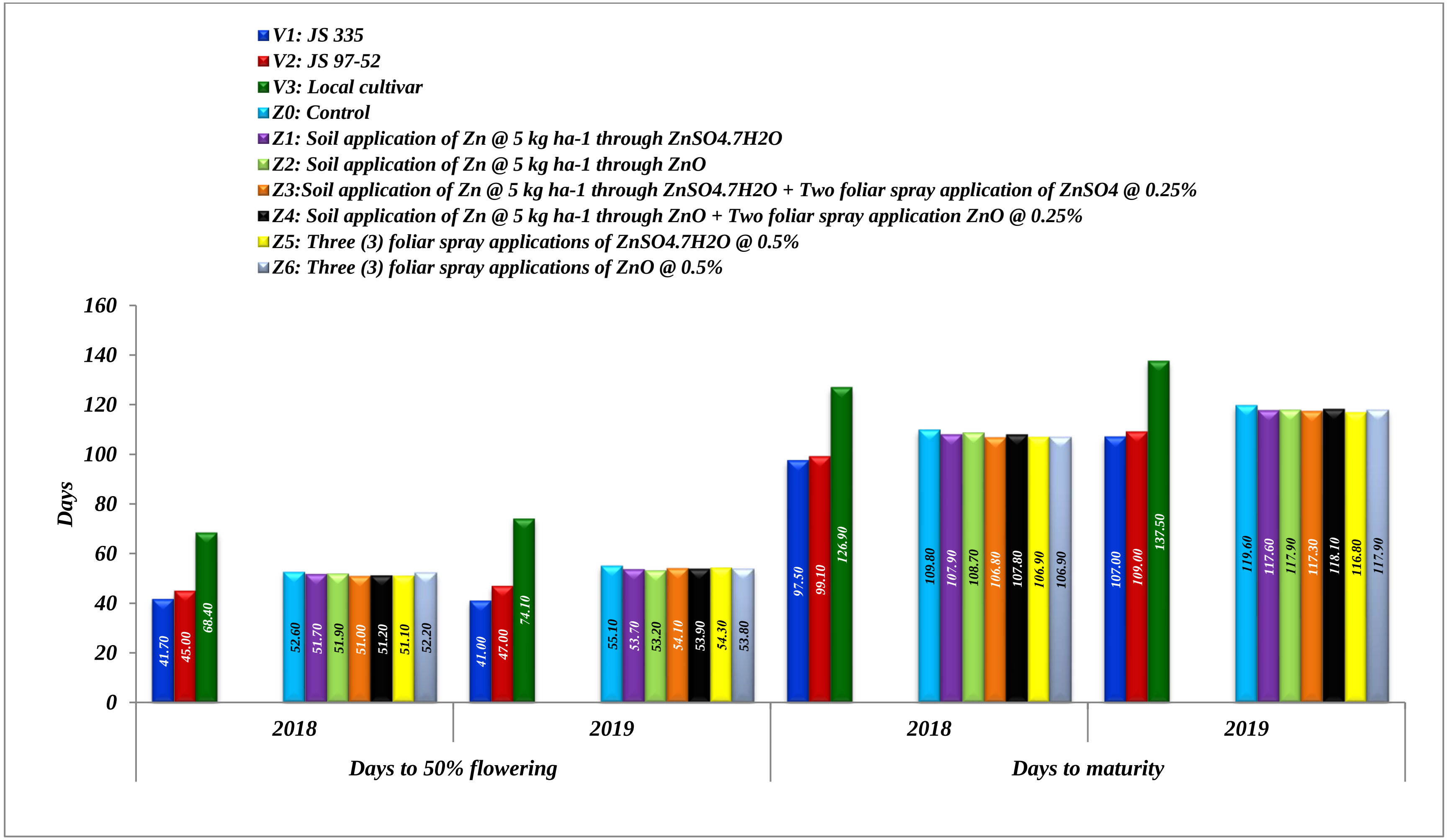


Fig 4.1.13 Effect of varieties and zinc application on days to 50% flowering and days to maturity of soybean during 2018 and 2019

also followed at 45 DAS where local cultivar found to have the maximum number of nodules plant^{-1} (33.31, 35.50) significantly higher than JS-335 (23.1, 28.70) and JS 97-52 (24.39, 23.47) while the two were statistically at par with each other.

The application of zinc significantly influenced on the number of nodules plant^{-1} in both the years of study. Among the treatments, Z_3 (Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$ + Two foliar spray application of $ZnSO_4$ @ 0.25%) recorded the highest number of nodules plant^{-1} (20.22, 20.44) which was significantly higher than the other zinc treatments. The data depicted that increasing level of zinc enhanced the nodulations and it was more prominent in the case where soil application was imposed. The findings were in agreements with those reported by Awlad *et al*. (2003), Goudar *et al*. (2008), Kobraee *et al.* (2011b) and Chauhan *et al*. (2013) who reported 91% higher nodulation in soybean under the application of Zn @ 5 kg ha^{-1} in consecutive years of study which revealed with increasing zinc nutrition increased the number of nodules. The enhancement in nodulation at low levels of Zn was probably associated with its role in auxin production through tryptophan synthesis. It was also observed that foliar application of Zn (Z_5 and Z_6) did not differ significantly on the number of nodules of soybean and this result is supported by the finding of Soni and Kushwaha (2020).

Table 4.1.10a Effect of varieties and zinc application on nodulation of soybean at 45 and 60 DAS

Treatments	**No. of nodules plant^{-1} at 45 DAS**			**Nodules dry weight at 45 DAS (g plant^{-1})**			**No. of nodules plant^{-1}at 60 DAS**			**Nodules dry weight at 60 DAS (g plant^{-1})**		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
Varieties												
V_1	15.59	16.45	16.02	0.43	0.61	0.52	23.12	28.70	25.91	0.64	0.32	0.48
V_2	16.19	17.14	16.67	0.42	0.64	0.53	24.39	23.47	23.93	0.64	0.45	0.55
V_3	21.55	21.76	21.66	0.52	0.74	0.63	33.31	35.50	34.41	0.75	0.55	0.65
SEm±	***0.37***	***0.35***	***0.25***	***0.01***	***0.01***	***0.01***	***0.55***	***0.86***	***0.51***	***0.01***	***0.01***	***0.01***
CD at 5%	***1.05***	***1.01***	***0.77***	***0.04***	***0.04***	***0.03***	***1.56***	***2.46***	***1.55***	***0.04***	***0.04***	***0.03***
Zinc fertilization												
Z_0	15.93	17.11	16.52	0.39	0.59	0.49	23.49	24.29	23.89	0.62	0.35	0.48
Z_1	17.96	18.36	18.16	0.45	0.69	0.57	27.13	27.20	27.17	0.66	0.42	0.54
Z_2	17.80	18.38	18.09	0.47	0.72	0.59	27.00	28.89	27.94	0.69	0.42	0.56
Z_3	20.22	20.44	20.33	0.47	0.69	0.58	30.62	32.56	31.59	0.74	0.54	0.64
Z_4	18.13	18.96	18.54	0.49	0.69	0.59	27.44	31.24	29.34	0.64	0.42	0.53
Z_5	17.44	18.04	17.74	0.45	0.65	0.55	26.56	32.24	29.40	0.71	0.46	0.58
Z_6	16.96	17.87	17.41	0.48	0.62	0.55	26.36	28.16	27.26	0.70	0.45	0.57
SEm±	***0.56***	***0.54***	***0.39***	***0.02***	***0.02***	***0.01***	***0.83***	***1.32***	***0.78***	***0.02***	***0.02***	***0.02***
CD at 5%	***1.60***	***1.54***	***1.09***	***0.06***	***0.06***	***0.04***	***2.38***	***3.76***	***2.19***	***0.06***	***0.06***	***0.04***

Table 4.1.10b Interaction effect of varieties and zinc application on nodulation of soybean at 45 and 60 DAS

V x Zn Interaction	*No. of nodules plant⁻¹ at 60 DAS*			*Nodules dry weight at 60 DAS (g plant⁻¹)*		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
V_1Z_0	20.60	24.00	22.30	0.59	0.28	0.43
V_1Z_1	23.40	25.87	24.63	0.63	0.28	0.45
V_1Z_2	22.00	24.20	23.10	0.71	0.29	0.50
V_1Z_3	26.60	29.47	28.03	0.70	0.35	0.53
V_1Z_4	24.40	35.80	30.10	0.54	0.33	0.43
V_1Z_5	21.80	34.33	28.07	0.66	0.34	0.50
V_1Z_6	23.07	27.27	25.17	0.64	0.39	0.51
V_2Z_0	20.47	19.67	20.07	0.62	0.37	0.50
V_2Z_1	23.60	19.60	21.60	0.64	0.38	0.51
V_2Z_2	22.27	23.80	23.03	0.60	0.47	0.53
V_2Z_3	26.07	26.53	26.30	0.70	0.54	0.62
V_2Z_4	27.00	25.00	26.00	0.55	0.47	0.51
V_2Z_5	26.13	25.20	25.67	0.70	0.46	0.58
V_2Z_6	25.20	24.47	24.83	0.70	0.44	0.57
V_3Z_0	29.40	29.20	29.30	0.64	0.41	0.53
V_3Z_1	34.40	36.13	35.27	0.72	0.60	0.66
V_3Z_2	36.73	38.67	37.70	0.77	0.50	0.64
V_3Z_3	39.20	41.67	40.43	0.81	0.72	0.77
V_3Z_4	30.93	32.93	31.93	0.81	0.48	0.65
V_3Z_5	31.73	37.20	34.47	0.76	0.58	0.67
V_3Z_6	30.80	32.73	31.77	0.76	0.53	0.64
SEm±	***1.44***	***2.28***	***1.35***	***0.04***	***0.04***	***0.03***
CD at 5%	***4.12***	***NS***	***3.80***	***NS***	***0.10***	***0.07***

4.1.1.13 Dry weight of nodules

The data on the effect of varieties and zinc application on dry weight of nodules plant^{-1} have been presented in Table 4.1.10a and Table 4.1.10b. The dry weight of nodules at 45 DAS was found to be significantly higher in local cultivar (0.52, 0.74 g plant^{-1}) as compared to JS 335 (0.42, 0.64 g plant^{-1}) and JS 97-52 (0.61, 0.52 g plant^{-1}). Similarly, the nodules dry weight at 60 DAS was observed to be significantly higher in local cultivar (0.76, 0.55 g plant^{-1}) while JS 335 and JS 97-52 were at par with each other in the first year.

Zinc fertilization found to significantly have influenced on the dry weightof nodules plant^{-1}. Z_3 resulted inhigher value of nodule dry weight (0.74, 0.54 g plant^{-1}) followed by Z_5 and lowest being the control treatment (0.62, 0.35 g plant^{-1}). At 60 DAS also, Z_3 found significantly superior (30.62, 32.56 g plant^{-1}) over other treatments. This result was supported by the finding reported by Bhanavase *et al*. (1994) and Ismail and Tariq (2018).

4.1.2 Yield attributing characters

The data pertaining to yield attributes as affected by different varieties and zinc levels is presented in Table 4.1.11.

4.1.2.1 Number of pods plant^{-1}

The data on number of pods plant^{-1} revealed that there were significant variations among varieties. The highest value was recorded in JS 97-52 in both the years (71.81, 53.53 pods plant^{-1}) followed by local cultivar (36.67, 36.42 pods plant^{-1}) and JS-335 (30.35, 33.39 pods plant^{-1}).

Zinc applications too significantly influenced the number of pods per plant in both the years. Z_5 (Three foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5%) recorded the highest pods plant^{-1} (49.84, 44.31 pods plant^{-1}) which was statistically at par with Z_3 (47.22, 43.00 pods plant^{-1}) and Z_4 (47.20, 43.02 plant^{-}

Table 4.1.11 Effect of varieties and zinc application on yield attributes of soybean

Treatments	No. of pods plant^{-1}			No. of seeds pod^{-1}			Pod length (cm)			100-seed weight (g)		
	2018	*2019*	*Pooled*	*2018*	*2019*	*Pooled*	*2018*	*2019*	*Pooled*	*2018*	*2019*	*Pooled*
Varieties												
V_1	30.35	33.39	31.87	2.50	2.42	2.46	3.41	3.45	3.43	10.00	10.01	10.01
V_2	71.43	53.53	62.48	2.61	2.58	2.60	3.09	3.08	3.08	8.01	8.25	8.13
V_3	35.95	36.42	36.19	2.53	2.43	2.48	3.40	3.37	3.39	6.55	6.58	6.56
SEm±	***0.92***	***0.80***	***0.61***	***0.05***	***0.05***	***0.04***	***0.04***	***0.03***	***0.03***	***0.20***	***0.18***	***0.13***
CD at 5%	***2.64***	***2.28***	***1.86***	***NS***	***NS***	***NS***	***0.11***	***0.10***	***0.08***	***0.56***	***0.52***	***0.41***
Zinc fertilization												
Z_0	41.67	36.42	39.04	2.47	2.33	2.40	3.23	3.27	3.25	7.88	8.05	7.97
Z_1	45.73	40.22	42.98	2.49	2.53	2.51	3.38	3.38	3.38	8.53	8.48	8.50
Z_2	43.96	40.36	42.16	2.64	2.51	2.58	3.22	3.24	3.23	8.41	8.53	8.47
Z_3	47.22	43.00	45.11	2.58	2.60	2.59	3.41	3.33	3.37	8.50	8.43	8.47
Z_4	47.20	43.02	45.11	2.53	2.33	2.43	3.33	3.31	3.32	8.05	8.32	8.19
Z_5	49.84	44.31	47.08	2.60	2.58	2.59	3.30	3.30	3.30	8.11	8.25	8.18
Z_6	45.76	40.47	43.11	2.53	2.44	2.49	3.25	3.26	3.26	7.84	7.87	7.86
SEm±	***1.41***	***1.22***	***0.93***	***0.07***	***0.08***	***0.05***	***0.06***	***0.05***	***0.04***	***0.30***	***0.28***	***0.20***
CD at 5%	***4.03***	***3.49***	***2.62***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***

^{1}). All the treatments were statistically superior over control. Yield of legumes highly depends on the number of pods plant^{-1} which is mostly correlated with yield. Therefore, pods plant^{-1} is the most effective and significant yield attribute and at the same time the most variable component. The main reason for higher value of this yield attribute upon zinc application might be due to the significant role of Zn in the synthesis and production of indole acetic acid (IAA) which resulted in higher number of pods plant^{-1}. It can also be explained by the role of micronutrients in increasing the number of branches due to the formation of stamens and pollens (Nadergoli *et al*., 2011). Zn is an important element and shows a key role in regulating the auxin concentration throughout the plant body, biosynthesis of indole acetic acid. Zn also controls the physiological and biochemical processes and stimuli for the initiation of primordia regarding reproductive growth. It has a positive influence on the translocation of required metabolites from the source to the sink of plants. Several workers have reported the effect of micronutrient on enhancing the number of pods plant^{-1} (Heidarian *et al*., 2011; Quddus *et al*., 2011). Our result was also supported by the findings of Kobraee *et al*. (2011) in soybean and Seifi-Nadergholi *et al*. (2011) in common bean who indicated that the number of pods plant^{-1} was enhanced by zinc foliar application. The increasing values of yield attributes upon zinc application (Soil or foliar or combined) to these pulses could be due to the favourable influence of the Zn application to crops on nutrient metabolism, biological activity and growth parameters and hence, applied zinc resulted in taller plants and higher enzyme activity which in turn encourage vegetative branches and pods plant^{-1}.

The interaction effect between varieties and zinc treatments was found non-significant during both the years.

4.1.2.2 Number of seeds pod^{-1}

The data pertaining to the number of seeds pod^{-1} are presented in 4.1.11. The data shows that there was no significant effect of varieties on the number of seeds per pod. The number of seeds per pod was found to be slightly more in JS-97-52 (2.61, 2.58 seeds pod^{-1}) which was followed by local (2.53, 2.43 seeds pod^{-1}) and JS-335 (2.50, 2.42 seeds pod^{-1}). The significant variation in yield attributing characters likepods $plant^{-1}$, seeds pod^{-1} and seed index were observed among the three varieties which was purely a varietal characteristic and due to difference in their genetic makeup.

There was no significant difference on the number of seeds pod^{-1} with the application of zinc during both the years of study. Although there was non-significant difference in the number of seed pod^{-1} under zinc fertilization, however when compared to control plots the zinc treated plants tend to have higher value. Similar results have also been reported by Heidarian *et al*. (2011), Nadergoli *et al*. (2011) in common bean and Nasri *et al.* (2011) on *Phaseolus vulgaris*.

The interaction effect between varieties and zinc treatments on number of seeds pod^{-1} was found non-significant during both the years.

4.1.2.3 Pod length (cm)

The results of pod length of soybean have been presented in Table 4.1.11. The data revealed that pod length differed significantly among varieties, and it was found to be significantly higher in JS-335 (3.41, 3.45 cm) which was statistically at par with the local cultivar (3.40, 3.37 cm) and least in JS-97-52 (3.09, 3.08 cm).

The zinc treatments did not cause any significant difference in pod length of soybean in both the years. The interaction effect too found non-significant in both the years.

4.1.2.4 Seed index

It is apparent from the Table 4.1.11 that the maximum seed index was recorded in JS-335 (10.00, 10.01 g) which was statistically superior over the other varieties. Local cultivarrecorded a barely low value of seed index (6.55, 6.58 g). All the varieties varied significantly among each other on this yield attribute. Seed index and seed boldness is purely a varietal characteristics and genetic makeup of the particular cultivar so therefore improved varieties were selected to have higher seed index or more seed boldness for better seed yield. The highest 100-seed weight was observed in Z_1 (8.53, 8.48 g) and least in control (7.88, 8.05 g).

Zinc fertilization failed to produce a significant difference on seed index of soybean in both the years. External application of zinc fertilizers has very negligible role or non-significant effect in altering such varietal characteristic of the crop. Although non-significant difference observed in 100-seed weight there was higher value in zinc fertilized plants compared to control. This increase in 100-seed weight can be explained by the fact Zn is an important element and shows a key role in regulating the auxin concentration throughout the plant body, biosynthesis of indole acetic acid. It is also reported that photosynthesis and respiration rates is enhanced and improved physiological and biochemical processes were observed by the application of Fe, Zn, and Mn (Zeidan *et al.*, 2010). Similar results on the effect of zinc in enhancing seed index have been reported by Sharma *et al*. (2010), Farhan and Al-Dulaemi (2011) and Abdel *et al.* (2014).

4.1.3 Yield

4.1.3.1 Seed yield

The seed yield of a crop is the net result of interaction of various factors and is a valid criterion for comparing the efficacy of various treatments. The data on seed yield as influenced by varieties and zinc fertilization is presented in Table 4.1.12 and Fig 4.1.14. All the three varieties varied significantly among each other on seed yield in both the years. JS 97-52 registered the highest seed yield (1.88, 1.69 t ha^{-1}) followed by JS-335 (1.49, 1.52 t ha^{-1}) and the least was recorded in local cultivar (1.29, 1.24 t ha^{-1}). In this study, the yield achieved from the two the improved varieties were much lower than their yield potentials

Table 4.1.12 Effect of varieties and zinc fertilization on seed yield, stover yield, biological yield and harvest index in soybean

Treatments	Seed yield (t ha^{-1})			Stover yield (t ha^{-1})			Biological yield (t ha^{-1})			Harvest index (%)		
	2018	*2019*	*Pooled*	*2018*	*2019*	*Pooled*	*2018*	*2019*	*Pooled*	*2018*	*2019*	*Pooled*
Varieties												
V_1	1.49	1.52	1.51	1.49	1.39	1.44	2.98	2.91	2.94	0.50	0.52	0.51
V_2	1.88	1.69	1.79	1.91	1.78	1.84	3.78	3.47	3.63	0.50	0.49	0.49
V_3	1.29	1.24	1.27	1.78	1.96	1.87	3.07	3.20	3.14	0.42	0.39	0.40
SEm±	*0.02*	*0.01*	*0.01*	*0.04*	*0.03*	*0.03*	*0.05*	*0.04*	*0.03*	*0.00*	*0.01*	*0.00*
CD at 5%	*0.05*	*0.04*	*0.04*	*0.11*	*0.10*	*0.08*	*0.13*	*0.11*	*0.09*	*0.01*	*0.01*	*0.01*
Zinc fertilization												
Z_0	1.38	1.32	1.35	1.55	1.54	1.54	2.93	2.85	2.89	0.47	0.46	0.47
Z_1	1.54	1.46	1.50	1.71	1.70	1.71	3.25	3.16	3.21	0.47	0.46	0.47
Z_2	1.50	1.46	1.48	1.60	1.66	1.63	3.10	3.12	3.11	0.48	0.47	0.48
Z_3	1.65	1.59	1.62	1.80	1.76	1.78	3.45	3.35	3.40	0.48	0.48	0.48
Z_4	1.61	1.50	1.56	1.80	1.75	1.77	3.41	3.25	3.33	0.47	0.47	0.47
Z_5	1.62	1.55	1.59	1.86	1.84	1.85	3.48	3.40	3.44	0.46	0.46	0.46
Z_6	1.57	1.51	1.54	1.75	1.71	1.73	3.32	3.22	3.27	0.47	0.47	0.47
SEm±	*0.03*	*0.02*	*0.02*	*0.06*	*0.05*	*0.04*	*0.07*	*0.06*	*0.05*	*0.01*	*0.01*	*0.01*
CD at 5%	*0.08*	*0.06*	*0.05*	*0.16*	*0.15*	*0.11*	*0.20*	*0.16*	*0.13*	*NS*	*NS*	*NS*

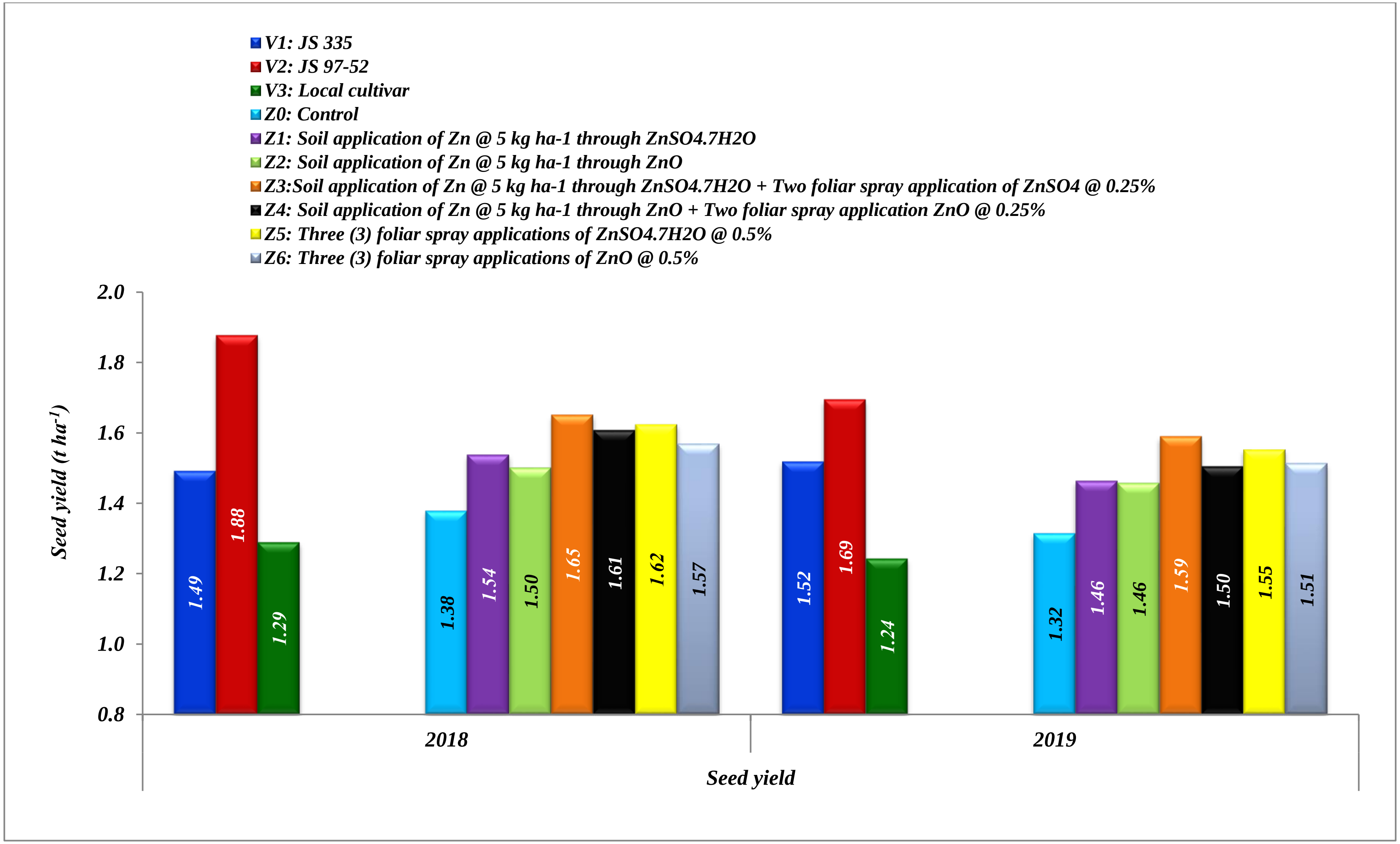


Fig 4.1.14 Effect of varieties and zinc application on seed yield of soybean during 2018 and 2019

(2.7-3.0 t ha^{-1}) which could be due to many factors *viz*., climatic, soil factors and genotype x environment interaction which eventually determined and reflected on their economicyield. The superiority of the variety JS 97-52 could be due to its higher potential yield and suitability in the location. One of the major factors for superiority of this variety was due to it significantly higher number of pods $plant^{-1}$ and 100-seed weight which has cumulatively attributed on overall yield dominance over to the other varieties.

Zinc fertilization significantly influenced on the seed yield of soybean during both the years of experimentation. All the zinc fertilization treatments were significantly higher than the control in seed yield. Zinc treatment, Z_3 (Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$ + Two foliar spray application of $ZnSO_4$ @ 0.25% at pre-flowering and pod formation stages) registered the highest seed yield (1.65, 1.59 t ha^{-1}) which was statistically at par with Z_5 (Three foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5%) (1.62, 1.55t ha^{-1}). Similar trend was also observed in the pooled data. The seed yield increased by (19.70, 20.88%) from control (13.79, 13.15 t ha^{-1}) to (16.51, 15.90 q ha^{-1}) in Z_3. Similarly, the enhanced seed yield in Z_5 over the control was (17.70, 18.03%) which was followed by Z_4 (16.56, 14.42%) in both the years.

The increase seed yield as observed in the experiment upon progressive increment of zinc nutrient quantity was likely due to abundant supply of Zn nutrition, which increased the protoplasmic constituents, helping the process of cell division and elongation, photosynthetic processes, respiration other biochemical and physiological activities (Maurya *et al*., 2010). The overall increase of these processes that involved in the plant systems might have improved the values of all growth and yield attributing parameters, which finally reflected in increased grain and straw yield. With zinc application there was an increase in yield attributes, grain and stover yield which might be due to higher uptake of zinc which led to higher biomass production as elaborated by Shivay *et al*. (2008a) and Pooniya *et al*. (2012) and more photosynthates translocation to reproductive parts (Ozkutlu *et al.*, 2006). As zinc helps in pollen germination and seed formation there could be more seed formation which resulted from increased fertility percentage under Zn applied plots. Zinc sulphate ($ZnSO_4.7H_2O$) was superior to zinc oxide (ZnO) in the effective enhancement of seed yield. This result was supported by the findings of Kanase *et al*. (2008) and Shivay *et al.* (2008b) in their experiments. Nayyar *et al*. (2001) also elaborated the same reasons that ZnO was inferior to Zn sulphate with respect to seed yield of rice which could be due to better solubility of $ZnSO_4.7H_2O$. The superiority of treatment Z_3 over Z_5 could be due to more assimilation of zinc nutrient to plant systems when higher amount of zinc supplied (5.63 kg ha^{-1}) as compared to sole foliar application of $ZnSO_4$ (1.89 kg ha^{-1}) treatments. The two foliar sprays coincided with flowering and pod formation stage of soybean could have improved Zn nutritional status of plant, thus filling the gap created in plant which was due to translocation effect and this helped in enhancing the seed yield which was observed in treatments with soil and two foliar spray applications. The increase in seed yield may be due to the higher efficiency of enzymatic activities which ultimately influenced the plant as Zn is an important component of all classes of enzymes that encourages growth and yield components.Through foliar application, the plant absorbed the applied nutrients via the stomata of the leaves faster and efficiently than the one applied through the soil which was similar to the results of Smolen (2012) as foliar uptake of mineral nutrients is ranged from 8 to 20 times more efficient than soil application.

The interaction effect between varieties and zinc fertilization was found non-significant in both the years of experimentation.

4.1.3.2 Stover yield

The data on stover yield of soybean as influenced by cultivar and zinc fertilization are presented in the Table 4.1.12. There was significant difference among varieties on the stover yield of soybean in both the years. Local cultivar recorded the highest stover yield (1.78, 1.96 t ha^{-1}) followed by JS 97-52 (1.91, 1.78 t ha^{-1}) which was significantly higher than and JS-335 (1.49, 1.39t ha^{-1}). Higher stover yield in local cultivar and JS 97-52 was mainly due to the varietal charactertic of the two for having more vegetative biomass as compared to JS-335.

Stover yield significantly differed in zinc applications in both the years. Among the different zinc fertilization treatments, Z_5 (Three foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5%) recorded the highest stover yield (1.86, 1.84 t ha^{-1}) which was statistically at par with almost all zinc treated plants. With application of zinc there was an increase in the values of all growth and yield attributing parameters, which finally reflected in increased both grain and straw yield. The results observed was in conformity with the findings of Nandanwar *et al*. (2007) where grain and straw yield of soybean increased significantly with Zn 5.0 kg Zn application as compared to control. Kanase *et al.* (2008) also reported that zinc application increased straw yield of soybean over control.

The interaction effect between varieties and and zinc fertilization on stover yield was found to be non-significant in both the years.

4.1.3.3 Biological yield

The data pertaining to biological yield are presented in Table 4.1.12. The biological yield of soybean significanty varied among varieties in both the years of study. The highest biological yield was recorded in JS 97-52 (3.78, 3.47 t ha^{-1}) which was followed by local cultivar (3.07, 3.20 t ha^{-1}). The lowest value was observed in JS-335 (2.98, 2.91 t ha^{-1}). The higher value of seed yield and stover yield in JS 97-52 cumulatively enhanced the biological yield. Whereas in the case of local cultivar owing to its high stover yield which is a common characteristic of local landraces resulted in increased biological yield when zinc fertilization significantly enhanced the biological yield of soybean

(3.48, 3.40 t ha^{-1}) and the lowest recorded in control (2.93, 2.85 t ha^{-1}). The result revealed that three foliar spray applications of zinc sulphate @ 0.5% slightly have higher biological yield than the rest might be due to better assimilation of zinc nutrient applied when compared to the other treatments. The increase in the values of biological yield with progressive increase in zinc application resulted the enhancement in biological yield could be due to the role of zinc that has catalytic and constructive role in the physiological and biochemical activities and in respiration and photosynthesis processes and thus resulting in higher economical yield. Our finding was supported by the result of the previous studies given by Ghasemian *et al*. (2010) and Kobraee *et al*. (2011a) in their experiments on soybean.

However, the interaction between varieties and zinc fertilization on biological yield was found non-significant in both the years.

4.1.3.4 Harvest Index

The harvest index was found to be significantly higher in JS-335 (0.50, 0.52) and JS 97-52 (0.50, 0.49) as compared to local cultivar (0.42, 0.39). Much lower value of harvest index in case of local cultivar was due to very low seed yield and comparatively high value of stover yield which is basically the character of the local cultivar.

Zinc fertilization failed to produce any significant influence on the harvest index of soybean in both the years of study. The present results on non-significant increase in harvest index were in agreement with the work of Hussain *et al*. (2005) and Abdoli *et al*. (2014) while it was contrary to the findings of Kobraee *et al*. (2011a); Nadergoli *et al*. (2011) and Hafeez *et al*. (2021).

Similarly, the interaction effect of cultivar and zinc application was found to be non-significant.

4.1.4 Nutrient concentration and uptake

4.1.4.1 Nitrogen content in grain

The perusal of data of nitrogen content in grain as influenced by varieties and zinc fertilization is presented in Table 4.1.13 and illustrated in Fig 4.1.15. Varieties did not vary significantly on nitrogen content in both the years of experiment. Although non-singificant the nitrogen content was numerically higher in JS 335 (6.19, 6.15%) followed by JS 97-52 (6.09, 6.10%).

Zinc fertilization resulted to significant difference in the N content in grain in both the years of experimentation. The highest N concentration was observed in Z_5 (Three foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5%) (6.36, 6.30%) which remained at par with the rest of zinc treatments but statistically superior over the control (5.74, 5.71%). The percentage increase in N concentration in grain of soybean with Z_5 over control was (10.82, 10.31%), (9.48, 10.09%) in Z_3 and (6.32, 7.70%) in Z_4 in both the years. The result of this investigation was in conformity to the study reported by Zhao *et al*. (2009) and Gomez-Beccera *et al*. (2010) who stated that there is a close relationship between Zn, Fe, N, P and K. Shivay *et al*. (2015) reported that with soil and foliar zinc biofortification resulted in enhancement of rice grain with N, P, K and Fe. The higher content of N in grain upon zinc application might be due the role of zinc in enhancing photosynthesis which resulted in higher nutrient accumulation. The finding is supported by those reported by Kobraee *et al.* (2011), Salih (2013) and Jat *et al*. (2021).

The interaction effect of cultivar and zinc application has no significant effect on N concentration in grain in both the years of study.

4.1.4.2 Nitrogen content by stover

The perusal of data of nitrogen content in stover as influenced by varieties and zinc fertilization is presented in Table 4.1.13. Nitrogen content in stover did not significantly differ among varieties. The N content in stover of

Table 4.1.13 Effect of varieties and zinc fertilization on N content in grain and stover and their uptake in soybean

Treatments	**N content in grain (%)**			**N content in stover (%)**			**N uptake in grain (kg ha^{-1})**			**N uptake in stover (kg ha^{-1})**			**Total N uptake (grain + stover) kg ha^{-1}**		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
Varieties															
V_1	6.19	6.15	6.17	2.04	2.09	2.07	92.33	93.39	92.86	30.45	29.00	29.73	122.79	122.38	122.59
V_2	6.09	6.10	6.10	1.91	1.96	1.94	114.19	103.48	108.84	36.58	34.96	35.77	150.77	138.44	144.61
V_3	6.00	5.99	6.00	2.02	2.05	2.04	77.42	74.58	76.00	36.01	40.48	38.25	113.43	115.06	114.24
SEm±	***0.09***	***0.08***	***0.06***	***0.04***	***0.04***	***0.03***	***1.43***	***1.49***	***1.03***	***0.97***	***0.97***	***0.68***	***1.88***	***1.82***	***1.31***
CD at 5%	***NS***	***NS***	***NS***	***NS***	***NS***	***0.09***	***4.09***	***4.25***	***3.13***	***2.76***	***2.77***	***2.08***	***5.36***	***5.19***	***3.97***
Zinc fertilization															
Z_0	5.74	5.71	5.72	1.96	1.91	1.93	79.48	75.28	77.38	30.21	29.27	29.74	109.69	104.56	107.12
Z_1	6.11	6.13	6.12	1.93	1.98	1.96	93.83	90.00	91.91	33.15	33.55	33.35	126.98	123.54	125.26
Z_2	6.03	6.08	6.06	1.91	1.97	1.94	90.47	88.54	89.50	30.61	32.61	31.61	121.08	121.15	121.11
Z_3	6.28	6.29	6.29	2.01	2.13	2.07	103.72	99.79	101.76	35.85	37.50	36.68	139.57	137.29	138.43
Z_4	6.10	6.15	6.13	2.06	2.01	2.04	98.19	92.95	95.57	36.72	35.15	35.93	134.91	128.10	131.51
Z_5	6.36	6.30	6.33	2.11	2.26	2.19	103.15	97.30	100.23	39.25	41.65	40.45	142.41	138.95	140.68
Z_6	6.01	5.92	5.96	1.97	1.99	1.98	93.68	89.52	91.60	34.65	33.95	34.30	128.33	123.47	125.90
SEm±	***0.13***	***0.13***	***0.09***	***0.06***	***0.06***	***0.05***	***2.18***	***2.27***	***1.58***	***1.48***	***1.48***	***1.05***	***2.86***	***2.77***	***1.99***
CD at 5%	***0.38***	***0.37***	***0.26***	***NS***	***0.19***	***0.13***	***6.24***	***6.49***	***4.43***	***4.22***	***4.23***	***2.94***	***8.19***	***7.93***	***5.61***

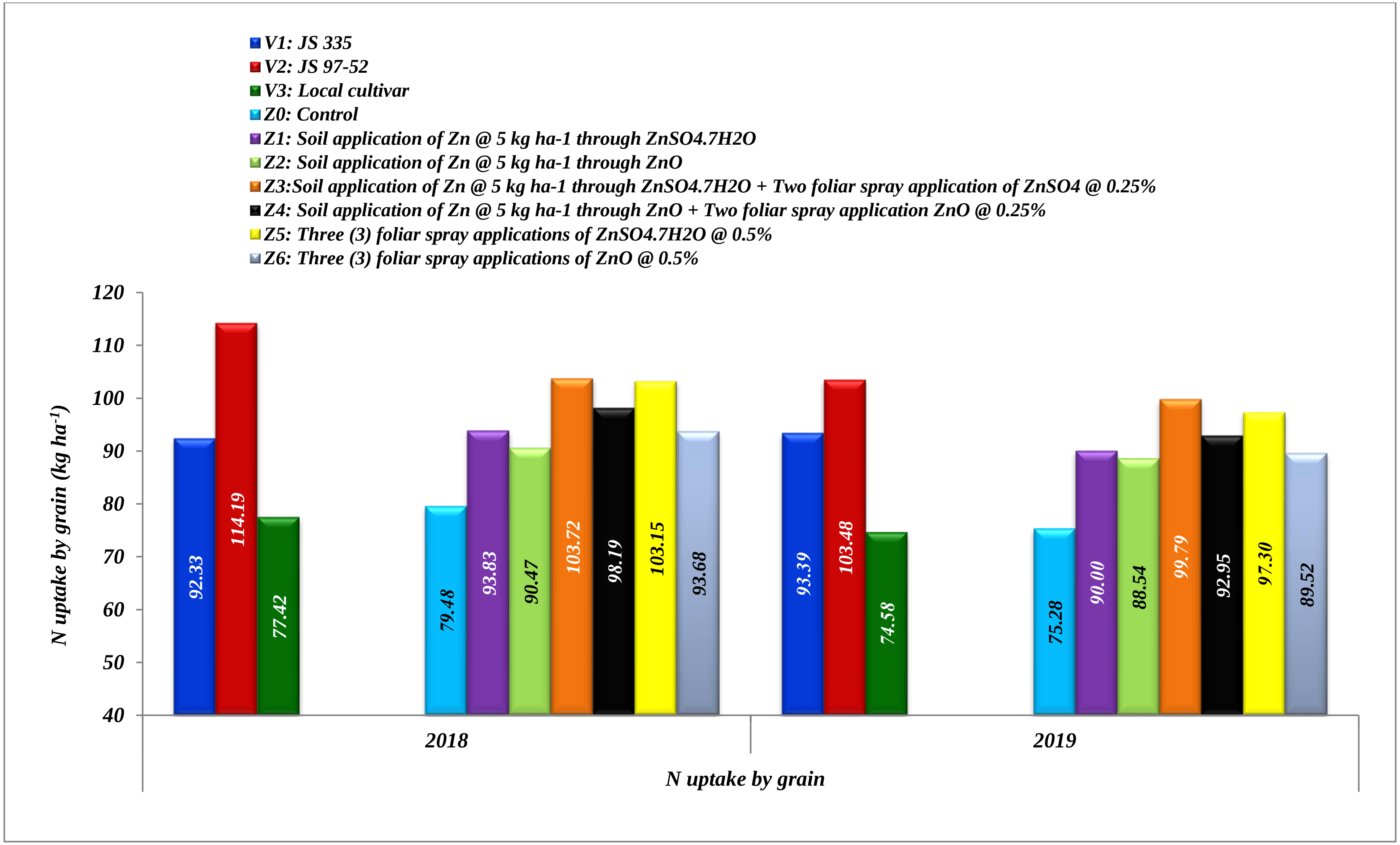


Fig 4.1.15 Effect of varieties and zinc application on N uptake by grain in soybean during 2018 and 2019

JS-335 (2.04, 2.09%), local cultivar (2.05, 2.04%) and JS 97-52 (1.91, 1.96%) was recorded.

Zinc fertilization did not significantly influence the N content in grain in the first year whereas in the second-year experiment and on the pooled data significant difference was observed. The treatment, Z_5 (Three foliar sprays of $ZnSO_4.7H_2O$ @ 0.5%) (2.11, 2.26%) was statistically at par with Z_3, Z_1 and Z_4 and significantly higher than the control (1.96, 1.91%).

The interaction effect was non-significant during both the years.

4.1.4.3 Nitrogen uptake by grain

The nitrogen uptake in grain as influenced by varieties and different zinc treatments are presented in Table 4.1.13. Nitrogen uptake is the product of multiplication between yield (Grain or straw) and nitrogen content. The data revealed the grain N uptake differed significantly among varieties for both the years of study. Grain N uptake by the variety JS 97-52 (114.19, 103.48 kg ha^{-1}) was significantly higher than JS-335 (92.33, 93.39 kg ha^{-1}) and local cultivar (77.42, 74.58 kg ha^{-1}). Owing to significantly higher grain yield in JS 97-52 the uptake of N was also correspondingly increased.

There was significant difference on the effect of zinc fertilization on N uptake. The zinc treatment Z_3 observed the highest grain N uptake (103.72, 99.79 kg ha^{-1}) in both the years which was statistically at par with Z_5 (103.15, 97.30 kg ha^{-1}). The percentage increase in N uptake by (30.50, 32.56%) due to the treatment Z_3 (Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$ + two foliar spray application of $ZnSO_4$ @ 0.25%) over control in both the years. Similarly, Z_5, Z_4 and Z_1 increased by (29.79, 29.26%), (23.54, 223.48%) and (18.06, 19.55%) respectively. Previous research works were supporting that application of Zn enhance the N, P and K content. A close relationship between Zn, Fe, N, P and K has been reported by some studies (Zhao *et al.*, 2009; Gomez-Beccera *et al.*, 2010). Shivay *et al.* (2015) had earlier indicated that Zn application increased Fe, N, P and K content and uptake in rice. Potarzycki and Grzebisz (2009) also reported that zinc foliar application increased nitrogen uptake and protein quality which ultimately improved growth and yield components of the crop.

The interaction effect between varieties and zinc fertilization on grain N uptake was observed to be non-significant in both the years.

4.1.4.4 Nitrogen uptake by stover

The perusal of data in Table 4.1.13 shows that all the three varieties were significantly different from each other for stover N uptake. The highest value of stover N uptake was recorded by soybean cultivar JS 97-52 (36.58, 34.96 kg ha^{-1}) which was statistically at par with local cultivar (36.01, 40.48 kg ha^{-1}), but both varieties were significantly higher than JS 335 (31.81, 29.00 kg ha^{-1}) during both years of study.

There was significant difference on the N uptake by stover upon zinc fertilization in both the years of experiment. The highest N uptake was observed in Z_5 (39.25, 41.65 kg ha^{-1}) while the other zinc treatments were statistically at par with each other. The lowest value was observed in control (30.21, 29.27 kg ha^{-1}).

The interaction of varieties and zinc application was found to be non-significant in both the years of study.

4.1.4.5 Total N uptake by soybean

The data on total N uptake in soybean is been presented in Table 4.1.13. Total N uptake differed significantly among varieties in both the years of study. Total N uptake by the cultivar JS97-52 (150.77, 138.44 kg ha^{-1}) was significantly higher than JS-335 (124.14, 122.38 kg ha^{-1}) and least in local cultivar (113.43, 115.06 kg ha^{-1}). The percentage difference in total N uptake by JS 97-52 was higher than local cultivar (32.92, 20.32%) and JS-335 (21.45, 17.31%).

The data revealed that there was significant difference in total N uptake under the effect of zinc fertilization. Among zinc treatments, Z_5 *i.e.*, three foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5% (143.78, 138.95 kg ha^{-1}) was statistically at par with and Z_3 (139.92, 137.29 kg ha^{-1}) but superior to other treatments in both the years. The increased of total N uptake by Z_5, Z_3, and Z_4 over control was (31.07, 32.84%), (27.55, 31.26%), (22.98, 22.47%) in both the years. In general observation the increased uptake of nitrogen, phosphorus and potassium content in seed and stover could be due to the fact that uptake of nutrient is a product of biomass and nutrient content. This can also be explained due to the synergistic interaction between zinc and nitrogen. The higher value of nitrogen content and uptake in seed and stover could be due to the reason that zinc is essential for synthesis of DNA and RNA and for metabolism to produce carbohydrate, lipids and proteins. Our result is supported by the findings of Keram *et al*. (2013) who stated that the increase could be attributed to the synergistic effect between N and Zn which might be due to increase enzymatic activity by zinc application.

The uptake of N, P, K by grain and stover was higher with applications of $ZnSO_4.7H_2O$ than with other ZnO. The ZnO was less effective Zn source in affecting the macronutrient uptake during both the year which was reflected by poorer performance in many growth and yield parameters. The results might be due to increase in nutrients availability by application of zinc and the higher yield ultimately leads to higher nutrients uptake by crops. This is also corroborated by the results reported by Khan *et al*. (2003), Afra and Mozafar (2017), Souza *et al.* (2019), Leite *et al*. (2020) and Meena *et al.* (2022) from the findings of different experiments. Pooniya *et al*. (2012) and Pooniya and Shivay (2013) also reported the similar findings.

4.1.4.6 Phosphorus content in grain

The data on phophorus (P) content in grain under the effect of varieties and zinc fertilization is presented in the Table 4.1.14. The data revealed that P content in grain varied significantly among the three varieties in both the years. The P content in grain was in the order of Local > JS 97-52 > JS-335 where the P content in local cultivar (0.39%) was significantly higher than JS-335 (0.35%) and JS 97-52 (0.37%) and the two were at par with each other. Local cultivar or landraces tend to have more ability to accumulate phytate which is a storage form of phosphorus in grain for which local cultivar has more P content in grain.

There was no significant difference on the P content in graindue to zinc treatments although the highest value was observed in Z_1 (Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$) and Z_6 (Three foliar spray applications of ZnO @ 0.5%). Lower value of P content was observed in Z_3 and Z_5 as compared to other treatments. With increase in zinc application there was a decline in P content in grain. This can be explained by the fact that zinc has antagonistic effect on P absorption in grain which infact is the phytate content in grain (Mirvat *et al*., 2006 and Cakmak. 2008). While the control one with no zinc absoption accumulated slighty more P in the grain. Antagonistic effects of Zn and phosphorous has been reported by several workers (Chaudhry *et al*., 1992; Yaseen *et al*., 1999).

The interaction effect was found non-significant in both the years.

4.1.4.7 P concentration in stover

Similar trend was also observed in the P content in stover as in grain. There was a significant difference among the varieties in the first year of the experiment although the highest P content was observed in local cultivar (0.32, 0.33%) and least was in JS-335 (0.28, 0.30%) in both the years.

There was no significant difference on P content in stover under different zinc applications and also the interaction effect between varieties and zinc fertilization was found non-significant during both years of experimentation.

Table 4.1.14 Effect of varieties and zinc fertilization on P content in grain and stover and their uptake in soybean

Treatments	**P content in grain (%)**			**P content in stover (%)**			**P uptake in grain (kg ha^{-1})**			**P uptake in stover (kg ha^{-1})**			**Total P uptake (grain + stover) kg ha^{-1}**		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
Varieties															
V_1	0.35	0.36	0.36	0.28	0.30	0.29	5.28	5.47	5.38	4.17	4.17	4.17	9.45	9.64	9.55
V_2	0.36	0.37	0.37	0.30	0.31	0.30	6.83	6.33	6.58	5.66	5.50	5.58	12.49	11.82	12.15
V_3	0.39	0.39	0.39	0.32	0.33	0.33	5.05	4.99	5.02	5.68	6.49	6.09	10.73	11.48	11.11
SEm±	***0.01***	***0.01***	***0.01***	***0.01***	***0.01***	***0.01***	***0.14***	***0.15***	***0.10***	***0.17***	***0.19***	***0.13***	***0.23***	***0.30***	***0.19***
CD at 5%	***0.02***	***0.03***	***0.02***	***0.02***	***NS***	***0.02***	***0.39***	***0.44***	***0.31***	***0.48***	***0.55***	***0.39***	***0.65***	***0.86***	***0.57***
Zinc fertilization															
Z_0	0.39	0.40	0.39	0.30	0.31	0.30	5.35	5.20	5.28	4.66	4.75	4.71	10.02	9.95	9.98
Z_1	0.38	0.39	0.38	0.30	0.31	0.31	5.87	5.59	5.73	5.12	5.40	5.26	10.99	10.99	10.99
Z_2	0.38	0.39	0.39	0.30	0.33	0.32	5.71	5.70	5.70	4.84	5.48	5.16	10.55	11.18	10.86
Z_3	0.35	0.36	0.36	0.28	0.29	0.29	5.77	5.74	5.75	5.07	5.18	5.12	10.84	10.92	10.88
Z_4	0.37	0.39	0.38	0.31	0.33	0.32	5.92	5.88	5.90	5.54	5.87	5.71	11.47	11.75	11.61
Z_5	0.35	0.35	0.35	0.30	0.28	0.29	5.56	5.37	5.46	5.58	5.23	5.40	11.14	10.59	10.87
Z_6	0.37	0.38	0.38	0.31	0.34	0.32	5.85	5.71	5.78	5.39	5.79	5.59	11.23	11.50	11.37
SEm±	***0.01***	***0.01***	***0.01***	***0.01***	***0.01***	***0.01***	***0.21***	***0.23***	***0.16***	***0.25***	***0.30***	***0.20***	***0.35***	***0.46***	***0.29***
CD at 5%	***NS***	***NS***	***NS***	***NS***	***NS***	***0.03***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***

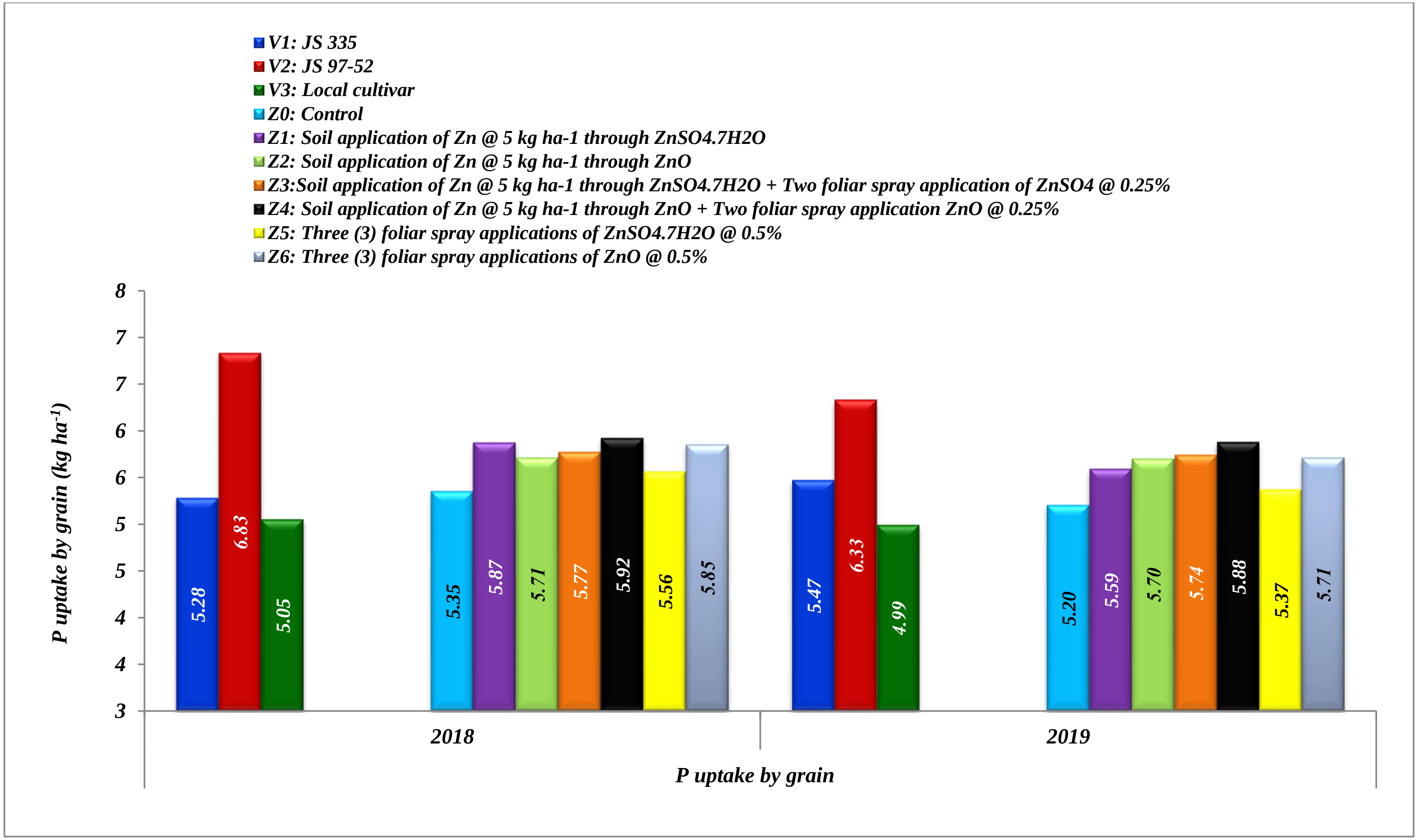


Fig 4.1.16 Effect of varieties and zinc application on P uptake by grain in soybean during 2018 and 2019

4.1.4.8 P uptake by grain

The data pertaining to P uptake by grain is presented in Table 4.1.14. There was significant variation among varieties on P uptake in grain and it was revealed that the cultivar JS 97-52 (6.91, 6.35 kg ha^{-1}) was significantly higher than JS-335 (5.31, 5.47 kg ha^{-1}) and which was at par with local cultivar (5.02, 4.97 kg ha^{-1}) for both the years. The variation in P uptake was mainly due to significant difference in seed yield which was significantly superior in JS 97-52 compared to the other two.

P uptake by grain did not differ significantly upon zinc fertilization. Although non-significant in P uptake but numerically zinc treated plots have higher P uptake by grain in both the years of experiment. The highest P uptake was observed in Z_4 (5.92, 5.88 kg ha^{-1}) while lowest was in control (5.35, 5.20 kg ha^{-1}). Although the P content in grain was low in zinc treated plot but the uptake was found to be the highest as the low content was compensated by the higher seed yield offsetting the negative antagonistic effect.

4.1.4.9 P uptake by stover

The data pertaining to P uptake by stover is presented in Table 4.1.14. There was significant variation among varieties in P uptake by stover in both the years of study. The P uptake by stover was highest in local cultivar (5.68, 6.49 $kgha^{-1}$) which was at par with JS 97-52 (5.66, 5.50 kg ha^{-}) and significantly higher than JS-335 (4.17, 4.17 kg ha^{-1}). The order in superiority of P uptake by stover was local cultivar > JS 97-52 > JS-335 with P uptake values of 6.49, 5.50 and 4.17 kg ha^{-1} respectively.

Zinc treatments resulted in no significant variations in P uptake in stover. The highest value was observed in Z_5 (Three foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5%) which was followed by Z_4 (Soil application of Zn @ 5 kg ha^{-1} through ZnO + Two foliar spray application ZnO @ 0.25%) and Z_6 (Three foliar spray applications of ZnO @ 0.5%) with P uptake values of 5.58, 5.54 and 5.39 kg ha^{-1}. This trend was not the same in the second year of the uptake was higher in zinc treated plots over the control was due to the significant yield improvement upon zinc application which offset the negative effect of zinc on P content. This result was in line with the one reported by Shivay *et al*. (2008b).

4.1.4.10 Total P uptake by soybean

The data pertaining to total P uptake by grain+stover is presented in Table 4.1.14. The total P uptake significantly differed among vaieties in both the years of study. Significantly higher total P uptake was observed in JS 97-52 (12.5, 11.8 kg ha^{-1}) followed by local cultivar (10.70, 11.50 kg ha^{-1}) and least was in JS-335 (9.40, 9.60 kg ha^{-1}).

When it comes to zinc application treatments there was non-significant effect on the total uptake. Although P content in grain and straw was reduced upon increasing Zn applications, however the P uptake increased due to overwhelming effect of increase in grain and straw yield. This result confirmed the findings of Shivay *et al*. (2008b). Yang *et al*. (2011) reported that with increasing P application, the proportion of Zn and P content in the grain relative to the whole plant decreased. Moreover, P and Zn acted antagonistically in roots and excess P inhibited Zn uptake in roots.

The interaction effect between varieties and zinc fertilization on total P uptake was non-significant in both the years of study.

4.1.4.11 Potassium content in grain

The data of K content in grain is presented in Table 4.1.15. It was revealed that there was no significant effect of varieties on K content in grain in both the years of experiment. The highest K content was in local (1.44, 1.47%) and lowest was in JS-335 (1.42, 1.40%).

Zinc treatments failed to produce any significant difference with respect to resulted to K content in grain although numerically zinc treated

Table 4.1.15 Effect of varieties and zinc fertilization on K content in grain and stover and their uptake in soybean

Treatments	K content in grain (%)			K content in stover (%)			K uptake in grain (kg ha^{-1})			K uptake in stover (kg ha^{-1})			Total K uptake (grain + stover) kg ha^{-1}		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
Varieties															
V_1	1.41	1.40	1.41	2.25	2.26	2.26	21.09	21.31	21.20	33.57	31.35	32.46	54.66	52.67	53.66
V_2	1.40	1.42	1.41	2.22	2.25	2.23	26.36	24.06	25.21	42.38	39.83	41.11	68.74	63.90	66.32
V_3	1.44	1.47	1.45	2.29	2.27	2.28	18.53	18.22	18.37	40.86	44.71	42.78	59.39	62.93	61.16
SEm±	***0.02***	***0.03***	***0.02***	***0.05***	***0.06***	***0.04***	***0.42***	***0.51***	***0.33***	***1.12***	***1.07***	***0.78***	***1.32***	***1.12***	***0.86***
CD at 5%	***NS***	***NS***	***NS***	***0.13***	***0.17***	***0.12***	***1.21***	***1.46***	***1.01***	***3.21***	***3.06***	***2.36***	***3.76***	***3.20***	***2.63***
Zinc fertilization															
Z_0	1.38	1.39	1.38	2.18	2.12	2.15	19.05	18.24	18.65	33.85	32.48	33.16	52.90	50.71	51.81
Z_1	1.39	1.40	1.40	2.20	2.23	2.22	21.19	20.62	20.90	37.88	37.91	37.90	59.07	58.52	58.80
Z_2	1.42	1.44	1.43	2.21	2.26	2.23	21.29	20.94	21.12	35.45	37.61	36.53	56.74	58.55	57.64
Z_3	1.44	1.46	1.45	2.33	2.31	2.32	23.76	23.18	23.47	41.95	40.93	41.44	65.71	64.12	64.91
Z_4	1.41	1.42	1.41	2.22	2.25	2.23	22.63	21.22	21.92	40.08	39.15	39.61	62.71	60.36	61.54
Z_5	1.46	1.47	1.46	2.36	2.34	2.35	23.63	22.72	23.17	43.72	42.94	43.33	67.35	65.66	66.50
Z_6	1.43	1.42	1.43	2.26	2.31	2.29	22.40	21.47	21.94	39.61	39.42	39.51	62.01	60.89	61.45
SEm±	***0.03***	***0.05***	***0.03***	***0.07***	***0.09***	***0.06***	***0.65***	***0.78***	***0.51***	***1.72***	***1.64***	***1.19***	***2.01***	***1.71***	***1.32***
CD at 5%	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***1.85***	***2.23***	***1.43***	***4.91***	***4.68***	***3.34***	***5.74***	***4.89***	***3.71***

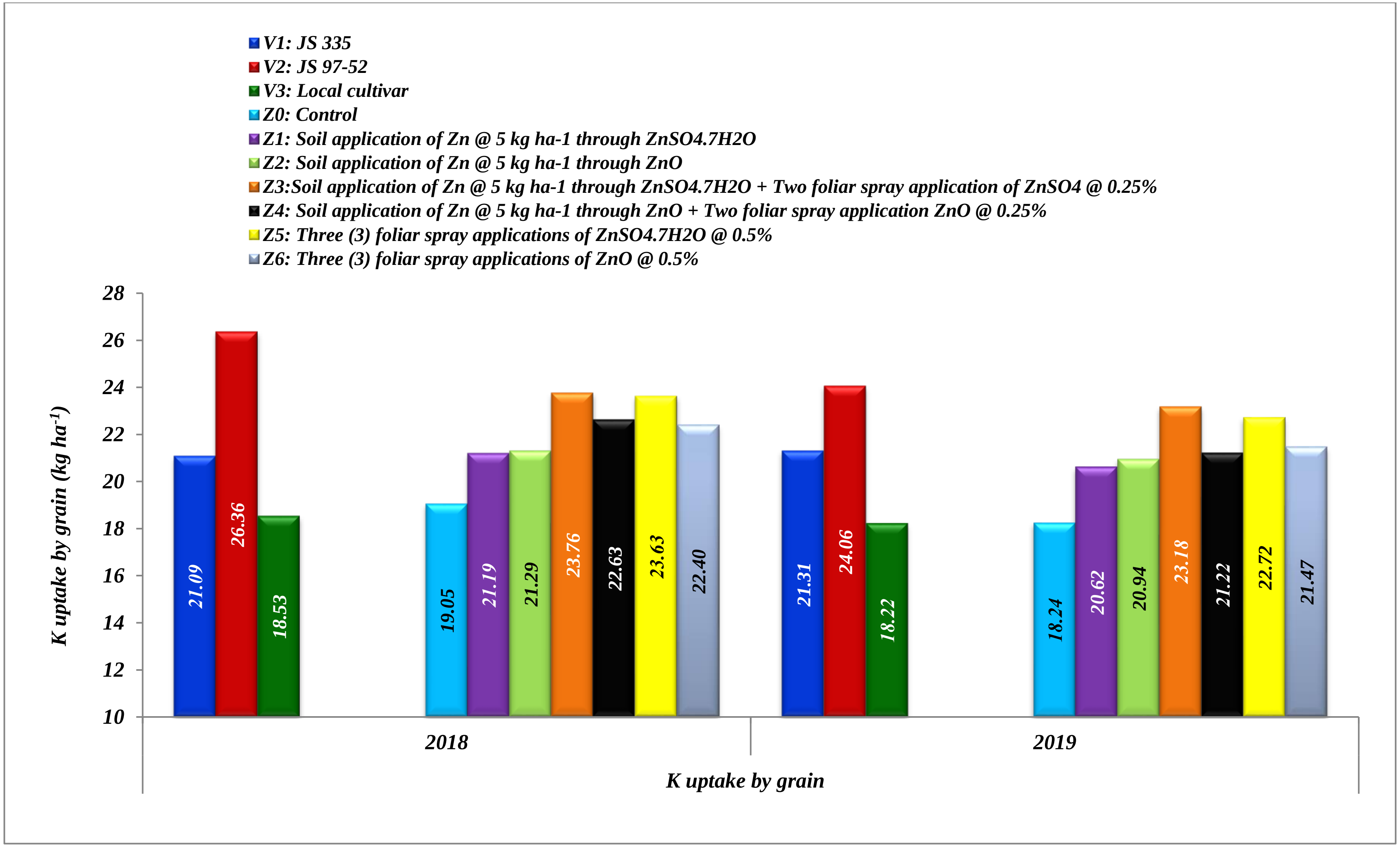


Fig 4.1.17 Effect of varieties and zinc application on K uptake by grain in soybean during 2018 and 2019

plots had slightly higher K content than the control ones. The highest value was observed in Z_6 (Three foliar spray applications of ZnO @ 0.5%) with 1.46% and lowest in control with 1.38%. Similar trend was also observed in the second year of the experiment. Since application of Zn might have stimulated the root and shoot growth which enhanced the nutrient uptake particularly with regard to N and K. When the Zn content is low, particularly in soils with low plant-available Zn, diffusion plays important role in the transport of Zn and other nutrients, such as P and K, to the root surface because mass flow can only carry a smallfraction of the nutrients required by the plants.

4.1.4.12 Potassium content in stover

The data pertaining to K content in stover is presented in Table 4.1.15. There was no significant variation due to varieties on the K content in grain. The K content ranges (1.41, 1.40 %), (1.40, 1.42%) and (1.44, 1.47%) in JS-335, JS 97-52 and local cultivar repectively.

Zinc fertilization failed to produce any significant effect on K content in stover in both the years of experiment. Z_5 (Three foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5%) recorded the highest K content (1.46, 1.47%) and the least in control (1.38, 1.39%). The interaction effect was non-significant in both the years of study.

4.1.4.13 Potassium uptake in grain

The perusal of data in Table 4.1.15 shows that all the three varieties were significantly differedwith respect to K uptake by grain in both the years of study. The highest K uptake was observed in JS 97-52 (26.51, 24.22 kg ha^{-1}) which is followed by JS-335 (21.20, 21.42 kg ha^{-1}) and least in local cultivar (18.53, 18.22 kg ha^{-1}). The higher value of K uptake by grain was due to the significantly higher yield advantage of JS 97-52 over local cultivar.

Zinc fertilization showed significant effect on the K uptake by grain in application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$ + Two foliar spray application of $ZnSO_4$ @ 0.25%) (23.76, 23.18 kg ha^{-1}) which was followed by Z_5 (23.63, 22.72 kg ha^{-1}) and was statistically at par with Z_4 and Z_6. The increase in potassium content and uptake over control due to interaction of K and zinc by the improvement of enzymatic activity and metabolic processes of plant which might has ultimately facilitated the removal of potassium and consequently the yield. The result obtained was supported by the finding of Shivay *et al*. (2015). As a result of increase in yield and K content in grain and straw there was corresponding increase in total K uptake. A positive impact on Zn fertilization on K uptake has also been reported by many researchers (Fageria, 2001; Ghatak et *al*., 2005; Fageria *et al*., 2011).

The interaction effect between varieties and zinc fertilizaiton on K uptake by grain was found non-significant in both years.

4.1.4.14 Potassium uptake by stover

The data pertaining to K uptake by stover under the effect of varieties and zinc fertilization is presented in Table 4.1.15. Varieties significantly differed with respect to K uptake by stover. The K uptake by stover in JS 97-52 (42.38 kg ha^{-1}) was found statistically at par with local cultivar (40.86 kg ha^{-1}) and least was in JS 335 (33.57 kg ha^{-1}). The variety JS 97-52 and local cultivar have significantly higher stover yield which resulted to corresponding increase in the K uptake.

There was significant difference in the K uptake by stover in different zinc fertilizations. The highest value was observed in Z_5 (Three foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5%) (43.72, 42.94kg ha^{-1}) which was statisticaly at par with Z_3 (Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$ + Two foliar spray application of $ZnSO_4$ @ 0.25%) (41.95, 40.93 kg ha^{-1}). The least value was observed in control treatment (33.85, 32.48kg ha^{-1}). The corresponding increase in K content in stover along with stover yield advantage upon Zn fertilization has cumulatively added to the significant increase in K uptake by grain under the zinc treated plots. Similar results have also been reported by Swami and Shekhawat (2009).

No significant variation due to interaction effect was observed both the years of the experiment

4.1.4.15 Total K uptake by grain and stover

The data pertaining to K uptake by grain and stover under the effect of varieties and zinc fertilization is presented in Table 4.1.15. Varieties varied significantly on the total K uptake on both the years of experimentation. The total K uptake among the varieties was least in JS-335 (54.70, 52.70 kg ha^{-1}) while the highest was observed in JS 97-52 (68.70, 63.90 kg ha^{-1}). There was no significant difference in the value of K content in both grain and stover in both the years. But due to combined effect of content and yield of grain and stover which has collectively enhanced the overall K uptake. It was also observed that JS 97-52 and local cultivar significantly possessed more biological yield which eventually has resulted to the increase in total K uptake in the particular varieties.

Zinc application significantly has influenced on the total K uptake by soybean in both the years of study. The highest total K uptake was observed in Z_5 (67.35, 65.66 kg ha^{-1}) which was statistically at par with Z_3 (65.71, 64.12 kg ha^{-1}) and least in control. As a result of increase in biological yield and K content in grain and straw there was corresponding increase in total K uptake. Our result on the positive influence of Zn fertilization on K uptake has also been reported by Fageria (2001), Ghatak *et al*. (2005) and Fageria *et al*. (2011).

The interaction effect between varieties and zinc fertilizaiton on total K uptake was found non-significant in both years.

4.1.4.16 Zinc content in grain and biofortification effect

The data pertaining to zinc content in grain under the influence of varieties and zinc fertilization is presented in Table 4.1.16 and illustrated in Fig

4.1.18. Varieties differed significantly with each other in the zinc content in both the years of study. The highest zinc content in grain was observed in JS-335 (31.58, 31.09 mg kg^{-1}) which was statistically at par with local cultivar (30.68, 31.40 mg kg^{-1}) and least being in JS 97-52 (28.42, 29.06 mg kg^{-1}). A superior genotype for Zn biofortification needs to have the following characteristics: high Zn acquisition efficiency, readily translocation of Zn to grain/edible part of plant, efficient remobilization of Zn from vegetative tissues to grain or edible part of the plant, and availability of Zn in the plant in a bioavailable form (Bouis & Welch, 2010; White & Broadley, 2011). It was also observed that varieties with lesser yield response tend to have higher zinc concentration in grain which is vice versa where JS-335 and local cultivar were having lower seed yield when compared to JS 97-52 which has lower zinc density in grain. The law of "dilution effect" might have played an important role in this case (Garvin *et al.*, 2006; Cakmak & Kutman, 2018). The reason could be varietal difference in efficiency level with respect to zinc acquisition which was supported by the findings of Rengel and Graham (1996), Cakmak (1999) and Khoshgoftarmanesh *et al.* (2004) and they reported that there are zinc efficient varieties which have higher zinc density in grain. In another study, Cakmak (1998) established that there is a genotypic difference in zinc efficiency among cereal species. Furthermore, the result on varietal difference was elaborated by Joshi *et al.* (2010) who found that genotype × environment interaction could be one of the factors for variation in zinc and iron concentration in edible parts of plants.

Zinc fertilizaition significantly influenced the zinc content in grain in both the years of experimentation. The highest zinc content in grain was observed in Z_5 (34.40, 33.25 mg kg^{-1}) at par with Z_3 (32.58, 32.68 mg kg^{-1}) and Z_4 (31.40, 31.55). The lowest zinc content in grain was recorded in

Table 4.1.16 Effect of varieties and zinc fertilization on zinc content in grain and stover (%)

Treatments	**Zn content in grain (mg kg^{-1})**			**% Increase in Zn content over control in pooled data**	**Zn content in stover (mg kg^{-1})**			**% Increase in Zn content over control in pooled data**
	2018	***2019***	***Pooled***		***2018***	***2019***	***Pooled***	
Varieties								
V_1	31.58	31.09	31.34		22.86	22.01	22.44	
V_2	28.42	29.06	28.74		21.54	21.14	21.34	
V_3	30.68	31.40	31.04		21.82	22.42	22.12	
SEm±	***0.76***	***0.66***	***0.50***		***0.41***	***0.54***	***0.34***	
CD at 5%	***2.17***	***1.89***	***1.53***		***NS***	***NS***	***NS***	
Zinc fertilization								
Z_0	25.66	26.72	26.19		20.28	19.32	19.80	
Z_1	29.77	29.54	29.66	13.24	21.94	22.06	22.00	11.11
Z_2	28.89	29.68	29.28	11.82	22.15	22.39	22.27	12.48
Z_3	32.58	32.68	32.63	24.60	23.76	23.29	23.52	18.80
Z_4	31.40	31.55	31.48	20.19	21.26	21.16	21.21	7.12
Z_5	34.40	33.25	33.83	29.17	23.73	23.29	23.51	18.75
Z_6	28.90	30.21	29.56	12.86	21.37	21.50	21.44	8.27
SEm±	***1.16***	***1.01***	***0.77***		***0.63***	***0.83***	***0.52***	
CD at 5%	***3.32***	***2.89***	***2.16***		***1.79***	***2.38***	***1.47***	

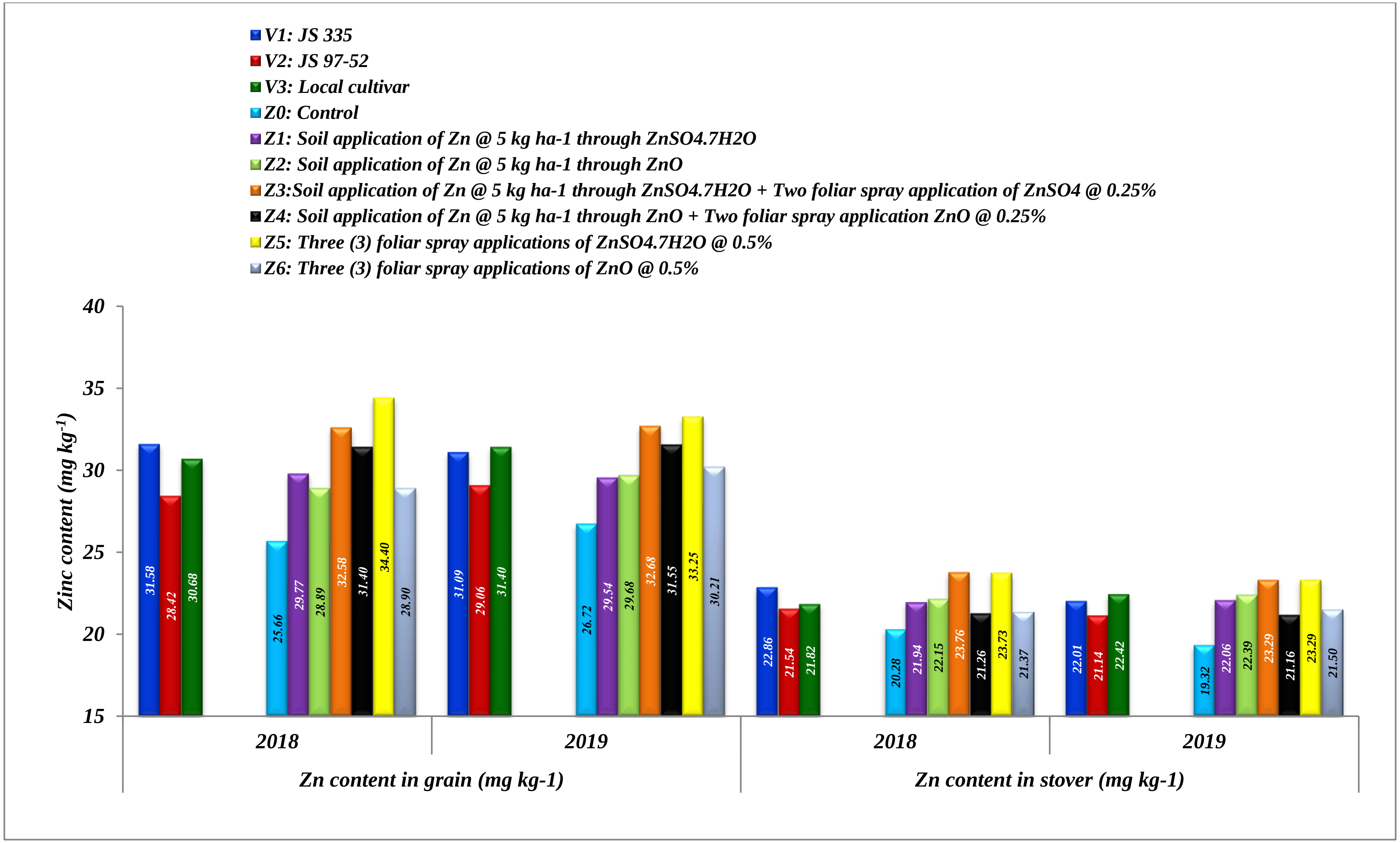


Fig 4.1.18 Effect of varieties and zinc application on zinc content in grain and stover of soybean during 2018 and 2019

control (25.66, 26.72 mg kg^{-1}). The results revealed that there was significant improvement in zinc density in grain upon zinc fertilization. Treatment with $ZnSO_4.7H_2O$ was found superior in result when compared to ZnO. The increase grain zinc density upon zinc fertilization treatments over control was (34.40, 26.97%), (26.98, 24.78%), (22.38, 20.45%) and (16.01, 12.80%) in Z_5, Z_3, Z_4 and Z_1 respectively for both the years.

Our results were in conformity to the findings of Ranjbar and Bahmaniar (2007), Cakmak (2008) and Pal *et al*. (2019) and application of Zn either foliar or in combination with soil application resulted significant improvement in zinc content in grains or edible portion of crops has been supported by the findings of many workers. Cakmak *et al*. (2010b) reported that (Soil + foliar) application of zinc fertilizers were a more effective method of application that could increase grain Zn concentration more than three folds. The increase in the Zn concentration and their uptake in soybean grain and stover with Zn fertilization may also be due to higher Zn availability to plants in treated plots compared to control (No Zn application). Shivay *et al.* (2008b) also reported that Zn concentration in rice grain and straw was higher with Zn application compared with no Zn application. As per our results, when comparing to foliar and combination of soil and foliar application methods, soil application as sole was found slight inferior towards enhancing grain zinc content which was in accordance to the findings of Cakmak *et al*. (2010a). The superiority of three foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5% over the other treatments was in line with the findings of Zhang *et al.* (2010) who elaborated that application of zinc at grain development stage contributes to enhanced zinc content in grain as the foliar application can be absorbed by the leaf epidermis and easily transported to the other parts of the plant parts via the xylem and phloem. Furthermore, three foliar spray applications which targets the sensitive stages *i.e*., flowering and pod formation of legume crop might have resulted in better zinc absorption through foliage and transported within the plant (Pathak *et al*., 2012). Application of zinc as foliar spray resulted to maximum absorption to the plant systems which helps in quick remedy to plant during deficiency coincided at reproductive stage due to translocation of Zn toward the grain. Similarly, soil application of zinc too helps in improving zinc content when compared to no zinc treatment although to a lesser extent possibly due to fact that Zn is absorbed and transported in divalent ionic form from roots to shoots through the xylem tissue (Clemens, 2001). When zinc is applied to soil, its uptake by plants is limited by its phyto availability and acquisition by roots as supported by the findings of White and Broadley (2009). Among the two sources of zinc applied, $ZnSO_4.7H_2O$ showed better results in enhancement of Zn density over ZnO which could be due its water solubility. Water solubility of Zn sources is considered an important criterion for Zn availability (Slaton *et al*., 2005a).

The interaction effect between varieties and zinc fertilizaiton on zinc content in grainwas found non-significant in both years.

4.1.4.17 Zinc content in stover

The data pertaining to zinc content in stover as influenced by varieties and zinc fertilization are presented in Table 4.1.16 and Fig 4.1.18. Varieties did not vary significantly on the zinc concentration in stover for both the years. JS-335, JS 97-52 and local cultivar recorded zinc content (22.86, 22.01%), (21.54, 21.14%) and (21.82, 22.42%) respectively.

There was significant variation in zinc concentration in stover under the influence of zinc treatments in both the years. The Z_3 (Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$ + Two foliar spray application of $ZnSO_4$ @ 0.25%) and Z_5 (Three foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5%) recorded zinc content of (23.76, 23.29%) and (23.73, 23.29%) respectively which were statistically at par with each other and significantly higher than control (20.28, 19.32%).

The interaction effect was found to be non-significant in both the years.

4.1.4.18 Zinc uptake by grain

The data pertaining to the zinc uptake by grain as influenced by varieties and zinc fertlization are presented in Table 4.1.17 and illustrated in Fig 4.1.19. Varieties significantly differed on the zinc uptake by grain. The highest zinc uptake in grain was in JS 97-52 (53.58, 49.44 g ha^{-1}) followed by JS-335 (47.29, 47.27 g ha^{-1}) and least in local cultivar (39.65, 39.10 g ha^{-1}). The significantly higher zinc uptake by grain in JS 97-52 and JS-335 was mainly due to the corresponding significant higher seed yield of the two varieties when compared to local cultivar. Significantly higher value of zinc uptake as observed in JS-97-52 as compared to other varieties was purely due to significantly higher value of seed yield which is purely a genotypic difference.

Zinc uptake by grain was significantly influenced by zinc fertilization treatments during both the years of experiment. It was found that Z_5 (55.63, 51.29 g ha^{-1}), Z_3 (53.18, 51.65 g ha^{-1}) and Z_4 (50.17, 47.27 29 g ha^{-1}) were statistically at par with each other in both the years of experimentation. The percent increase in zinc uptake (57.78, 46.51%), (50.81, 47.52%) and (42.29, 35.03%) over control in both the years in Z_5, Z_3 and Z_4, respectively.

4.1.4.19 Zinc uptakeby stover

The data on zinc uptake by stover is presented in Table 4.1.17 and Fig 4.1.19. It was revealed that there were significant variations among varieties on zinc uptake by stover during the two years of experiment. The highest zinc uptake by stover was observed inlocal cultivar (39.02, 44.01g ha^{-1}), followed by JS 97-52 (41.09, 37.81 g ha^{-1}) and least in JS-335 (34.01, 30.50 g ha^{-1}). As higher stover yield was recorded in JS 97-52 and local cultivar, hence corresponding result was reflected on their significantly higher zinc uptake by their stover.

Zinc treatments have significant influence on the zinc uptake by stover in both the years. It was observed that Z_5 (Three foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5%) recorded zinc uptake of (43.84, 43.10 g ha^{-1}) which was

Table 4.1.17 Effect of varieties and zinc fertilization on total zinc uptake by grain and stover (q ha^{-1})

Treatments	**Zn uptake in grain (g ha^{-1})**			**% Increase in Zn uptake over control in pooled data**	**Zn uptake in stover (g ha^{-1})**			**% Increase in Zn uptake over control in pooled data**	**Total Zn uptake by grain + stover (g ha^{-1})**			**% Increase in Zn uptake over control in pooled data**
	2018	***2019***	***Pooled***		***2018***	***2019***	***Pooled***		***2018***	***2019***	***Pooled***	
Varieties												
V_1	47.29	47.27	47.28		34.01	30.50	32.25		81.30	77.78	79.54	
V_2	53.58	49.44	51.51		41.09	37.81	39.45		94.68	87.24	90.96	
V_3	39.65	39.10	39.38		39.02	44.01	41.52		78.68	83.11	80.90	
SEm±	***1.31***	***1.03***	***0.84***		***0.98***	***1.02***	***0.71***		***1.68***	***1.50***	***1.13***	
CD at 5%	***3.76***	***2.96***	***2.54***		***2.79***	***2.92***	***2.15***		***4.80***	***4.29***	***3.42***	
Zinc fertilization												
Z_0	35.26	35.01	35.14		31.33	29.80	30.56		66.59	64.81	65.70	
Z_1	45.27	42.95	44.11	25.53	37.43	37.65	37.54	22.83	82.70	80.59	81.64	26.19
Z_2	43.11	43.07	43.09	22.64	35.41	37.44	36.42	19.18	78.52	80.50	79.51	22.89
Z_3	53.18	51.65	52.41	49.16	42.74	40.77	41.75	36.62	95.91	92.41	94.16	45.54
Z_4	50.17	47.27	48.72	38.66	38.40	36.71	37.55	22.89	88.57	83.98	86.28	33.35
Z_5	55.63	51.29	53.46	52.16	43.84	43.05	43.44	42.16	99.47	94.34	96.91	49.78
Z_6	45.28	45.66	45.47	29.40	37.16	36.68	36.92	20.80	82.43	82.33	82.38	27.33
SEm±	***2.01***	***1.58***	***1.28***		***1.49***	***1.56***	***1.08***		***2.56***	***2.29***	***1.72***	
CD at 5%	***5.74***	***4.52***	***3.59***		***4.26***	***4.46***	***3.04***		***7.33***	***6.55***	***4.84***	

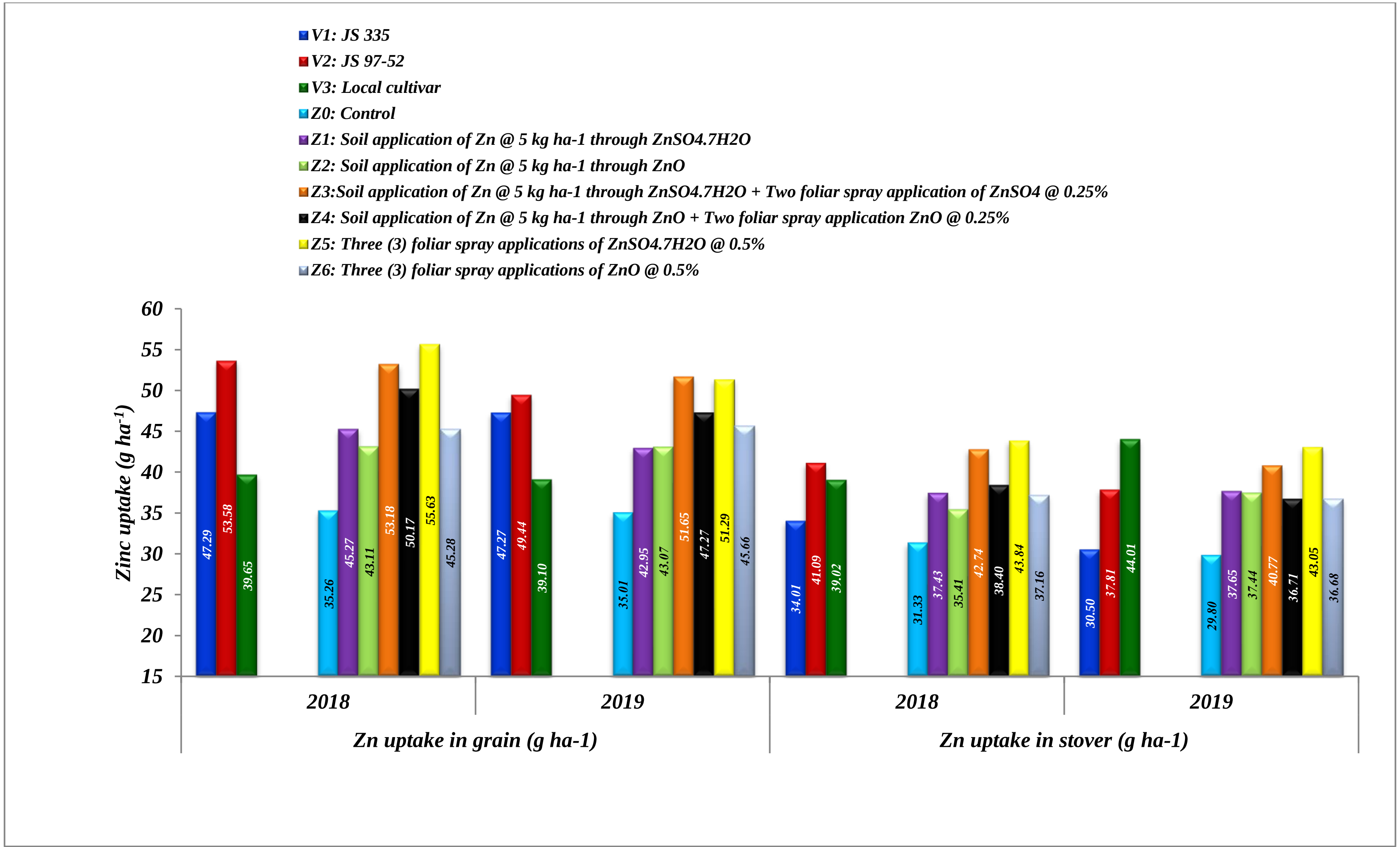


Fig 4.1.19 Effect of varieties and zinc application on zinc uptake in grain and stover of soybean during 2018 and 2019

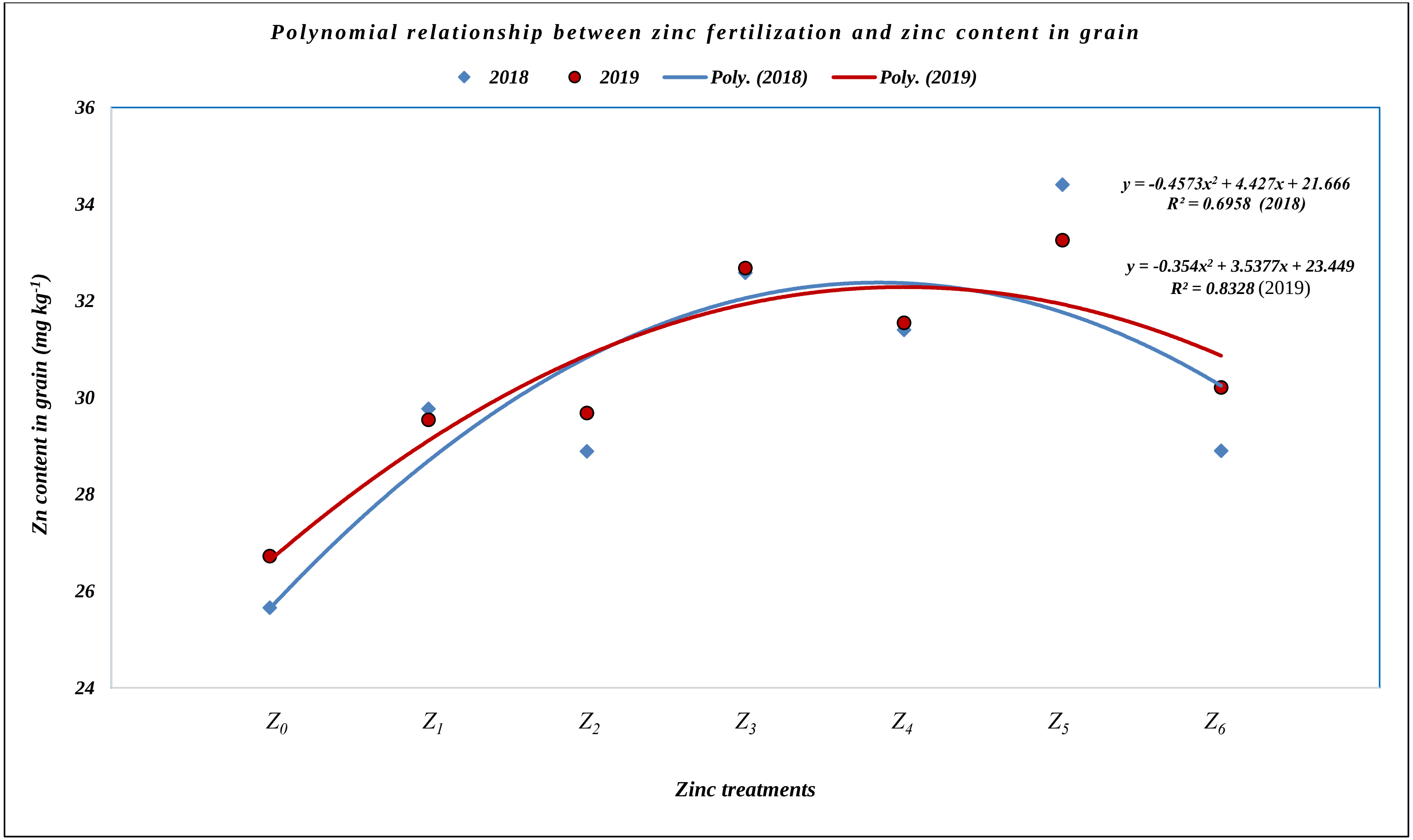


Fig 4.1.20 Polynomial relationship between zinc fertilization and zinc content in grain

at par with Z_3 (Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$ + Two foliar spray application of $ZnSO_4$ @ 0.25%) (42.74, 40.77 g ha^{-1}) and the least was in control (31.33, 29.80 g ha^{-1}). Due to zinc fertilization, there was enhancement in zinc uptake over control. The increase zinc uptake in Z_5 (39.91, 44.47%), Z_3 (36.41, 36.80%) followed by Z_4 (22.57, 23.18%). The zinc uptake due to zinc treatments followed in the decreasing order of $Z_5 > Z_3 > Z_4 > Z_1 > Z_6 > Z_2 > Z_0$.

4.1.4.20 Total zinc uptake by soybean

The perusal of data given in Table 4.1.17 showed that there were significant variations among varieties on total zinc uptake in both the years. The cultivar JS 97-52 recorded the highest total zinc uptake (94.70, 87.20 g ha^{-1}) which was statistically higher than the other two varieties. The higher value of total zinc uptake in JS 97-52 as compared to other varieties was mainly due to higher grain and stover yield. This result was in conformity to the findings reported by Yadi *et al*. (2012) and Kabeya and Shankar (2013) as genotypes have inherent differences in Zn concentration and uptake.

Among zinc fertilization treatments, Z_5 (Three foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5%) recorded the highest total zinc uptake (99.50, 94.30 g ha^{-1}) which was at par with Z_3 (Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$ + Two foliar spray application of $ZnSO_4$ @ 0.25%) (95.9, 92.4 g ha^{-1}) was superior over the other treatments. The least uptake was observed in control (66.60, 64.80 g ha^{-1}) in both the years. With the application of zinc in different forms and application methods found to increase the zinc uptake by grain, stover and the total uptake. These positive results in zinc uptake might have been due to enhancement in nutrient availability by application of zinc and also the higher yield ultimately leads to higher nutrients uptake by crops. Similar results were also reported by Afra and Mozafar (2017), Souza *et al*. (2019) and Leite *et al*. (2020) from the findings of different experiments. This might be due to better supply of zinc and greater yield of soybean with application of zinc.

The interaction effect between varieties and zinc fertilizationon total zinc uptake was found non-significant in both the years of study.

4.1.5 Quality parameters

4.1.5.1 Protein content in grain

The data pertaining to protein content of soybean as influenced by varieties and zinc treatments are presented in Table 4.1.18a and Fig 4.1.21. It was revealed that varieties did not vary significantly in protein content during both the years of study. The protein content of variety JS-335 (38.66, 38.44%), JS 97-52 (38.06, 38.14%) and local (37.50, 37.46%) was observed in both the years. The diference among varieties is purely genetical makeup and quality characteristic of the variety.

Protein content was found to differ significantly on zinc fertilization. The highest protein content was observed in Z_5 (39.76, 39.37%) which was statistically at par with Z_3 (39.27, 39.29%) and Z_4 (38.14, 38.44%). The lowest protein content was observed in control treatment which might be due to inhibition of protein synthesis and lower activity of Zn containing RNA polymerage. The increased crude protein content in soybean seed with Zn application could be due to increased N-metabolism by Zn application which enhanced accumulation of amino acids and increased the rate of protein synthesis. Our results were in good agreement with the hypothesis that protein represents a sink for Zn in the grain (Morgounov *et al*., 2007; Cakmak *et al*., 2010). Liu *et al*. (2014) highlighted that increase in protein content and grain zinc content is mostly parallel to each other. Also, Fe andZn concentrations were positively correlated with the grain protein concentration in wheat (Cakmak *et al*., 2004 and Peleg *et al*., 2008). Zn application in soil enhanced the Zn concentration in the plant which is associated with RNA and ribosome induction resulting in accelaration protein synthesis (Sonune *et al*. 2001). In biological systems, proteins are highly dependent on Zn ions to maintain

Table 4.1.18a Effect of varieties and zinc fertilization on protein and oil content of soybean

Treatments	Protein content (%)			Protein yield (kg ha^{-1})			Oil content (%)			Oil yield (kgha^{-1})		
	2018	*2019*	*Pooled*	*2018*	*2019*	*Pooled*	*2018*	*2019*	*Pooled*	*2018*	*2019*	*Pooled*
Varieties												
V_1	38.66	38.44	38.55	577.08	583.67	580.37	16.91	17.45	17.18	252.14	265.25	258.69
V_2	38.06	38.14	38.10	713.68	646.78	680.23	17.97	17.94	17.95	337.77	304.50	321.13
V_3	37.50	37.46	37.48	483.87	466.13	475.00	16.52	17.00	16.76	213.13	211.29	212.21
SEm±	***0.54***	***0.53***	***0.38***	***8.94***	***9.29***	***6.45***	***0.17***	***0.12***	***0.11***	***4.21***	***3.25***	***2.66***
CD at 5%	***NS***	***NS***	***NS***	***25.55***	***26.55***	***19.59***	***0.50***	***0.34***	***0.32***	***12.03***	***9.28***	***8.08***
Zinc fertilization												
Z_0	35.85	35.70	35.78	496.76	470.53	483.64	16.45	16.74	16.59	227.38	220.44	223.91
Z_1	38.22	38.34	38.28	586.44	562.49	574.46	16.92	16.96	16.94	261.41	248.36	254.88
Z_2	37.70	37.99	37.85	565.44	553.37	559.40	17.00	17.48	17.24	257.05	255.76	256.41
Z_3	39.27	39.29	39.28	648.25	623.70	635.98	17.59	18.04	17.82	292.26	287.88	290.07
Z_4	38.14	38.44	38.29	613.69	580.96	597.32	17.19	17.37	17.28	276.20	261.73	268.96
Z_5	39.76	39.37	39.56	644.72	608.15	626.43	17.93	18.15	18.04	293.50	283.19	288.34
Z_6	37.55	36.97	37.26	585.50	559.48	572.49	16.85	17.48	17.17	265.95	265.06	265.50
SEm±	***0.82***	***0.81***	***0.58***	***13.65***	***14.19***	***9.85***	***0.27***	***0.18***	***0.16***	***6.43***	***4.96***	***4.06***
CD at 5%	***2.35***	***2.31***	***1.62***	***39.03***	***40.55***	***27.71***	***0.76***	***0.52***	***0.45***	***18.37***	***14.18***	***11.43***

Table 4.1.18b Interaction effect of varieties and zinc fertilization on protein and oil content of soybean

V x Zn Interaction	Oil content (%)			Oil yield (kgha^{-1})		
	2018	*2019*	*Pooled*	*2018*	*2019*	*Pooled*
V_1Z_0	17.12	17.00	17.06	221.64	226.32	223.98
V_1Z_1	16.11	17.00	16.56	234.24	247.44	240.84
V_1Z_2	16.44	16.67	16.56	235.57	251.62	243.59
V_1Z_3	16.56	17.90	17.23	258.42	291.16	274.79
V_1Z_4	17.22	17.44	17.33	265.79	268.68	267.24
V_1Z_5	17.89	18.44	18.17	281.41	288.08	284.74
V_1Z_6	17.00	17.67	17.33	267.90	283.43	275.67
V_2Z_0	16.67	16.78	16.72	278.08	249.07	263.58
V_2Z_1	17.77	17.11	17.44	335.02	287.27	311.14
V_2Z_2	18.56	18.78	18.67	329.74	307.47	318.61
V_2Z_3	18.78	18.67	18.72	384.58	345.87	365.22
V_2Z_4	17.22	17.56	17.39	334.83	302.17	318.50
V_2Z_5	19.11	18.89	19.00	377.58	341.83	359.71
V_2Z_6	17.67	17.78	17.72	324.55	297.83	311.19
V_3Z_0	15.56	16.44	16.00	182.43	185.94	184.19
V_3Z_1	16.89	16.78	16.83	214.96	210.37	212.67
V_3Z_2	16.00	17.00	16.50	205.85	208.20	207.03
V_3Z_3	17.44	17.56	17.50	233.80	226.60	230.20
V_3Z_4	17.11	17.11	17.11	227.96	214.35	221.16
V_3Z_5	16.78	17.11	16.94	221.50	219.66	220.58
V_3Z_6	15.89	17.00	16.44	205.40	213.92	209.66
SEm±	***0.46***	***0.32***	***0.28***	***11.13***	***8.59***	***7.03***
CD at 5%	***1.32***	***0.90***	***0.79***	***NS***	***24.56***	***19.79***

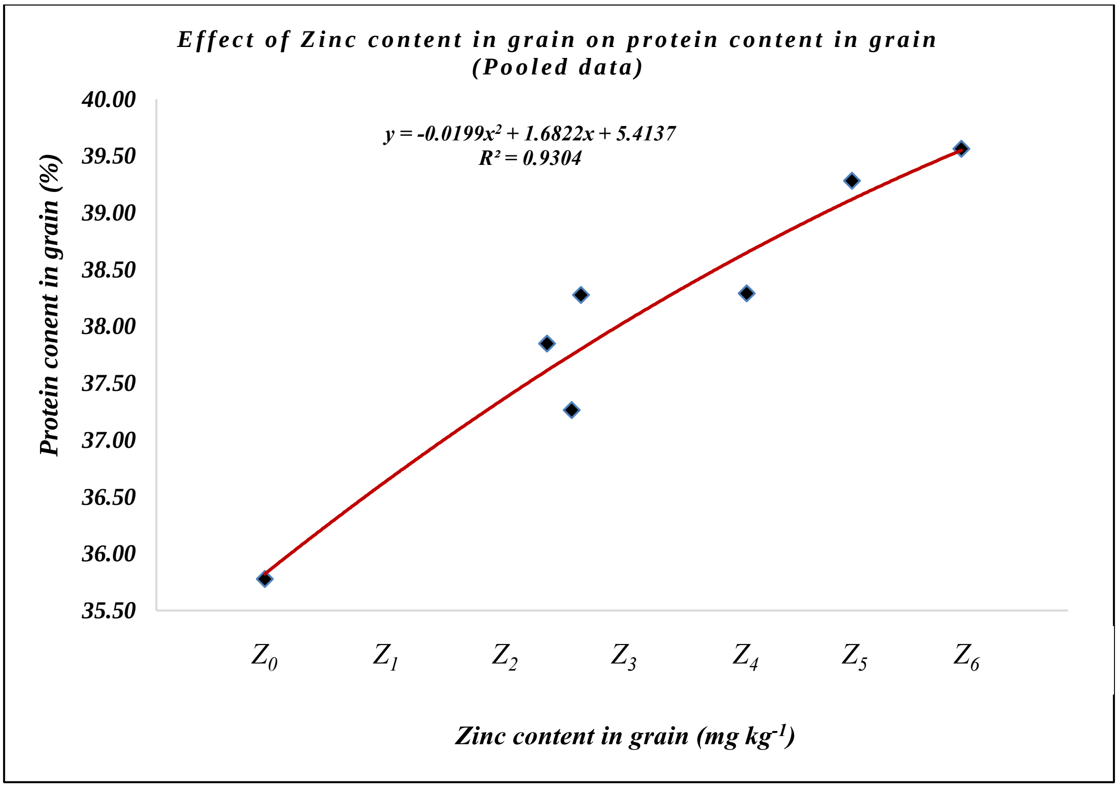


Fig 4.1.21 Polynomial relationship between zinc content and protein content in grain

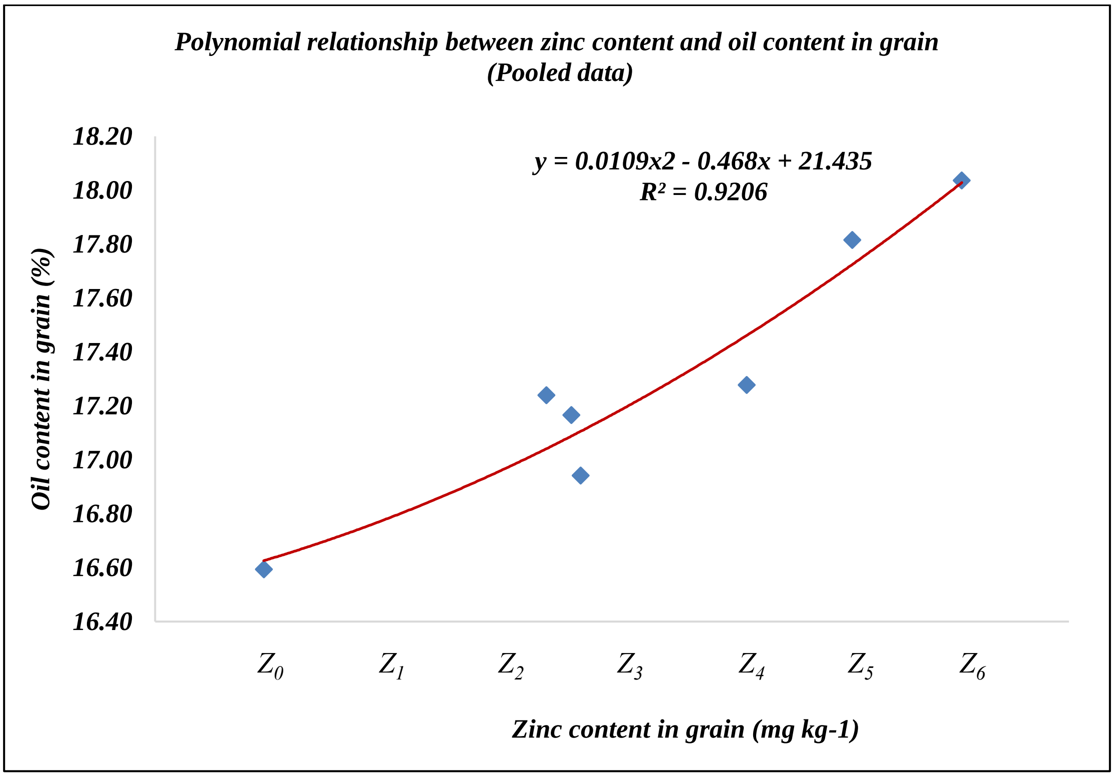


Fig 4.1.22 Polynomial relationship between zinc content and oil content in grain

their activities. Zn is needed for numerous proteins, having both a catalytic and a structural role.

Increase in protein content in grain and straw with Zn application might also due to the fact that Zn is required by the largest number of proteins in the biological systems. Zinc helps to maintain structural stability and functionality of proteins and transcription factors. The significant increase in protein may be attributed since zinc plays an important in nitrate conversion to ammonia in plants (Boorboori *et al*., 2012) and also zinc fertilizer stimulates IAA and acid makes amino acids to protein (Moussavi-Nik & Kiani, 2012). Zinc also helps to improve more nodulation and leghaemoglobin formation which might result higher nitrogen and protein content in soybean. The zinc treatments with $ZnSO_4.7H_2O$ found superior over ZnO in enhancing protein content in grain. The reason might be due to its better solubility and efficiency as compared to ZnO that has resulted to more effectiveness in enhancing protein content. Similar results were also reported by Majumdar *et al*. (2001), Ranjbar and Bahmaniar (2007) and Ravi *et al*. (2008).

The interaction effect between varieties and zinc fertilization on protein content in grain was found non-significant in both the years of study (Table 4.1.18b).

Fig 4.1.21 representing the polynomial relationship between zinc content and protein content in grain that depicts the significantly positive correlation between the two (R^2=0.93).

4.1.5.2 Protein yield in grain

Protein yield is the multiplication of seed yield of soybean with its protein content as presented in Table 4.1.18a. The results revealed that there was significance variation among varieties on the protein yield where JS 97-52 recorded the highest value of (713.68, 646.78 kg ha^{-1}) which was statistically superior over JS-335 (577.08, 583.67 kg ha^{-1}) and local cultivar

(483.87, 466.13 kg ha^{-1}). The higher value of protein yield in JS 97-52 and JS-335 was mainly due to their significant higher value of seed yield when compared to local cultivar.

The zinc applications too have shown significant results on the protein yield of soybean where the highest value was observed in Z_3 (Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$ + Two foliar spray application of $ZnSO_4$ @ 0.25%) (648.25, 623.70 kg ha^{-1}) which was followed by Z_5 (Three foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5%) (644.72, 608.15 kg ha^{-1}) and was at par with Z_4 (Soil application of Zn @ 5 kg ha^{-1} through ZnO + Two foliar spray application ZnO @ 0.25%). The least protein yield was observed in control (496.76, 470.53 kg ha^{-1}) and statistically inferior to the rest.

The interaction effect between varieties and zinc fertilization on protein yield in grain was found non-significant in both the years of study.

4.1.5.3 Oil content in grain

The data pertaining to the effect of varieties and zinc fertilization on oil content in grain are presented in Table 4.1.18a & Fig 4.1.22. The result revealed that varieties varied significantly on oil content in both the years of study. JS 97-52 recorded the highest oil content (17.97, 17.94%) in both the years which was followed by JS-335 (16.91, 17.45%).

Application of different levels of zinc fertilizers resulted in significant effect on oil content in both the years. Z_5 (Three foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5%) recorded in the highest oil content (17.93, 18.15%) which was statistically at par with Z_3 (17.59, 18.04%) respectively. The oil content was least in control (16.45, 16.74%). The increase in oil content in soybean seed with Zn application might be due to activation of NADPH dependent dehydrogenase involved in fat synthesis by Zn. Similar findings have been reported by Bairagi *et al*. (2007), Dhanshree *et al*. (2010) and

Kulhare *et al*. (2014). This result was also further in line with the findings of Ravi *et al*. (2008) and Majumdar *et al*. (2001) in Meghalaya.

The interaction effect between varieties and zinc fertilizationon protein content in grain was found significant in both the years of study. The highest value of the interaction was observed in V_2Z_3 (18.78, 18.67%) and least in V_3Z_0 (15.56, 16.44%).

Fig 4.1.22 representing the polynomial relationship between zinc content and oil content in grain that depicts the significantly positive correlation between the two (R^2=0.92). With increasing content and uptake of zinc in grain there is positive concurrent increase in oil content.

4.1.5.4 Oil yield

The data on oil yield is presented in table 4.1.18a. Oil yield significantly varied among varieties in both the years of experiment. Cultivar JS 97-52 recorded the highest oil yield (337.77, 304.50 kg ha^{-1}) which was superior over local (213.13, 211.29 kg ha^{-1}) and JS-335 (252.14, 265.25 kg ha^{-1}). The superiority of JS 97-52 in oil yield was mainly due to its significant higher seed yield.

There was significant difference on the oil yield under the effect of zinc fertilization in both the year of study. Z_3 (292.26, 287.88kg ha^{-1}) recorded the highest oil yield which was statistically at par with Z_5 (293.50, 283.19 kg ha^{-1}). The least oil yield value was observed in control (227.38, 220.44 kg ha^{-1}). The significant increase in seed yield under the respective zinc treatments has enhanced the oil yield significantly.

The interaction effect between varieties and zinc fertilization on protein yield in grain was found significant in both the years of study. The highest value of the interaction was observed in V_2Z_3 (384.58, 345.87 kg ha^{-1}) and least in V_3Z_0 (182.43, 185.94 kg ha^{-1}).

4.1.5.5 Phytic acid content and Phytic acid: Zinc molar (PA: Zn) ratio

Data pertaining to phytic acid (PA) content and phytic acid: Zn molar ratio (PA: Zn) as influenced by varieties and zinc application are presented in Table 4.1.19a and Fig 4.2.23 & 4.2.24. The data revealed that there was significant difference among varieties in phytic acid content. In both the years of the experiment, the local cultivar recorded the highest phytic acid content (713.17, 724.25 mg/100 g) which was significantly higher than JS-97-52 (607.43, 624.94 mg/100 g). The least phytic acid content was observed in JS-335 (568.77, 585.46 mg/100 g). The above findings are in line with the results illustrated by many workers (Raboy *et al*., 1984; Wise, 1995; Lu *et al.*, 2011). The data clearly revealed that there were genotypic differences in the value of phytic acid content and as well as phytic: Zn molar ratio. The values were significantly higher in local cultivar as compared to the improved varieties JS-335 and JS 97-52 in both the years. This result was similar to the findings reported by Erdal *et al.* (2002) and Karkle and Beleia (2010). Our results also are supported by the findings of Chitra *et al*. (1995) who reported there was variability of phytic acid content and total phosphorus in different genotypes of legumes who further indicated that this anti-nutritional factor significantly varied among and within the same species of legumes and the highest phytic acid content found in soybean. The data revealed that there was significant variation among the varieties on phytic acid: zinc molar ratio in both the years of experiment. JS-335 recorded the least value of ratio (18.23, 18.97) which was statistically lower than JS-97-52 (21.50, 21.64). The highest phytic acid: zinc molar ratio was observed in local cultivar (23.56, 23.15) in both the years

Zinc fertilization differed significantly on the phytic acid content in both the years. Z_3 (579.69, 597.64 mg/100 g) and Z_5 (610.49, 626.67 mg/100 g) have least phytic acid content for both the years of experiment. Whereas the control plot recorded the highest phytic acid content (685.28, 689.82 mg/100 g). Zinc fertilization treatments resulted in significant reduction of phytic

Table 4.1.19a Effect of varieties and zinc fertilization on phytic acid content in soybean grain

Treatments	*Phytic acid content (mg/100g) in grain*			*Phytic acid: Zinc molar ratio*		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
Varieties						
V_1	568.77	585.46	577.12	18.23	18.97	18.60
V_2	607.43	624.94	616.18	21.50	21.64	21.57
V_3	713.17	724.25	718.71	23.56	23.15	23.36
SEm±	***9.06***	***11.93***	***7.49***	***0.60***	***0.63***	***0.43***
CD at 5%	***25.89***	***34.10***	***22.77***	***1.71***	***1.79***	***1.32***
Zinc fertilization						
Z_0	685.28	689.82	687.55	26.50	25.69	26.10
Z_1	616.53	655.02	635.78	20.81	22.37	21.59
Z_2	641.73	664.21	652.97	22.26	22.29	22.27
Z_3	579.69	597.64	588.67	17.83	18.30	18.07
Z_4	622.71	632.39	627.55	19.98	19.95	19.97
Z_5	610.49	626.67	618.58	17.85	18.87	18.36
Z_6	652.09	648.43	650.26	22.45	21.30	21.88
SEm±	***13.84***	***18.22***	***11.44***	***0.92***	***0.96***	***0.66***
CD at 5%	***39.55***	***52.09***	***32.20***	***2.62***	***2.74***	***1.86***

Table 4.1.19b Interaction effect of varieties and zinc fertilization on phytic acid content in soybean grain

Treatments	*Phytic acid content (mg/100g) in grain*			*Phytic acid: Zinc molar ratio*		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
V_1Z_0	579.72	627.34	603.53	22.01	22.36	22.18
V_1Z_1	543.70	609.77	576.74	17.78	19.47	18.63
V_1Z_2	567.48	612.35	589.91	18.40	21.49	19.94
V_1Z_3	532.90	558.53	545.71	15.69	16.76	16.23
V_1Z_4	575.82	554.72	565.27	17.29	17.52	17.40
V_1Z_5	565.20	566.26	565.73	15.20	16.24	15.72
V_1Z_6	616.60	569.28	592.94	21.26	18.95	20.11
V_2Z_0	667.30	659.14	663.22	26.66	26.39	26.52
V_2Z_1	612.75	642.88	627.82	22.14	23.85	23.00
V_2Z_2	619.59	640.10	629.85	23.06	22.10	22.58
V_2Z_3	548.38	563.10	555.74	18.03	18.13	18.08
V_2Z_4	597.81	622.54	610.18	20.27	20.39	20.33
V_2Z_5	580.54	599.38	589.96	18.47	19.53	19.00
V_2Z_6	625.64	647.40	636.52	21.88	21.10	21.49
V_3Z_0	808.82	782.99	795.91	30.84	28.32	29.58
V_3Z_1	693.13	712.42	702.78	22.51	23.78	23.15
V_3Z_2	738.13	740.18	739.15	25.32	23.29	24.30
V_3Z_3	657.80	671.30	664.55	19.78	20.00	19.89
V_3Z_4	694.50	719.89	707.20	22.39	21.96	22.17
V_3Z_5	685.73	714.37	700.05	19.89	20.85	20.37
V_3Z_6	714.05	728.61	721.33	24.21	23.86	24.03
SEm±	***23.96***	***31.57***	***19.82***	***1.59***	***1.66***	***1.15***
CD at 5%	***68.50***	***90.22***	***55.77***	***4.53***	***4.74***	***3.23***

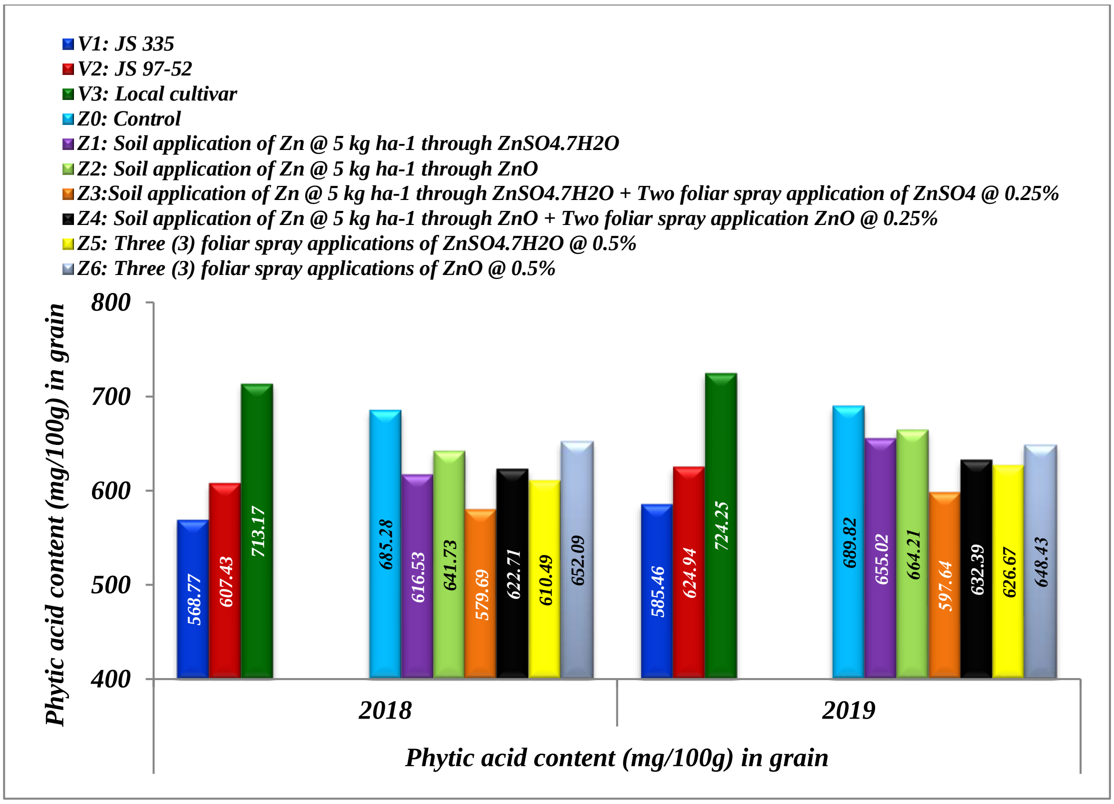


Fig 4.1.23 Effect of varieties and zinc Ferti-fortification on phytic acid content in soybean during 2018 and 2019

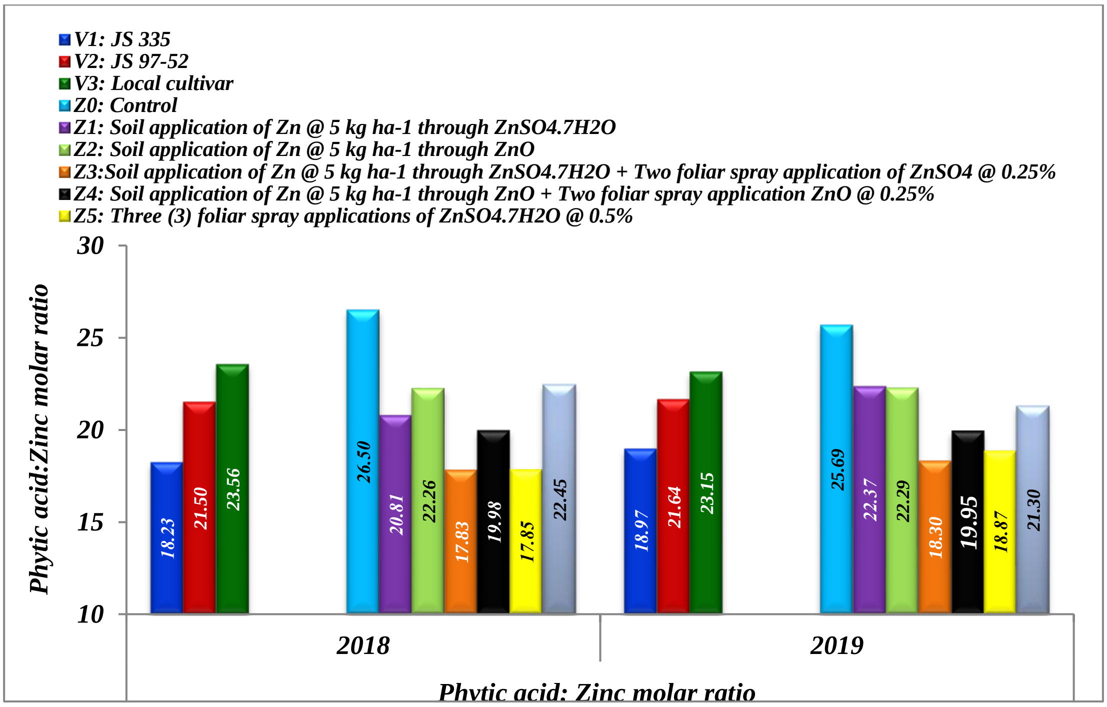


Fig 4.1.24 Effect of zinc application on phytic acid: zinc molar ratio in soybean during 2018 and 2019

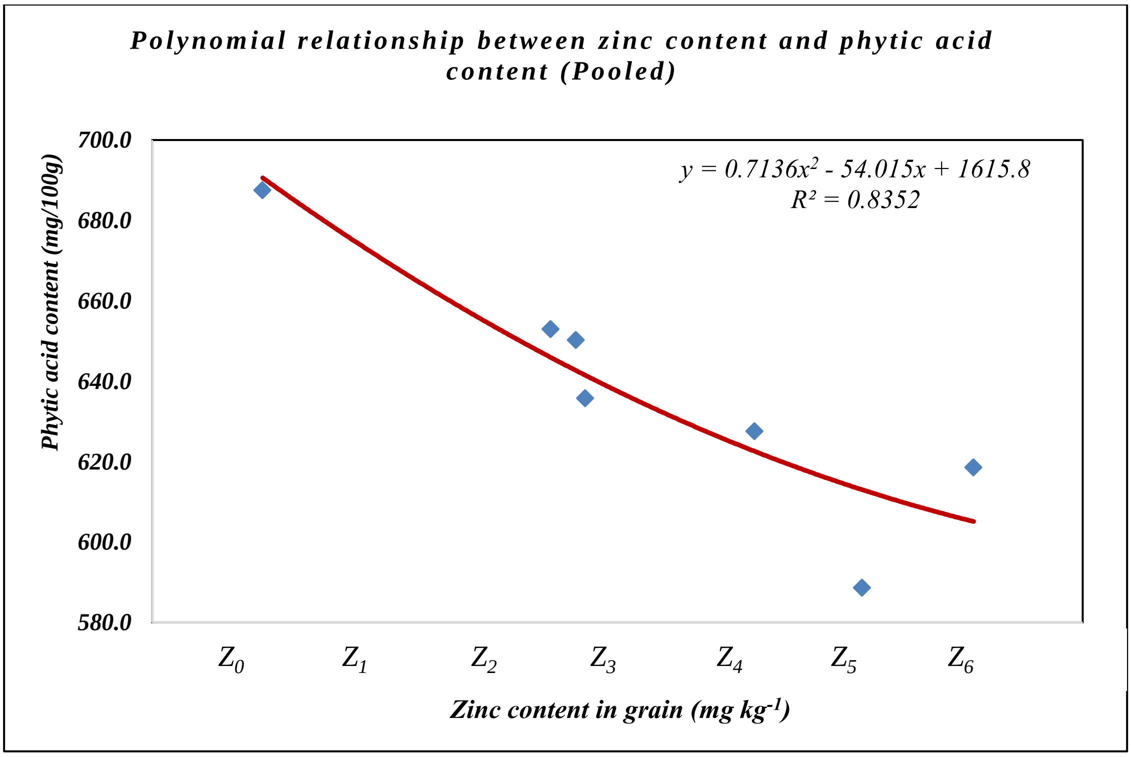


Fig 4.1.25 Polynomial relationship between zinc content and phytic acid of grain in soybean

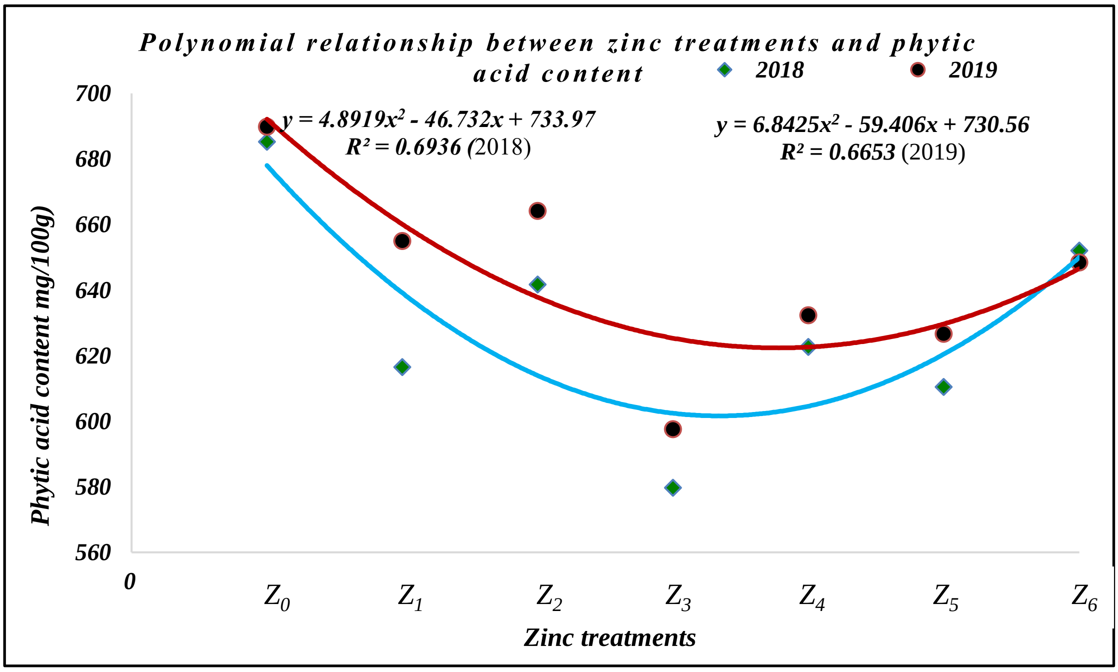


Fig 4.1.26 Polynomial relationship between zinc treatments on phytic acid content

acid and correspondingly to the phytic acid: zinc molar ratio which actually a desirable trend. The lowest value of phytic acid (579.69, 597.64 mg/100 g) was recorded in Z_3 with a corresponding phytic acid: Zn molar ratio of (17.83, 18.30).

The control treatment (No zinc) has the highest value of phytic acid (685.28, 689.82 mg/100 g) and PA:Zn ratio in both the years. The result also elaborated that irrespective to the varieties and zinc application methods and type of zinc fertilizer, there was significant reduction in the value of phytic acid content and phytic: molar ratio when compared to control treatment. This result was in confirmation to the findings of Mirvat *et al.* (2006), Cakmak (2008) and Lu *et al.* (2011) who indicated that applying of zinc to plants under potentially zinc deficient soils is effective in reducing uptake and accumulation of phosphorus and thus phytate.In our results we found that soil + foliar treatment, Z_3 (Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$ + Two foliar spray application of $ZnSO_4$ @ 0.25%) was superior and statistically at par with Z_5 which was corroborated by the findings of Ram *et al.* (2011) and Zhang *et al.* (2011). The lower value of phytic acid under two-three foliar spray of zinc which coincided with the flowering and early grain development is further supported by the results of Wen *et al.* (2011) who reported an increased grain Zn concentration and reduction in the phytic acid concentration and the phytic acid to Zn molar ratio. In the latest reports by Hao *et al.* (2021) it was found that molar ratio of PA: Zn was significantly decreased by foliar application of zinc who reiterated that across genotypes, foliar zinc application reduced PA: Zn molar ratio by 17.80% (from 22.30 to 18.00) which was similar to our findings.

The polynomial relationship presented in Fig 4.1.25 showed that with increasing zinc content in grain there is progressive decline in the phytic acid content and both were highly negatively correlated (R^2=0.835). Fig 4.1.26 is illustrating the relationship of phytic acid under different zinc fertilization treatments which depicted that lowest PA observed in Z_3 and Z_5 and higher in control.

The interaction effect between varieties and zinc fertilization treatment was found significant in both the years of study. Data on Table 4.1.19b depicted that the highest value of phytic acid was observed in the treatment combination V_3Z_0 (808.82, 782.99 mg/100 g). The reason for this high value can be explained that local cultivar might have the highest potential to store organic phosphorus as phytate in the seed and under no zinc application there was the high level as compared to zinc treated plants (Cakmak, 2008, Lu *et al*., 2011; Hao *et al*., 2021).

4.1.6 Zinc use indices

4.1.6.1 Partial factor productivity

Data pertaining to partial factor productivity (PFP) in soybean is presented in Table 4.1.20a. The data revealed that varieties varied significantly to each other with respect to kg grain kg^{-1} Zn where the JS 97-52 showed significantly higher value (379.81, 345.10 kg grain kg^{-1} Zn) as compared to JS-335 (352.74, 305.63 kg grain kg^{-1} Zn) and local cultivar (258.32, 249.73 kg grain kg^{-1} Zn). Fig 4.1.27 is representing the partial factor productivity (PFP) of soybean under the influence of varieties and zinc fertilization.

PFP significantly differed with zinc fertilization in both the years. Z_5 (858.77, 821.21 kg grain kg^{-1} Zn) recorded the highest PFP value whereas Z_4 (217.21, 203.33 kg grain kg^{-1} Zn) recorded the least value. In general, the PFP value for this zinc treatment is comparatively very high (213.96-858.77 kg grain kg^{-1} Zn) as opposed to the value of 37-44 reported by N (Prasad *et al*., 2000). These high values of PFP, AE and PE were due to very small amounts of Zn needed for soybean or any other crops for growth and grain production as compared to N (Prasad *et al*., 2000; Shivay *et al*., 2010). Interestingly,

Table 4.1.20a Effect of varieties and zinc fertilization on Partial productivity, Agronomic use efficiency and Zinc apparent recovery

Treatments	Partial factor productivity (kg grain kg^{-1} Zn)			Agronomic use efficiency (kg grain increased kg^{-1} Zn applied)			Biofortification Recovery Efficiency BRE_{Zn} (%)		
	2018	*2019*	*Pooled*	*2018*	*2019*	*Pooled*	*2018*	*2019*	*Pooled*
Varieties									
V_1	352.74	305.63	329.18	47.00	43.35	45.18	0.51	0.39	0.45
V_2	379.81	345.10	362.45	50.62	52.18	51.40	0.49	0.53	0.51
V_3	258.32	249.73	254.02	26.82	26.70	26.76	0.43	0.42	0.43
SEm±	***4.99***	***3.80***	***3.14***	***3.90***	***3.89***	***2.75***	***0.05***	***0.05***	***0.03***
CD at 5%	***14.26***	***10.87***	***9.53***	***11.14***	***11.11***	***8.37***	***NS***	***NS***	***NS***
Zinc fertilization									
Z_0	--	--	--	--	--	--	--	--	--
Z_1	307.42	292.63	300.03	31.62	29.61	30.61	0.32	0.32	0.32
Z_2	300.07	291.44	295.76	24.26	28.42	26.34	0.24	0.31	0.28
Z_3	293.19	282.34	287.76	48.24	48.75	48.49	0.52	0.49	0.51
Z_4	217.21	203.33	210.27	30.85	25.62	28.23	0.30	0.26	0.28
Z_5	858.77	821.21	839.99	129.11	125.38	127.25	1.74	1.56	1.65
Z_6	217.81	210.10	213.96	26.28	27.44	26.86	0.22	0.19	0.20
SEm±	***7.62***	***5.81***	***4.79***	***5.95***	***5.94***	***4.20***	***0.07***	***0.08***	***0.05***
CD at 5%	***21.78***	***16.60***	***13.48***	***17.01***	***16.97***	***11.83***	***0.21***	***0.22***	***0.15***

Table 4.1.20b Interaction effect of varieties and zinc fertilization on Partial productivity, Agronomic use efficiency and Zinc apparent recovery

V x Zn Interaction	**Partial factor productivity (kg grain kg^{-1} Zn)**			**Agronomic use efficiency (kg grain increased kg^{-1} Zn applied)**		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
V_1Z_0	--	--	--	--	--	--
V_1Z_1	290.85	291.20	291.03	31.95	25.27	28.61
V_1Z_2	287.27	302.07	294.67	28.36	36.13	32.25
V_1Z_3	277.96	288.57	283.27	48.03	52.40	50.21
V_1Z_4	208.50	208.11	208.31	33.57	28.42	31.00
V_1Z_5	832.95	826.63	829.79	148.01	123.10	135.56
V_1Z_6	218.89	222.82	220.86	39.09	38.15	38.62
V_2Z_0	--	--	--	--	--	--
V_2Z_1	376.85	335.83	356.34	43.07	38.83	40.95
V_2Z_2	355.60	327.20	341.40	21.81	30.20	26.01
V_2Z_3	363.65	329.19	346.42	67.21	65.42	66.32
V_2Z_4	262.88	232.61	247.75	37.35	31.94	34.64
V_2Z_5	1044.55	958.20	1001.38	161.52	172.49	167.00
V_2Z_6	255.17	232.64	243.90	23.37	26.39	24.88
V_3Z_0	--	--	--	--	--	--
V_3Z_1	254.57	250.87	252.72	19.83	24.73	22.28
V_3Z_2	257.33	245.07	251.20	22.60	18.93	20.77
V_3Z_3	237.95	229.25	233.60	29.48	28.42	28.95
V_3Z_4	180.23	169.28	174.76	21.63	16.49	19.06
V_3Z_5	698.80	678.78	688.79	77.81	80.55	79.18
V_3Z_6	179.38	174.83	177.11	16.37	17.80	17.08
SEm±	*13.20*	*10.06*	*8.30*	*10.31*	*10.29*	*7.28*
CD at 5%	*37.72*	*28.75*	*23.35*	*29.46*	*29.40*	*20.49*

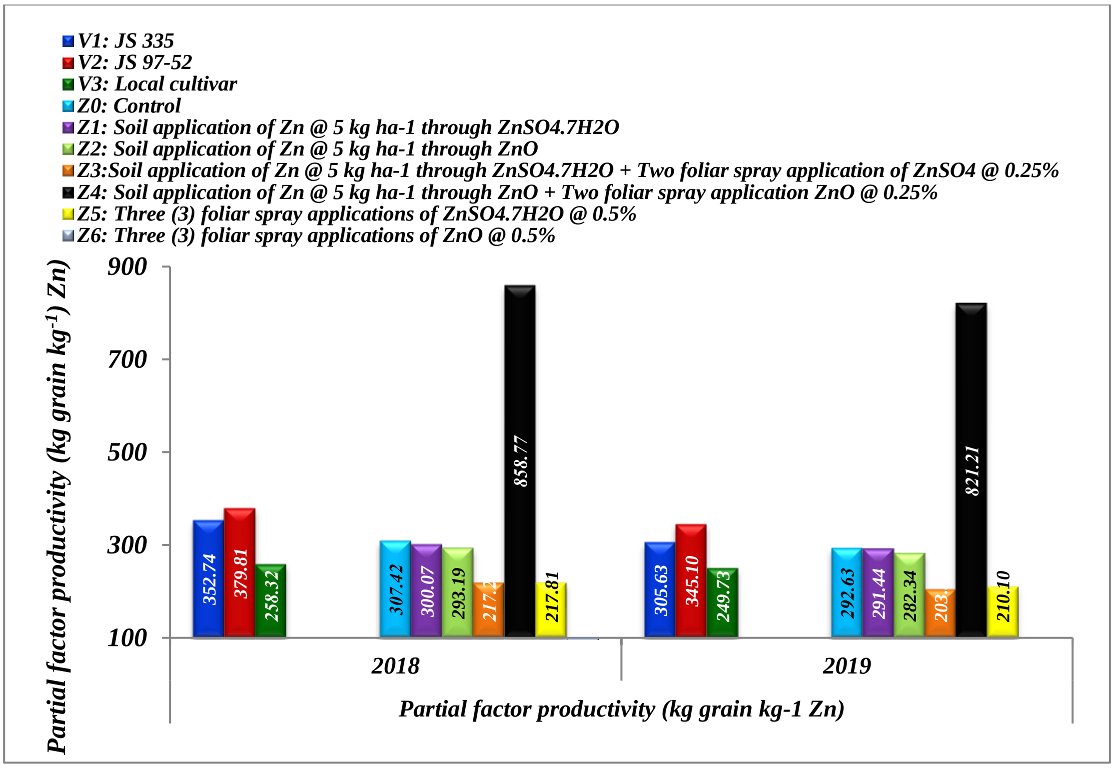


Fig 4.1.27 Effect of varieties and zinc application on Partial factor productivity during 2018 and 2019

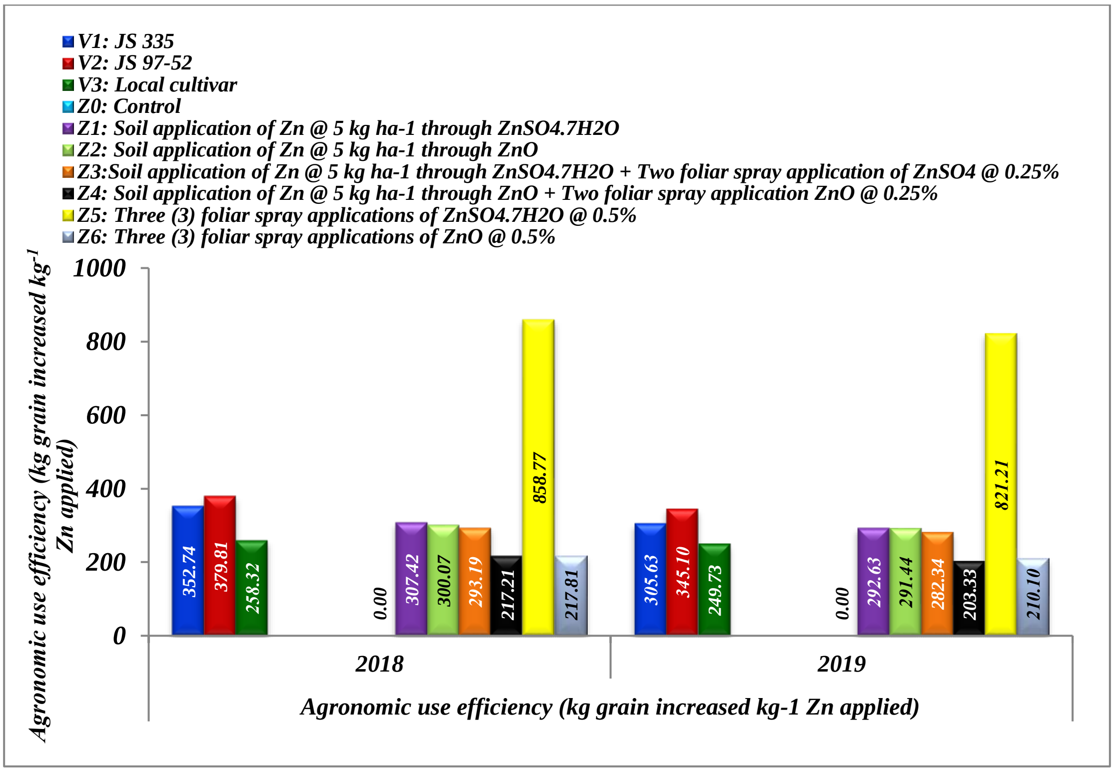


Fig 4.1.28 Effect of varieties and zinc application on Agronomic use efficiency during 2018 and 2019

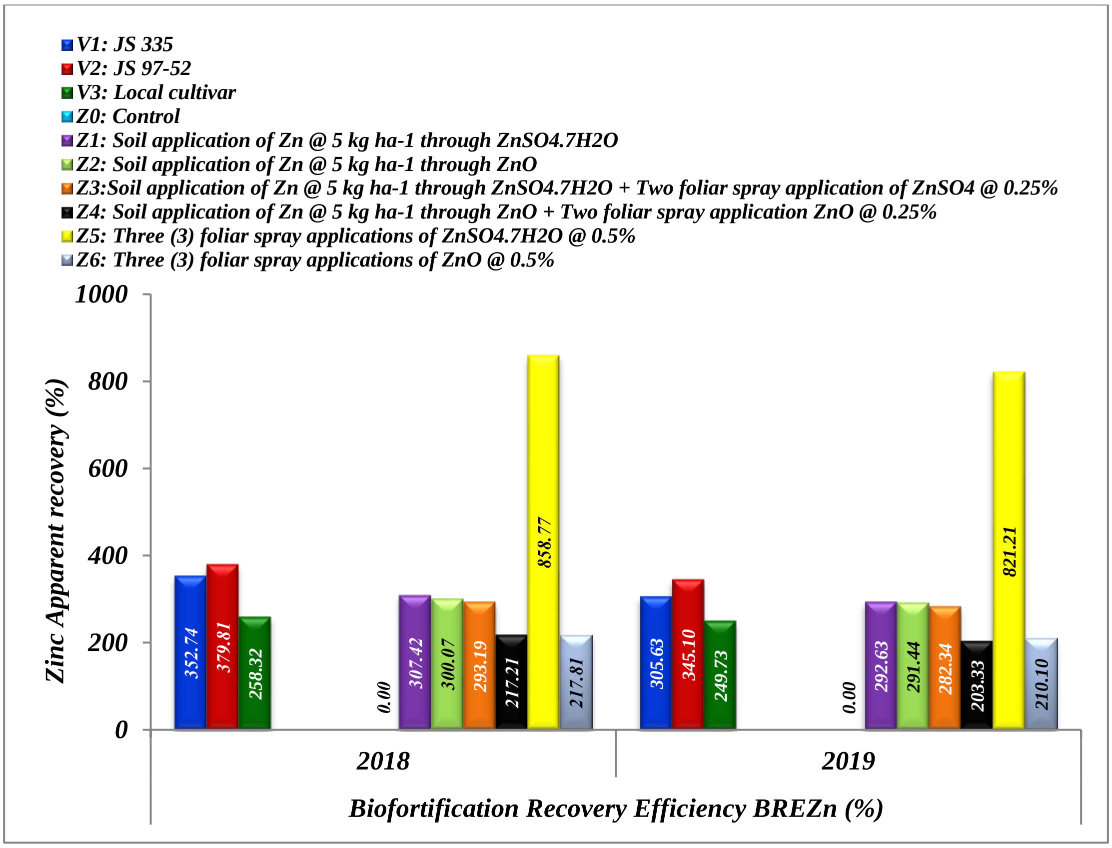


Fig 4.1.29 Effect of varieties and zinc application on Zinc Apparent recovery during 2018 and 2019

compared to other zinc treatments in this experiment, three foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5% (Z_5) required the least quantity of Zn nutrient as compared to ZnO applications. Therefore, the value observed significantly very high whencompared from the rest. The superior performance of $ZnSO_4.7H_2O$ over ZnO was due to its water solubility. $ZnSO_4.7H_2O$ is more water-soluble and therefore readily available, while ZnO is sparingly soluble and was not readily available to crop plants. Water solubility of Zn sources is considered an important criterion for Zn availability (Slaton *et al*., 2005a). Nayyar *et al*. (1990) from Punjab (India) also showed that Zn oxide was inferior to Zn sulphate. The data also revealed that with progressive increase in quantity of zinc nutrient added there was a significant decrease in PFP value which was also reported by Shivay *et al*. (2007) and Shivay *et al*. (2008b).

The interaction effect between varieties and zinc fertilizaiton on PFP was found significant in both years (Table 4.1.20b). The interaction effect was found to be highest in V_2Z_5 **(**1044.55, 958.20) which was followed by V_1Z_5 (832.95, 826.63) and least in V_3Z_4 (180.23, 169.28). V_2Z_5 was a combined effect of JS 97-52 (highest seed yield) with Z_5 (the least amount of Zn nutrient used) which resulted to highest PFP value.

4.1.6.2 Agronomic efficiency

Data pertaining to agronomic efficiency (AE) (kg grain increased kg^{-1} Zn applied) are presented in Table 4.1.20a and illustrated in Fig 4.1.28. The varieties varied significantly with respect to agronomic efficiency where the highest AE was obtained in JS 97-52 (50.62, 52.18 kg grain increased kg^{-1} Zn applied) and least was observed in local (26.82, 26.70 kg grain increased kg^{-1} Zn applied).

Zinc fertilization resulted in asignificant differenceon the agronomic efficiency in both the years. Z_5 (Three foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5%) recorded the AE in both the years (129.11, 125.38 kg grain increased kg^{-1} Zn applied) which was followed by Z_3(Soil application of Zn @ 5 kg ha^{-1}

through $ZnSO_4.7H_2O$ + Two foliar spray application of $ZnSO_4$ @ 0.25%) (48.24, 48.75kg grain increased kg^{-1} Zn applied). The performance of Zn fertilizationin agronomic efficiency on soybean was in the order; $Z_5 > Z_3 > Z_4 > Z_1 > Z_2$. Similar result of AE like the PFP was observed, where very high value of Agronomic efficiency in Z_5 treatment due to very lesser quantity of Zn nutrient was used to achieve almost equivalent yield. Similar findings were also reported by Shivay *et al*. (2008b) to support this result. With increasing level of zinc nutrient added to the crop there was significant decrease of Agronomic efficiency value due to comparatively similar or higher yield under relatively very low of zinc nutrient added in those treatments.

The interaction effect was found to be significantly high in V_2Z_5 and V_1Z_5 (JS 97-52 or JS-335+ Z_5)

4.1.6.3 Biofortification Recovery Efficiency BRE_{Zn}

Data pertaining to apparent recovery efficiency (RE) of applied zinc and varieties of soybean are presented in Table 4.1.20a and illustrated in Fig 4.1.29. Varieties did not vary significantly with respect to apparent recovery efficiency although higher value of pooled data was observed in JS 97-52 (0.51%).

Zinc treatments resulted to significant variation in apparent recovery efficiency (RE) where the Z_5 (Three foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5%) recorded the highest value (1.74, 1.56%) which was statistically superior to the rest of the treatments. The least of value was observed in Z_6 (Three foliar spray applications of ZnO @ 0.5%). As compared to the results of PFP, AE on the other hand, recovery efficiency for soil applied Zn as against 33-40% reported for N in rice (Ladha *et al*., 2005; Prasad, 2005). The main reason for the low Recovery efficiency (RE) for Zn might be due to its rapid adsorption on clay minerals (Hazra & Mandal, 1995) and its subsequent slow desorption (Mandal *et al*., 2000). Foliar applied Zn comparatively has higher BRE_{Zn} as compared to the soil applied as efficiency is more and much lesser quantity of zinc nutrient was utilized in treatments with foliar applications.

4.1.6.4 Zinc Mobilization Efficiency Index (Zn content in grain/ Zn content in stover)

Data on Zinc Mobilization Efficiency Index (ZnMEI) are presented in Table 4.1.21. The results revealed that there were no significant variations with respect to varieties in both the years of experimentations. Local cultivar recorded (1.41, 1.41), followed by JS 335 (1.39, 1.44) and JS 97-52 (1.33, 1.38).

The zinc applications too have no significant effect on the Zinc Mobilization Efficiency Index in both the years although the lowest value was observed in control in both the years. The highest value of ZnMEI was recorded in Z_4 (Soil application of Zn @ 5 kg ha^{-1} through ZnO + Two foliar spray application ZnO @ 0.25%) with 1.49, 1.53 respectively. The interaction effect was not significant in both the years.

4.1.6.5 Zinc Harvest Index

The perusal of data presented in Table 4.1.20a revealed that there were significant variations among varieties on zinc harvest index (ZHI) where the highest ZHI was observed in JS-335 (57.92, 60.75) which was at par with JS 97-52 (56.51, 56.71) followed by local cultivar (50.35, 47.09).

Zinc Harvest Index did not vary significantly due to zinc treatments in both the years of experiment. The interaction effect between the varieties and zinc treatments on ZHI was not significant in both the years.

4.1.6.6 Physiological efficiency

Physiological efficiency (PE) did not vary significantly due to varieties though the highest value was observed in JS 97-52 (17117.41, 16574.69 kg grain kg^{-1} Zn uptake).

The data presented in the Table 4.1.21 revealed that PE varied with application of zinc in both the years. During the first year of experiment, the

Table 4.1.21 Effect of varieties and zinc fertilization on Zinc Mobilization Efficiency Index, Zinc Harvest Index and Physiological efficiency

Treatments	**Zinc Mobilization Efficiency Index (Zn content in grain/ Zn content in stover)**			**Zinc Harvest Index (%)**			**Physiological efficiency (kg grain kg^{-1} Zn uptake)**		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
Varieties									
V_1	1.39	1.44	1.42	57.92	60.75	59.34	13972.32	14996.24	14484.28
V_2	1.33	1.38	1.35	56.51	56.71	56.61	17117.41	16574.69	16846.05
V_3	1.41	1.41	1.41	50.35	47.09	48.72	15303.45	13814.92	14559.19
SEm±	***0.04***	***0.05***	***0.03***	***0.91***	***0.86***	***0.63***	***2530.34***	***2644.29***	***1829.95***
CD at 5%	***NS***	***NS***	***NS***	***2.60***	***2.45***	***1.90***	***NS***	***NS***	***NS***
Zinc fertilization									
Z_0	1.28	1.39	1.33	52.85	54.17	53.51	--	--	--
Z_1	1.37	1.35	1.36	54.54	53.59	54.07	17106.13	24262.11	20684.12
Z_2	1.31	1.35	1.33	54.88	53.79	54.33	20826.98	12351.61	16589.29
Z_3	1.38	1.42	1.40	55.32	55.84	55.58	15011.90	17251.56	16131.73
Z_4	1.49	1.53	1.51	56.69	56.39	56.54	22922.07	17805.28	20363.68
Z_5	1.45	1.43	1.44	55.54	54.71	55.12	12639.73	15625.95	14132.84
Z_6	1.36	1.42	1.39	54.68	55.45	55.06	19743.96	18603.80	19173.88
SEm±	***0.07***	***0.08***	***0.05***	***1.39***	***1.31***	***0.96***	***3865.16***	***4039.22***	***2795.30***
CD at 5%	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***11047.52***	***11545.02***	***7867.01***

highest value was observed in Z_4 (Soil application of Zn @ 5 kg ha^{-1} through ZnO + Two foliar spray application ZnO @ 0.25%) with 22,922.07 followed by Z_2 (Soil application of Zn @ 5 kg ha^{-1} through ZnO) with 20,826.98 and Z_6 (Three foliar spray applications of ZnO @ 0.5%) with 19,743.96. But the data in the second year revealed that did not follow the same trend as in the first year.

4.1.7 Correlation study of zinc and other crop parameters

The correlation matrix of the relationship of zinc fertilization effect on different crop parameters is presented in Table 4.1.22. The data revealed that certain parameters were significantly correlated with each other either positively or negatively. Zn content of grain found to be positively correlated with N content in grain (0.902 at 1% level of significance), protein content (0.959), oil content (0.949). Similar trend was also observed in zinc uptake by grain with those parameters. Whereas, zinc content in grain has strongly negative correlation with phytic acid (-0.901) and Phytic acid: Zn molar ratio (-0.982). Zinc uptake too has a very strong negative correlation with PA: Zn molar ratio (-0.992). Phosphorus content in seed has a positive correlation with phytic acid: Zn molar (0.831) which signifies that phytic acid is a storage form of phosphorus in seed. Seed yield has a positive correlation with zinc content (0.934) and zinc uptake (0.972).

4.1.8 Available nutrient status in soil after harvest of soybean

4.1.8.1 Organic carbon

The results on soil organic carbon of soil after harvest (Table 4.1.23a) revealed that its value was not significantly affected by cultivar and zinc applications. The local cultivar recorded slightly higher organic carbon (1.54, 1.58%) with a pooled data of 1.56% which was followed by JS 97-52 with a pooled data of 1.53%.

Zinc applications did not show any significant trend with respect to organic carbon after soybean harvest in both the years.

Table 4.1.22 Correlation study of zinc fertilization and different crop parameters

Pearson Correlation coefficient	***DMA***	***Nodule dry wt.***	***Chlorophyll content***	***N content on grain***	***P content in grain***	***Protein content***	***Oil content***	***No. of pods plant^{-1}***	***Zn content grain***	***Zn uptake grain***	***Agronomic efficiency***	***Recovery Efficiency***	***Phytic acid***	***PA: Zn molar***	***Seed yield***
DMA	1														
Nodule dry wt.	.921**	1													
Chlorophyll content	.713	.833*	1												
N content on grain	.701	.538	.433	1											
P content in grain	-.819*	-.691	-.555	-.945**	1										
Protein content	.884**	.772*	.797*	.794*	-.821*	1									
Oil content	.887**	.818*	.687	.897**	-.899**	.898**	1								
number of pods per plant	.815*	.675	.603	.890**	-.841*	.930**	.903**	1							
Zn content grain	.856*	.748	.696	.902**	-.881**	.959**	.949**	.987**	1						
Zn uptake grain	.879**	.803*	.718	.862*	-.861*	.943**	.938**	.979**	.991**	1					
Agronomic efficiency	.752	.506	.337	.926**	-.895**	.779*	.859*	.817*	.827*	.771*	1				
Recovery Efficiency	.693	.436	.290	.912**	-.870*	.737	.822*	.771*	.784*	.716	.995**	1			
Phytic acid	-.840*	-.856*	-.902**	-.699	.781*	-.923**	-.833*	-.854*	-.901**	-.924**	-.573	-.514	1		
PA: Zn molar	-.878**	-.819*	-.790*	-.815*	.831*	-.965**	-.917**	-.962**	-.982**	-.992**	-.724	-.668	.959**	1	
Seed yield	.883**	.856*	.742	.732	-.764*	.897**	.868*	.928**	.934**	.972**	.631	.559	-.932**	-.973**	1

*. Correlation is significant at the 0.05 level (2-tailed); **. Correlation is significant at the 0.01 level (2-tailed).

Table 4.1.23 Effect of varieties and zinc fertilization on OC, soil pH, available soil N, P, K and Zn at harvest

Treatments	**Organic carbon (%)**			**Soil pH**			**Available Nitrogen (kg ha^{-1})**			**Available Phosphorus (kg ha^{-1})**			**Available Potassium (kg ha^{-1})**			**DTPA-Extractable Zinc (ppm)**		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
Varieties																		
V_1	1.49	1.50	1.49	4.67	4.65	4.66	493.0	496.4	494.7	34.2	32.3	33.3	266.9	250.3	258.6	2.68	2.56	2.62
V_2	1.58	1.62	1.60	4.78	4.85	4.81	532.3	531.4	531.8	34.3	32.3	33.3	268.2	267.8	268.0	2.85	2.91	2.88
V_3	1.54	1.59	1.57	4.74	4.73	4.74	525.1	538.0	531.6	32.9	33.2	33.0	273.0	273.2	273.1	2.47	2.55	2.51
SEm±	***0.03***	***0.04***	***0.02***	***0.07***	***0.11***	***0.07***	***7.7***	***10.5***	***6.5***	***1.0***	***1.0***	***0.7***	***6.7***	***7.1***	***4.9***	***0.08***	***0.08***	***0.06***
CD at 5%	***NS***	***0.10***	***0.07***	***NS***	***NS***	***NS***	***21.9***	***30.0***	***19.7***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***0.24***	***0.23***	***0.18***
Zinc fertilization																		
Z_0	1.48	1.50	1.49	4.53	4.73	4.63	496.2	500.9	498.6	30.7	29.6	30.1	257.0	247.7	252.4	2.40	2.38	2.39
Z_1	1.51	1.56	1.54	4.65	4.73	4.69	521.2	507.3	514.2	33.1	34.5	33.8	261.0	268.8	264.9	2.59	2.71	2.65
Z_2	1.57	1.57	1.57	4.68	4.70	4.69	496.3	514.9	505.6	33.1	32.8	33.0	268.2	254.7	261.4	2.58	2.50	2.54
Z_3	1.58	1.65	1.61	4.81	4.78	4.79	543.3	544.8	544.1	37.6	36.1	36.8	284.8	274.1	279.4	2.91	2.97	2.94
Z_4	1.52	1.55	1.53	4.74	4.64	4.69	513.4	520.2	516.8	34.3	30.6	32.5	264.0	265.8	264.9	2.73	2.74	2.74
Z_5	1.57	1.63	1.60	4.90	4.85	4.88	526.7	535.2	530.9	34.3	33.4	33.9	278.8	270.8	274.8	2.77	2.80	2.79
Z_6	1.51	1.54	1.53	4.81	4.79	4.80	520.7	530.1	525.4	33.5	31.2	32.4	272.1	264.7	268.4	2.68	2.61	2.65
SEm±	***0.04***	***0.05***	***0.03***	***0.11***	***0.16***	***0.10***	***11.72***	***16.01***	***9.92***	***1.59***	***1.48***	***1.09***	***10.22***	***10.89***	***7.47***	***0.13***	***0.12***	***0.09***
CD at 5%	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***4.24***	***3.06***	***NS***	***NS***	***NS***	***NS***	***0.36***	***0.25***

4.1.8.2 Soil pH

Soil pH too remained unaffected and did not show any significant variations under the influence of varieties and zinc applications. The result indicated that the pooled data was slightly higher in JS 97-52 (4.68) than the other varieties (Table 4.1.23a).

4.1.8.3 Available soil nitrogen after harvest

Data pertaining to available N in soil at harvest as influenced by varieties and zinc application are presented in Table 4.1.23a. The data revealed that there was significant difference among varieties towards available soil N. In both the years of the experiment, the JS-97-52 (532.29, 531.36 kg ha^{-1}) was at par with local cultivar (525.14, 538.00 kg ha^{-1}) which was significantly higher than local (493.00, 496.39 kg ha^{-1}).

Zinc supply had no significant effect on $KMnO_4$ oxidizable N (available N) in soil after harvest. However, the data revealed that available N in soil was in the higher side in treatments with zinc sulphate heptahydrate as compared to Zinc oxide fertilizer. Highest available N was observed Z_3 (543.27, 544.84 kg ha^{-1}) which was followed by Z_5 (526.67, 535.18 kg ha^{-1}) in both the years of study.

4.1.8.4 Available soil phosphorus after harvest

The data on available soil P at harvest of soybean are presented in Table 4.1.23a. It is revealed that there was no significant of varieties on available soil P in both the years. The soil available P after the harvest of JS-335, JS 97-52 and local was (34.21, 32.30 kg ha^{-1}), (34.31, 32.34 kg ha^{-1}) and (32.91, 33.18 kg ha^{-1}), respectively. All remains at par with each other in both the years of the experimentation.

The different zinc application treatments too resulted to no significant effect on available soil P in the first year but in the subsequent year it is observed that Z_3 (Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$ +

Two foliar spray application of $ZnSO_4$ @ 0.25%) resulted in significantly higher value of available soil P over control with 29.56 kg ha^{-1} which was followed by Z_4 (Soil application of Zn @ 5 kg ha^{-1} through ZnO + Two foliar spray application ZnO @ 0.25%) with 30.57 kg ha^{-1} and Z_6 (Three foliar spray applications of ZnO @ 0.5%) with 31.23 kg ha^{-1}.

The interaction effect was found to be non-significant in both the years of the experiment.

4.1.8.5 Available soil potassium after harvest

The data pertaining to available soil K are presented in Table 4.1.23a. The data revealed that there were no significant variations among soybean varieties on soil available K in both the years. The available K after harvest of JS-335, JS 97-52 and local cultivar was (266.94, 250.33 kg ha^{-1}), (268.25, 267.83 kg ha^{-1}) and (273.03, 271.33 kg ha^{-1}) respectively in both years of experimentations.

The application of zinc treatments did not vary significantly on the available soil K in both the years although the value was observed to be slightly higher in Z_3 (Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$ + Two foliar spray application of $ZnSO_4$ @ 0.25%) with 284.75, 274.13 kg ha^{-1} followed by Z_5 (Three foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5%) with 278.78, 270.78 kg ha^{-1} and least value was observed in control with 257.03, 247.75 kg ha^{-1}. The interaction effect of the two factors remained non-significant in both the years (Table 4.1.23a).

4.1.8.6 DTPA-Extractable zinc after harvest

Data pertaining to available (DTPA-extractable) Zn in soil after harvest of soybean as influenced by varieties and zinc supply are presented in Table 4.1.23a and Table 4.1.23b. There were significant variations among varieties on on soil available (DTPA-extractable) Zn after harvest. The value was in the order JS 97-52 > JS-335 > local cultivar with their respective values of (2.85, 2.91 ppm), (2.68, 2.57 ppm) and (2.47, 2.55 ppm).

Data with respect to zinc application effect on soil available (DTPA-extractable) Zn indicated that there was no significant difference among the treatments in the first year of the experimentation. Although, the highest available (DTPA-extractable) Zn was observed in Z_3 (Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$ + Two foliar spray application of $ZnSO_4$ @ 0.25%) with a value of 1.91, 2.97 ppm which was followed by Z_5 (Three foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5%) with value of 2.77, 2.80 ppm. The lowest values were recorded with control (No zinc) in both the years. The increase in DTPA-extractable Zn after harvest of soybean was due to different fertilizer applications which have added to building the available zinc in the soil. Z_3 resulted to highest value could be the fact that $ZnSO_4$ is water soluble and therefore readily available, whereas ZnO is sparingly soluble and was not readily available to plants. Water solubility of Zn sources is considered important criteria for Zn availability (Slaton *et al*., 2005b). An increase in Zn status of soil after Zn application has been reported by several workers (Lu *et al*., 2011; Pooniya & Shivay, 2011).

4.1.9 Soil biological properties

4.1.9.1 Dehydrogenase activity

The data pertaining to dehydrogenase activity (DHA) of soil at harvest are presented inTable 4.1.24 and Fig 4.1.30. The data revealed that varieties significantly vary with respect to soil biological properties like the dehydrogenase activity in both the years. The cultivar JS 97-52 (30.84. 29.51ugTPF g^{-1} soil hr^{-1}) recorded the highest value which was followed by local cultivar (28.47, 27.72 ugTPF g^{-1} soil hr^{-1}) and the least dehydrogenase activity observed in JS-335 (25.17, 25.29 ugTPF g^{-1} soil hr^{-1}) which was statistically inferior to the first two varieties.

Higher value of dehydrogenase activity in JS 97-52 and local cultivar

Table 4.1.24 Effect of Varieties and Zinc fertilization on soil microbial activity in soybean

Treatments	Dehydrogenase activity (ug TPFg^{-1}soil hr^{-1})			Fluorescein diacetate FDA (µg gm^{-1} soil0.5 hr^{-1})			SMBC (µg g^{-1})		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
Varieties									
V_1	25.17	25.29	25.23	4.75	4.78	4.77	243.96	236.54	240.25
V_2	30.84	29.51	30.18	5.33	5.49	5.41	273.59	275.05	274.32
V_3	28.33	27.72	28.03	5.20	5.38	5.29	268.86	270.93	269.89
SEm±	***0.67***	***0.60***	***0.45***	***0.09***	***0.09***	***0.06***	***5.13***	***5.18***	***3.64***
CD at 5%	***1.90***	***1.71***	***1.36***	***0.25***	***0.26***	***0.19***	***14.65***	***14.80***	***11.08***
Zinc fertilization									
Z_0	25.53	24.74	25.13	4.79	4.69	4.74	244.69	248.59	246.64
Z_1	28.12	26.49	27.31	4.99	5.12	5.06	260.31	253.83	257.07
Z_2	27.28	27.93	27.60	4.91	4.94	4.93	261.04	260.93	260.99
Z_3	31.16	32.29	31.72	5.37	5.64	5.51	278.30	271.13	274.72
Z_4	28.75	26.80	27.77	5.14	5.39	5.26	261.37	261.84	261.60
Z_5	29.25	28.84	29.04	5.27	5.59	5.43	274.01	268.38	271.19
Z_6	26.71	25.46	26.08	5.18	5.15	5.17	255.23	267.82	261.52
SEm±	***1.02***	***0.92***	***0.68***	***0.14***	***0.14***	***0.10***	***7.83***	***7.91***	***5.57***
CD at 5%	***2.91***	***2.62***	***1.93***	***NS***	***0.39***	***0.27***	***NS***	***NS***	***NS***

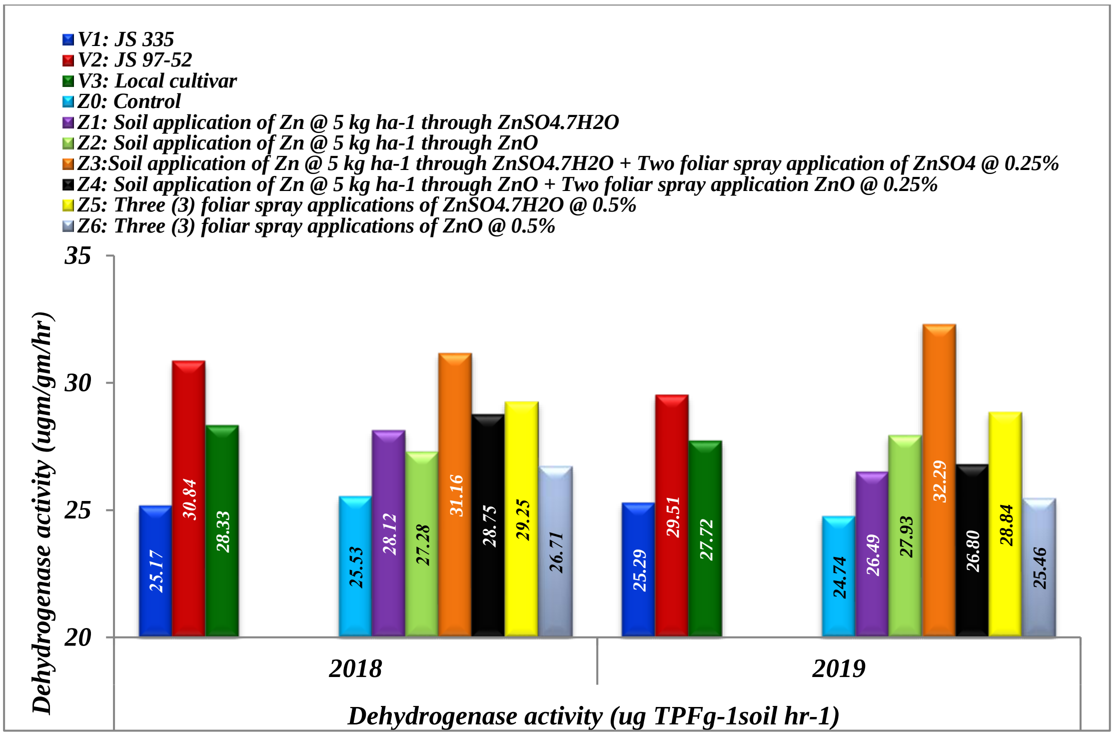


Fig 4.1.30 Effect of varieties and zinc application on Dehydrogenase activity during 2018 and 2019

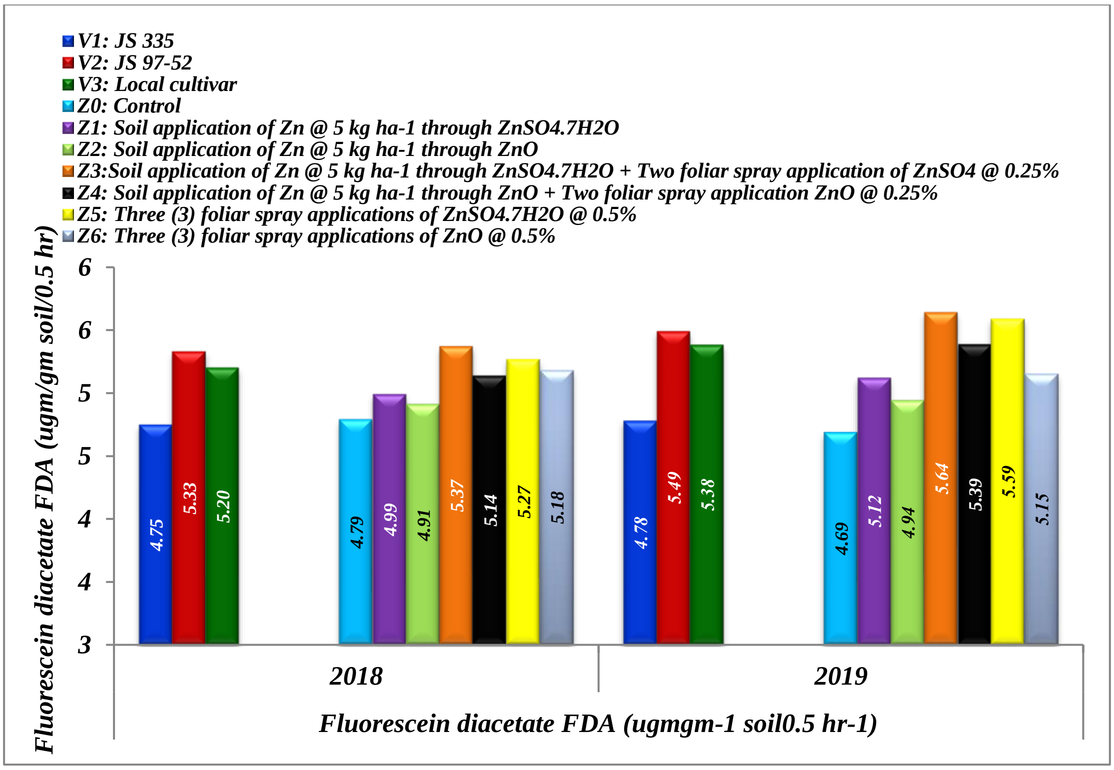


Fig 4.1.31 Effect of varieties and zinc application on Fluorescein diacetate during 2018 and 2019

could be due to their higher dry matter production which added higher amount of substrate to the soil for supporting the proliferation of microbial population. This result is supported by the finding of Lizarazo *et al*. (2005), Ramesh *et al*. (2008) and Aher *et al*. (2015).

The zinc application has resulted significant difference on its soil dehydrogenase activity in both the years of experimentation. It was observed that the Z_3 (Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$ + Two foliar spray application of $ZnSO_4$ @ 0.25%) recorded the highest value which was statistically at par with Z_5 and Z_4 with dehydrogenase activity value of (31.16, 32.29 ugTPF g^{-1} soil hr^{-1}), (29.25, 28.84 µgTPF g^{-1} soil hr^{-1}) and (28.75, 26.80 ugTPF g^{-1} soil hr^{-1}) respectively. The least value was observed in control treatment in both the years (25.53, 24.74 µgTPF g^{-1} soil hr^{-1}).

The interaction effect of varieties and zinc fertilization on DHA was found to be non-significant in both the years.

4.1.9.2 Fluorescein diacetate activity

The data pertaining to Fluorescein diacetate activity (FDA) in soil are given in Table 4.1.24 and illustrated in Fig 4.1.31. The data revealed that varieties varied significantly in FDA in soil in both the years. The cultivar JS-97-52 resulted in highest value (5.33, 5.49 ugm gm^{-1} soil 0.5 hr^{-1}) which was at par with local cultivar (5.20, 5.38 ugm gm^{-1} soil 0.5 hr^{-1}) and least on JS-335 (4.75, 4.78 ugm gm^{-1} soil 0.5 hr^{-1} hr).

In the first year of the experiment (2018), it was observed that the FDA value did not vary significantly with respect to zinc application although we observed similar trend as in other soil microbial parameters. The effect of zinc supply in the second year of the experiment did vary FDA of soil significantly. The highest FDA was observed in Z_3 followed by Z_5 and Z_4 with FDA value of 5.64, 5.59 and 5.39 ugm gm^{-1} soil/0.5 hr, respectively. Fluorescein diacetate hydrolysis is widely accepted as an accurate and simple method for measuring total microbial activity. FDA is hydrolysed by ubiquitous free and membrane-bound hydrolytic enzymes, such as lipase, protease and esterase enzymes produced by soil microbes (Green *et al*., 2006). Hydrolysis of FDA is generally proportional to the microbial population. Zn fertilization appreciably improved the soil microbial biomass carbon and soil enzyme activities, irrespective of the sources applied during both the years of experimentation. The results were similar to the findings of Pooniya and Shivay (2012).

The interaction effect was observed to be non-significant in both the years.

4.1.9.3 Soil microbial biomass carbon

The perusal of data on SMBC of soil are given in Table 4.1.24 and illustrated in Fig 4.1.32. It shows that there were significant variations among varieties on soil microbial biomass carbon (SMBC) in both the years. The cultivar JS 97-52 recorded the highest soil microbial biomass carbon (273.59, 275.05 $\mu g\ g^{-1}$) which was statistically at par with local cultivar (268.86, 270.93 $\mu g\ g^{-1}$) and least SMBC was observed in JS-335 (243.96, 236.54 05 $\mu g\ g^{-1}$). This result could be due to more dry matter production in those varieties which added more organic matter due to leaf senescence before harvest of the crop.

There was no significant difference among zinc applications on the SMBC value of soil. However, the data revealed that Z_3 (Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$ + Two foliar spray application of $ZnSO_4$ @ 0.25%) and Z_5 (Three foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5%) recorded the highest SMBC values (278.04, 260.93 $\mu g\ g^{-1}$) and (274.01, 268.38 $\mu g\ g^{-1}$). The least of SMBC was observed in control (No zinc) in both the years. Soil microbial biomass C is a small component of soil organic matter and is directly related to soil organic matter status (Dhull *et al*., 2004; Jedidi *et al*., 2004). Therefore, zinc treated plots are found to enhance dry biomass production and improve soil organic carbon. Soil microbial biomass carbon increase affects enzymatic activities positively. Enzymes play a crucial role in soil ecosystems since they are involved in the biogeochemical cycling of C, N, P and other nutrients (Tejada *et al*., 2008). When compared to control (No zinc), those with zinc nutrition irrespective of the sources was observed to have slightly higher value of SMBC in both the years of experimentation even though may not be of significant difference. The one with soil application combined with foliar zinc application showed numerically higher value of SMBC which might be due to the role zinc in enhancing its value. It might be due to the supply of additional mineralizable and readily hydrolysable C due to higher organic matter which resulted in higher microbial activity and in return higher microbial biomass carbon. Wright and Hons (2005), Thakare and Bhoyar (2012) and Datt *et al*. (2013) have also reported similar findings. Application of $ZnSO_4.7H_2O$ found slight superiority over ZnO might be due to better solubility and easily available to the plant rhizosphere. In this study, Zn nutrition, irrespective of source applied appears to increase soil enzyme activities which suggest that Zn is essential for microbial population.

The interaction effect was found to be non-significant in both the years of the experiment.

4.1.10 Relative economics of soybean as influenced by varieties and zinc fertilization

Data pertaining to cost of cultivation, gross returns, net returns and net B: Cof soybean under the influence of varieties and zinc fertilization are presented in Table 4.1.25, Fig 4.1.33 and Fig 4.1.34. The the fixed cost and variable cost are presented in Annexture II and III.

Cost of cultivation

The cost of cultivation among the varieties remained the same ₹46,447.90. Whereas the cost of cultivation varied among the zinc fertilization

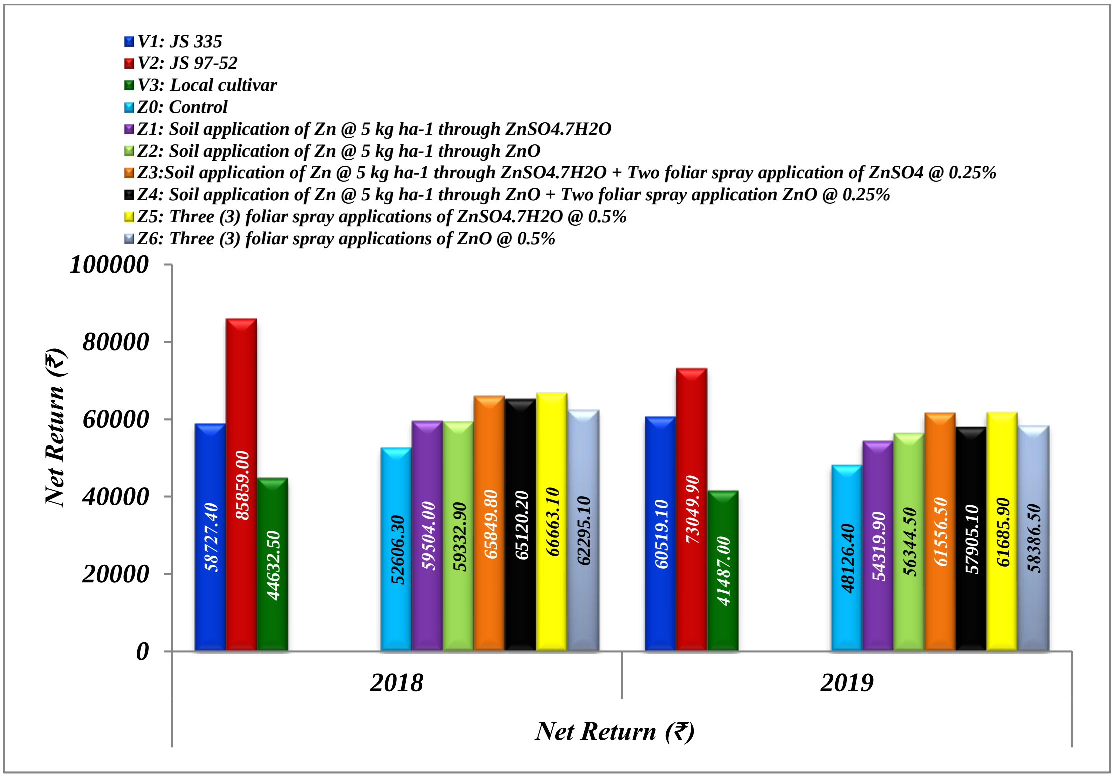


Fig 4.1.33 Effect of varieties and zinc ferti-fortification on net return during 2018 and 2019

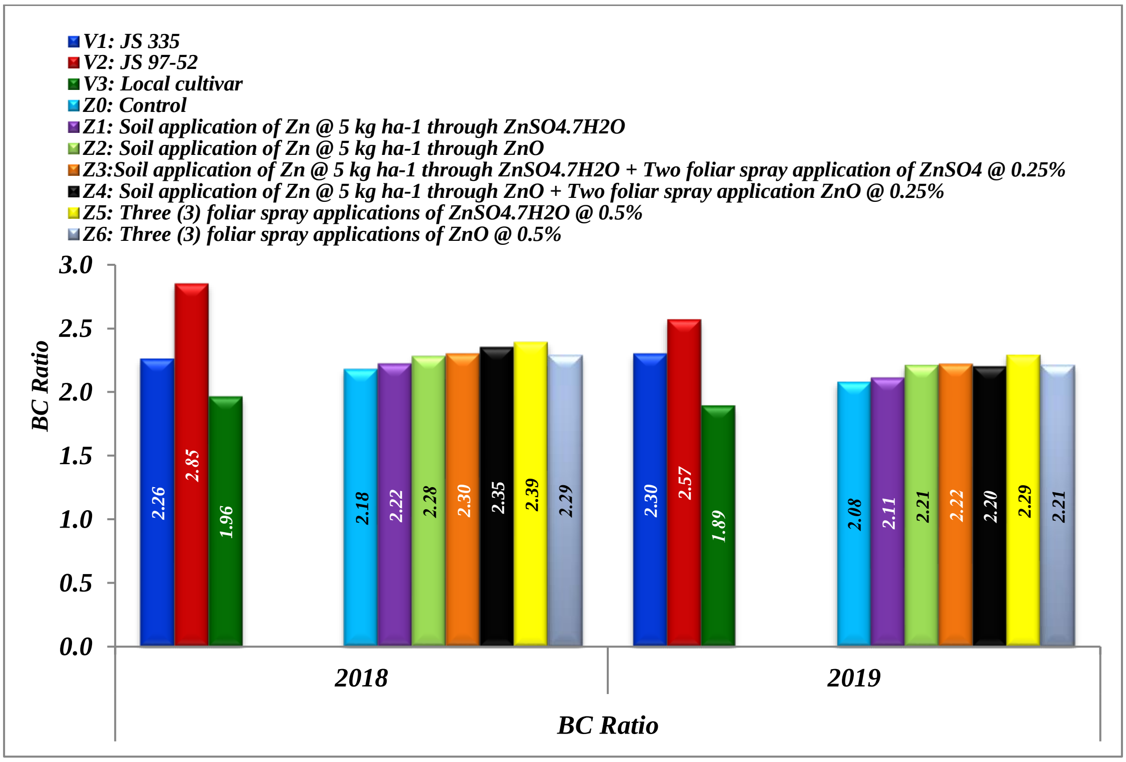


Fig 4.1.34 Effect of varieties and zinc ferti-fortification BCR during 2018 and 2019

treatments. The highest cost was in Z_3 (₹50,594.90) followed by Z_1 (₹48,951.90) and least cost of cultivation among the zinc treatments was in control (₹44,701.30).

Gross return

Among the varieties the gross return was found highest in JS 97-52 (₹1,32,306.90, ₹1,19,497.80) and least in local cultivar (₹91,080.40, ₹87,934.90).

Among the zinc fertilization treatments, the highest gross return was observed in Z_3 (Rs. 1,16444.60, Rs. 1,12151.30) which was followed by Z_5 (Rs. 1,14544.30, Rs. 1,09567.10) and the least gross return was observed in control (₹. 97,307.60, ₹. 92,827.70) in both the years of study

Net return

Among the varieties the net return was found highest in JS 97-52 (₹85859.00, ₹73049.90) and least in local cultivar (₹44632.50, ₹41487.00) in both years.

Among the zinc fertilization treatments, the highest net return was observed in Z_5 (₹66663.10, ₹61685.90) which was followed by Z_3 (₹65849.80, ₹61556.50) and the least gross return was observed in control (₹52606.30, ₹48126.40) in both the years of study.

B: C Ratio

Among the varieties the BC ratio was found highest in JS 97-52 (2.85, 2.57) and least in local cultivar (1.96, 1.89) in both years.

Among the zinc fertilization treatments, the highest BC ratio was observed in Z_5 (2.39, 2.29) which was followed by Z_4 (2.35, 2.20) and the least BC ratio was observed in control (2.18, 2.08) in both the years of study.

Table 4.1.25 Economics under the influenced of varieties and Zinc fertilization (2018 & 2019)

Treatments	**Cost of Cultivation (₹ ha^{-1})**		**Gross Return (₹ ha^{-1})**		**Net Return (₹ ha^{-1})**		**B:C Ratio**	
	2018	***2019***	***2018***	***2019***	***2018***	***2019***	***2018***	***2019***
Varieties								
V_1	46,447.9	46,447.90	1,05175.30	1,06967.00	58727.40	60519.10	2.26	2.30
V_2	46,447.90	46,447.90	1,32306.90	1,19497.80	85859.00	73049.90	2.85	2.57
V_3	46,447.90	46,447.90	91,080.40	87,934.90	44632.50	41487.00	1.96	1.89
Zinc fertilization								
Z_0	44,701.30	44,701.30	97,307.60	92,827.70	52606.30	48126.40	2.18	2.08
Z_1	48,951.90	48,951.90	1,08455.90	1,03271.80	59504.00	54319.90	2.22	2.11
Z_2	46,492.70	46,492.70	1,05825.50	1,02837.10	59332.90	56344.50	2.28	2.21
Z_3	50,594.90	50,594.90	1,16444.60	1,12151.30	65849.80	61556.50	2.30	2.22
Z_4	48,294.70	48,294.70	1,13414.80	1,06199.70	65120.20	57905.10	2.35	2.20
Z_5	47,881.30	47,881.30	1,14544.30	1,09567.10	66663.10	61685.90	2.39	2.29
Z_6	48,358.30	48,358.30	1,10653.30	1,06744.80	62295.10	58386.50	2.29	2.21

Labour wages: ₹220; Soybean grain: ₹70/-; $ZnSO_4.7H_2O$: ₹150; ZnO: ₹200; Urea: ₹12 kg^{-1}, SSP: ₹15.8; MOP: ₹25

4.2 Experiment II: "Biofortification of iron in Soybean (*Glycine max* (L.) Merrill) under foothill of Nagaland"

4.2.1 Growth parameters

4.2.1.1 Periodic plant height

Plant height as influenced by varieties and iron (Fe) application at different crop stages are presented in Table 4.2.1 and Fig. 4.2.1 and Fig. 4.2.2. The data indicated that the plant height at all stages of crop growth found to be significantly affected by the varieties. At 30 days after sowing (DAS), the plant height of local cultivar (34.57, 33.28 cm) and JS 97-52 (34.43, 34.14 cm) found to be significantly higher than JS-335 (30.82, 30.99 cm) in both the years. The iron (Fe) application did not have any significant effect on plant height at this stage. At 60 DAS, a similar trend was observed as there were significant variations on plant height as influenced by varieties. Local cultivar registered the highest plant height (66.02, 66.48 cm) which was significantly superior over JS 97-52 (56.49, 56.29 cm) and JS-335 (48.84, 49.56 cm) in both the years. Plant height at 90 DAS was found superior in local cultivar (69.98, 72.39 cm) which was statistically higher than JS 97-52 (58.08, 58.86 cm) and JS-335 (50.24, 53.03 cm). At harvest the highest plant height was observed in local cultivar (72.81, 71.34 cm) and lowest was JS-335 (47.37, 51.23 cm). Among the varieties, local cultivar found to be much superior in plant height being a traditional taller cultivar when compared to short duration high yielding improved varieties. The main reason for this is due to varietal and genotypic differences which were shown in crop morphology.

Iron fertilization failed to produce any significant difference on plant height of soybean at all crop stages and in both the years of experiment. Although, there was no significant variations on imposition of Fe fertilization on plant height, however Fe_3 (Foliar spray application of $FeSO_4.7H_2O$@ 1.5% at pre-flowering stage) has numerical superiority (59.81, 59.95cm) over the rest in both the years. Interestingly, the data revealed that with increasing level of

Table 4.2.1 Effect of varieties and iron fertilization on plant height (cm) at 30, 60, 90 DAS and at harvest in soybean

Treatments	**30 DAS**			**60DAS**			**90 DAS**			**at harvest**		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
Varieties												
V_1	30.82	30.99	30.91	48.84	49.56	49.20	50.24	53.03	51.64	47.37	51.23	49.30
V_2	34.43	34.14	34.28	56.49	56.29	56.39	58.08	58.86	58.47	55.45	57.86	56.66
V_3	34.57	33.28	33.93	66.02	66.48	66.25	69.98	72.39	71.19	72.81	71.34	72.07
SEm±	***0.79***	***0.76***	***0.55***	***1.50***	***1.25***	***0.98***	***1.65***	***1.45***	***1.10***	***1.92***	***1.71***	***1.29***
CD at 5%	***2.27***	***2.17***	***1.54***	***4.30***	***3.58***	***2.75***	***4.74***	***4.15***	***3.10***	***5.51***	***4.90***	***3.62***
Fe fertilization												
Fe_0	32.10	31.72	31.91	52.81	53.35	53.08	54.36	57.56	55.96	54.35	55.68	55.01
Fe_1	32.99	31.96	32.47	56.47	55.84	56.16	58.77	60.43	59.60	57.64	59.10	58.37
Fe_2	33.41	31.16	32.29	58.87	58.24	58.55	62.51	62.79	62.65	60.16	60.91	60.54
Fe_3	33.02	33.74	33.38	59.81	59.95	59.88	63.01	63.43	63.22	60.13	61.56	60.85
Fe_4	33.45	34.48	33.96	57.15	58.53	57.84	58.67	60.48	59.57	58.66	60.04	59.35
Fe_5	34.67	33.76	34.21	57.61	58.76	58.18	59.30	63.86	61.58	60.32	63.55	61.94
SEm±	***1.12***	***1.07***	***0.77***	***2.12***	***1.77***	***1.38***	***2.34***	***2.05***	***1.55***	***2.72***	***2.42***	***1.82***
CD at 5%	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***

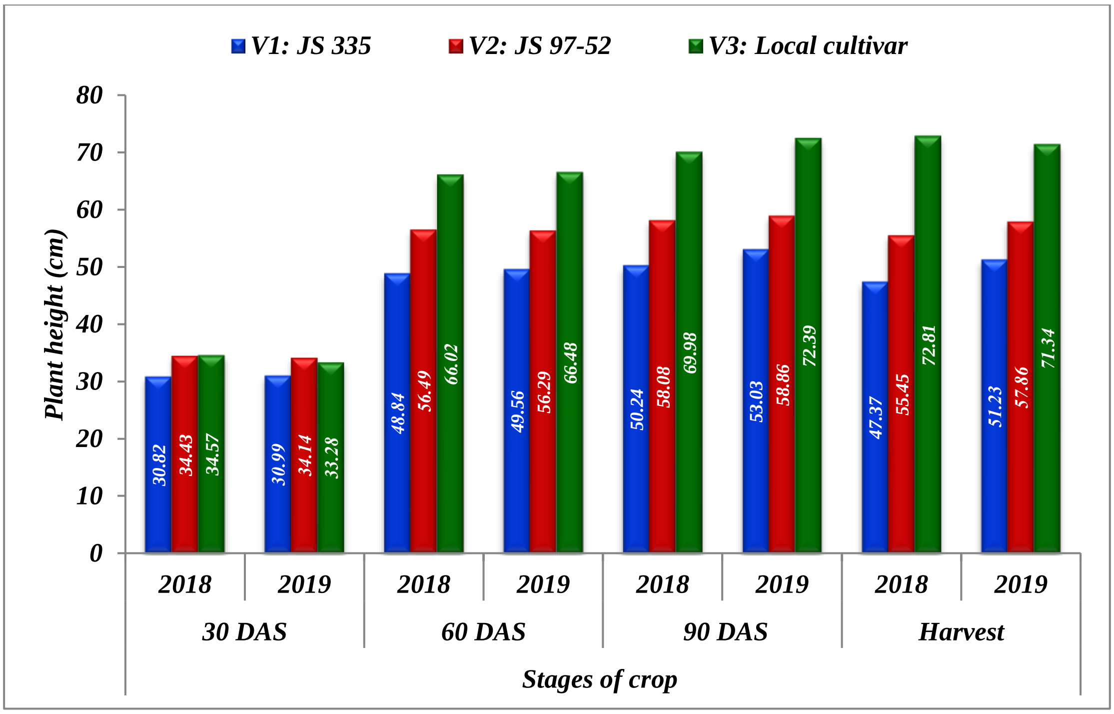


Fig 4.2.1 Effect of varieties on plant height of soybean at different stages of crop during 2018 and 2019

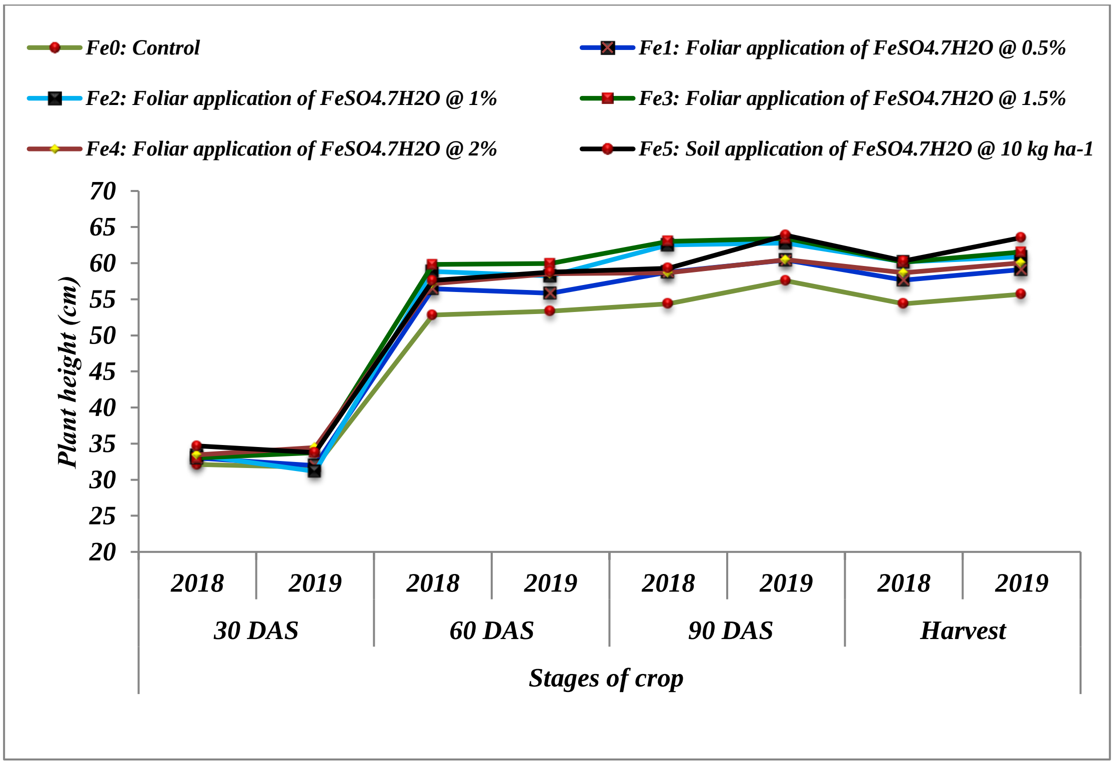


Fig 4.2.2 Effect of iron application on plant height of soybean at different stages of crop during 2018 and 2019

Plate No.4 Overview of pots experimental area (Experiment II)

$FeSO_4.7H_2O$ concentration plant height tends to increase up to certain limit. The lowest value was observed in no $FeSO_4.7H_2O$ application. The highest plant height was recorded at Fe_3 (63.01, 63.43 cm) in both the years. The same trend was observed in plant height till harvest stage. Iron (Fe) fertilization treatments did not have much impact on improving plant height. However, there was slight improvement from 60 DAS onwards when compared to control. The reason for this could be due to increase in the availability of iron to plant which might have stimulated the metabolic and enzymatic activities thereby increasing the growth of the plant reported by (Trivedi *et al.*, 2011). It can also be explained by the fact that Fe treated plants have better uptake of plant nutrients due to which might enhance more photosynthesis in turn resulted to more leaves, leaf area and dry matter accumulation and ultimately on plant height. This finding was corroborated by the results reported by Kamble *et al.* (2021) who indicated that soil application of $FeSO_4$ @ 10 and 20 kg ha^{-1} with two sprays of chelated Fe @ 0.2% treatments were found to result higher in plant height. Balachander *et al.* (2003), Kobraee*et al.* (2011a), Dhaliwal *et al.* (2013) and Soni and Kushwaha (2020) also reported similar findings with respect to effect of Fe on plant height.

The interaction effect of varieties and Fe fertilization on plant was found non-significant in both the years of study.

2.2.1.2 Number of leaves

The data pertaining to the number of leaves as influence by varieties and iron fertilization are presented in Table 4.2.2 and depicted in Fig 4.2.3 & Fig 4.2.4. There was significant difference among varieties on number of leaves $plant^{-1}$ at all crop stages. It also indicated that there was an appreciable increase in the number of leaves with the advancement of crop stages up to 90 DAS and there on the crop started leaf senescence. At 60 DAS as revealed from the data there were significant variations among varieties. The cultivar JS 97-52 recorded the highest value (19.83, 20.61) which was at par with JS-335 (18.17,

Table 4.2.2 Effect of varieties and iron fertilization on number of leaves at 30, 60 and 90 DAS in soybean

Treatments	**30 DAS**			**60 DAS**			**90 DAS**		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
Varieties									
V_1	7.39	7.70	7.55	18.17	20.91	19.54	16.61	9.02	12.81
V_2	7.76	7.80	7.78	19.83	20.61	20.22	19.19	15.50	17.34
V_3	6.96	6.44	6.70	17.72	17.72	17.72	25.94	31.78	28.86
SEm±	***0.20***	***0.16***	***0.13***	***0.52***	***0.49***	***0.36***	***0.60***	***0.51***	***0.39***
CD at 5%	***0.59***	***0.45***	***0.36***	***1.49***	***1.42***	***1.01***	***1.72***	***1.47***	***1.11***
Fe fertilization									
Fe_0	7.37	7.63	7.50	18.22	18.30	18.26	21.22	19.11	20.17
Fe_1	7.00	7.52	7.26	18.81	19.00	18.91	21.26	17.78	19.52
Fe_2	7.04	7.33	7.19	19.81	20.37	20.09	20.26	19.89	20.07
Fe_3	7.30	7.04	7.17	19.26	21.93	20.59	20.70	19.41	20.06
Fe_4	7.56	7.15	7.35	17.19	19.07	18.13	19.33	19.04	19.19
Fe_5	7.96	7.22	7.59	18.15	19.81	18.98	20.70	17.37	19.04
SEm±	***0.29***	***0.22***	***0.18***	***0.73***	***0.70***	***0.51***	***0.85***	***0.73***	***0.56***
CD at 5%	***NS***	***NS***	***NS***	***NS***	***2.01***	***1.43***	***NS***	***NS***	***NS***

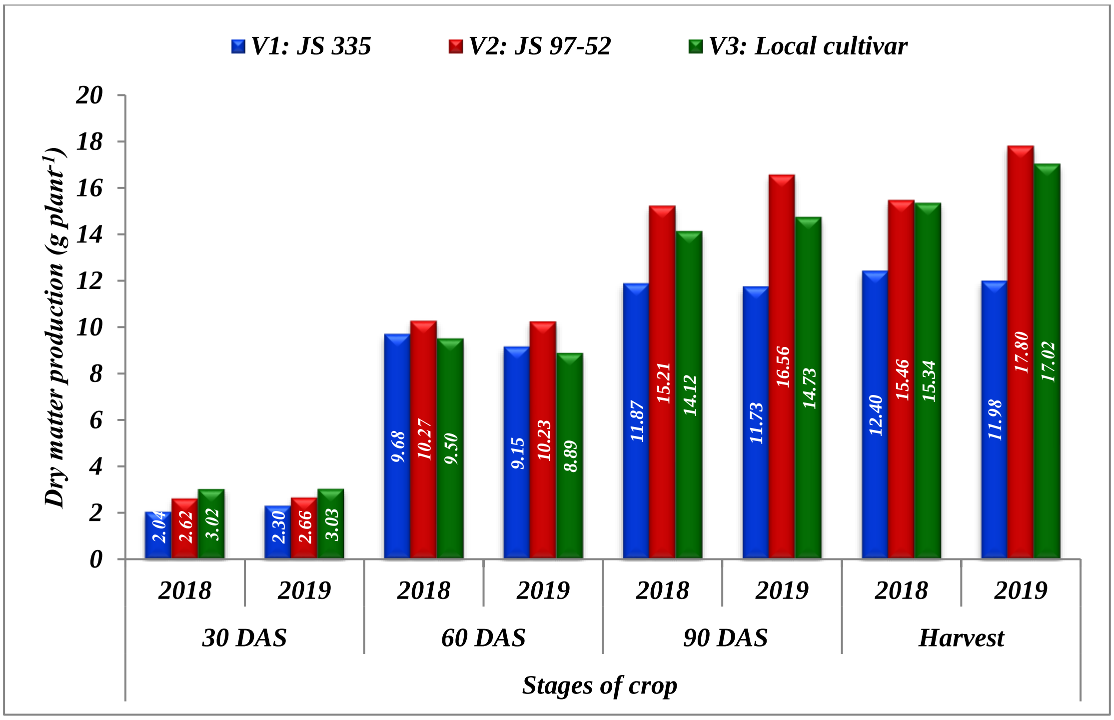


Fig 4.2.3 Effect of varieties on number of leaves of soybean at different stages of crop during 2018 and 2019

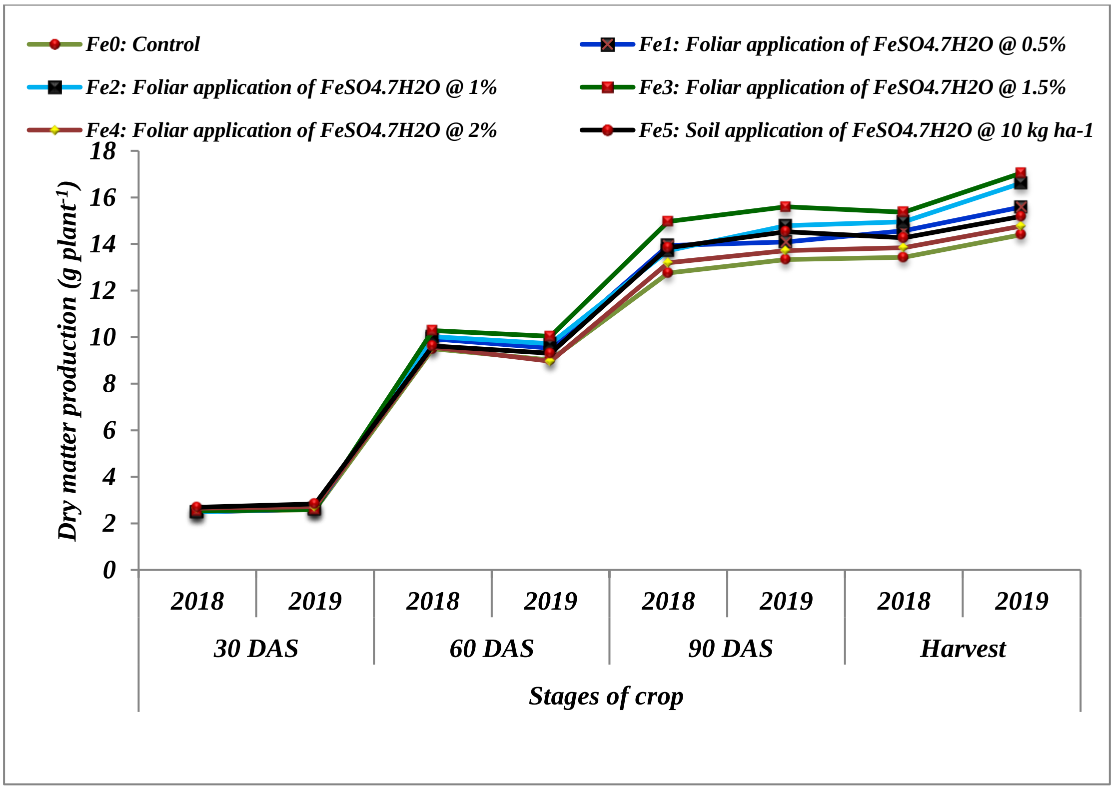


Fig 4.2.4 Effect of iron application on number of leaves of soybean at different stages of crop during 2018 and 2019

21.06) in both the years. At 90 DAS, varieties differed significantly in this parameter as heavy leaf senescence initiated at the stage earlier to this as indicated by the data in Table 4.2.2. The cultivar JS-335 (16.61, 9.02) has the least leaves intact to the plant followed by JS 97-52 (19.19, 15.50) as both were about to attain physiological maturity.

Fe nutrition has non significant effect on number of leaves but slightly higher number was observed in Fe treated plants. The reason for this may be due to better uptake and translocation of plant nutrients to growing plants and more photosynthesis which in turn promoted a higher number of leaves. Similar findings were also reported by Trivedi *et al*. (2011) and Kamble*et al*. (2021) in soybean and Farhan and Al-Dulaemi (2011) on wheat. There were no significant differences in the number of leaves plant^{-1} under the influence of Fe fertilization except in the second-year study at 60 DAS.

Interaction effect of varieties and Fe fertilization factors remained non-significant in both the years however it was significant in the pooled data.

4.2.1.3 Number of branches

The data pertaining to number of branches at different stages of crop is presented in Table 4.2.3. There was no significant difference on the number of branches at 30 DAS among varieties. However, at 60 DAS, that the number of branches apparently start to vary significantly where higher value was recorded in JS-97-52 (3.67, 3.74) which was at par with JS-335 (3.54, 3.42) and least in local cultivar (3.22, 3.15) in both the years. At 90 DAS stage, the number of branches was highest in JS 97-52 (4.22, 4.18) which was significantly higher than the rest in the first year only. However, the second-year data showed no significant variations among varieties.

In the first year of the experiment, it was observed that Fe applications resulted in significant variations in number of branches. The number of branches significantly increased with increasing dose of ferrous sulphate. Fe

Table 4.2.3 Effect of varieties and iron fertilization on number of branches in soybean

Treatments	**30 DAS**			**60 DAS**			**90 DAS**			**at harvest**		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
Varieties												
V_1	0.13	0.11	0.12	3.54	3.42	3.48	3.94	3.98	3.96	4.14	4.08	4.11
V_2	0.13	0.13	0.13	3.67	3.74	3.70	4.22	4.18	4.20	4.11	4.17	4.14
V_3	0.20	0.19	0.19	3.22	3.15	3.19	3.89	3.85	3.87	3.92	4.03	3.97
SEm±	***0.06***	***0.05***	***0.04***	***0.12***	***0.11***	***0.08***	***0.10***	***0.11***	***0.07***	***0.14***	***0.13***	***0.09***
CD at 5%	***NS***	***NS***	***NS***	***0.33***	***0.31***	***0.22***	***0.28***	***NS***	***0.21***	***NS***	***NS***	***NS***
Fe fertilization												
Fe_0	0.11	0.11	0.11	3.33	3.26	3.30	3.70	3.74	3.72	3.72	4.11	3.92
Fe_1	0.15	0.26	0.20	3.48	3.29	3.39	4.00	3.89	3.94	3.94	3.94	3.94
Fe_2	0.26	0.22	0.24	3.52	3.52	3.52	4.26	4.07	4.17	4.28	4.11	4.19
Fe_3	0.15	0.11	0.13	3.63	3.59	3.61	4.30	4.37	4.33	4.17	4.33	4.25
Fe_4	0.11	0.04	0.07	3.44	3.44	3.44	3.85	3.93	3.89	4.17	3.94	4.06
Fe_5	0.15	0.11	0.13	3.44	3.52	3.48	4.00	4.04	4.02	4.06	4.11	4.08
SEm±	***0.09***	***0.07***	***0.06***	***0.16***	***0.15***	***0.11***	***0.14***	***0.16***	***0.11***	***0.20***	***0.18***	***0.13***
CD at 5%	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***0.40***	***NS***	***0.30***	***NS***	***NS***	***NS***

fertilization did not significantly influence on the number of branches in both the years. Numerically we could observe an increasing trend with increasing dose of ferrous sulphate but limited up to 1.5% concentration. The increase in the number of branches and dry matter upon application of ferrous sulphate might be due adequate supply of nutrients at crop critical stages which resulted in better photosynthesis rate, assimilation and translocation of photosynthates from source to sink (Muthal *et al*., 2016). These results were in conformity to the findings reported by Kumar *et al*. (2009), Farhan and Al-Dulaemi (2011), Abdel *et al.* (2014) and Soni and Kushwaha (2020).

4.2.1.4 Dry matter accumulation

The results on the dry matter accumulation (DMA) as influence by varieties and Fe fertilization have presented in Table 4.2.4. There was appreciable increase in the dry weight of plants with the advancement of crop stages. There was significant variation in DMA among varieties at all crop stages and in both the years of study. At 30 DAS the dry matter accumulation was significantly higher in local cultivar (3.04, 3.03 g $plant^{-1}$) followed by JS 97-52 (2.66, 2.69 g $plant^{-1}$) and JS 335 (2.04, 2.30 g $plant^{-1}$). The same trend was observed in pooled data. With the progress of crop stages, DMA at 60 DAS recorded to be significantly higher in JS-97-52 (10.27, 10.23 g $plant^{-1}$) which was followed by JS-335 (9.69, 9.15 g $plant^{-1}$) and local cultivar (9.50, 8.98 g $plant^{-1}$). At 90 DAS the variety JS 97-52 (15.21, 16.56 g $plant^{-1}$) was superior over the local cultivar (14.12, 14.73 g $plant^{-1}$) and JS-335 (11.87, 11.79 g $plant^{-1}$). Varietal difference in dry matter accumulation was sole due to genotypic and morphological difference in the varieties.

Table 4.2.4 indicated that with increasing Fe application doses resulted in increase in DMA although not appreciably significant. At 60 DAS the order followed was $Fe_3 > Fe_2 > Fe_1 > Fe_5 > Fe_4 > Fe_0$ with DMA values (10.28, 10.04 g $plant^{-1}$), (10.02, 9.72 g $plant^{-1}$), (9.92, 9.52 g $plant^{-1}$), (9.62, 9.31 g $plant^{-1}$), (9.57, 8.96 g $plant^{-1}$), (9.50, 9.01 g $plant^{-1}$), respectively for both the years. At

Table 4.2.4 Effect of varieties and iron fertilization on dry matter accumulation (g plant^{-1}) of soybean

Treatments	*30 DAS*			*60 DAS*			*90 DAS*			*harvest*		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
Varieties												
V_1	2.04	2.30	2.17	9.68	9.15	9.42	11.87	11.73	11.80	12.40	11.98	12.19
V_2	2.62	2.66	2.64	10.27	10.23	10.25	15.21	16.56	15.88	15.46	17.80	16.63
V_3	3.02	3.03	3.02	9.50	8.89	9.20	14.12	14.73	14.42	15.34	17.02	16.18
SEm±	***0.08***	***0.08***	***0.06***	***0.21***	***0.17***	***0.13***	***0.24***	***0.28***	***0.18***	***0.42***	***0.47***	***0.32***
CD at 5%	***0.22***	***0.24***	***0.16***	***0.60***	***0.48***	***0.37***	***0.68***	***0.79***	***0.51***	***1.20***	***1.36***	***0.89***
Fe fertilization												
Fe_0	2.50	2.59	2.54	9.50	9.01	9.26	12.75	13.33	13.04	13.42	14.40	13.91
Fe_1	2.49	2.61	2.55	9.92	9.52	9.72	13.93	14.09	14.01	14.57	15.59	15.08
Fe_2	2.49	2.64	2.57	10.02	9.72	9.87	13.72	14.79	14.26	14.95	16.62	15.79
Fe_3	2.53	2.60	2.57	10.28	10.04	10.16	14.96	15.60	15.28	15.36	17.05	16.20
Fe_4	2.65	2.71	2.68	9.57	8.96	9.26	13.19	13.71	13.45	13.84	14.77	14.30
Fe_5	2.69	2.84	2.76	9.62	9.31	9.46	13.84	14.52	14.18	14.26	15.19	14.72
SEm±	***0.11***	***0.12***	***0.08***	***0.29***	***0.23***	***0.19***	***0.33***	***0.39***	***0.26***	***0.59***	***0.67***	***0.45***
CD at 5%	***NS***	***NS***	***NS***	***NS***	***0.67***	***NS***	***0.96***	***1.12***	***0.72***	***NS***	***NS***	***1.26***

90 DAS, the DMA was significantly affected by the Fe fertilization. Application of ferrous sulphate, Fe_3 resulted in maximum value (14.96, 15.60 g $plant^{-1}$) followed by Fe_2 (13.72, 14.79 g $plant^{-1}$) and the least was in control (12.75, 13.33 g $plant^{-1}$). The same trend was also observed in dry matter accumulation at harvest as seen in the previous stage of the crop. Fe application did cause significant differences at some stages of the crop and numerically higher over control at some stages. The positive effect of Fe nutrition in enhancing DMA might be due to the balanced application of plant nutrients has enhanced the growth and development of the crop. Also, ferrous sulphate tends to increase the synthesis of enzymes like IAA production and protein synthesis, which helps promote vegetative growth. The results of this investigation are in accordance with the findings of Meena *et al*. (2006), Bellaki *et al*. (2013) and Kamble *et al*. (2021).

The interaction of varieties and Fe fertilization remained non-significant at all crop stages.

4.2.1.5 Leaf area

Leaf area or LAI is an important indicator of crop growth. Higher the LAI, higher will be PAR interception which is the source of energy for the process of photosynthesis and consequently leading to higher biomass accumulation by crop. The data pertaining to leaf area $plant^{-1}$ as influenced by varieties and iron fertilization are presented in Table 4.2.5 and Fig 4.2.5 and Fig 4.2.6. Leaf area differed significantly among varieties at all stages of crop growth. At 30 DAS, JS-97-52(478.54, 480.44 cm^2 $plant^{-1}$) and local cultivar (472.59, 470.69 cm^2 $plant^{-1}$) recorded higher leaf area as compared to JS-335 (332.32, 354.88 cm^2 $plant^{-1}$. At 60 DAS local cultivar recorded the highest leaf area (1692.06, 1566.36 cm^2 $plant^{-1}$) which was significantly superior over JS 97-52 (1104.00, 1115.18 cm^2 $plant^{-1}$) and JS-335 (1098.71, 1080.67 cm^2 $plant^{-1}$).

There was significant difference of Fe fertilization on leaf area at 60 DAS only whereas at 30 DAS and 90 DAS was observed to be non-significant.

Table 4.2.5 Effect of varieties and iron fertilization on leaf area (cm^2 $plant^{-1}$) in soybean

Treatments	30 DAS			60 DAS			90 DAS		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
Varieties									
V_1	332.32	354.88	343.60	1098.71	1080.67	1089.69	689.76	687.81	688.78
V_2	478.54	484.25	481.39	1104.27	1115.18	1109.73	604.98	630.17	617.57
V_3	472.59	470.69	471.64	1692.06	1566.36	1629.21	2063.34	2073.54	2068.44
SEm±	***12.71***	***11.49***	***8.57***	***22.98***	***21.45***	***15.72***	***26.85***	***36.25***	***22.55***
CD at 5%	***36.46***	***32.95***	***24.15***	***65.90***	***61.53***	***44.31***	***77.01***	***103.96***	***63.58***
Zinc fertilization									
Fe_0	427.53	432.77	430.15	1124.19	1109.79	1116.99	1053.92	1063.72	1058.82
Fe_1	435.60	433.41	434.51	1285.52	1248.76	1267.14	1109.14	1267.92	1188.53
Fe_2	419.79	276.44	348.11	1389.81	1312.73	1351.27	1140.42	1063.93	1102.18
Fe_3	414.66	434.83	424.74	1409.53	1392.51	1401.02	1164.60	1155.01	1159.81
Fe_4	420.69	428.14	424.41	1276.12	1205.34	1240.73	1130.77	1103.81	1117.29
Fe_5	448.63	452.63	450.63	1304.91	1255.30	1280.10	1117.32	1128.64	1122.98
SEm±	***17.98***	***16.25***	***12.12***	***32.49***	***30.34***	***22.23***	***37.97***	***51.26***	***31.90***
CD at 5%	***NS***	***NS***	***NS***	***93.19***	***87.02***	***62.66***	***NS***	***NS***	***NS***

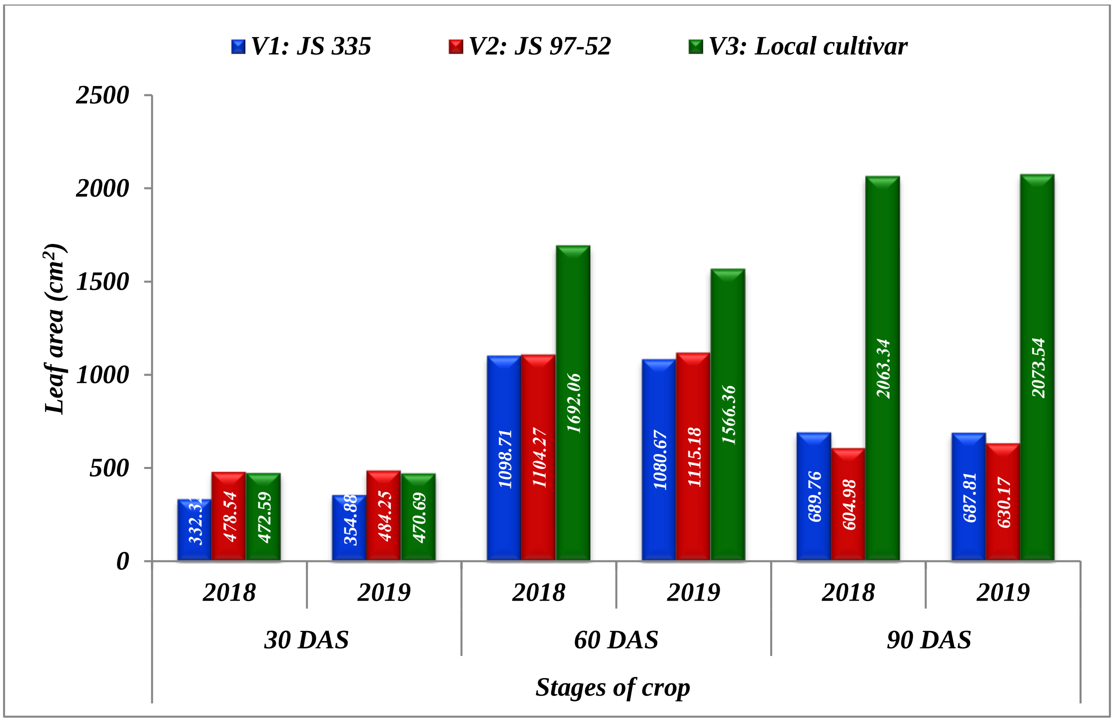


Fig 4.2.5 Effect of varieties on leaf area of soybean at different stages of crop during 2018 and 2019

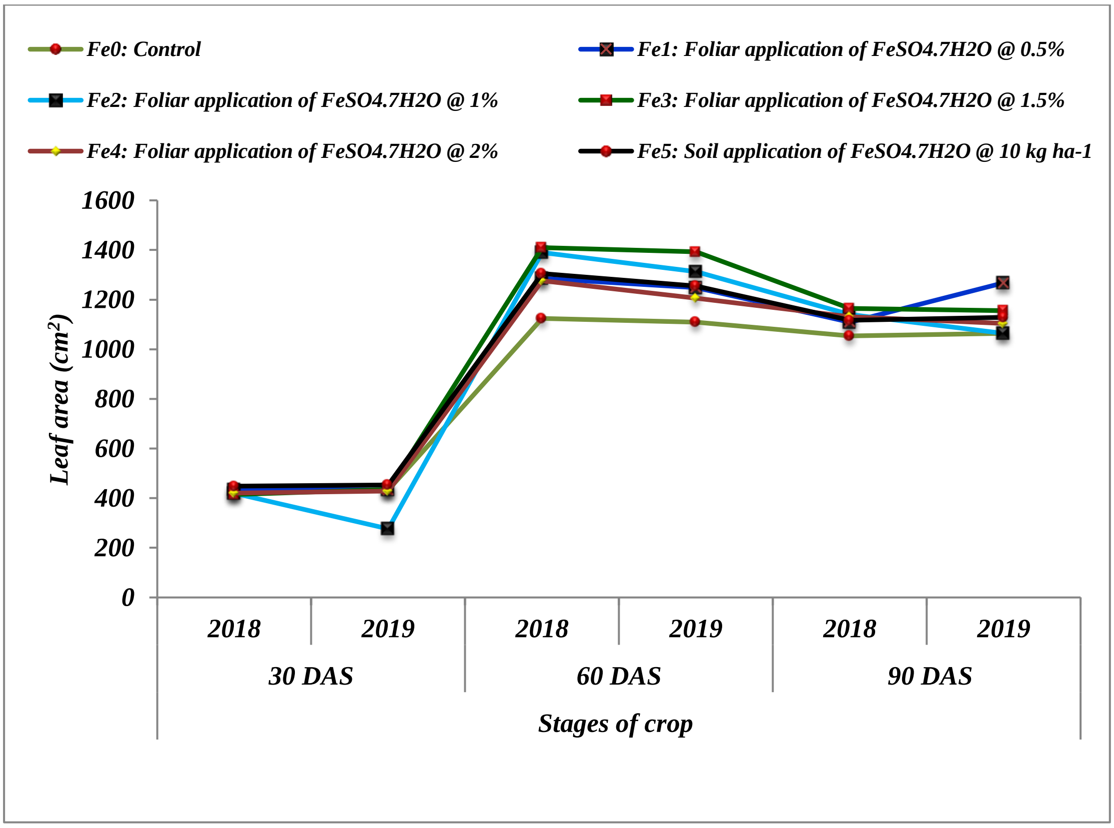


Fig 4.2.6 Effect of iron application on leaf area of soybean at different stages of crop during 2018 and 2019

At 30 DAS as Fe treatment imposition has not been carried out except Fe_5 so practically no significant results observed. At 60 DAS, it was observed that foliar spray application of ferrous sulphate @ 1.5% (Fe_3) recorded the highest leaf area (1409.53, 1392.51 cm^2 $plant^{-1}$) which was followed by Fe_2 (1389.81, 1312.73 cm^2 $plant^{-1}$) and soil application of $FeSO_4.7H_2O$ @ 10 kg ha^{-1}(1304.91, 1255.30 cm^2 $plant^{-1}$). The least leaf area was recorded in control (1124.19, 1109.79 cm^2 $plant^{-1}$). At 90 DAS leaf area remained non-significant among Fe treatments as the two varieties achieved senescence stage and started leaf littering which resulted in drastic decline in leaf area except for local cultivar which leaf area was progressing (2063.34, 2073.54 cm^2 $plant^{-1}$). The observed improvement in crop growth like leaf area on Fe fertilization could be explained by the fact that iron is the component of the photosynthetic apparatus as well as its rate and formation of pigment chlorophyll. Iron applied acts as an important catalyst in the enzymatic reaction of metabolism. This ultimately would have helped in larger biosynthesis of photoassymilates, thereby enhanced vegetative growth of plant. It was also reported that enhanced photosynthesis and respiration rates, more crop growth, and improved physiological and biochemical processes were observed by the application of Fe (Zeidan *et al.*, 2010) which could ultimately increase the leaf area of crop. These results are in accordance with earlier results that reported by Farhan and Al-Dulaemi (2011), Kamble *et al*. (2021) and Trivedi *et al*. (2011).

The interaction effect between varieties and iron applications was non-significant at all crop stages.

4.2.1.6 Chlorophyll content

The data pertaining to chlorophyll content at different stages of soybean as influenced by varieties and Fe fertilization are presented in Table 4.2.6a and illustrated in Fig 4.2.7 &Fig 4.2.8. Chlorophyll content varied significantly among varieties at all crop stages. Chlorophyll "a", "b” and total chlorophyll content at 30 DAS was significantly higher in JS-335 and was at par with JS-97-

Table 4.2.6 Effect of varieties and ironfertilization on chlorophyll "a", "b" and total chlorophyll at 30 and 60 DAS in soybean

Treatments	Chlorophyll a at 30 DAS (mgg^{-1})			Chlorophyll b at 30 DAS ($mg\ g^{-1}$)			Total chlorophyll b at 30 DAS (mgg^{-1})			Chlorophyll 'a' at 60 DAS (mgg^{-1})			Chlorophyll 'b' at 60 DAS (mgg^{-1})			Total chlorophyll at 60 DAS (mgg^{-1})		
	2018	*2019*	*Pooled*	*2018*	*2019*	*Pooled*	*2018*	*2019*	*Pooled*	*2018*	*2019*	*Pooled*	*2018*	*2019*	*Pooled*	*2018*	*2019*	*Pooled*
Varieties																		
V_1	0.843	0.861	0.852	0.52	0.53	0.52	1.36	1.39	1.37	0.92	0.91	0.92	0.56	0.56	0.56	1.48	1.47	1.47
V_2	0.811	0.833	0.822	0.50	0.50	0.50	1.31	1.33	1.32	0.91	0.88	0.90	0.56	0.55	0.55	1.47	1.43	1.45
V_3	0.782	0.775	0.779	0.48	0.47	0.48	1.26	1.25	1.26	0.82	0.77	0.80	0.50	0.48	0.49	1.32	1.25	1.28
SEm±	*0.013*	*0.011*	*0.009*	*0.01*	*0.01*	*0.01*	*0.02*	*0.02*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.00*	*0.02*	*0.01*	*0.01*
CD at 5%	*0.038*	*0.032*	*0.024*	*0.02*	*0.02*	*0.02*	*0.06*	*0.05*	*0.04*	*0.03*	*0.02*	*0.02*	*0.02*	*0.02*	*0.01*	*0.05*	*0.04*	*0.03*
Zinc fertilization																		
Fe_0	0.812	0.811	0.812	0.50	0.48	0.49	1.31	1.29	1.30	0.84	0.81	0.83	0.51	0.51	0.51	1.35	1.32	1.33
Fe_1	0.814	0.818	0.816	0.50	0.50	0.50	1.31	1.32	1.32	0.91	0.85	0.88	0.54	0.52	0.53	1.44	1.37	1.41
Fe_2	0.809	0.824	0.817	0.50	0.50	0.50	1.31	1.33	1.32	0.90	0.86	0.88	0.55	0.53	0.54	1.44	1.38	1.41
Fe_3	0.830	0.824	0.827	0.50	0.51	0.51	1.33	1.34	1.33	0.93	0.91	0.92	0.57	0.56	0.56	1.49	1.47	1.48
Fe_4	0.808	0.833	0.820	0.50	0.52	0.51	1.31	1.35	1.33	0.86	0.85	0.86	0.53	0.53	0.53	1.39	1.37	1.38
Fe_5	0.799	0.827	0.813	0.49	0.50	0.50	1.29	1.33	1.31	0.87	0.86	0.86	0.53	0.54	0.53	1.40	1.40	1.40
SEm±	*0.019*	*0.016*	*0.012*	*0.01*	*0.01*	*0.01*	*0.03*	*0.03*	*0.02*	*0.02*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.03*	*0.02*	*0.02*
CD at 5%	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*0.05*	*0.03*	*0.03*	*0.03*	*0.02*	*0.02*	*0.08*	*0.06*	*0.05*

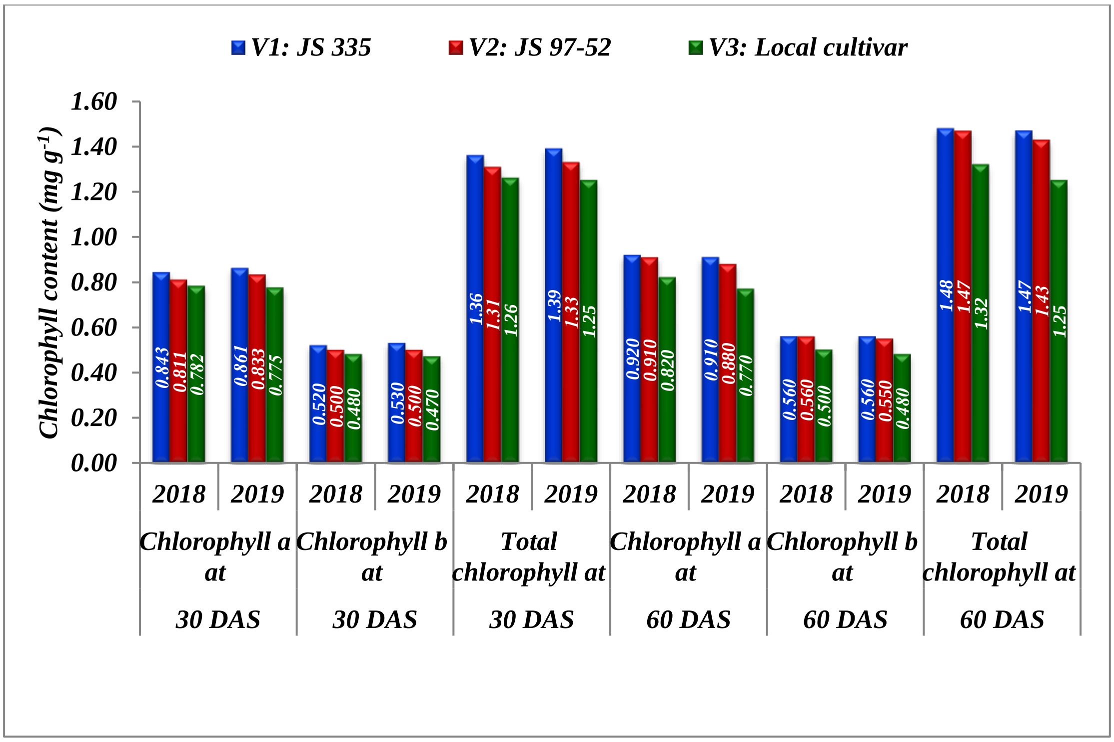


Fig 4.2.7 Effect of varieties on chlorophyll content of soybean at different stages of crop during 2018 and 2019

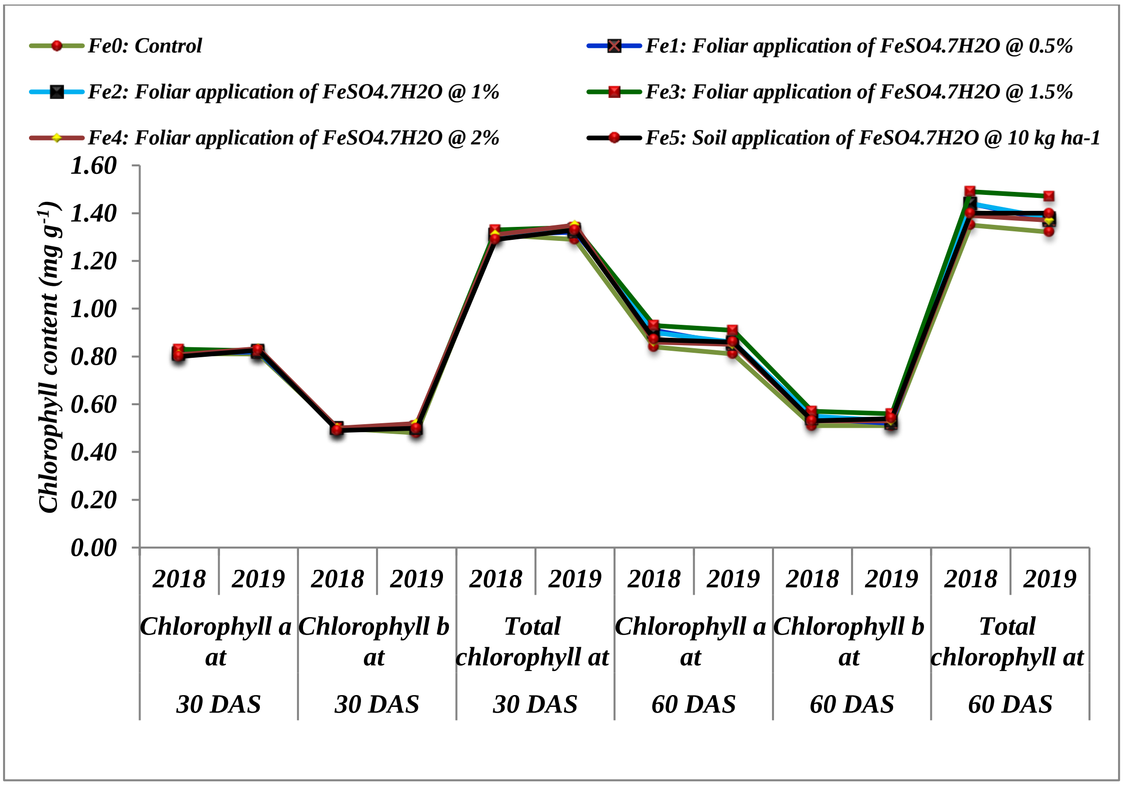


Fig 4.2.8 Effect of iron application on chlorophyll content of soybean at different stages of crop during 2018 and 2019

52 and least in local cultivar in both the years. The total chlorophyll content was significantly higher in JS-335 (1.36, 1.39 mg g^{-1}), followed JS 97-52(1.31, 1.33 mg g^{-1}) and local cultivar (1.26, 1.25 mg g^{-1}). At 60 DAS, the same trend was observed with respect to varietal difference towards chlorophyll content. The chlorophyll "a", "b" and total chlorophyll content was significantly higher in JS-335 which was at par with JS 97-52 and least in local cultivar. The difference among the varieties on the chlorophyll content was mainly due to genotypic difference which is supported by another study given by Mahmoudi *et al.* (2007) who elaborated that chickpea treated with different Fe treatments (0 ppm and 20 ppm) had significant variation of chlorophyll symptoms between genotypes.

Fe fertilization significantly has influenced the chlorophyll content of soybean at all crop stages. At 60 DAS with increasing spray concentration of $FeSO_4.7H_2O$ there was incremental improvement in chlorophyll content up to 1.5% $FeSO_4.7H_2O$. Foliar spray application of 1.5% $FeSO_4.7H_2O$ resulted in significantly higher chlorophyll "a" content (0.92, 0.91 mg g^{-1}) than the other treatments and was at par with Fe_2 foliar spray application of $FeSO_4.7H_2O$ @ 1% (0.91, 0.88 mg g^{-1}). Percentage increase upon foliar spray of $FeSO_4.7H_2O$ @ 1.5%, 1.0%, 0.5% over control was (10.72, 11.01%), (6.84, 4.73%) and (6.86, 3.87%) respectively. Iron is known as the main factor for chlorophyll formation and photosynthesis and its vital role plant enzyme systems and respiration (Halvin *et al.*, 1999). The increase value of chlorophyll content under Fe treatments was likely because of its role or involvement in the biosynthesis pathway of chlorophyll and haeme (Baele, 1999). According to the study of Chereskin and Castelfrance (1982), iron is the metabolic constituent of caproporphyrinogen oxidase which is part of the biosynthesis of δ-aminolevulinic acid (ALA). From these facts, it is well concluded that Fe involves in chlorophyll synthesis indirectly by affecting its precursor ALA. With deficiency of iron, chloroplast functioning and structure will be affected which results in reduction in leaf Fe concentration and ultimately leads to reduction in levels of chlorophyll content (Gogorcena *et al*., 2005), decrease in the chlorophyll fluorescence and photosynthesis. Iron also plays a major role in the structure porphyrin of chlorophyll as well as a component of chloroplasts (Rout and Sahoo, 2015). Iron sulphate application plays an important role in synthesis of chlorophyll and plant growth regulator (Jin *et al*., 2008). Adams *et al*. (2000) reported that in soil with iron deficiency conditions, leaf chlorophyll concentration also found to be reduced. With application of $FeSO_4.7H_2O$ either to soil or foliar there is possible increment in the level of ferrous ion (Fe^{2+}) uptake by the plant leaves which resulted in better absorption and translocation of iron. This might help the cellular activity and directly or indirectly take part in the formation of chlorophyll. Similar results were also reported by Kandoliya *et al*. (2018). As per our observation in the correlation matrix study (Table 4.2.18), we found that iron content and total chlorophyll content at 60 DAS was highly positive correlated (0.932 at 1% significance) and same against Fe uptake (0.984 at 1% significance). This finding was also in agreement with the previous research reported by Shukla and Shukla (1999), Brand *et al*. (2000) and Kumawat *et al*. (2006).

Interaction effect of the varieties and Fe application on chlorophyll content remained non-significant in both the years of study.

4.2.1.7 Days to 50% flowering

The perusal of data of days to 50% flowering is presented in Table 4.2.7 and illustrated in Fig 4.2.9. It indicated that there was significant difference among varieties on days to 50% flowering in both the years of experiment. It is observed that JS-335 recorded the shortest time to achieve 50% flowering (39.28, 38.44 days) which is followed by JS 97-52 (42.61, 41.39 days). Local cultivar took the longest time to achieve 50% flowering (72.00, 71.39 days).

Treatment imposition of $FeSO_4.7H_2O$ resulted to non-significant effect on this parameter in both the years.

4.2.1.8 Days to maturity

Similar trend was also observed in days to maturity as in recorded in days to 50% flowering. Among the varieties, local cultivar took the longest period to reach maturity stage (137.89, 137.94 days) whereas JS-335 (110.94, 109.33 days) was statistically at par with JS-97-52 (112.06, 109.89 days). The iron application has no significant effect on maturity of the crop in both the years (Table 4.2.7).

4.2.3 Nodulation

4.2.3.1a Number of nodules and nodule dry weight at 45 DAS

The results on the number of nodules in different treatments have been presented in Table 4.2.8 and Fig 4.2.10 and Fig 4.2.11. There was an appreciable increase in the number of nodules with the advancement of days which was significantly different among different treatments. Number of nodules plant^{-1} and nodule dry weight at 45 DAS was recorded and there were significant variations among varieties. The local cultivar (25.28, 24.83) recorded the highest numbers per plant at 45 DAS which was followed by JS-97-52 (22.83, 23.67) and least was recorded in JS-335 (20.44, 20.73) in both the years of the experimentation. As apparent from the data the nodule dry weight plant^{-1} was recorded to be higher in local cultivar (0.298, 0.305 g plant^{-1}) which was significantly higher than JS-97-52 (0.258, 0.266 g plant^{-1}) and JS-335 (0.249, 0.252 g plant^{-1}).

Although the Fe application did not have any significant effect on the nodule dry weight per plant at this stage, however, there was a slight improvement in nodulation with increasing level of Fe fertilization. This result was in line with the one reported by Soni and Kushwaha (2020).

The interaction effect between varieties and Fe fertilization on number of nodule and dry weight was non-significant in both the years of study.

Table 4.2.7 Effect of cultivar and iron application on days to 50% flowering and maturity

Treatments	Days to 50% flowering			Days to maturity		
	2018	*2019*	*Pooled*	*2018*	*2019*	*Pooled*
Varieties						
V_1	39.28	38.44	38.86	110.94	109.33	110.14
V_2	42.61	41.39	42.00	112.06	109.89	110.97
V_3	72.00	71.39	71.69	137.89	137.94	137.92
SEm±	***0.66***	***0.60***	***0.45***	***1.36***	***0.74***	***0.78***
CD at 5%	***1.89***	***1.73***	***1.26***	***3.91***	***2.14***	***2.19***
Fe fertilization						
Fe_0	52.11	52.00	52.06	121.22	119.67	120.44
Fe_1	51.00	50.78	50.89	120.89	119.78	120.33
Fe_2	51.33	49.67	50.50	121.11	119.33	120.22
Fe_3	50.78	49.44	50.11	119.56	118.00	118.78
Fe_4	50.89	50.22	50.56	119.78	119.33	119.56
Fe_5	51.67	50.33	51.00	119.22	118.22	118.72
SEm±	***0.93***	***0.85***	***0.63***	***1.93***	***1.05***	***1.10***
CD at 5%	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***

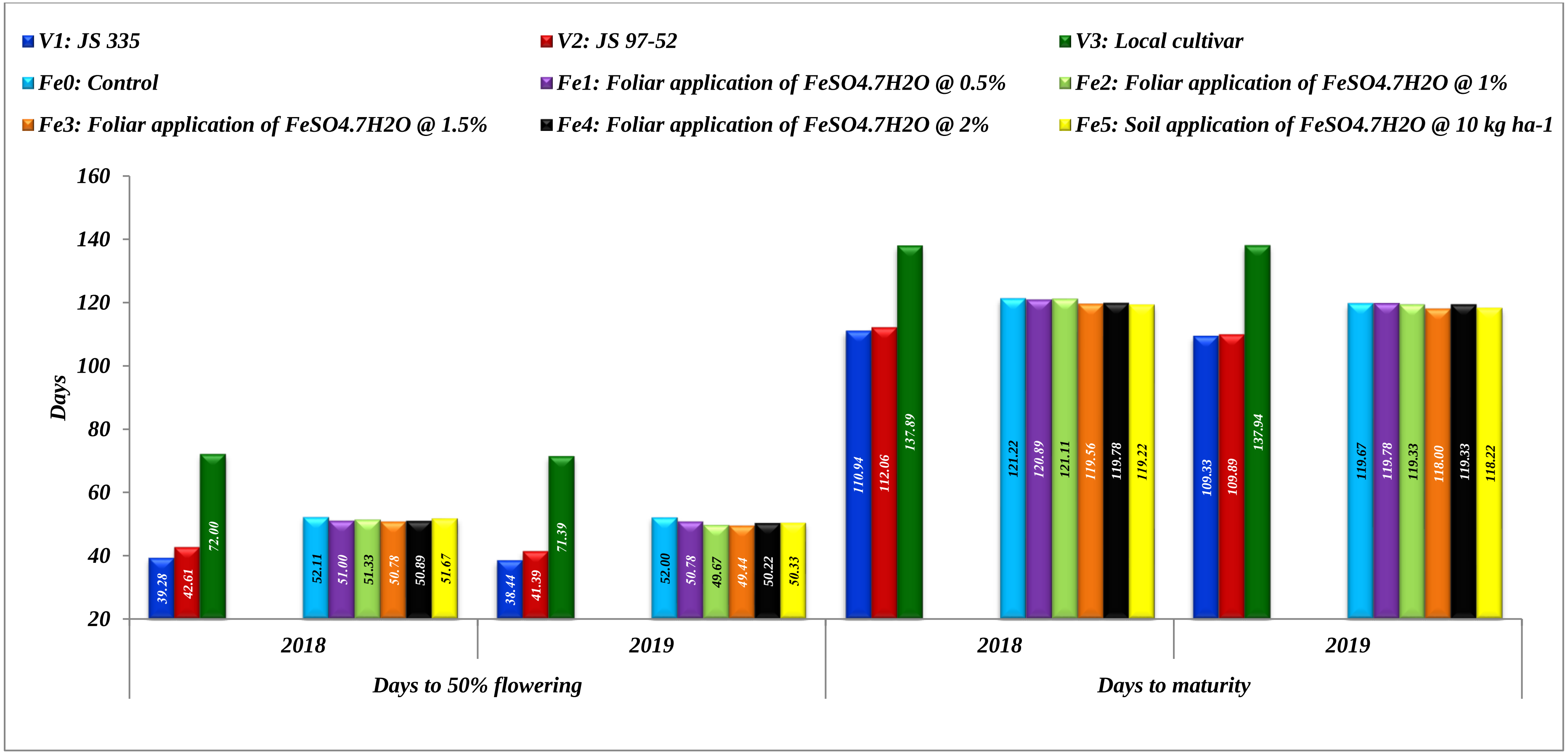


Fig 4.2.9 Effect of varieties on 50% flowering and maturity of soybean at different stages of crop during 2018 and 2019

Table 4.2.8 Effect of cultivar and iron application on number of nodules plant^{-1}and nodules dry weight (g plant^{-1}) in soybean

Treatments	**Number of nodules plant^{-1} at 45 DAS**			**Nodules dry weight at 45 DAS (g plant^{-1})**			**Number of nodules plant^{1} at 60 DAS**			**Nodules dry weight at 60 DAS (g plant^{-1})**		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
Varieties												
V_1	20.56	20.72	20.64	0.249	0.252	0.251	30.00	32.83	31.42	0.358	0.365	0.362
V_2	22.61	23.67	23.14	0.258	0.266	0.262	32.46	34.06	33.26	0.359	0.369	0.364
V_3	24.78	24.83	24.81	0.298	0.305	0.301	37.67	36.61	37.14	0.410	0.425	0.418
SEm±	***0.72***	***0.69***	***0.50***	***0.007***	***0.009***	***0.006***	***1.12***	***1.05***	***0.76***	***0.013***	***0.012***	***0.009***
CD at 5%	***2.07***	***1.97***	***1.40***	***0.021***	***0.025***	***0.016***	***3.20***	***3.00***	***2.16***	***0.037***	***0.035***	***0.025***
Fe fertilization												
Fe_0	21.78	21.11	21.44	0.256	0.267	0.262	31.56	32.00	31.78	0.339	0.373	0.356
Fe_1	22.44	22.56	22.50	0.261	0.274	0.267	32.89	33.11	33.00	0.367	0.385	0.376
Fe_2	22.56	23.44	23.00	0.261	0.274	0.267	34.11	32.89	33.50	0.378	0.401	0.389
Fe_3	22.33	23.00	22.67	0.277	0.275	0.276	34.89	36.67	35.78	0.398	0.402	0.400
Fe_4	22.44	23.56	23.00	0.266	0.269	0.267	32.24	36.89	34.57	0.371	0.382	0.377
Fe_5	24.33	24.78	24.56	0.291	0.285	0.288	34.56	35.44	35.00	0.402	0.374	0.388
SEm±	***1.02***	***0.97***	***0.70***	***0.010***	***0.012***	***0.008***	***1.58***	***1.48***	***1.08***	***0.018***	***0.017***	***0.013***
CD at 5%	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***

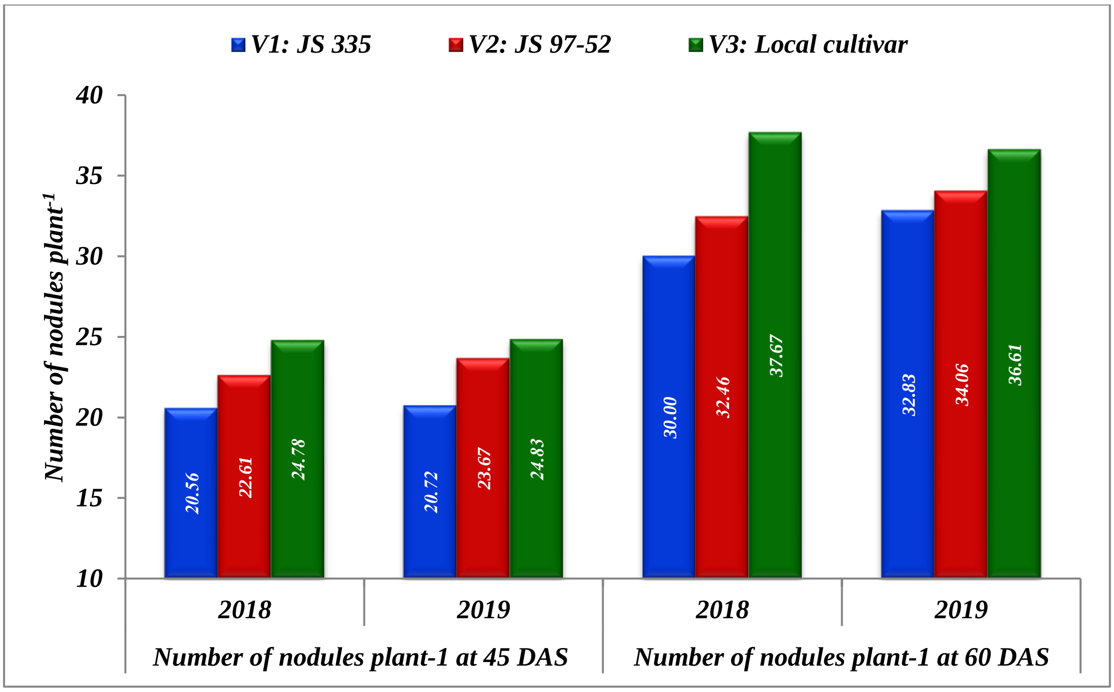


Fig 4.2.10 Effect of varieties on number of nodules per plant of soybean at different stages of crop during 2018 and 2019

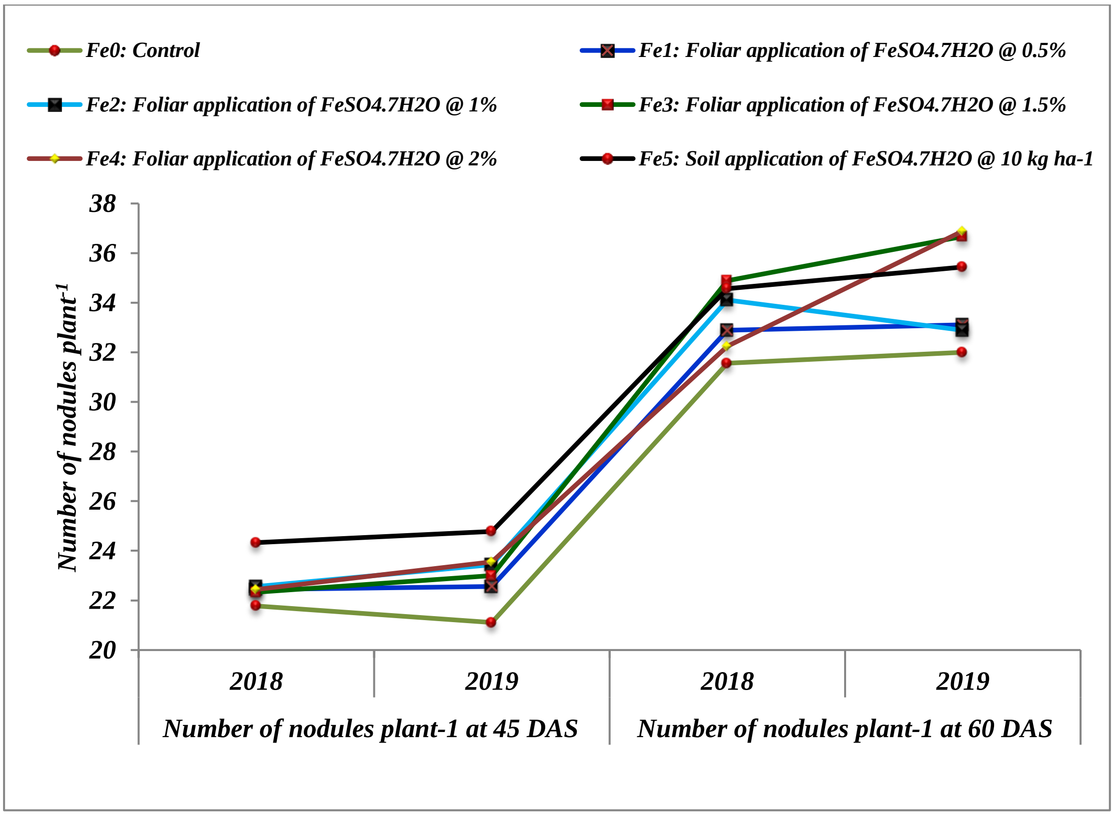


Fig 4.2.11 Effect of iron application on number of nodules per plant of soybean at different stages of crop during 2018 and 2019

The data pertaining to the number of nodules and nodules dry weight at 60 DAS are presented in Fig 4.2.12 and Fig 4.2.13. Varieties found to vary significantly in the number of nodules and nodule dry weight per plant at 60 DAS in both the years. The same trend as observed at 45 DAS was also observed at this stage. More number of nodules per plant was recorded in local cultivar (38.39, 36.61) which was significantly higher than in JS-335 (30.50, 32.61). At 60 DAS nodules dry weight was observed to be more in local cultivar (0.41, 0.42 g $plant^{-1}$) as recorded at 45 DAS which was significantly higher than the other varieties. The difference among the varieties can be explained by the genotypic difference which some are having different capacity to produce effective nodules.

Application of $FeSO_4.7H_2O$ did not significantly vary the number of nodules as well as its dry weight at 60 DAS. Eventhough, no significant difference with Fe application in nodulation but numerically the treated plant has higher value of nodules number and dry weight in both the years of experiment when compared to control (Table 4.2.8). Iron fertilization did not significantly enhance the nodule number and weight in both the years. However, there were slight numerically higher values in nodulation in Fe treated plants over the control plants. Similar results have been reported by many workers in the past (Bhanavase *et al*., 1994; Janakiraman *et al.* 2005; Kamble *et al*., 2021).

The interaction effect between varieties and Fe fertilization was not significant in both numbers of nodules as well its dry weight.

4.2.4 Yield attributes

The data pertaining to yield attributes as affected by different varieties and iron fertilization is presented in Table 4.2.9.

4.2.4.1 Number of pods $plant^{-1}$

The data pertaining to the number of pods $plant^{-1}$ is presented in Table 4.2.9. The data showed that varieties varied significantly with respect to the number of pods $plant^{-1}$. During both the years, the cultivar JS 97-52 produced the

Table 4.2.9 Effect of cultivar and iron application on yield attributes of soybean

Treatments	**No. of pods plant^{-1}**			**pod length (cm)**			**No. of seeds pod^{-1}**			**100-seed weight (g)**		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
Varieties												
V_1	35.97	35.81	35.89	3.79	3.78	3.79	2.53	2.52	2.53	12.82	12.51	12.67
V_2	64.50	68.14	66.32	3.22	3.18	3.20	2.57	2.56	2.56	11.37	11.16	11.27
V_3	43.36	40.61	41.99	3.49	3.30	3.39	2.47	2.44	2.46	7.19	7.25	7.22
SEm±	***1.53***	***1.69***	***1.14***	***0.05***	***0.06***	***0.04***	***0.04***	***0.04***	***0.03***	***0.29***	***0.25***	***0.19***
CD at 5%	***4.39***	***4.85***	***3.22***	***0.13***	***0.16***	***0.10***	***NS***	***NS***	***NS***	***0.82***	***0.72***	***0.54***
Fe fertilization												
Fe_0	42.56	45.67	44.11	3.48	3.30	3.39	2.42	2.44	2.43	9.90	9.40	9.65
Fe_1	47.61	46.06	46.83	3.49	3.37	3.43	2.53	2.44	2.49	10.49	10.20	10.34
Fe_2	47.33	47.94	47.64	3.50	3.48	3.49	2.58	2.53	2.56	10.21	10.74	10.48
Fe_3	52.72	51.67	52.19	3.58	3.54	3.56	2.53	2.56	2.54	11.09	10.40	10.74
Fe_4	47.61	46.89	47.25	3.51	3.42	3.46	2.51	2.49	2.50	10.39	10.35	10.37
Fe_5	49.83	50.89	50.36	3.45	3.42	3.43	2.56	2.58	2.57	10.68	10.77	10.73
SEm±	***2.17***	***2.39***	***1.61***	***0.07***	***0.08***	***0.05***	***0.06***	***0.05***	***0.04***	***0.40***	***0.35***	***0.27***
CD at 5%	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***

Plate No. 5 Soybean crop under different varieties and iron fertilization

highest number of pods plant^{-1} (64.50, 68.14) which was significantly higher than local cultivar (43.36, 40.61) and JS 335 (35.97, 35.81).

Fe fertilization treatments did not result to any significant effect on the number of pods plant^{-1} although numerically higher value was observed Fe treated plants. The maximum value was recorded in Fe_3 ($FeSO_4.7H_2O$ @ 1.5% at pre-flowering stage) (52.72, 51.67) followed by Fe_5 (49.83, 50.89) and the least value was observed in control (42.56, 45.67). Our results indicated that foliar application of $FeSO_4.7H_2O$ slightly enhanced the number pods plant^{-1} which might been due to iron significant role in the reproductive organs, such as stamens and pollens as reported by Siefi- Nadergholi *et al*. (2011). Our result also supported by the findings of Bohra *et al*. (2006) who revealed that upon Fe fertilization increased the number of podsplant^{-1} in mothbean which might be due improved translocation of photosynthates to the productive sink. Soni and Kushwaha (2020) also reported that with 0.5% $FeSO_4$ spray at flower initiation in mungbean significantly increased the number of pods per plant. Similar results have also been stated by Majumdar *et al*. (2001), Heidarian *et al*. (2011), Kobraee *et al*. (2011a) and Pooladvand *et al.* (2012) in soybean and related crops on the positive effect of Fe on number of pods plant^{-1}.

The interaction effect between varieties and Fe fertilization on number of pods plant^{-1}was found non-significant.

4.2.4.2 Number of seeds pod^{-1}

The data on the number of seeds per pod are presented in Table 4.2.9 which depicted to have no significant effect of varieties as well as Fe fertilization. The number of seeds pod^{-1} was found to be slightly higher in JS-97-52 (2.57, 2.56) over JS-335 (2.53, 2.52) and local cultivar (2.47, 2.44) although all were par with each other. The zinc applications have no significant effect on the number of seeds pod^{-1}. Interaction effect of the two factors remained non-significant in both the years.

No significant difference on the number of seed pod^{-1}observed. The slight improvement in number of seeds pod^{-1} upon Fe fertilization might possibly have been due to role of Fe in enhancing the activity of bio-substances or improving photosynthesis (Quary *et al*., 2006) which was reflected in the yield attributes like the number of seeds pod^{-1}. Other investigations as reported by Kumar *et al*. (2009), Sharma *et al*. (2010), Trivedi *et al*. (2011) and Abdel *et al.* (2014) revealed similar results with respect to the number of seeds per pod.

The interaction effect between varieties and Fe fertilization on Number of seeds pod^{-1}was found non-significant.

4.2.4.3 Pod length

The data on pod length is presented on Table 4.2.9 which shows that there was significant variation among the varieties on pod length of soybean where JS-335 recorded the highest value (3.79, 3.78 cm) followed by local cultivar (3.49, 3.30 cm) and least observed in JS 97-52 (3.22, 3.18 cm).

Application of Fe treatments found to result no significant effect on this yield attribute although slightest higher value (3.58, 3.54 cm) observed in Fe_3 (Foliar spray application of $FeSO_4.7H_2O$ @ 1.5% at pre-flowering stage). Interaction effect of the two factors remained non-significant with respect to this yield attribute in both the years. Similar results have also been reported by Ghasemian *et al*. (2010) and Trivedi *et al*. (2011) in soybean.

4.2.4.3 100- seed weight

As apparent from the Table 4.2.9, the maximum seed index was recorded in JS-335 (12.82, 12.51 g) which was statistically superior over the other varieties. JS 97-52 recorded (11.37, 11.16) with the least value observed in local cultivar (7.19, 7.25).

Fe fertilization did not differ significantly over seed index in both the years of experimentation although higher value was recorded in foliar spray application of $FeSO_4.7H_2O$ @ 1.5% (11.09, 10.40 g) and least in control treatment.

As revealed by the data there was no significant effect of Fe nutrition on yield attributes of soybean in both the years of study. The reason could be due to lesser impact from the applied Fe as the soil in the experimental site was in Fe sufficient range (50-100). However, when compared to the control plants the yield attributes slightly showed higher values which to some extent $FeSO_4$ plays its role in the plant system. The slight improvement in the number of pods plant^{-1}, number of seeds pod^{-1}, 100-seed weight etc. may be attributed to the fact that favourable nutritional environment in rhizosphere and absorption of Fe by foliage led to enhanced photosynthesis and production of assimilates. This further led to more translocation of photosynthates in the reproductive structures and thus to the yield attributes. With foliar application of $FeSO_4$ entry and absorption of Fe in the plant system became easier which then might have enhanced availability of iron, increased the chlorophyll content and thus more to the accumulation of carbohydrates. This produces positive effect on flowering and pod development and ultimately on the yield attributes of soybean. Similar findings were also reported by Umamaheswari and Singh (2002), Moosavi and Ronaghi (2011), Trivedi *et al*. (2011) and Sale *et al*. (2017).

The interaction effect of Fe fertilization and varieties was found non-significant in all the yield attributes and in both the years of experimentation.

4.2.5 Yields

4.2.5.1 Seed yield

The data on seed yield is presented in Table 4.2.10 and fig. 4.2.14. Significant variation among varieties on seed yield per pot was observed in both the years of experiment. Significantly higher value was observed in JS-97-52 (29.31, 28.77 g pot^{-1}) which was followed by JS-335 (20.95, 20.56 g pot^{-1}) and the lowest was recorded in local cultivar (17.76, 16.96 g pot^{-1}). Yield difference due to varieties is determined by their genetic make-up and varied yield potential resulted to variation in seed yield among the three varieties. Improved variety like JS 97-52 markedly surpassed over the other two in yield potentials over the two

Table 4.2.10 Effect of cultivar and iron application on grain yield, stover yield, biological yield and harvest index in soybean

Treatments	Seed yield (g pot^{-1})			Stover yield (g pot^{-1})			Biological yield (g pot^{-1})			Harvest Index (%)		
	2018	*2019*	*Pooled*	*2018*	*2019*	*Pooled*	*2018*	*2019*	*Pooled*	*2018*	*2019*	*Pooled*
Varieties												
V_1	20.95	20.56	20.76	21.49	20.28	20.89	42.44	40.84	41.64	49.38	50.45	49.92
V_2	29.31	28.77	29.04	30.56	28.79	29.68	59.87	57.56	58.72	49.04	50.23	49.64
V_3	17.76	16.96	17.36	20.23	19.14	19.69	37.99	36.10	37.05	46.78	47.17	46.97
SEm±	***0.56***	***0.44***	***0.36***	***0.75***	***0.75***	***0.53***	***1.21***	***1.08***	***0.81***	***0.56***	***0.69***	***0.45***
CD at 5%	***1.61***	***1.26***	***1.00***	***2.14***	***2.15***	***1.49***	***3.48***	***3.08***	***2.29***	***1.60***	***1.99***	***1.25***
Fe fertilization												
Fe_0	19.54	19.46	19.50	21.72	19.29	20.51	41.27	38.75	40.01	47.09	49.96	48.52
Fe_1	22.70	22.61	22.66	23.89	21.99	22.94	46.59	44.60	45.60	48.66	50.49	49.58
Fe_2	22.40	21.34	21.87	23.98	23.84	23.91	46.38	45.18	45.78	48.26	47.16	47.71
Fe_3	24.46	25.33	24.89	26.22	26.33	26.28	50.67	51.66	51.17	48.41	49.05	48.73
Fe_4	23.04	21.83	22.44	24.10	22.52	23.31	47.14	44.35	45.74	48.85	49.31	49.08
Fe_5	23.91	22.01	22.96	24.64	22.46	23.55	48.55	44.47	46.51	49.14	49.74	49.44
SEm±	***0.79***	***0.62***	***0.50***	***1.06***	***1.06***	***0.75***	***1.72***	***1.52***	***1.15***	***0.79***	***0.98***	***0.63***
CD at 5%	***2.28***	***1.78***	***1.42***	***NS***	***3.04***	***2.11***	***4.93***	***4.36***	***3.23***	***NS***	***NS***	***NS***

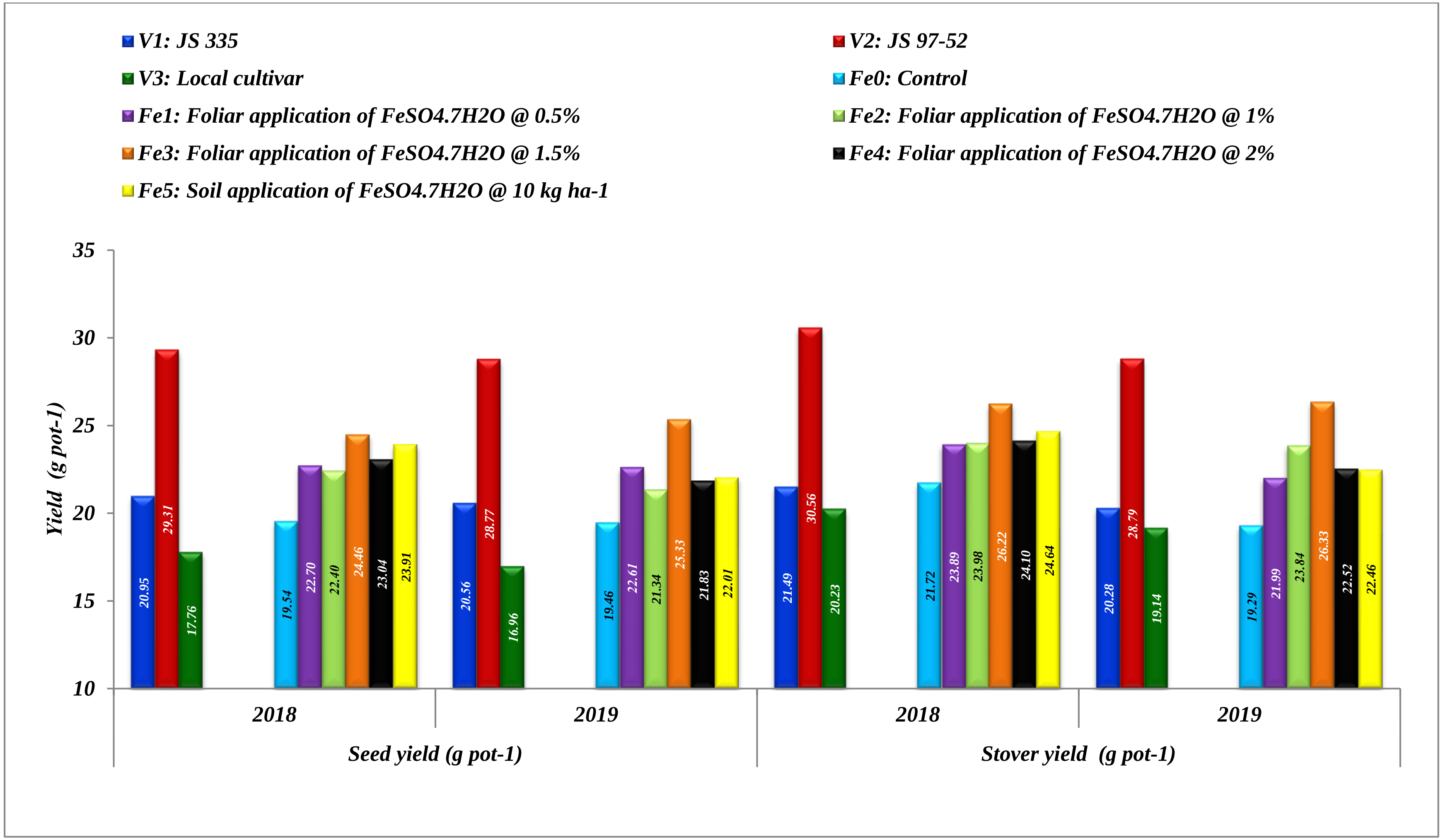


Fig 4.2.12 Effect of varieties and iron application on seed yield and biological yield per pot of soybean during 2018 and 2019

years of experiment irrespective of the treatments imposed mainly is rooted to the effect of Genotype x Environment interaction.

Iron ferti-fortification resulted in significant variations among the treatments. All the Fe treated pots were statistically at par with each other and significantly higher than the controlled plants value (19.54, 19.46 g pot^{-1}). Slightly higher value (24.46, 25.33 g pot^{-1}) of seed yield was observed in foliar spray application of $FeSO_4.7H_2O$ @ 1.5% at pre-flowering stage. The per cent increase in seed yield with two foliar applications of $FeSO_4.7H_2O$ @ 1.5% was to the tune of (25.15, 30.16%) over control followed by Fe_5 (Soil application of 10 kg ha^{-1} $FeSO_4.7H_2O$) (22.37, 13.08%). The increase in yield due to Fe application was attributed to better performance in the growth and yield parameters which could have influenced the physiological processes and photosynthates build up under adequate availability of major and micro nutrients in soil as explained by Tabassum *et al*. (2013). Fe fertilization treatments might have enhanced availability of micro and macro nutrients to the crop. This might have helped in early crop development stage and cell multiplication which eventually led to more absorption of other nutrients thereby improving crop yield upon increased translocation of photosynthates accumulated. Further, the translocation and accumulation of photosynthates in the economic sinks resulted in increased seed, stover and biological yields. As per the results revealed in Table 4.2.10, foliar application of $FeSO_4.7H_2O$ significantly improved crop yield over the control. This has resulted owing to improved Fe absorption through foliage which is then translocated in the plant system and ultimately improved seed and straw yield of soybean. Further, it can also be explained by the fact that Fe is part of ferrodoxin and cytochrome structures which are electron carrier and plays vital role in various metabolic processes *viz*., hormone production, nitrogen fixation, chlorophyll construction, photosynthesis, respiration, DNA synthesis (Vaghar *et al*., 2020). Iron plays an important role in the photosynthesis efficiency and the functioning of the photosynthetic apparatus and upon its deficiency, chlorophyll synthesis and crop growths are affected. Thus, significant increase in the biological yield of soybean might be due to the improved leaf and stem nutrition and intensification of photosynthesis due to foliar application of Fe (Rai *et al.*, 2021). Further, Fe application through different treatments might have increased number of enzymatic activities of Fe-containing enzymes which cumulatively have positive effect on crop yield. The results of the present study were in concordance with the results obtained from Revathy *et al.* (1997), Valenciano *et al*. (2009), Ghasemian *et al*. (2010), Farhan and Al-Dulaemi (2011), Kobraee *et al*. (2011a), Abbas, *et al*. (2012) and Kumar *et al*. (2016). This finding is supported by the result reported by Hemantaranjan and Garg (1988).

The interaction between varieties and Fe fertilization was found non-significant in both the years of study.

4.2.5.2 Stover yield

The data on stover yield of soybean as influenced by cultivar and Fe fertilization are presented in the Table 4.2.10and Fig 4.2.14. Stover yield was significantly affected by cultivar as well as Fe treatments. Among the varieties, JS 97-52 recorded the highest stover yield (30.56, 28.79 g pot^{-1}) which was significantly higher than JS-335 (21.49, 20.28 g pot^{-1}) and local cultivar (20.23, 19.14 g pot^{-1}) although the two were statistically at par to each other.

Iron fertilization effect also found to differ significantly in the second year and on the pooled data. The highest value of stover yield was observed in Fe_3 (26.22, 26.33 g pot^{-1}). The least stover yield was recorded in control (21.72, 19.29 g pot^{-1}). Application of 1.5% $FeSO_4.7H_2O$ foliar spray enhanced the stover yield by (20.71, 36.52%) over the control. Iron known to improves photosynthesis and assimilates transportation to sinks which then finally increases stover yield of crop. It also increases carbohydrate synthesis. Similar effect of foliar spray of iron was observed in cowpea in sandy loam soil of Kerala by Anitha *et al*. (2005). Our results were in conformity to the findings reported by Sahu *et al*. (2008), Yadav *et al*. (2013) in mungbean.

4.2.5.3 Biological yield

The data pertaining to biological yield are presented in Table 4.2.10. The highest biological yield was observed in JS 97-52 (59.87, 57.56 g pot^{-1}) which was significant compared to JS-335 (42.44, 40.84 g pot^{-1}) and least in local cultivar (37.99, 36.10 g pot^{-1}).

Iron sulphate application resulted in significant enhancement in biological yield in both the years. Similar trend was observed where application of 1.5% $FeSO_4.7H_2O$ foliar spray (Fe_3) resulted in significantly high value (50.67, 51.66 g pot^{-1}) followed by soil application of $FeSO_4.7H_2O$ @ 10 kg ha^{-1} (Fe_5) over control and the rest treatments were at par with each other. The percentage increase in biological yield over the control was highest in application of 1.5% $FeSO_4.7H_2O$ foliar spray (Fe_3) (22.78, 33.32%) followed by $FeSO_4.7H_2O$ @ 10 kg ha^{-1} (Fe_5) (17.65, 14.75%). Our findings were in line with the findings reported by Ghasemian *et al*. (2010), Kobraee *et al*. (2011a), Nasri *et al.* (2011) and Rahevar *et al*. (2015).

The interaction effect was found non-significant in both the years of the experiment although the highest value was observed in V_2Fe_3 (68.54, 67.24 g pot^{-1}).

4.2.5.4 Harvest Index

The harvest index was found to be significantly high in JS-335 (49.38, 50.45) and JS 97-52 (49.04, 50.23) compared to local cultivar (46.78, 47.17). Improved varieties (JS-335 and JS 97-52) are normally short stature with lesser biomass production compared to long duration taller local cultivar. The genotypic differences among the varieties, where improved ones were having desirable yield attributes which was the main factor for cumulative effect on overall seed yield of the crop. This possibly resulted to more economic yield over stover yield in JS-335 and JS 97-52 ultimately led to higher harvest index value.

No significant variations on harvest index upon Fe fertilization treatments in both the years. The interaction effect was non-significant in both the years.

4.2.6 Nutrient concentration and uptake

4.2.6.1 Nitrogen concentration in grain

The perusal of data in Table4.2.11a shows that there was significant variation in N content in grain in the three varieties. The highest value N content in grain was recorded in JS-335 (6.06, 6.08%) which was statistically at par with JS 97-52 (6.05, 6.03%). The least value was observed in local cultivar (5.90, 5.85%). N content in grain was found to differ significantly with iron fertilization.

The highest N content in grain in both the years of experiment was observed in the treatment of 1.5% foliar application of $FeSO_4.7H_2O$ (Fe_3) (6.27, 6.19%) which was at par with soil application of $FeSO_4.7H_2O$ @ 10 kg ha^{-1} (6.03, 6.03%) and superior than the rest of Fe application. The lowest value was recorded in control (5.82, 5.67%). It was found that the grain N content increased by (7.79, 9.21%) in Fe_3 over the control for both years of study. The significant effect of Fe application on N content might be due to role of Fe in photosynthetic activity which helps in accumulation of more photosynthates which ultimately on the N content in grain and stover. The result was corroborated by the findings reported by Farhan and Al-Dulaemi (2011), Abbas *et al*. (2012) and Gomaa *et al*. (2015).

4.2.6.2 Nitrogen concentration in stover

From the Table 4.2.11a it was revealed that the N concentration in stover of soybean was significantly higher in JS-335 (2.09, 2.08%) followed by JS 97-52 (1.93, 1.97%) over the local cultivar (1.89, 1.88%). The two varieties, JS 97-52 and local were found to be statistically at par with respect to N content in stover in both the years of study.

With respect to Fe application there was no significant effect on N content in stover observed in both the years of experiment. Although slight superiority

Table 4.2.11 Effect of varieties and iron application on N content in grain and stover and their uptake in soybean

Treatments	N content in grain (%)			N content in stover (%)			N uptake in grain (kg ha^{-1})			N uptake in stover (kg ha^{-1})			Total N uptake (grain + stover) kg ha^{-1}		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
Varieties															
V_1	6.06	6.08	6.07	2.09	2.08	2.09	1.27	1.25	1.26	0.45	0.42	0.44	1.72	1.67	1.70
V_2	6.05	6.03	6.04	1.93	1.97	1.95	1.78	1.74	1.76	0.59	0.57	0.58	2.37	2.31	2.34
V_3	5.90	5.85	5.87	1.89	1.88	1.89	1.05	0.99	1.02	0.38	0.36	0.37	1.43	1.35	1.39
SEm±	***0.05***	***0.06***	***0.04***	***0.05***	***0.05***	***0.03***	***0.04***	***0.02***	***0.02***	***0.02***	***0.02***	***0.01***	***0.05***	***0.04***	***0.03***
CD at 5%	***0.13***	***0.17***	***0.11***	***0.14***	***0.13***	***0.10***	***0.11***	***0.07***	***0.06***	***0.05***	***0.05***	***0.04***	***0.15***	***0.10***	***0.09***
Fe fertilization															
Fe_0	5.82	5.67	5.75	1.89	1.91	1.90	1.13	1.10	1.12	0.41	0.37	0.39	1.54	1.47	1.51
Fe_1	5.92	6.02	5.97	1.91	1.94	1.93	1.35	1.37	1.36	0.45	0.43	0.44	1.80	1.79	1.80
Fe_2	6.02	6.05	6.03	1.97	2.00	1.99	1.35	1.29	1.32	0.47	0.47	0.47	1.82	1.77	1.79
Fe_3	6.27	6.19	6.23	2.15	2.13	2.14	1.53	1.57	1.55	0.56	0.56	0.56	2.10	2.14	2.12
Fe_4	5.96	5.94	5.95	1.98	1.97	1.97	1.38	1.30	1.34	0.48	0.45	0.46	1.86	1.75	1.80
Fe_5	6.03	6.03	6.03	1.93	1.92	1.92	1.45	1.33	1.39	0.47	0.43	0.45	1.93	1.76	1.84
SEm±	***0.07***	***0.08***	***0.05***	***0.07***	***0.07***	***0.05***	***0.06***	***0.03***	***0.03***	***0.03***	***0.03***	***0.02***	***0.07***	***0.05***	***0.04***
CD at 5%	***0.19***	***0.24***	***0.15***	***NS***	***NS***	***NS***	***0.16***	***0.10***	***0.09***	***0.08***	***0.08***	***0.05***	***0.21***	***0.14***	***0.12***

was observed in (Fe_3) foliar spray application of $FeSO_4.7H_2O$ @ 1.5% (2.15, 2.13%) over the control treatment but it remained at par in with the rest of the Fe treatments. The stover N increased by (12.57, 11.99%) of Fe_3 in over the control for both the years of study.

4.2.6.3 Nitrogen uptake in grain

The nitrogen uptake in grain as influenced by varieties and different Fe treatments are presented in Table 4.2.11a. Nitrogen uptake is the product of multiplication between yield (Grain or straw) and nitrogen concentration. The data revealed the grain N uptake differed significantly among varieties for both the years of study. Grain N uptake by the cultivar JS 97-52 (1.78, 1.74 g pot^{-1}) was significantly higher than JS-335 (1.27, 1.25 g pot^{-1}) and local cultivar (1.05, 0.99 g pot^{-1}).

N uptake by grain was significantly superior in all the Fe application treatments than control. The best treatment was Fe_3 (Foliar spray application of $FeSO_4.7H_2O$ @ 1.5% at pre-flowering stage) (1.53, 1.57 g pot^{-1}) followed by Fe_5 (1.45. 1.33 g pot^{-1}) with the least value in control (1.13, 1.10 g pot^{-1}). The rest of the treatments were statistically at par with each other in both the years of experiment. Grain N uptake increased by (35.74, 42.88%) in treatment Fe_3 over control. Iron nutrition in plants helps in number of enzymatic and physiological processes which are directly linked to photosynthetic activities and accumulation of photosynthates in grain. These results in improvement in overall grain yield and thus to the nutrient uptake like nitrogen and other nutrients. The results are corroborated by the findings of Pande *et al*. (1993), Singh *et al*. (2004) and Abbas *et al*. (2012).

4.2.6.4 Nitrogen uptake in stover

The nitrogen uptake in stover as influenced by varieties and different Fe treatments are presented in Table 4.2.11a. The data revealed the stover N uptake differed significantly among varieties for both the years of study. Stover N uptake by the cultivar JS 97-52 (0.59, 0.57 g pot^{-1}) was significantly higher than JS-335

(0.45, 0.42 g pot^{-1}) and local cultivar (0.38, 0.36g pot^{-1}).

With respect to iron biofortification treatments, two foliar spray application of $FeSO_4.7H_2O$ @ 1.5% (Fe_3) was found superior over the other treatments (0.56, 0.56 g pot^{-1}) with the lowest value observed in control (0.41, 0.37 g pot^{-1}).

The interaction effect of varieties and Fe fertilization treatments was non-significant in both the years of experiment.

4.2.6.5 Total N uptake by soybean

The data on total N uptake in crop have been presented in Table 4.2.11a. Total N uptake differed significantly among varieties for both years of study. Total N uptake by the cultivar JS 97-52 (2.37, 2.31 g pot^{-1}) was significantly higher than JS-335 (1.72, 1.67 g pot^{-1}) and local cultivar (1.43, 1.35 g pot^{-1}).

The Fe biofortification treatments found to significantly affect the total N uptake by the crop. As revealed by the data, foliar application of $FeSO_4.7H_2O$ @ 1.5% at pre-flowering stage (Fe_3) registered the highest value (2.10, 2.14 g pot^{-1}). The least total N uptake was observed in control (1.5, 1.47 g pot^{-1}). The increase in total N uptake was (36.15, 45.32%) in Fe_3 and (25.13, 19.52%) in Fe_5 over control treatment.

4.2.6.6 Phosphorus content in grain

The data pertaining to P content in grain is presented in Table 4.2.12 and illustrated in Fig 4.2.15. There was no significant variation among varieties on P content in grain although the local cultivar found to have comparatively higher value (0.386, 0.389%) over JS 97-53 (0.371, 0.373%) and JS-335 (0.358, 0.361%). Fe application treatments did not differ significantly on phosphorus content.

Interestingly with increasing level of $FeSO_4.7H_2O$ foliar application there was progressive reduction in P content in grain which was represented in

Table 4.2.12 Effect of varieties and iron application on P content in grain and stover and their uptake in soybean

Treatments	P content in grain (%)			P content in stover (%)			P uptake in grain (kg ha^{-1})			P uptake in stover (kg ha^{-1})			Total P uptake (grain + stover) kg ha^{-1}		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
Varieties															
V_1	0.358	0.361	0.359	0.278	0.286	0.282	0.075	0.074	0.074	0.060	0.058	0.059	0.135	0.132	0.133
V_2	0.371	0.373	0.372	0.297	0.302	0.299	0.108	0.107	0.108	0.090	0.086	0.088	0.199	0.193	0.196
V_3	0.386	0.389	0.388	0.321	0.317	0.319	0.068	0.066	0.067	0.065	0.060	0.063	0.133	0.126	0.130
SEm±	***0.008***	***0.009***	***0.006***	***0.008***	***0.008***	***0.006***	***0.003***	***0.003***	***0.002***	***0.003***	***0.003***	***0.002***	***0.005***	***0.005***	***0.004***
CD at 5%	***0.02***	***0.03***	***0.02***	***0.02***	***NS***	***0.02***	***0.39***	***0.44***	***0.31***	***0.48***	***0.55***	***0.39***	***0.65***	***0.86***	***0.57***
Fe fertilization															
Fe_0	0.394	0.409	0.402	0.319	0.321	0.320	0.077	0.079	0.078	0.069	0.062	0.065	0.146	0.141	0.143
Fe_1	0.391	0.372	0.382	0.299	0.303	0.301	0.089	0.083	0.086	0.071	0.067	0.069	0.160	0.150	0.155
Fe_2	0.373	0.360	0.367	0.298	0.293	0.296	0.083	0.077	0.080	0.071	0.070	0.070	0.154	0.147	0.150
Fe_3	0.353	0.354	0.354	0.283	0.278	0.281	0.086	0.089	0.088	0.074	0.073	0.074	0.160	0.162	0.161
Fe_4	0.353	0.366	0.359	0.282	0.291	0.287	0.081	0.080	0.080	0.068	0.066	0.067	0.149	0.146	0.148
Fe_5	0.363	0.383	0.373	0.310	0.321	0.316	0.087	0.085	0.086	0.077	0.072	0.074	0.164	0.157	0.160
SEm±	***0.012***	***0.013***	***0.009***	***0.011***	***0.011***	***0.008***	***0.004***	***0.004***	***0.003***	***0.004***	***0.004***	***0.003***	***0.007***	***0.007***	***0.005***
CD at 5%	***NS***	***NS***	***0.025***	***NS***	***NS***	***0.022***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***

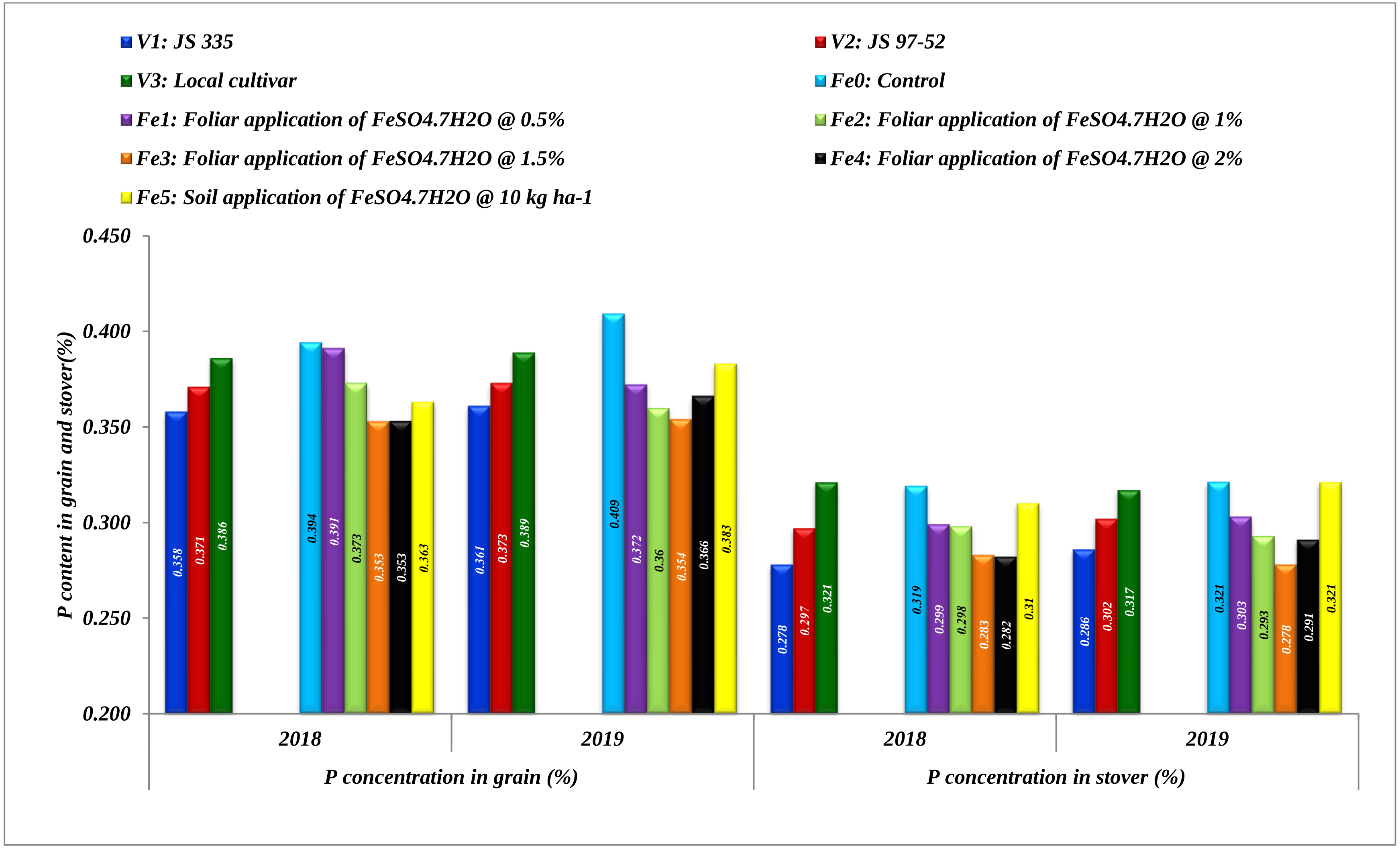


Fig 4.2.13 Effect of varieties and iron application on P content in grain and stover of soybean during 2018 and 2019

Fig 4.2.15 and depicted in Table 4.2.12. The reverse declining effect of phosphorus content in grain and stover upon Fe fertilization could be due to the antagonistic effect of iron and phosphorus. With the increased of concentration of iron in soil led to formation of iron phosphate which reduce uptake of phosphorus by grain and straw, thereby affecting the phosphorus content in grain and straw. This result was similar to the one reported by Mundra and Bhati (1991), Sahu *et al*. (2008) and Kumar *et al*. (2009).

4.2.6.7 Phosphorus content in stover

The perusal of data in Table 4.2.12 shows that straw P content among varieties differed significantly where the highest P content was recorded in local cultivar (0.321, 0.317%) followed by JS 97-52 (0.297, 0.302%) and least content in JS-335 (0.278, 0.286%).

As revealed by the data there was no significant variation on P content in stover upon imposition of Fe fertilization treatments in both the years of experiment. However, the data clearly shows that control treatment has the highest value of stover P content (0.319, 0.321%) and reduces with application of Fe as seen in the Table 4.2.12. The least P content was recorded in Fe_3 (0.283, 0.278%). The reduced P content in grain with increasing Fe fertilization will be the same antagonistic effect of P and Fe as explained grain P content which was supported by the findings of Mundra and Bhati (1991), Sahu *et al*. (2008) and Kumar *et al*. (2009).

The interaction effect of cultivar and Fe application was non-significant in both the years.

4.2.6.8 Phosphorus uptake by grain

The data on P uptake by grain in crop have been presented in Table 4.2.12. Grain P uptake differed significantly among varieties for both years of study. Grain P uptake by the cultivar JS 97-52 (0.108, 0.107 g pot^{-1}) was significantly higher than all other varieties. The other two varieties *i.e.*, JS-335 and local cultivar were statistically at par with each other with P uptake value of (0.075, 0.074 g pot^{-1}) and (0.068, 0.066 g pot^{-1}) respectively.

As per the data presented, it was observed that higher value of P uptake in Fe_1 foliar spray application of $FeSO_4.7H_2O$ @ 0.5% (0.089, 0.083 g pot^{-1}).

Iron sulphate application did not significantly affect the value of stover P uptake in both the years. Although there was drastic reduction in phosphorus content in grain upon application of Fe yet the P uptake was found to be significantly higher upon Fe fertilization. The reason was due to significant enhancement in grain yield which might have offset the negative effect of Fe over P content. This finding was in line to the one reported upon by Shukla and Shukla (1994), Sahu *et al*. (2008), Mundra and Bhati (1991), Pande *et al*. (1993), Yadav *et al*. (2002) and Gomaa *et al*. (2015).

The interaction effect was found to be non-significant in both years.

4.2.6.9 Phosphorus uptake by stover

Data pertaining to P uptake by stover in crop are given in Table 4.2.12. Stover P uptake differed significantly among varieties for both years of study. P uptake by stover by the cultivar JS 97-52 (0.090, 0.086 g pot^{-1}) was significantly way higher than all other varieties. The other two varieties *i.e*., JS-335 and local cultivar were statistically at par with each other with P uptake value of (0.060, 0.058g pot^{-1}) and (0.065, 0.060 g pot^{-1}) respectively. Similar trend as observed in P uptake by grain was also observed in uptake by stover with no significant variation for both the years of experimentation.

4.2.6.10 Total P uptake by grain + stover

The data pertaining to total P uptake by grain and stover is presented in Table 4.2.12. The value was observed to differ significantly among the varieties. The highest total P uptake was recorded in JS 97-52 (0.199, 0.193 g pot^{-1}) and JS-335 (0.135, 0.132 g pot^{-1}) was statistically at par with local cultivar (0.133, 0.126

g pot^{-1}) in both the years of experiment.

Application of Fe treatments has non-significant effect of the total P uptake. The interaction effect between varieties and Fe on P uptake was found non-significant.

4.2.6.11 Potassium content in grain

The data pertaining to potassium (K) content in grain is presented in Table 4.2.13. The results revealed that there were no significant variations among the varieties as well as Fe fertilization in both the years of study. However, among the varieties there is more concentration of K in local cultivar compared to the improved ones although non-significant.

Though there was no significant difference in K content in grain among the Fe fertilization, however Fe application resulted in slightly numerically higher value in both the years over control. Control one has the least value and the data range varied as 1.38-1.44% and 1.39-1.45% for the first and second year respectively. The influence of cultivar and Fe interaction was non-significant in both the years. This increased grain K content in Fe treated plants over the control could be due to the synergistic relationship between iron and potassium for better root and shoot growth. This might have enhanced the uptake of potassium in grain and straw. This result was in line to the one reported by Mundra and Bhati (1991), Pande *et al*. (1993), Kumawat *et al*. (2006) and Sahu *et al*. (2008).

4.2.6.12 K content in stover

As revealed by the data presented in Table 4.2.13, varieties and Fe fertilization as well as their interaction did not significantly influence on K content in stover in both the years. There was no significant trend observed in K content in stover.

4.2.6.13 K uptake by grain

Varieties and Fe fertilization significantly influenced the K uptake by grain in both the years of study (Table 4.2.13). Among the varieties, JS 97-52 (0.413,

Table 4.2.13 Effect of varieties and iron application on K content in grain and stover and their uptake in soybean

Treatments	**K content in grain (%)**			**K content in stover (%)**			**K uptake in grain (kg ha^{-1})**			**K uptake in stover (kg ha^{-1})**			**Total K uptake (grain + stover) kg ha^{-1}**		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
Varieties															
V_1	1.373	1.377	1.375	2.221	2.234	2.228	0.288	0.284	0.286	0.479	0.454	0.467	0.767	0.738	0.753
V_2	1.409	1.426	1.417	2.209	2.258	2.234	0.413	0.409	0.411	0.677	0.651	0.664	1.090	1.060	1.075
V_3	1.443	1.445	1.444	2.263	2.226	2.244	0.256	0.245	0.251	0.456	0.429	0.443	0.713	0.674	0.693
SEm±	***0.023***	***0.024***	***0.017***	***0.049***	***0.063***	***0.040***	***0.010***	***0.008***	***0.006***	***0.023***	***0.023***	***0.016***	***0.028***	***0.026***	***0.019***
CD at 5%	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***0.028***	***0.022***	***0.017***	***0.065***	***0.066***	***0.046***	***0.080***	***0.074***	***0.054***
Fe fertilization															
Fe_0	1.384	1.390	1.387	2.233	2.114	2.174	0.272	0.272	0.272	0.486	0.412	0.449	0.758	0.684	0.721
Fe_1	1.409	1.406	1.407	2.198	2.237	2.217	0.321	0.317	0.319	0.521	0.492	0.507	0.842	0.809	0.826
Fe_2	1.398	1.429	1.413	2.230	2.242	2.236	0.310	0.304	0.307	0.530	0.532	0.531	0.840	0.836	0.838
Fe_3	1.436	1.452	1.444	2.274	2.317	2.296	0.349	0.364	0.357	0.597	0.608	0.603	0.946	0.973	0.959
Fe_4	1.412	1.393	1.403	2.200	2.234	2.217	0.324	0.306	0.315	0.532	0.501	0.517	0.856	0.807	0.832
Fe_5	1.412	1.424	1.418	2.250	2.292	2.271	0.338	0.313	0.326	0.560	0.523	0.541	0.898	0.836	0.867
SEm±	***0.033***	***0.034***	***0.024***	***0.070***	***0.089***	***0.056***	***0.014***	***0.011***	***0.009***	***0.032***	***0.033***	***0.023***	***0.039***	***0.037***	***0.027***
CD at 5%	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***0.039***	***0.031***	***0.024***	***NS***	***0.094***	***0.064***	***0.113***	***0.105***	***0.076***

409 g pot^{-1}) surpassed the other in K uptake which was followed by JS-335 (0.288, 0.284 g pot^{-1}) and least in local (0.256, 0.245 g pot^{-1}). JS 97-52 was 61% higher than the local control in K uptake.

The Fe nutrition both foliar and soil application significantly influenced the K uptake. Two foliar spray applications of $FeSO_4.7H_2O$ @ 1.5% at pre-flowering stage (Fe_3) were found superior in K uptake (0.349, 0.364 g pot^{-1}) value in both the years. The percentage increase in K uptake over the control was (28.30, 34.00%) in Fe_3 followed by soil application of $FeSO_4.7H_2O$ @ 10 kg ha^{-1} (24.36, 15.05%). As revealed by the yield data (Table 4.2.19) there was significant influence of Fe application on grain and stover yield which resulted in enhancement of K uptake both grain and stover both the years of experiment. This result was in confirmation to the findings of Pande *et al*. (1993), Kumawat *et al*. (2006) and Sahu *et al*. (2008).

4.2.6.14 K uptake by stover

Similar trend was also observed in the case of K uptake by stover as in grain (Table 4.2.13). The highest value of K uptake by stover was recorded by JS 97-52 (0.677, 0.651 g pot^{-1}) which was significantly higher than JS-335 (0.479, 0.454 g pot^{-1}) and local cultivar (0.456, 0.429 g pot^{-1}).

Fe fertilization did not significantly influence on the K uptake by stover in the first year but although numerically the value was following the similar trend. But significant effect was observed in the second year of experiment and the highest value was observed in Fe_3 (0.597, 0.608 g pot^{-1}) followed by soil applied treatment Fe_5 (0.523, 0.541 g pot^{-1}). The significant improvement in stover yield upon Fe application eventually improved the K uptake. The result also confirmed by those investigations reported by Ramesh *et al*. (2007), Darwesh (2011), Abbas *et al*. (2012) and Sunder *et al.* (2017).

4.2.6.15 Iron content (mg kg^{-1} DM) in grain

The data pertaining to Fe content in grain or the biofortification effect with Fe fertilization treatments is presented in Table 4.2.14 and illustrated in Fig 4.2.16. All the three varieties were significant different from each other in grain Fe concentration during both years. The highest value of grain Fe concentration (66.84, 68.15 mg kg^{-1}) was found in cultivar JS-335 which was statistically at par with JS 97-52 (64.96, 65.30 mg kg^{-1}) followed by statistically inferior local cultivar (58.98, 54.58 mg kg^{-1}). The varietal difference in Fe content was supported by Dhaliwal *et al*. (2013). The significant variation of grain Fe content among the varieties could be explained by the varietal difference in efficiency level with respect to Fe acquisition which was supported by the findings of Rengel and Graham (1996), Graham *et al*. (1997), Cakmak, (1999) and Khoshgoftarmanesh*et al.* (2004). They reiterated the fact that there was iron or zinc efficient varieties with higher iron and zinc concentration in grain. Furthermore, the result on varietal difference was elaborated by Joshi *et al.* (2010) who found that genotype × environment interaction could be one of the factors for variation in zinc and iron concentration in edible parts of plants.

With application of $FeSO_4.7H_2O$ there was positive effect on the Fe biofortification and enhancement in grain Fe concentration. Among the treatments, Fe_3 (Foliar spray application of $FeSO_4.7H_2O$@ 1.5% at pre-flowering stage) recorded the maximum grain Fe concentration (67.77, 66.81 mg kg^{-1}) in both the years. All the Fe treated was found to be at par with each other when compared to control. The next best treatment in enhancing grain Fe concentration was the Fe_2 (Foliar spray application of $FeSO_4.7H_2O$ @ 1%) (66.49, 65.38 mg kg^{-1}). The percentage increase in grain Fe density upon Fe fertilization over the control was (18.37, 15.73%) in Fe_3 followed by Fe_2 (16.15, 13.89%) which is fairly appreciable result as far as biofortification of micronutrient is concerned. Several studies have reported the positive effect of agronomic biofortification of iron on enhancing the iron density of food grains. With Fe application, plant

Table 4.2.14 Effect of varieties and iron application on zinc content in grain andstover (%)

Treatments	**Fe content in grain (ppm)**			**% Increase in Fe conc. over control in pooled data**	**Fe content in stover (ppm)**			**% Increase in Zn conc. over control in pooled data**
	2018	**2019**	**Pooled**		**2018**	**2019**	**Pooled**	
Varieties								
V_1	66.84	68.15	67.50		111.72	115.79	113.76	
V_2	64.96	65.30	65.13		117.50	118.40	117.95	
V_3	58.98	54.58	56.78		118.99	120.02	119.50	
SEm±	*1.51*	*1.53*	*1.07*		*2.86*	*3.22*	*2.15*	
CD at 5%	*4.32*	*4.38*	*3.02*		*NS*	*NS*	*NS*	
Fe fertilization								
Fe_0	57.25	56.30	56.78		105.97	106.27	106.12	
Fe_1	64.72	63.75	64.24	13.13	115.93	114.48	115.21	8.56
Fe_2	66.49	65.38	65.94	16.13	115.31	124.08	119.70	12.79
Fe_3	67.77	66.81	67.29	18.51	125.54	123.42	124.48	17.30
Fe_4	62.37	61.52	61.94	9.10	115.41	123.53	119.47	12.58
Fe_5	62.96	62.29	62.63	10.29	118.25	116.64	117.45	10.67
SEm±	*2.13*	*2.16*	*1.52*		*4.04*	*4.55*	*3.04*	
CD at 5%	*6.11*	*6.19*	*4.27*		*NS*	*NS*	*8.58*	

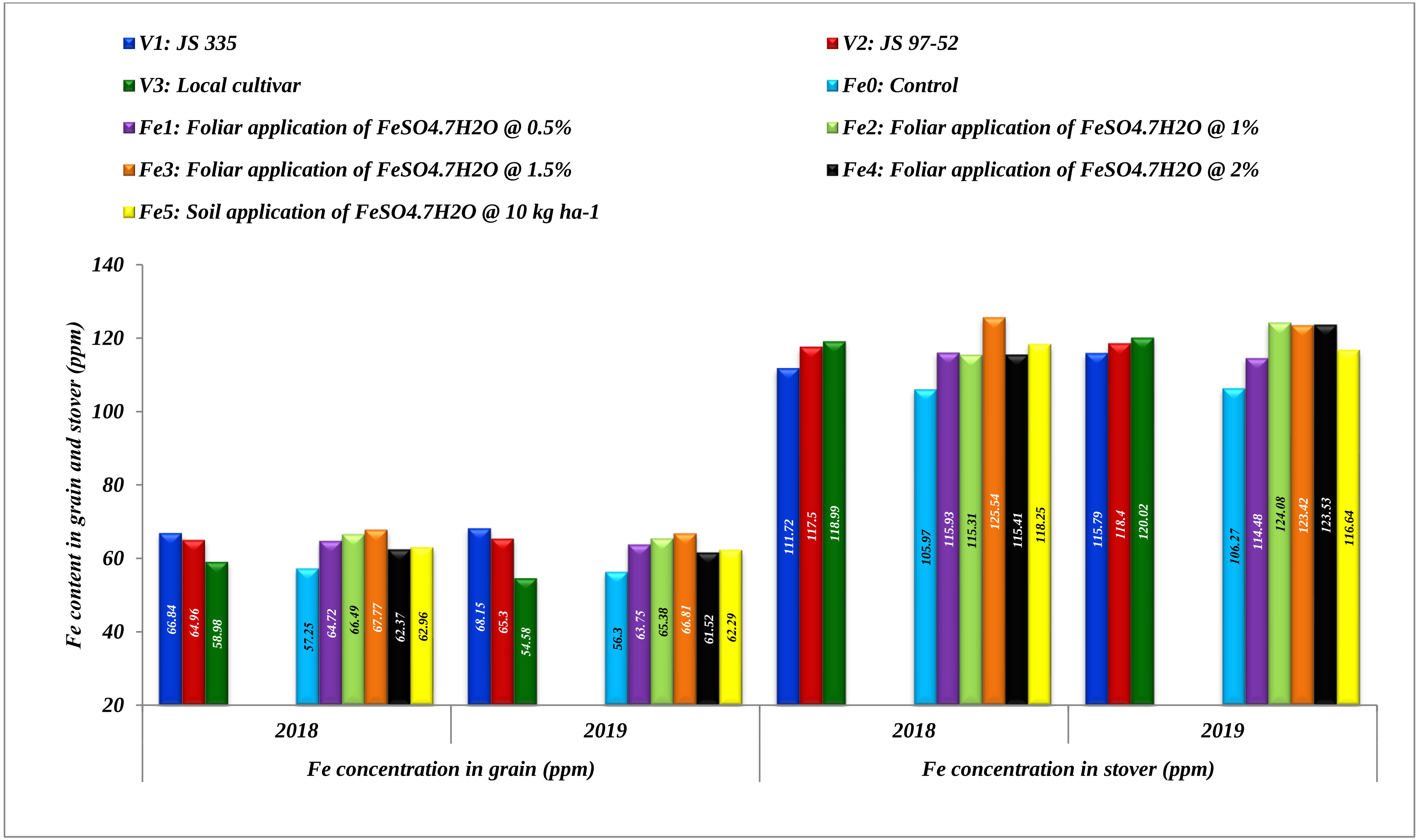


Fig 4.2.14 Effect of varieties and iron application on Fe content in grain and stover of soybean during 2018 and 2019

systems are under congenial conditions for various enzymatic and physiological processes. The plausible reason for higher Fe content could be due to higher synthesis of photosynthetic product with specific absorption and transport sites which increases plant biomass. It is also elaborated that upon foliar spray of ferrous sulphate, Fe absorption in plant leaves is accompanied by its translocation in the plant system. Similar results have also been reported by Dhaliwal *et al*. (2010) who reported that significant increase of 22.30-38.20% of grain Fe concentration of rice cultivars through foliar application of $FeSO_4.7H_2O$. In the latest experiment conducted in soybean by Dhaliwal *et al*. (2022), it was indicated that maximum increase in Fe density can be achieved through either 2-3 foliar sprays of 0.5% $FeSO_4.7H_2O$ and upon higher concentration resulted to lower Fe content in grain. Their result substantiated the findings of our experiment (Table 4.2.27), where spray concentrations of $FeSO_4.7H_2O$ at 1.5%, 1% and 0.5% yielded higher value of iron biofortification on soybean grain. As revealed by the data it was found that foliar application of iron sulphate was superior over soil application which further corroborated by the findings of Nayyar and Takkar (1989) and Duraisamy and Mani (2001). Comparing to the soil application, foliar spray of $FeSO_4.7H_2O$ found to be more effective in the plant systems which were in line with the result reported by Mohamed *et al*. (2011). The findings of this experiment were in conformity to the results reported upon by Kobraee *et al*. (2011c), Hanumanthappa *et al*. (2018), Pal *et al*. (2019) and Sunder *et al.* (2017).

The interaction effect between varieties and and Fe applications on Fe content in grainwas not significant.

4.2.6.16 Iron content (mg kg^{-1} DM) in stover

The data pertaining to iron content in stover is presented in Table 4.2.14 and depicted in Fig 4.2.16. Varieties and Fe application did not differ significantly with respect to stover Fe content during both the years. Local cultivar registered slightly higher value of Fe concentration (118.99, 120.02 mg kg^{-1}) over JS 97-52 (117.50, 118.40 mg kg^{-1}) and JS- 335 (111.72, 115.79 mg kg^{-1}).

Although no significant differences observed upon Fe fertilization in both the years, however higher value of Fe concentration in stover was observed upon Fe application when compared to control. All the Fe fertilization treatments were statistically at par with each other where slightly higher value was recorded in Fe_3 (125.54, 123.42 mg kg^{-1}) and least in control (105.97, 106.27 mg kg^{-1}). The other Fe treatments were not much different in their values.

The interaction effect of cultivar and Fe application were not significant.

4.2.6.17 Iron uptake by grain

The perusal of data given in Table 4.2.15 indicated that all the three varieties of soybean were significantly different in the grain Fe uptake in both the years. It was observed that cultivar JS 97-52 (1.92, 1.89 mg pot^{-1}) recorded significantly higher value of grain Fe uptake during both the years when compared to the other varieties. The next best efficient cultivar in Fe uptake by grain was JS-335 (1.41, 1.40 mg pot^{-1}) and least was observed in local cultivar (1.05, 0.93 mg pot^{-1}).

With Fe fertilization treatments, there were significant differences in Fe uptake by grain in both the years of study. Foliar spray application of $FeSO_4.7H_2O$ @ 1.5% at pre-flowering stage (Fe_3) resulted in significant high grain Fe uptake (1.69, 1.71 mg pot^{-1}) which was followed by Fe_5 and Fe_2 in the first year and least Fe uptake recorded in control (1.12, 1.12 mg pot^{-1}). In the second-year similar trend was observed as the highest Fe grain uptake recoded in Fe_3 which was statistically way higher than the rest of the treatments and the others being at par with each other. The percentage increase upon Fe fertilization treatments was found to be highest in Fe_3 (50.46, 52.66%) followed by Fe_2 (Foliar spray application of $FeSO_4.7H_2O$ @ 1%) with (33.85, 27.87%) over control. Fig 4.2.16 representing the effect of varieties and Fe fertilization on Fe uptake by

Table 4.2.15 Effect of varieties and iron application on iron uptake in grain, stover and total of soybean (mg pot^{-1})

Treatments	Fe uptake by grain (mg pot^{-1})			Fe uptake by stover (mg pot^{-1})			Total Fe uptake by grain + stover (mg pot^{-1})		
	2018	*2019*	*Pooled*	*2018*	*2019*	*Pooled*	*2018*	*2019*	*Pooled*
Varieties									
V_1	1.41	1.40	1.40	2.40	2.35	2.38	3.81	3.75	3.78
V_2	1.92	1.89	1.90	3.60	3.45	3.53	5.52	5.34	5.43
V_3	1.05	0.93	0.99	2.41	2.31	2.36	3.46	3.25	3.35
SEm±	***0.05***	***0.05***	***0.04***	***0.10***	***0.12***	***0.08***	***0.14***	***0.15***	***0.10***
CD at 5%	***0.14***	***0.15***	***0.10***	***0.29***	***0.35***	***0.22***	***0.39***	***0.44***	***0.29***
Zinc fertilization									
Fe_0	1.12	1.12	1.12	2.32	2.05	2.18	3.44	3.17	3.30
Fe_1	1.47	1.46	1.47	2.75	2.50	2.63	4.22	3.97	4.09
Fe_2	1.50	1.43	1.46	2.75	2.94	2.85	4.25	4.37	4.31
Fe_3	1.69	1.71	1.70	3.30	3.24	3.27	4.99	4.95	4.97
Fe_4	1.45	1.35	1.40	2.79	2.80	2.80	4.24	4.16	4.20
Fe_5	1.52	1.38	1.45	2.92	2.68	2.80	4.44	4.06	4.25
SEm±	***0.07***	***0.07***	***0.05***	***0.14***	***0.17***	***0.11***	***0.19***	***0.22***	***0.15***
CD at 5%	***0.20***	***0.21***	***0.14***	***0.41***	***0.50***	***0.32***	***0.55***	***0.62***	***0.41***

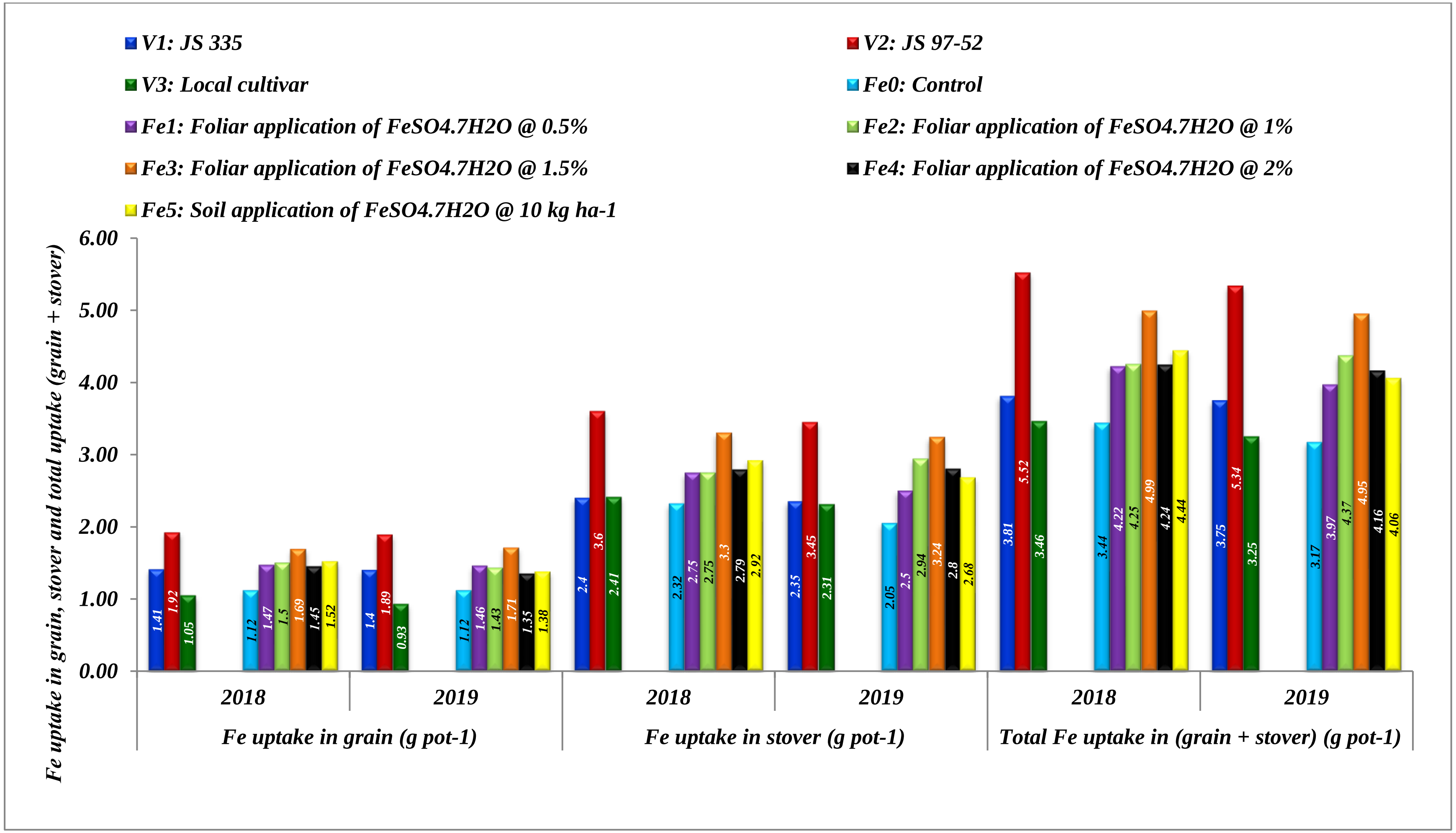


Fig 4.2.15 Effect of varieties and iron application on Fe uptake in grain and stover and total uptake (grain + stover) of soybean during 2018 and 2019

grain and stover.

Since there was significant influence of Fe fertilization on the grain and stover yield of soybean in both the years, this resulted in higher Fe uptake in Fe treated plants compared to the untreated control. This result was in conformity to the findings reported by Thavarajah *et al*. (2009), Dhaliwal *et al*. (2010) and Yadav *et al*. (2013).

4.2.6.18 Iron uptake by stover

The data on Fe uptake by stover of soybean are given in Table 4.2.15 which indicated that all the three varieties of soybean varied significantly among each other in both years. JS 97-52 (3.60, 3.45 mg pot^{-1}) recorded significantly higher value of Fe stover uptake during both the years when compared to the other varieties, while the other two varieties were statistically at par with each other.

Fe application resulted to significant enhancement in Fe uptake in stover in both the years. The treatment Fe_3 (Foliar spray application of $FeSO_4.7H_2O$ @ 1.5%) recorded the highest value (3.30, 3.24 mg pot^{-1}) and was significantly higher than the rest of Fe treatments while they were statistically at par with each other. This finding was supported by the finding of Dhaliwal *et al*. (2022).

4.2.6.19 Total iron uptake by soybean

Similar trend was also observed with respect to total Fe uptake in both the years. Varieties were significantly different with each other with respect to this observation in both the years. The highest total Fe uptake was observed in JS 97-52 (5.52, 5.34 mg pot^{-1}) which was followed by JS-335 (3.81, 3.75 mg pot^{-1}) and least in local (3.46, 3.25 mg pot^{-1}) where the latter two were at par to each other (Table 4.2.15).

Application of Fe significantly affected the total Fe uptake (Grain + stover) in both the years. The highest value was recorded in Fe_3 (Foliar spray application of $FeSO_4.7H_2O$ @ 1.5% at pre-flowering stage) (4.99, 4.95 mg pot^{-1})

which was significantly higher than the rest and the other treatment being statistically at par with each other.

Interaction effect of varieties and Fe uptake remained non-significant in both the varieties.

4.2.7 Quality parameters

4.2.7.1 Protein content in grain

The data pertaining to protein content of soybean as influenced by varieties and Fe fertilization treatments is presented in Table 4.2.16 and depicted in Fig 4.2.18 & Fig 4.2.19. It was revealed that varieties differed significantly with respect to protein content both the years of experimentation where JS-335 recorded slightly higher value (37.88, 37.99%) and was at par with JS 97-52 (37.80, 37.66%) and significantly higher than the local cultivar (37.50, 37.46%).

Application of Fe fertilization also affects the protein content of grain during both the years of the experiment. Higher value of protein was observed in Fe_3 (Foliar spray application of $FeSO_4.7H_2O$ @ 1.5%) with (39.21, 38.70%) which was significantly higher than the rest of the treatments and the latter being at par with each other. The least protein content was recorded in control.

There was slight enhancement of protein content upon Fe application. With Fe_3 (Foliar spray application of $FeSO_4.7H_2O$ @ 1.5%) the percentage increase of protein was (7.78, 9.21%) and followed by Fe_5, (Soil application of $FeSO_4.7H_2O$ @ 10 kg ha^{-1}) with (3.62, 6.37%). Increase in protein content might be due to role of iron which is a vital element of structure of enzymes involved in amino acids synthesis and ultimately protein synthesis. Hence, with application and assimilation of external applied Fe via iron sulphate might have enhanced the protein content. It can also be explained by the fact that iron is an essential component for nitrogen fixation and this might have resulted in better availability of nitrogen and its absorption hence led toincrease in protein content in grain of soybean. Enhancement in grain protein content increased the storage

Table 4.2.16 Effect of varieties and iron application on protein and oil content in grain soybean (%)

Treatments	***Protein content in grain (%)***			***Oil content in grain (%)***		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
Varieties						
V_1	37.88	37.99	37.94	17.90	17.83	17.87
V_2	37.80	37.66	37.73	18.13	18.03	18.08
V_3	36.89	36.53	36.71	17.00	17.41	17.21
SEm±	***0.26***	***0.28***	***0.19***	***0.48***	***0.39***	***0.31***
CD at 5%	***0.74***	***0.81***	***0.58***	***1.37***	***1.11***	***0.94***
Fefertilization						
Fe_0	36.38	35.44	35.91	17.15	17.27	17.21
Fe_1	36.99	37.60	37.29	17.85	17.96	17.91
Fe_2	37.59	37.83	37.71	17.96	17.74	17.85
Fe_3	39.21	38.70	38.96	18.14	18.44	18.29
Fe_4	37.27	37.11	37.19	17.56	17.59	17.57
Fe_5	37.70	37.70	37.70	17.42	17.56	17.49
SEm±	***0.41***	***0.52***	***0.33***	***0.37***	***0.27***	***0.23***
CD at 5%	***1.18***	***1.50***	***0.94***	***NS***	***NS***	***NS***

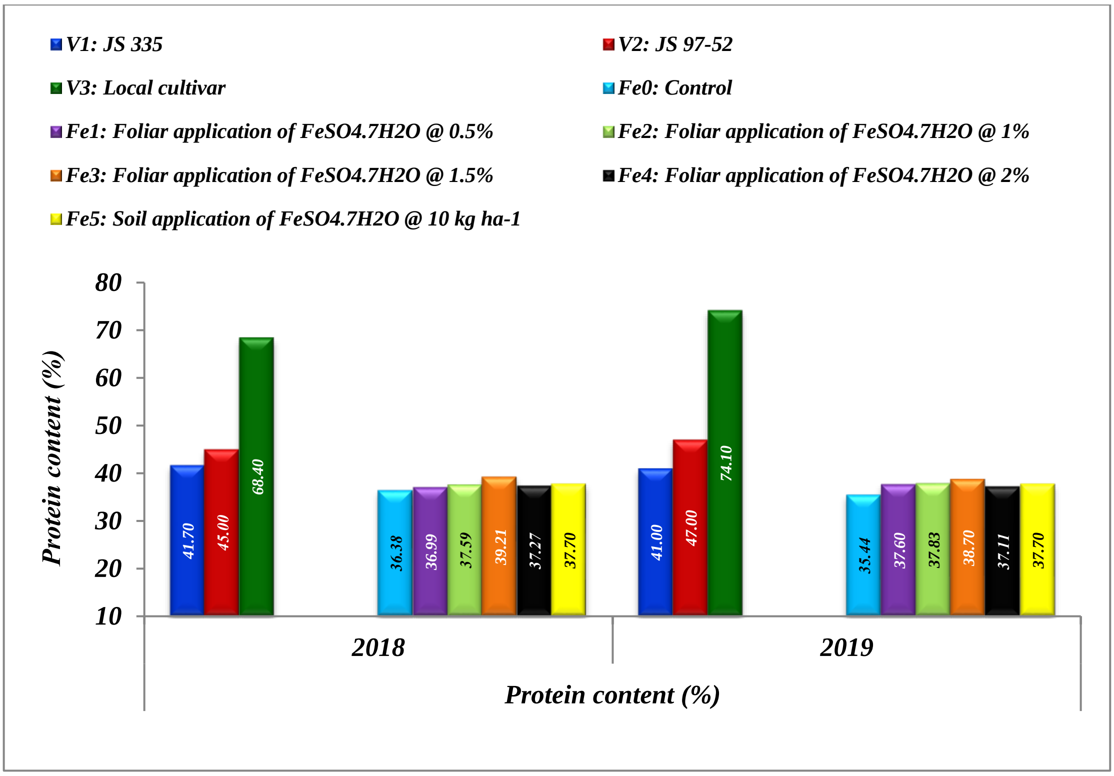


Fig 4.2.16 Effect of varieties and iron fertilization on protein content during 2018 and 2019

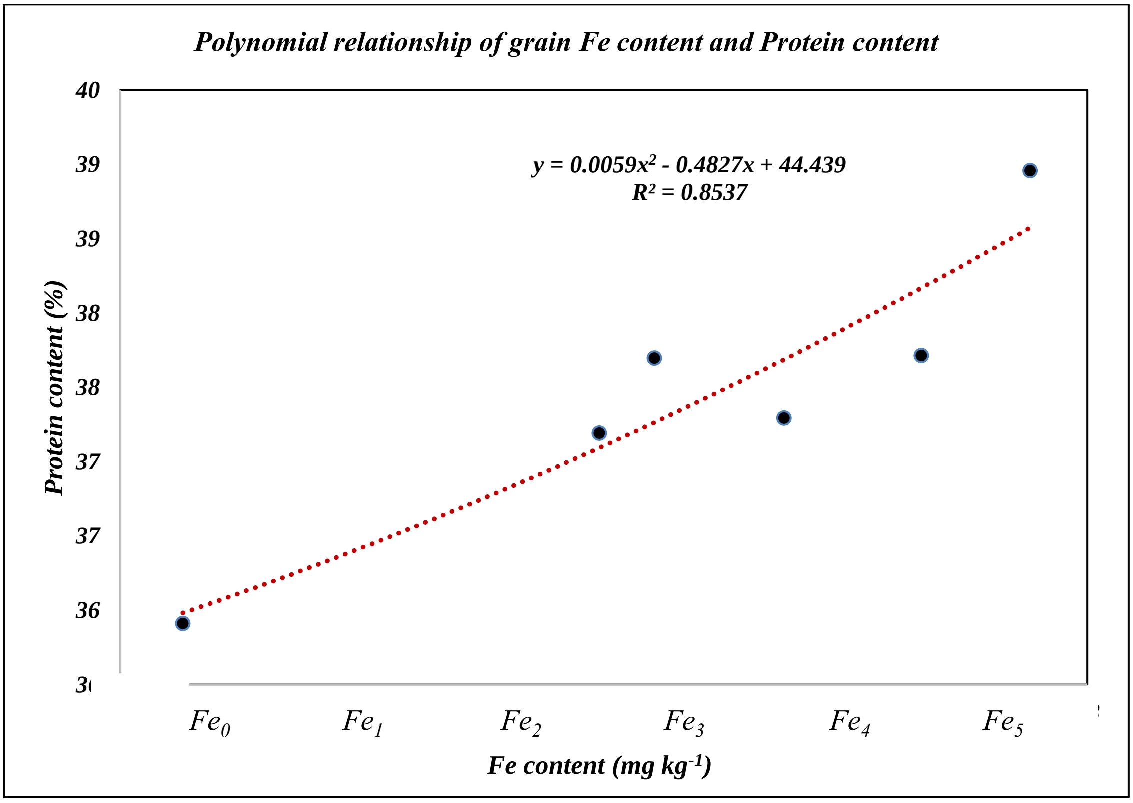


Fig 4.2.17 Polynomial relationship of grain iron content and protein content

capacity for Fe and Zn (Cakmak *et al*., 2010b) which supports the idea that grain protein largely influences the grain capacity to accumulate Fe (Gomez-Becerra *et al*., 2010). Similar results on the effect of ferrous sulphate (Fe) on grain protein is supported by the findings of Yadav *et al*. (2002), Abdel *et al.* (2014), Khattak *et al.* (2015) and Sale *et al*. (2017).

The interaction effect of the two factors was found to be not significant.

4.2.7.2 Oil content in grain

Data pertaining to oil content of soybean as influenced by varieties and Fe application are presented in Table 4.2.16 and illustrated in Fig 4.2.20 & Fig 4.2.21. The data revealed that there was slight significant variation among varieties in oil content in the first year where the highest value was observed in JS 97-52 (18.13, 18.03%) which was statistically at par with JS-335 (17.83, 17.87%). The least value was observed in local cultivar (17.00, 17.41%) which was inferior to the other two varieties.

However, the data as indicated in the Table 4.2.16 shows that oil content did not significantly vary with Fe application although numerically higher value was observed in Fe_3 (Foliar spray application of $FeSO_4.7H_2O$ @ 1.5%) with (18.14, 18.44%) followed by Fe_1 (Foliar spray application of $FeSO_4.7H_2O$ @ 0.5% at pre-flowering stage) with (17.85, 17.96%). Ferrous sulphate also contains sulphur in addition to iron. Sulphur being one of the important secondary nutrients required by the crops, sulphur and iron might have helped to obtain a higher oil yield of soybean as sulphur resulted in better biosynthesis of oil in soybean. The results on the effect of Fe on oil content was supported by the findings of Janakiraman *et al.* (2005), Ravi *et al*. (2008), Abdel *et al.* (2014), on groundnut, safflower and soybean respectively. The Fig 4.2.20 shows a positive polynomial relationship between Fe content and oil content in grain. With increasing Fe grain content there was positive increasing response in oil content.

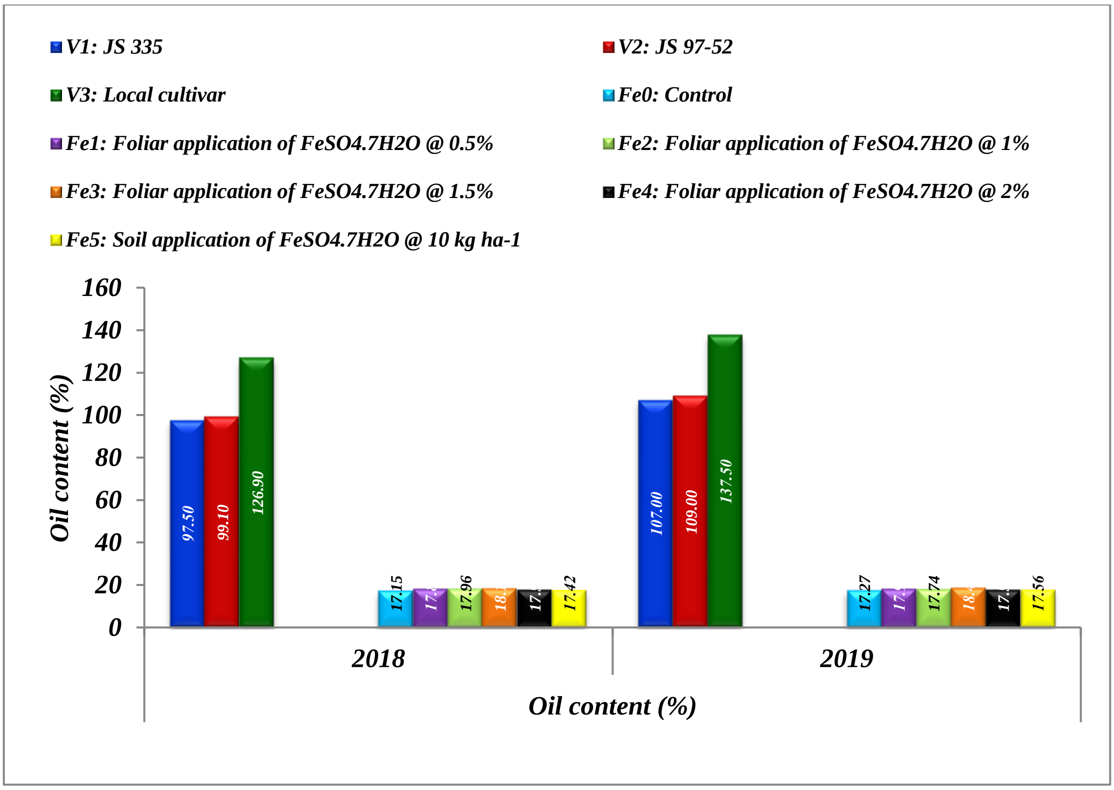


Fig 4.2.18 Effect of varieties and iron fertilization on oil content during 2018 and 2019

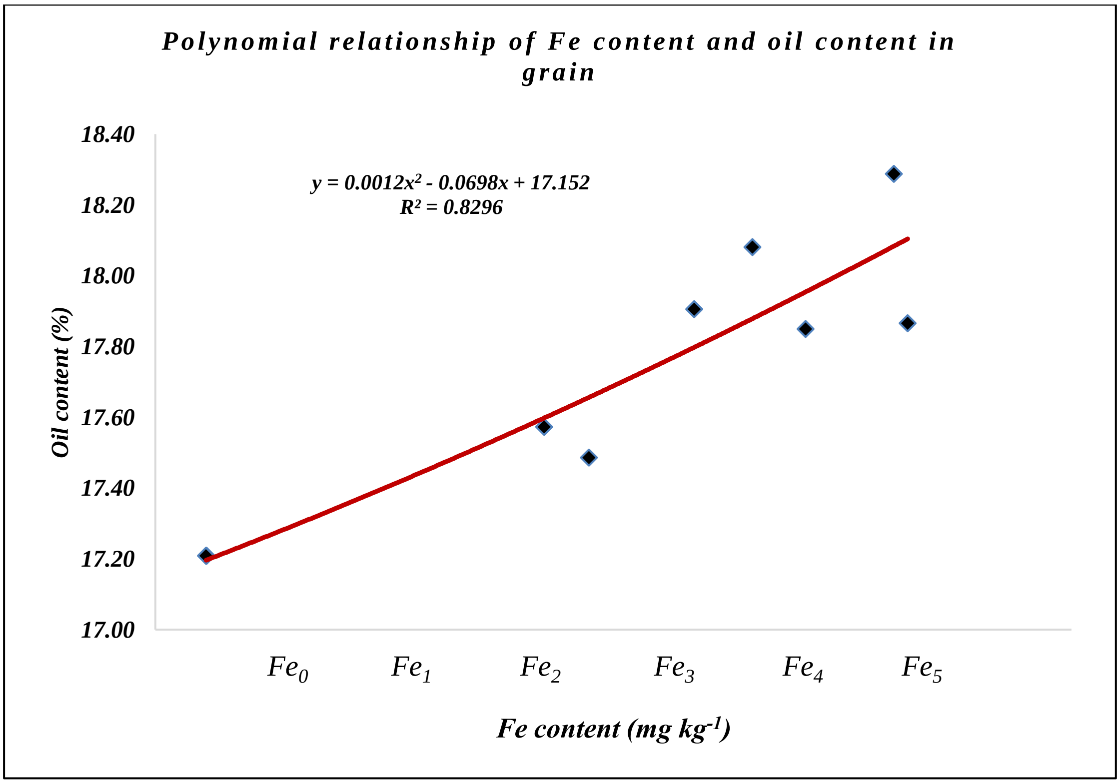


Fig 4.2.19 Polynomial relationship of grain iron content and oil content

4.2.7.3 Phytic acid content and Phytic acid: iron molar (PA: Fe) ratio

Data on phytic acid content as influenced by varieties and zinc application are presented in Table 4.2.17 and illustrated in Fig 4.2.22 & Fig 4.2.23. Higher phytic acid content in food grain found to reduce the bioavailability of micronutrient in human guts. The general fact is different varieties have variation in the concentration of this anti nutritional factor phytic acid. The phytic acid content in grain of soybean varied significantly with each other and the highest phytic acid content was observed in local cultivar (689.38, 699.54 mg/100 g) which was significantly higher than JS 97-52 (606.45, 609.32 mg/100 g) and JS-335 (567.13, 593.16 mg/100 g).

Also, a general observation is that with external application of micronutrient in term of ferti-biofortification tends to reduce the phytic acid as well as its phytic acid: iron molar ratio which is the desirable goal of agronomic biofortification. Data pertaining to phytic acid: Fe molar ratio is presented in Table 4.2.17 indicated that varieties significantly differed among each other with respect to phytic: Fe molar ratio in both the years of experiment. Local cultivar recorded the highest ratio (9.97, 11.13), which was followed by JS 97-52 (8.04, 8.07). The least value of phytic: Fe molar ratio was observed in JS-335 (7.26, 7.44). The lesser is the phytic acid: Fe molar ratio the more will be the bioavailability of this micronutrient in human system which is in fact the desirable goal of any biofortification programme.

Under $FeSO_4.7H_2O$ application, phytic acid content did not differ significantly, although control (671.71, 679.93 mg/100 g) treatment numerically recorded the highest value. Foliar spray application of $FeSO_4.7H_2O$ @ 1.5% at pre-flowering stage (Fe_3) (568.22, 601.89 mg/100 g) resulted in drastic reduction in phytic acid content in both the years of experiment. The reduction of phytic acid upon biofortification with $FeSO_4.7H_2O$ was to the tune of 13.43% and 9.58% in Fe_3 and Fe_4, respectively.

Table 4.2.17 Effect of varieties and iron application on phytic acid content and phytic iron molar ratio in grain and of soybean

Treatments	**Phytic acid content (mg/100g)**			**% reduction of phytic acid over control**	**Phytic acid: Fe molar ratio**			**% reduction of phytic acid: Fe over control**
	2018	**2019**	**Pooled**		**2018**	**2019**	**Pooled**	
Varieties								
V_1	567.13	593.16	580.15		7.26	7.44	7.35	
V_2	606.45	609.32	607.89		8.04	8.07	8.06	
V_3	689.38	699.54	694.46		9.97	11.13	10.55	
SEm±	***18.70***	***16.37***	***12.43***		***0.29***	***0.39***	***0.24***	
CD at 5%	***53.64***	***46.96***	***35.04***		***0.84***	***1.11***	***0.68***	
Fe fertilization								
Fe_0	671.71	679.93	675.82		10.05	10.68	10.37	
Fe_1	632.84	631.79	632.31	6.44	8.39	8.63	8.51	17.91
Fe_2	641.05	645.05	643.05	4.85	8.27	8.74	8.50	18.01
Fe_3	568.22	601.89	585.06	13.43	7.26	7.79	7.53	27.41
Fe_4	581.82	640.30	611.06	9.58	7.97	8.91	8.44	18.58
Fe_5	630.29	605.11	617.70	8.60	8.60	8.54	8.57	17.37
SEm±	***26.45***	***23.15***	***17.58***		***0.42***	***0.55***	***0.34***	
CD at 5%	***NS***	***NS***	***NS***		***1.19***	***1.57***	***0.97***	

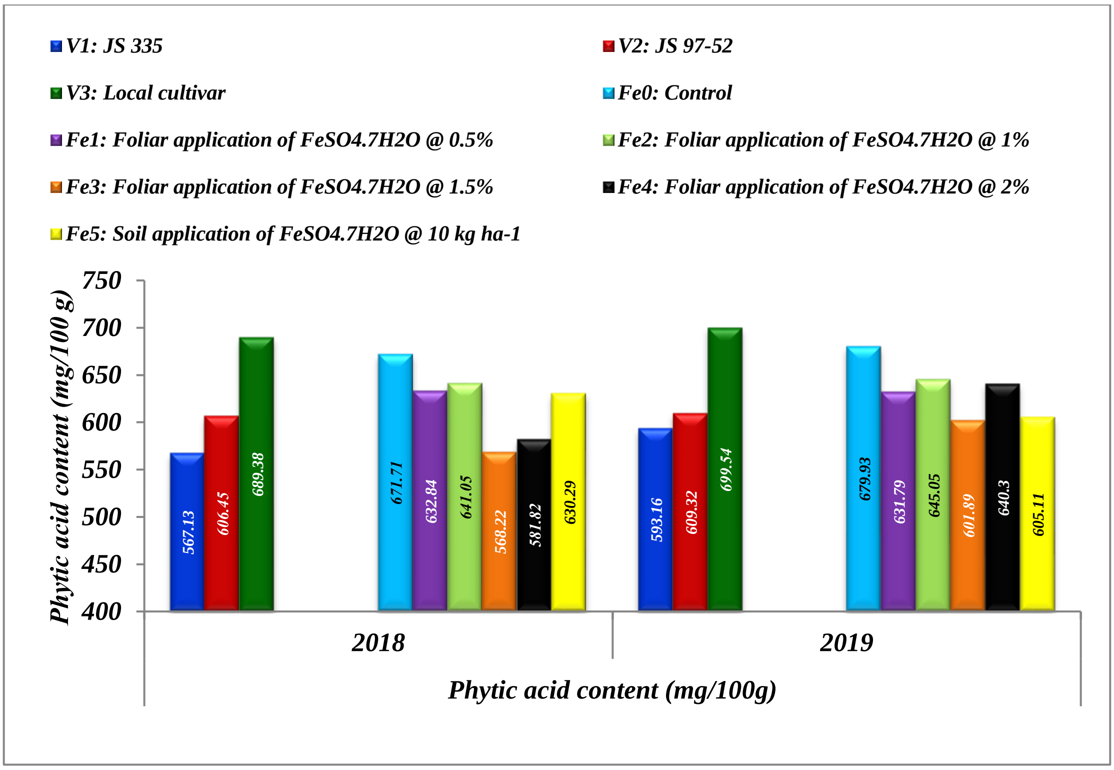


Fig 4.2.20 Effect of varieties and iron fertilization on phytic acid content during 2018 and 2019

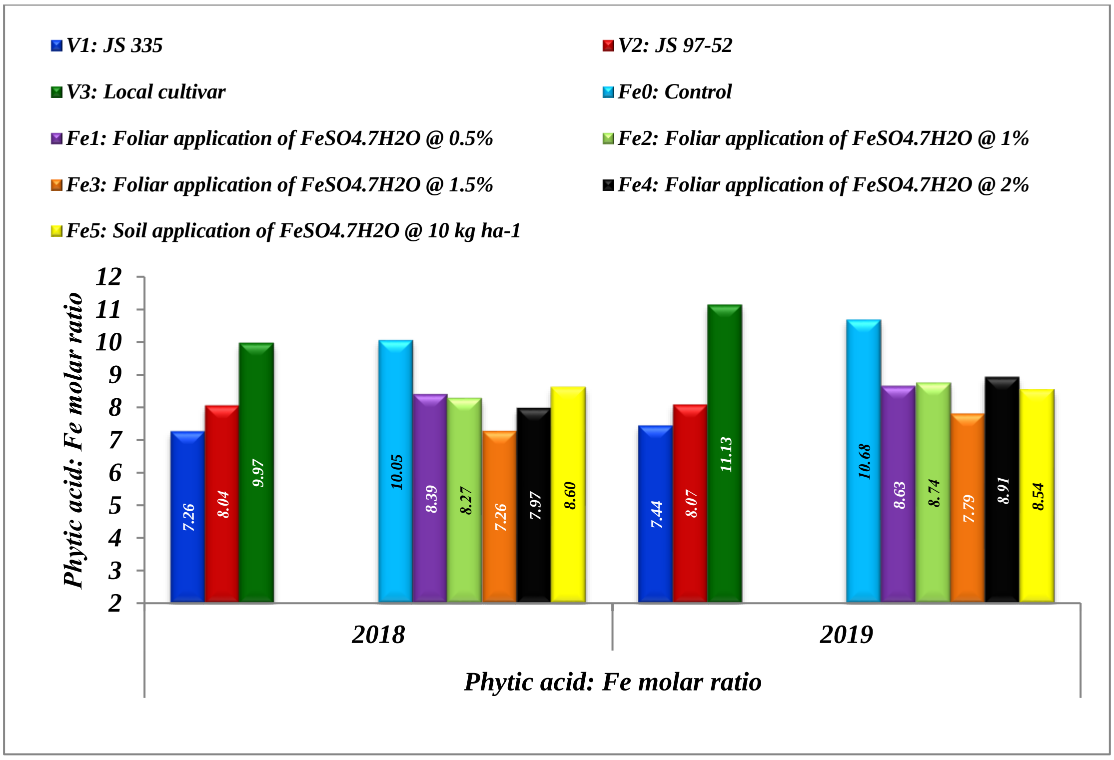


Fig 4.2.21 Effect of varieties and iron fertilization on phytic acid content during 2018 and 2019

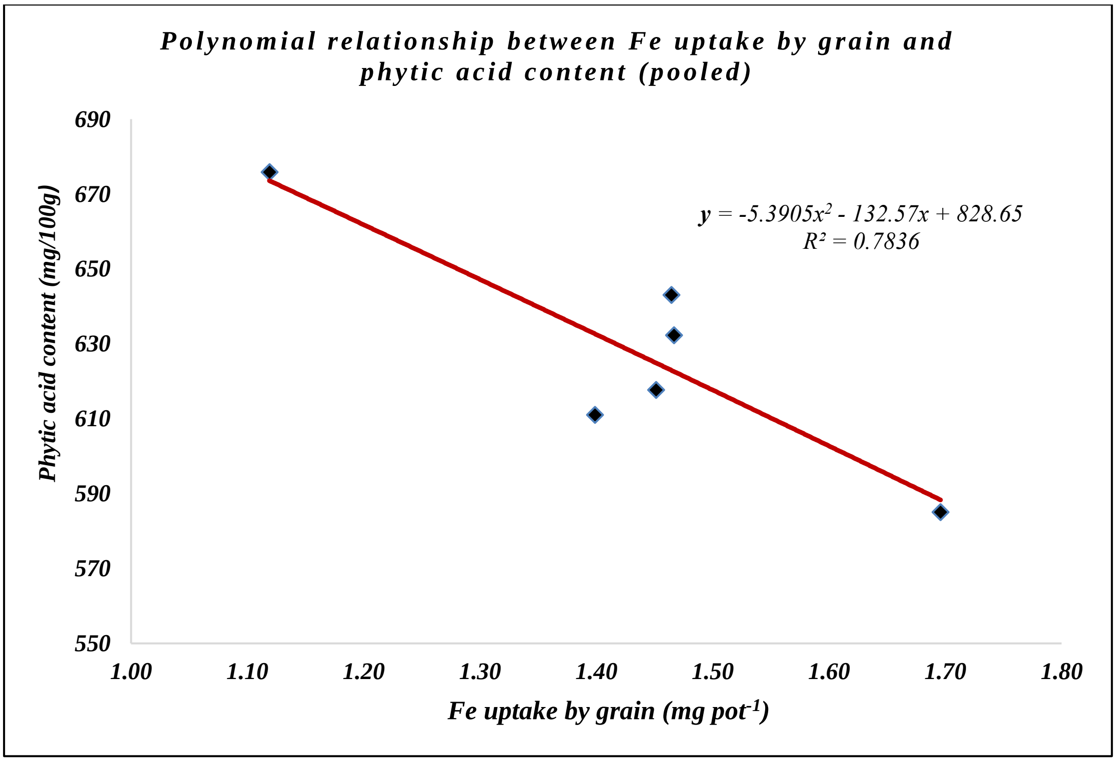


Fig 4.2.22 Polynomial relationship between Fe uptake by grain and phytic acid content

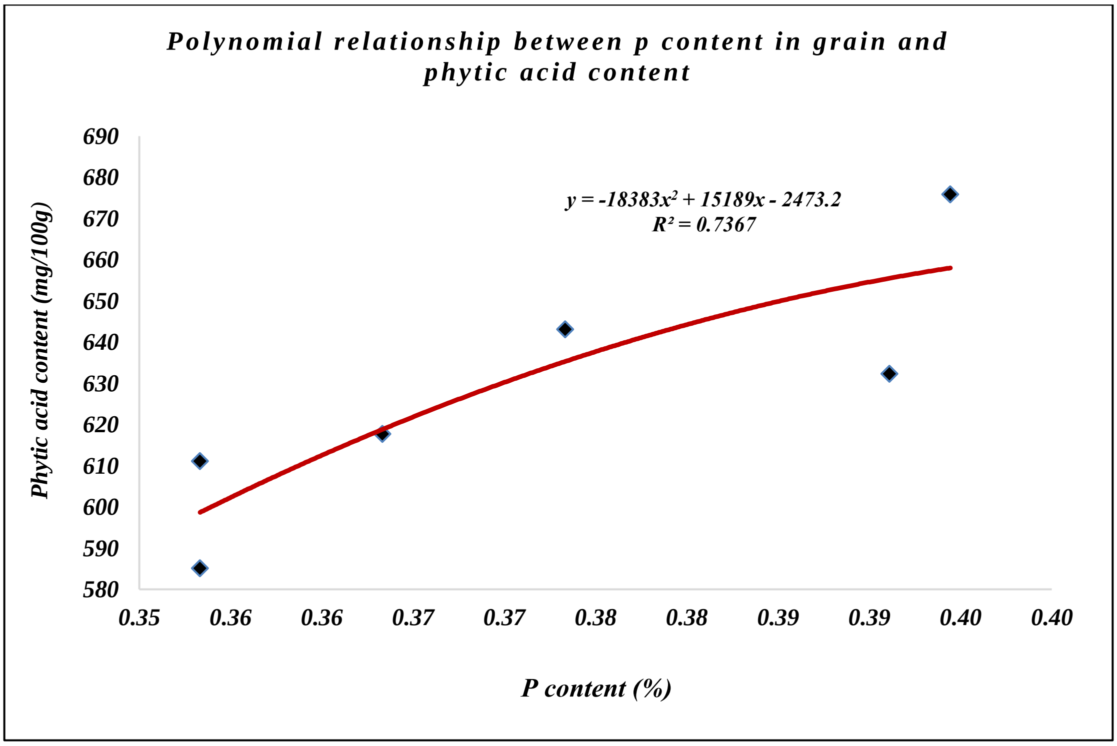


Fig 4.2.23 Polynomial relationship between P content in grain and phytic acid content

The above-mentioned findings were in line with the one reported by many workers (Raboy *et al*., 1984; Wise, 1995; Lott *et al*., 2000; Lu *et al.*, 2011). The data clearly revealed that there was genotypic difference in the value of phytic acid content and as well as phytic: Zn molar ratio. The values were significantly higher in local cultivar as compared to the improved varieties JS-335 and JS 97-52 in both the years. This result was similar to the findings reported by Erdal *et al.* (2002), Karkle and Beleia (2010). Our results also supported by the findings of Chitra *et al*. (1995) who reported there was variability of phytic acid content and total phosphorus in different genotypes of legumes who further indicated that this anti-nutritional factor significantly varied among and within the same species of legumes and the highest phytic acid content found in soybean. Significant difference on the phytic acid: Fe molar ratio was observed upon Fe fertilization treatments. The highest value of the ratio was observed in control which reduces with increasing level of ferrous sulphate till certain limit as depicted in Table 4.2.17. Control treatment recorded the highest value (10.05, 10.68) and lowest was observed in Fe_3 (Foliar spray application of ferrous sulphate @ 1.5%) with (7.26, 7.79) and Fe_4 (Foliar spray application of $FeSO_4.7H_2O$ @ 2% at pre-flowering stage) with (7.97, 8.91). There was significant reduction upon foliar application of $FeSO_4.7H_2O$ across all the varieties. As revealed by the pooled data there was an appreciable percent reduction of phytic acid: Fe molar ratio in Fe_3 (27.41%) against the control. The reduction percentage in other treatments was in the range of 17.37-18.58%. Our result on the effect of ferrous sulphate on phytic acid: Fe molar ratio were in conformity to the finding of Hao *et al*. (2021) in the experiment on wheat who indicated that upon application of Fe there was a slight reduction of the phytic acid: Fe molar ratio (7.90%) although not significant.

4.2.7.4 Correlation study of Fe fertilization on different important parameters

Correlated studies of different plant parameters under the influence of Fe

Table 4.2.18 Correlation study of Fe fertilization on important parameters (from pooled data)

Pearson Correlation coefficient	*Chlorophyll content @ 60 DAS*	*N content in grain (%)*	*P content in grain (%)*	*K content in grain (%)*	*Protein content in grain (%)*	*Oil content in grain (%)*	*Number of pods plant^{-1}*	*100- seed weight (g)*	*Fe content in grain (mg kg^{-1})*	*Fe uptake by grain (mg pot^{-1})*	*Phytic acid content (mg/100 g)*	*PA: Fe Molar ratio*	*Seed yield (g pot^{-1})*
Chlorophyll content @ 60DAS	1												
N content in grain (%)	.978**	1											
P content in grain (%)	-.763	-.843*	1										
K content in grain (%)	.949**	.956**	-.673	1									
Protein content in grain (%)	.975**	1.000**	-.846*	.954**	1								
Oil content in grain (%)	.950**	.879*	-.687	.815*	.875*	1							
Number of pods plant^{-1}	.877*	.941**	-.770	.957**	.941**	.685	1						
100- seed weight (g)	.829*	.907*	-.830*	.842*	.908*	.668	.916*	1					
Fe contentin grain (%)	.932**	.920**	-.787	.812*	.920**	.927**	.753	.841*	1				
Fe uptake by grain (mg pot^{-1})	.984**	.982**	-.836*	.923**	.980**	.921**	.890*	.895*	.944**	1			
Phytic acid content (mg/100 g)	-.830*	-.876*	.889*	-.817*	-.875*	-.706	-.885*	-.851*	-.718	-.888*	1		
PA: Fe Molar	-.923**	-.944**	.913*	-.835*	-.943**	-.863*	-.850*	-.915*	-.925**	-.975**	.920**	1	
Seed yield (g pot^{-1})	.936**	.950**	-.831*	.917*	.948**	.831*	.923**	.902*	.843*	.970**	-.960**	-.960**	1

*. Correlation is significant at the 0.05 level (2-tailed);

**. Correlation is significant at the 0.01 level (2-tailed).

Table 4.2.19 Effect of varieties and iron application on available soil NPK & DTPA- Extractable Fe

Treatments	**Available Nitrogen (kg ha^{-1})**			**Available Phosphorus (kg ha^{-1})**			**Available Potassium (kg ha^{-1})**			**DTPA-Extractable Fe (ppm)**		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
Varieties												
V_1	348.44	362.12	355.28	23.69	24.71	24.20	271.68	275.21	273.45	82.03	84.05	83.04
V_2	356.82	352.26	354.54	24.62	24.88	24.75	295.28	269.59	282.43	75.97	80.89	78.43
V_3	340.41	344.11	342.26	24.15	23.35	23.75	260.73	273.97	267.35	78.34	74.37	76.36
SEm±	***10.56***	***9.85***	***7.22***	***0.72***	***0.83***	***0.55***	***8.05***	***8.70***	***5.92***	***2.48***	***2.72***	***1.84***
CD at 5%	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***23.07***	***NS***	***NS***	***NS***	***7.79***	***NS***
Fertilization												
Fe_0	341.44	358.85	350.15	24.41	24.61	24.51	276.24	267.17	271.71	72.12	73.08	72.60
Fe_1	338.69	320.71	329.70	25.66	25.38	25.52	275.41	274.39	274.90	81.23	76.84	79.03
Fe_2	347.64	341.45	344.54	24.29	25.45	24.87	282.66	275.47	279.06	73.89	81.69	77.79
Fe_3	360.99	365.28	363.13	24.36	23.91	24.14	276.50	271.74	274.12	80.62	77.12	78.87
Fe_4	347.15	358.80	352.97	23.09	23.19	23.14	272.53	265.50	269.02	85.89	87.34	86.62
Fe_5	355.45	371.91	363.68	23.11	23.33	23.22	272.03	283.26	277.65	78.93	82.54	80.74
SEm±	***14.93***	***13.92***	***10.21***	***1.02***	***1.18***	***0.78***	***11.38***	***12.30***	***8.38***	***3.50***	***3.84***	***2.60***
CD at 5%	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***

found in this study was that Fe content was significantly correlated with protein content (0.920 at 1 % level) and with oil content of grain (0.927). Protein content positively correlated with N content in grain (1.0 at 1% level). Phytic acid was found to be positively correlated with P content in grain (0.889). Similarly, it shows it was highly correlated with the PA: Fe molar ratio (0.913). But phytic acid was negatively correlated with Fe uptake by grain (-0.888) and much more on PA: Fe molar ratio against Fe uptake (-0.975). Seed yield was highly significant correlated with Fe content (0.843) and Fe uptake (0.970).

4.2.8 Postharvest soil chemical and biological properties

4.2.8.1 Available soil NPK

Data pertaining to available soil NPK after harvest of soybean are presented in Table 4.2.19.

Available nitrogen, phosphorus, potassium and DTPA-Extractable Fe status of the post-harvest soil of crop was determined separately in both the years of study and pooled analysis data was also depicted accordingly. Different varieties, application rate of iron (Fe) along with RDF and their interaction did not influence the available nitrogen, available potassium, available phosphorus and DTPA-Extractable Fe of soil as shown in pooled data. However, in varieties data ranges varied as 340.41-362.12 kg ha^{-1} (N), 260.73-295.28 kg ha^{-1} (K), 23.35-24.88 kg ha^{-1} (P) and 74.37-84.05 ppm (DTPA-Extractable Fe). Upon Fe fertilization the soil data ranges 320.71-365.28 kg ha^{-1} (N), 265.50-283.26 kg ha^{-1} (K), 23.11-25.45 kg ha^{-1} (P) and 72.12-87.34 ppm (DTPA-Extractable Fe) respectively.

The non-significant variations in the values of soil chemical properties *viz*., N, P and K upon foliar application and soil application of $FeSO_4.7H_2O$ may be due to its insignificant or negligible contribution. The soil applied $FeSO_4.7H_2O$ was of very low quantity to produce any significant role in soil chemical properties. Therefore, this application could not bring to any differences in the soil chemical properties in both the years.

4.2.8.2 Soil organic carbon and pH status:

Different varieties and foliar application of iron (Fe) along with RDF and their interaction did not influence the organic carbon content and pH status of soil after harvest of maize crop in both the year of study as well as in pooled data. However, among the varieties, the organic carbon data ranges varied as 1.28-1.34% and 1.24-1.35% respectively (Fig 4.2.20).

With the Fe fertilization, Soil pH data ranges varied as 4.52-4.64 and 4.48-4.73 respectively.

4.2.8.3 Dehydrogenase activity and Fluorescein diacetate

The data on dehydrogenase activity (DHA) and fluorescein diacetate (FDA) is presented in Table 4.2.21 and illustrated in Fig 4.2.26 & Fig 4.2.27. Each experimental year soil samples were collected to study the post-harvest microbial activities. As revealed by the pooled data, dehydrogenase activity was influenced by different varieties and application rates of iron (Fe). JS-335 showed the best results (43.53, 43.31µg TPF g^{-1} soil hr^{-1}) for both experimental years and among the various iron fertilization, Fe_5 revealed the best results (44.91 and 42.83 µg TPF g^{-1} soil hr^{-1}).

As per the results higher value of dehydrogenase among varieties was found to be superior in JS-335. The reason for this could be due to early maturity of this cultivar which premature leaf senescence and leaf shedding was observed to be higher resulting to more leaf litters added to soil. This effect might have resulted to comparatively higher dehydrogenase activity in JS-335 compared to the other two varieties. The positive response of Fe application on dehydrogenase activity of soil is supported by the finding of Kumawat *et al*. (2008).

Table 4.2.20 Effect of varieties and iron application on soil organic carbon and pH

Treatments	**Organic carbon (%)**			**Soil pH**		
	2018	***2019***	***Pooled***	***2018***	***2019***	***Pooled***
Varieties						
V_1	1.38	1.31	1.34	4.64	4.62	4.63
V_2	1.35	1.30	1.32	4.53	4.54	4.53
V_3	1.28	1.29	1.28	4.52	4.61	4.56
SEm±	***0.03***	***0.02***	***0.02***	***0.06***	***0.06***	***0.04***
CD at 5%	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***
Fertilization						
Fe_0	1.28	1.24	1.26	4.48	4.54	4.51
Fe_1	1.34	1.27	1.30	4.57	4.59	4.58
Fe_2	1.35	1.33	1.34	4.53	4.60	4.57
Fe_3	1.31	1.35	1.33	4.48	4.51	4.49
Fe_4	1.38	1.30	1.34	4.58	4.59	4.58
Fe_5	1.36	1.30	1.33	4.73	4.69	4.71
SEm±	***0.04***	***0.03***	***0.03***	***0.08***	***0.09***	***0.06***
CD at 5%	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***

Table 4.2.21 Effect of varieties and and iron application on soil microbial properties

Treatments	Dehydrogenase activity (µgTPF g^{-1} hr^{-1})			Fluorescein diacetate (FDA) (µg g^{-1} soil/0.5 hr)		
	2018	*2019*	*Pooled*	*2018*	*2019*	*Pooled*
Varieties						
V_1	43.53	43.31	43.42	3.36	3.45	3.40
V_2	39.54	40.17	39.86	3.33	3.27	3.30
V_3	36.16	36.20	36.18	3.32	3.37	3.34
SEm±	***1.35***	***1.37***	***0.96***	***0.11***	***0.11***	***0.08***
CD at 5%	***3.86***	***3.94***	***2.71***	***NS***	***NS***	***NS***
Fertilization						
Fe_0	35.19	36.61	35.90	3.15	3.10	3.13
Fe_1	39.20	39.20	39.20	3.21	3.35	3.28
Fe_2	36.80	37.11	36.96	3.25	3.28	3.27
Fe_3	39.83	41.09	40.46	3.62	3.63	3.63
Fe_4	42.54	42.54	42.54	3.44	3.46	3.45
Fe_5	44.91	42.83	43.87	3.35	3.35	3.35
SEm±	***1.90***	***1.94***	***1.36***	***0.16***	***0.16***	***0.11***
CD at 5%	***5.46***	***NS***	***3.83***	***NS***	***NS***	***NS***

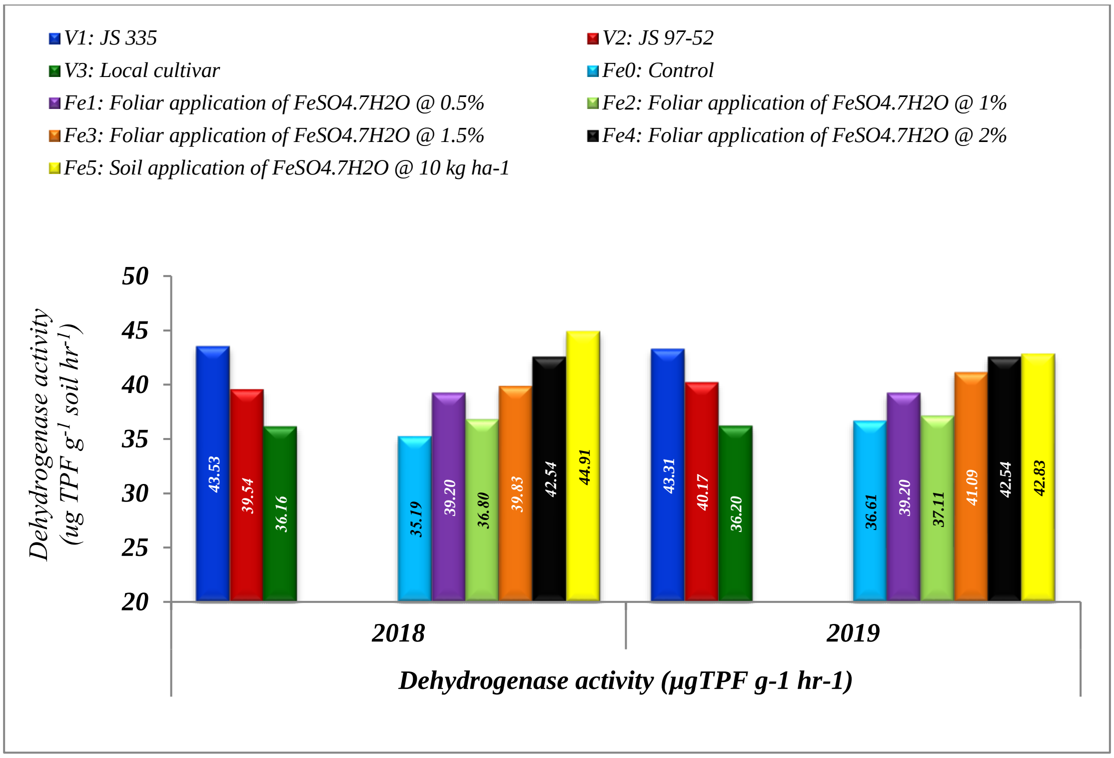


Fig 4.2.24 Effect of varieties and iron fertilization on dehydrogenase activity during 2018 and 2019

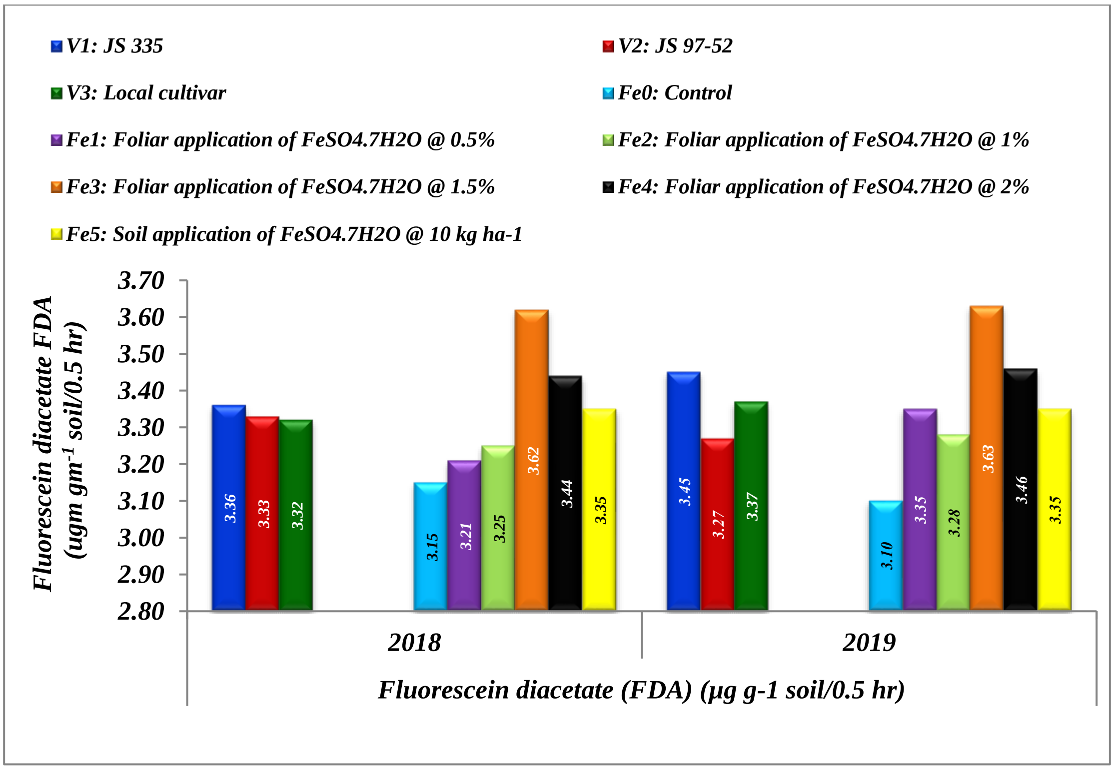


Fig 4.2.25 Effect of varieties and iron fertilization on Fluorescein diacetate FDA during 2018 and 2019

CHAPTER V

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

5.1 Experiment I: "Biofortification of zinc in Soybean (*Glycine max* (L.) Merrill) under foothill of Nagaland"

The field experiment was conducted for two years during *kharif* 2018 and 2019 at Agronomy research farm of SASRD, Nagaland University, Medziphema, Nagaland to assess the agronomic and biofortification response of soybean varieties to different Zn fertilization. The experiment was laid out in factorial RBD with three varieties of soybean (JS-335, JS 97-52 and local cultivar) under seven Zn fertilization treatments (Z_0- control, Z_1: Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$, Z_2: Soil application of Zn @ 5 kg ha^{-1} through ZnO, Z_3: Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$ + Two foliar spray application of $ZnSO_4$ @ 0.25% at pre-flowering and pod formation stages, Z_4: Soil application of Zn @ 5 kg ha^{-1} through ZnO + Two foliar spray application ZnO @ 0.25% at pre-flowering and pod formation stages, Z_5: Three (3) foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5% at maximum vegetative stage, pre-flowering and pod formation stage and Z_6:Three (3) foliar spray applications of ZnO @ 0.5% at maximum vegetative stage, pre-flowering and pod formation stage). Recommended dose of NPK (RDF) of 20-60-40 kg ha^{-1} NPK (in the form of Urea, SSP and MOP) was used along with FYM @ 10 t ha^{-1} as general dose for all plots irrespective of treatments. The source of zinc usewaszinc sulphate (21% zinc) and zinc oxide (80% zinc) during both the year of experimentation.

The important salient findings of the experiments are summarized as below

- Plant height varied significantly among varieties irrespective of zinc fertilization at all crop stages where local cultivar markedly superior over the others. Plant height was found to vary significantly upon zinc fertilization. Three foliar spray application of zinc sulphate @ 0.5% found to effectively improve plant height. Among the two sources, $ZnSO_4.7H_2O$ was found to be more effective over ZnO.
- The number of leaves was found significantly higher in JS 97-52 at 60 DAS and local cultivar at 90 DAS. Zinc application failed to produce significant effect on number of leaves except at 60 DAS. The number of branches was found to be significantly higher in JS 97-52 and local cultivar and zinc fertilization effectively

resulted in higher branches under three foliar spray application of zinc sulphate @ 0.5% than the others.

- The dry matter accumulation was significantly higher in local cultivar over the other two varieties at all crop stages. Zinc fertilization was significantly different on the dry matter yield from 60 DAS onwards and was found significantly higher over the control. Slightly higher DMA was observed in three (3) foliar application of zinc sulphate @ 0.5% and soil application of zinc sulphate @ 5 kg ha^{-1} with two foliar spray $ZnSO_4.7H_2O$ @ 0.25%.
- Leaf area varied significantly among varieties where local cultivar markedly superior over the others at all crop stages. Among zinc fertilization treatments, three foliar sprays of $ZnSO_4.7H_2O$ @ 0.5% showed superiority over the other treatments but at par with combined soil (5 kg ha^{-1}) and foliar spray of $ZnSO_4.7H_2O$ @ 0.25%. The same trend was observed in LAI.
- Crop growth rate (CGR) at 30-60 DAS was significantly high in local cultivar followed by JS 97-52. Irrespective of varieties, three foliar applications of $ZnSO_4.7H_2O$ @ 0.5% and combined application of soil + foliar (Z_3) were found superior over others. The CGR value at 60-90 DAS was lesser than at the previous crop stage. JS-335 found to be significantly higher than the other two. Significantly higher value observed in Z_5.
- Relative growth rate (RGR) at 30-60 DAS was significantly higher in JS 97-52 and remained at par with local cultivar. Zinc fertilization failed to produce any significant variations at this stage. RGR at 60-90 DAS was observed to be reversed of the previous stage as JS-335 was way higher than the other two. While zinc application resulted to no significant effect on RGR.
- Net assimilation rate (NAR) at 30-60 DAS was found significantly high in JS 97-52 followed by local cultivar. Zinc fertilization failed to cause any significant difference in both years of investigations. The interaction effect was found significant in the first year of study and the pooled data.
- Variety JS 97-52 (0.87mgg^{-1}) was statistically at par with JS 335 in chlorophyll "a" and "b" and significantly higher than local variety at all the crop stages. Zinc fertilization found to significantly enhance the chlorophyll content at 60 DAS. Z_5 (Three foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5%) significantly surpassed the rest of zinc treatments while they were statistically at par to each other. Interaction effect was found significant only in chlorophyll "b" at 60 DAS.

- Varieties were found to differ significantly on the phenological parameters. JS-335 took the shortest time to achieve 50% flowering and maturity stage when compared to the other two. Local cultivar took the longest time to achieve both stages. Zinc application failed to cause any significant effect on both days to 50% flowering and maturity during both the years of study.
- Number of nodules and nodule dry weight were found to be significantly higher in local variety both at 45 and 60 DAS while the two varieties were at par with each other during both the years of study. Among zinc fertilization treatments, the one with soil and foliar application (Z_3 & Z_4) were found significantly superior over the others on nodules number in $ZnSO_4.7H_2O$.
- Yield attributing characters except number of seeds pod^{-1} differed significantly among the varieties. Whereas zinc fertilization failed to result any significant variation on same attributes except on the number of pods plant^{-1}. The highest number of pods plant^{-1} was found in JS 97-52 which was statistically significant over the other two. 100 seed weight was significantly higher in JS-335. Zinc fertilization resulted to significant variation in the number of pods plant^{-1}with highest value observed in Z_5 (Three foliar spray of $ZnSO_4.7H_2O$ @ 0.5%).
- Seed yield significantly varied among the varieties where JS 97-52 recorded the highest seed yield which was followed by JS-335 and least in local cultivar. Zinc fertilization significantly affects the seed yield in both years. The highest value observed in Z_3 (Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$ + 2 foliar spray @ 0.25%) which was statistically at par with almost all zinc treatments except control. Superiority with respect to seed yield was in the order $Z_3 > Z_5 > Z_4 > Z_6 > Z_1 > Z_2 > Z_0$.
- Stover yield was significantly affected by varieties and zinc fertilization as well in both the years of study. The variety JS 97-52 had the highest stover yield which was significantly higher than local and JS-335. Among zinc fertilization treatments, three (3) foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5% (Z_5) resulted to highest stover yield followed by Z_3.
- Harvest index varied significantly among varieties with the highest value observed in JS-335 which was statistically at par with JS 97-52 and lowest in local cultivar. There was a no significant difference in harvest index of different Zn fertilization.
- N content in grain and stover did not vary significantly among the varieties in both the years. However, N uptake by grain and stover varied significantly among the

varieties as the highest N uptake by grain observed in JS 97-52 followed by JS-335. The stover N uptake was significantly higher in JS 97-52 which was statistically at par with local cultivar. Zinc fertilization resulted in significant variation in N content in grain and stover. Three (3) foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5% (Z_5) resulted in highest N content in grain and stover as well and the rest being at par each other. Similarly, N uptake by grain and stover was significantly higher in Z_3 and Z_5 and total N uptake was highest in Z_5.

- Phosphorus content in grain and stover were significantly varied among varieties. Similarly, P uptake by grain and stover differed significantly among varieties. Higher P content was observed in local cultivar and least in JS-335. P uptake by grain and total P uptake was significantly high in JS 97-52. Zinc fertilization did not result to any significant difference on the P content both grain and stover and uptake by grain and stover as well in both the years.
- Potassium content in grain was non-significant among varieties as well as zinc fertilization in both years of study. Whereas K content in grain differed significantly among the varieties where slightly higher K was seen in local cultivar. K uptake by grain differed significantly among varieties as well as zinc fertilization. Higher K uptake by grain was observed in JS 97-52. Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$ + Two foliar spray (Z_3) and three foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5% (Z_5) significantly enhanced the K uptake by grain and stover.
- Zinc content in grain varied significantly among varieties where JS-335 and local cultivar were found statistically at par with each other but significantly superior over JS 97-52. Among zinc fertilizations, three foliar applications of $ZnSO_4.7H_2O$ @ 0.5% (Z_5) were found superior and were at par with Z_3 and Z_4in both the experimental years. Zinc content in stover was found non-significant among varieties in both years.
- Zinc uptake by grain and stover varied significantly among varieties as well as zinc fertilization. Zinc uptake by grain observed to be significantly higher in JS 97-52 compared to other varieties owing to it superiority in yield. Among zinc fertilizations, three foliar sprays of $ZnSO_4.7H_2O$ @ 0.5% (Z_5) markedly superior over the others but statistically at par with Z_3 and Z_4. Zinc uptake by stover was found significantly high in both local cultivar which was at par with JS 97-52. Similar trend was also observed under zinc fertilization as that of grain uptake.

- Protein content in grain did not differ significantly among varieties. Zinc fertilization significantly influenced the protein in grain. The highest protein content was observed in Z_5- three foliar sprays of $ZnSO_4.7H_2O$ @ 0.5%which was at par with the rest of the zinc treatments. Protein yield was significantly superior in JS 97-52and least in local cultivar.
- Oil content varied significantly among varieties where JS 97-52 was found highest value and least in local cultivar. Three foliar sprays of $ZnSO_4.7H_2O$ @ 0.5% (Z_5) was found to be significantly higher than the rest but remained at par with (Z_3) soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$ + Two foliar spray application @ 0.25%. Oil yield was found to be highest in JS 97-52 was significantly higher than the two varieties. The interaction effect of variety and zinc was found significant in both the years. The combination V_2Z_5 found to be the highest followed by V_2Z_3.
- The phytic acid content in grain is an antinutritional factor which reduces phyto availability of micronutrient of grain. Local cultivar was found to have the highest phytic acid content and lowest recorded in JS-335. With zinc fertilization, phytic tend to decline where the highest value was recorded in control and lowest in Z_3 which was at par with Z_5. Similar trend was also observed in Phytic acid: zinc molar ratio. Among the varieties, local cultivar has the highest value and least in JS-335. Control treatment significantly has the highest value and least with Z_3 in both the years.
- Partial factor productivity was significantly influenced by varieties where the highest value was observed in JS 97-52 and least in local cultivar. Among Zinc fertilization, three foliar sprays of $ZnSO_4.7H_2O$ @ 0.5% (Z_5) gave the highest PFP value whereas the least value was in Z_4 (Soil application of Zn @ 5 kg ha^{-1} through ZnO + Two foliar spray application ZnO @ 0.25%).
- Similar trend was also observed in agronomic efficiency (AE) as PFP. The highest AE was found in JS 97-52 and lowest in local cultivar. Among zinc treatments, the highest value was found in (Z_5) three foliar sprays of $ZnSO_4.7H_2O$ @ 0.5%.
- Biofortification Recovery Efficiency BRE_{Zn} was found non-significant among varieties and significantly influenced by zinc fertilization. The highest value was observed in (Z_5) three foliar sprays of $ZnSO_4.7H_2O$ @ 0.5%.

- Zinc harvest index was found significant among the varieties and non-significant with zinc fertilization. The highest value was observed in JS-335 which was statistically at par with JS 97-52.
- The physiological efficiency was non-significant among varieties whereas varied significantly with zinc fertilization. The highest value upon zinc fertilization was observed in Z_3 (soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$ + Two foliar spray application of $ZnSO_4$ @ 0.25%).
- Soil pH and organic carbon was not significantly influenced by varieties and zinc fertilization in both the years of investigation.
- Soil available nitrogen (N) significantly varied among varieties where the highest value was recorded in JS 97-52 which was statistically at par with local cultivar. Fe fertilization failed to produce significant effect on the soil available N in both the years.
- Available soil phosphorus (P) did not vary significantly among varieties varied significantly in Fe fertilization. Available soil potassium did not vary significantly among varieties and Fe applications.
- DTPA-extractable Znvaried significantly among varieties and Zn fertilization. The highest value was recorded in JS 97-52. Zn fertilization resulted in significant variation in the second year of experiment. Highest values ware observed in combined treatments of soil and foliar applications (Z_3 Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$ + Two foliar spray application of $ZnSO_4$ @ 0.25%).
- The highest net return was observed in JS 97-52 in both the years of experimentation while the lowest in local variety. Among Zn treatments, application of three foliar spray of $ZnSO_4.7H_2O$ @ 0.5% resulted the maximum net return and BC ratio in both the years.

5.2 Experiment II: "Biofortification of iron in soybean (*Glycine max* (L.) Merrill) under foothill of Nagaland"

This second experiment was conducted in as pot experiment. It was laid out in factorial CRD with three varieties of soybean (JS-335, JS 97-52 and local cultivar) under sixFe fertilization treatments (Fe_0- control, Fe_1: Foliar spray application of $FeSO_4.7H_2O$ @ 0.5% at pre-flowering stage, Fe_2:$FeSO_4.7H_2O$ @ 1% at pre-flowering stage, Fe_3: $FeSO_4.7H_2O$ @ 1%at pre-flowering stage, Fe_4: Foliar spray application of $FeSO_4.7H_2O$ @ 1.5% at pre-flowering stage, Fe_5: Soil application of $FeSO_4.7H_2O$ @ 10 kg ha^{-1}.

- Plant height significantly differed among varieties but failed to show significance difference upon zinc fertilization. Local cultivar significantly the tallest plant followed by JS 97-52 and JS-335. Under Fe fertilization although no significant difference observed however the treated plants showed numerical higher value.
- The number of branches was significant influenced only at 60 DAS and 90 DAS among varieties and Fe fertilization failed to produce significant effect except at 90 DAS. Significantly more branches recorded in JS 97-52 and least in local cultivar. At peak crop stage, 90 DAS Fe_3: $FeSO_4.7H_2O$ @ 1%at pre-flowering stage recorded the highest value.
- Number of leaves per plant varied significantly among the varieties with crop stages. At 60 DAS, highest leaves plant^{-1} observed in JS 97-52 whereas as 90 DAS local cultivar recorded more leaves. Fe fertilization caused significant effect at 60 DAS in the second year only, where significantly higher number of leaves recorded in Fe_3 ($FeSO_4.7H_2O$@ 1%at pre-flowering stage).
- Dry matter accumulation (DMA) significantly differed among varieties throughout the crop duration. JS 97-52 was significantly recorded higher DMA although at par with local cultivar at 90 DAS and harvest stage. Fe fertilization showed no significant influenced on DMA except at 90 DAS where significantly higher value recorded under Fe_3.
- Leaf area significantly differed among varieties where highest value observed in local cultivar all through the crop stages. Fe fertilization did cause significant variation at 60 DAS. Highest value observed at Fe_3 (1.5% $FeSO_4$) followed by Fe_2 (1% $FeSO_4$).
- Chlorophyll content significantly differed among varieties throughout the crop stages. Significantly more value observed in JS-335 which remained at par with JS 97-52 and least in local. There was significant variation under Fe fertilization at 60 and 90 DAS. Highest chlorophyll content observed in Fe_3 ($FeSO_4.7H_2O$ @ 1.5%).
- Days to 50% flowering and days to maturity was significantly differed among varieties where the longest duration was observed in local cultivar and the other two at par to each other. Fe fertilization failed to produce any significant effect on these parameters.

- Number of nodules and nodules dry weight significantly varied among varieties. Local cultivar significantly recorded higher values while JS-335 and JS 97-52 were at par with each other in most cases.
- Yield attributing characters was found significantly differed among varieties except number of seeds pod^{-1}. Significantly higher number of pods plant^{-1}was observed in JS 97-52. Pod length and 100-seed weight was significantly higher in JS-335. Fe fertilization did not cause any significant difference in all the yield attributes although the Fe treated plant had slightly higher value over the control plants.
- Seed yield pot^{-1}was recorded highest in JS 97-52 which was significantly superior to the other two. Fe fertilization did cause significant difference on the seed yield where the highest value observed in Fe_3 (Foliar application of $FeSO_4.7H_2O$ @ 1.5%).
- Similarly, stover yield was significantly high in JS 97-52 while JS-335 and local cultivar were at par with each other. Fe fertilization resulted to significant difference in the second year and the pooled data. Significantly highest value was recorded in Fe_3 (Foliar application of $FeSO_4.7H_2O$ @ 1.5%). The harvest index was significantly high in JS-335 and remained at par with JS 97-52 while Fe fertilization did not cause any significant effect.
- Nitrogen content (N) in grain and stover significantly varied among the varieties. Higher values of N content in grain and stover was observed in JS-335 and JS 97-52. Significantly high value of N content in grain observed in Fe_3 (Foliar application of $FeSO_4.7H_2O$ @ 1.5%) whereas no significant effect of Fe on N content in stover observed.
- Nitrogen uptake was significantly high in JS 97-52 and least in local cultivar in both the years. Uptake of N by grain and stover was significantly high in Fe_3 (Foliar application of $FeSO_4.7H_2O$ @ 1.5%). Similar trend on total N uptake also observed in both the factors.
- P content in grain was non-significant among varieties as well as Fe fertilization although a reverse trend was observed with Fe application. Whereas, P content in stover was significantly higher in local cultivar and no $FeSO_4.7H_2O$ (Control) recorded highest P content numerically although non-significant.

- The P uptake by grain and stover was significant among varieties where highest value was observed in JS 97-52 while Fe fertilization failed to produce significant results in both years.
- K content in grain and stover was observed to be non-significant among varieties as well as with Fe fertilization in both years of study. But the K uptake by grain was significantly higher in JS 97-52 and Fe_3 (Foliar application of $FeSO_4.7H_2O$@ 1.5%) recorded the highest K uptake among the Fe treatments. The same trend was also observed in total K uptake by grain+stover.
- Iron content in grain was significantly influenced by varieties as well as Fe fertilization. JS 97-52 and JS-335 were at par with each other and observed with higher Fe content in grain. The application of $FeSO_4.7H_2O$ resulted in biofortification effect which significantly enhanced Fe density in grainin both years. The highest Fe content in grain was highest in Fe_3 (Foliar application of $FeSO_4.7H_2O$@ 1.5%) although statistically at par with the rest of Fe treatments.
- Iron content in stover was not significantly affect by varieties as well as Fe fertilization in both the years although Fe treated plants contained higher value of Fe over control.
- Iron uptake by grain and stover found to be significantly affected by varieties and Fe fertilization as well. Higher uptake by grain and stover was observed in JS 97-52 while Fe_3 (Foliar application of $FeSO_4.7H_2O$ @ 1.5%) recorded highest among Fe treatments.
- Protein content found to be significantly affected by varieties where JS-335 recorded the highest seed crude protein and at par with JS 97-52. Fe_3 (Foliar application of $FeSO_4.7H_2O$ @ 1.5%) significantly resulted the highest protein content.
- Oil content varied significantly among varieties only in the first year with significant higher oil observed in JS 97-52. Fe fertilization did not result to significant difference in oil content in both years.
- The phytic acid content in grain varied significantly among varieties where local cultivar contained the highest value and JS-335 observed the lowest value in both years. Application of $FeSO_4.7H_2O$ did not significantly change the phytic acid content although the highest value observed in control treatment. With Fe fertilization, there was reduction in phytic acid content. The same trend was also

observed in the phytic acid: Fe molar ratio but significant difference in both varieties and Fe applications.

- Soil chemical properties *viz*., soil pH, organic carbon and available NPK did not vary significantly among varieties and upon Fe fertilization in both the years. The same was in the case of DTPA-Extractable Fe except in the second-year experiment in varieties where JS-335 recorded the highest value.
- Dehydrogenase activity varied significantly among varieties as well as Fe fertilization. The highest value was observed in JS 97-52 and application of $FeSO_4.7H_2O$ @ 2% as foliar recorded the highest value.
- Fluorescein diacetate (FDA) did not vary significantly among varieties as well as under Fe fertilization in both the years of experimentation although numerically Fe treated pots recorded higher values over the control.

Conclusion:

From these studies it is concluded that agronomic biofortification of zinc in soybean is possible with the application of zinc. Application of three foliar sprays of $ZnSO_4.7H_2O$ resulted to the highest response in enhancement of grain Zn content, grain quality and reduction of antinutrient factors like phytic acid with the highest net profits and BC ratio. Among the varieties, JS 97-52 showed highest response in respect of quality, yield and profit. Foliar application of $FeSO_4.7H_2O$ @ 2% was the most effective methods in enhancing grain yield, quality, and enrichment of Fe density in grain. These two applications *viz*. three foliar sprays of $ZnSO_4.7H_2O$ and foliar application of $FeSO_4.7H_2O$ @ 2% which are easy, low cost and effective alternative means can be recommended for biofortifying soybean grain with supplementation of zinc and iron in the region.

Recommendation:

Based on the aboved-mentioned findings through the experiment I on biofortification of zinc in soybean, it may be recommended that variety JS 97-52 is a better option as far as yield and net return is concerned. However, with respect to grain quality like zinc content and lower phytic acid, JS-335 was found superior. Three foliar applications of zinc sulphate @ 0.5% at maximum vegetative stage, pre-flowering and pod formation stage can be recommended as zinc biofortification strategy for achieving higher seed yield, zinc content in grain and lowering phytic acid along with higher net return.

Similarly, through the experiment II on biofortification of iron in soybean it may be recommended that two foliar spray applications of iron sulphate @ 1.5% at preflowering stage was found most effective for enhancing growth, yield and quality of soybean and the variety JS 97-52 was found most preferable as far as yield and quality is concerned.

REFERENCES

REFERENCES

Abbas, G., Hussain, F., Anwar, Z., Khattak, J.Z.K. and Ishaque, M. 2012. Effects of iron on the wheat crop (*Triticum aestivum* L.) by uptake of nitrogen, phosphorus and potassium. *Asian Journal of Agricultural Sciences*. **4**(3): 229-235.

Abdel, E., Latif, M. A. and Haggan, E. L. 2014. Effect of micronutrients foliar application on yield and quality traits of soybean cultivars. *International Journal of Agriculture and Crop Science*. **7**(11): 908-914.

Abdoli, M., Esfandiari, E., Mousavi, S.B. and Sadeghzadeh, B. 2014. Effects of foliar application of zinc sulfate at different phenological stages on yield, formation and grain zinc content of bread wheat (cv. Kohdasht). *Azarian Journal of Agriculture*. **1**(1): 11-16.

Adam, G. and Duncan, H. 2001. Development of a Sensitive and Rapid Method for the Measurement of Total Microbial Activity Using Fluorescein Diacetate (FDA) in a Range of Soils. *Soil Biology & Biochemistry*. **33**. 943-951.

Adams, M.L., Norvell, W.A., Philpot, W.D. and Peverly, J.H. 2000. Spectral detection of micronutrient deficiency in 'Bragg' soybean. *Agronomy Journal*. **92**(2): 261-268.

Afra, J. M. and Mozafar, M. 2017. The Effect of Phosphorus and Zinc Fertilizer on the Elements Concentration of Soybean Cultivars Seed (*Glycine max* L.*). Bulletin Environment, Pharmacology and Life Sciences*. **6**: 41-48.

Aher, S. B., Lakaria, B. L., Kaleshananda, S., Singh, A. B., Ramana, S., Ramesh K. and Thakur, J. K. 2015. Effect of organic farming practices on soil and performance of soybean (*Glycine max* (L.) Merrill) under semi-arid tropical conditions in Central India. *Journal of Applied and Natural Science*. **7**(1): 67-71.

Ahmed, N., Hussain, H.Z., Ali, M.A., Rahi, A.A., Saleem, M. and Ahmad, F. 2022. Effect of zinc on chlorophyll contents, gas exchange attributes and zinc concentration in rice. *Pakistan Journal of Botany*. **54**(1): 17-24.

Ali, B., Ali, A., Tahir, M. and Ali, S. 2014. Growth, Seed yield and quality of mungbean as influenced by foliar application of iron sulfate. *Pakistan Journal of Life and Social Sciences*. **12**(1): 20-25.

Ali, S., Shah, S. and Arif, M. 2021. Agronomic Biofortification with Zinc and Iron for the Improvement of Wheat Phenology and Yield. *Sarhad Journal of Agriculture*. **37**(3): 901-914.

Anitha, S., Sreenivasan, E. and Purushothaman, S.M. 2005. Response of cowpea {*Vigna unguiculata* (L.) Walp.} to foliar nutrition of zinc and iron in the oxisols of Kerala. *Legume Research-An International Journal*. **28**(4): 294-296.

Anonymous. 2009. Nutrient requirement and recommended dietary allowancesfor Indians. National Institute of Nutrition, ICMR, Hyderabad. 331-332.

Anonymous. 2010. Directorate of Agriculture, Department of Agriculture. Report, Government of Nagaland. Directorate of Soil and Water conservation, Government of Nagaland.

Anonymous. 2017. Directorate of Economics and Statistics. Department of Agriculture, Cooperation & Farmers' Welfare, Ministry of Agriculture.

Anonymous. 2020. Directorate of Economics and Statistics, MOA & FW, New Delhi.

AOAC (1960) Official Methods of Analysis. 10th Edition, Association of Official Analytical Chemists, Washington DC.

Arif, M., Chohan, M.A., Ali, S., Gul, R. and Khan, S. 2006. Response of wheat to foliar application of nutrients. *Journal of Agricultural, Biological and Environment.* **1**(4): 30-34.

Awlad, H M., Choudhary, M.A.H. and Talukder, N.M. 2003. Effect of Sulphur and Zinc on Nodulation Dry matter yield and Nutrient content of soybean. *Pakistan Journal of Biological sciences.* **6**(5): 461-466.

Bairagi, B.N., Mahulikar, D.N. and Hiwarale, J.S. 2007. Effect of Zn and P on yield, oil and protein content of soybean. *Journal of Soil and Crops.* **17**: 292-293.

Baishya, L. K., Sarkar, D., Jamir, T., Rajkhowa, D. J. 2019. Effect of foliar application of zinc and iron on growth, yield and quality of rice (Oryza sativa) in acid soils of Eastern Himalayan region. *Indian Journal of Agricultural Sciences*. **89**(8): 1312-1316.

Balachandar, D., Nagarajan, P. and Gunasekaran, S. 2003. Effect of organic amendments and micronutrients on nodulation and yield of blackgram in acid soil. *Legume Research-An International Journal*. **26**(3): 192-195.

Bandyopadhay, S., Baruah, U., Das, T.H., Dutta, D., Reza, S.K., Padua, S., Sarkar Dipak, Sah, K.D and Singh, S.K. 2014. Assessment and mapping of some important soil parameters including macro and micronutrients for the state of

Nagaland towards optimimum utilization of land resources for integrated and sustainable development. NBSS Publ. 1080, Nagpur; 287.

Beale, S.I. 1999. Enzymes of chlorophyll biosynthesis. *Photosynthesis research*. **60**(1): 43-73.

Bellakki, M.A., Budihal, S.L., Ravi, M.V. 2013. Response of sunflower (*Helianthus annus* L.) to zinc and iron fertilization under irrigation. (Doctoral dissertation) university of Agricultural Sciences, Raichur.

Bhanavase, D.B., Jadhav, B.R. and Patil, C.R. 1994. Studies on chlorophyll, nodulation, nitrogen fixation, soybean yield and their correlation as influenced by micronutrient. *The Madras Agriculture Journal*. **81**(6): 325-328.

Bhatia, V.S., Tiwari, S.P. and Joshi, O.P. 1999. Yield and its attributes as affected by planting dates in soybean (*Glycine max* L.) varieties. *Indian Journal of Agricultural Sciences*. **69:** 696-699.

Black, C.A. 1965. Methods of soil Analysis, Part I and II. American Society of Agronomy, Inc, Madison, Wisconsin, USA.

Black, R. E., Cousens, S., Johnson, H. L., Lawn, J. E., Rudan, I. and Bassani, D. G. 2010. Child Health Epidemiology Reference Group of WHO and UNICEF. **In**: Global, regional, and national causes of child mortality in 2008: a systematic analysis**.** *The Lancet.* **375**: 1969-1987.

Bohra, S., Mathur, N., Singh, J., Bohra, A. and Vyas, A. 2006. Changes in morpho-biochemical characteristics of moth bean in Indian Thar Desert-due to sulphur and iron nutrition. *American-Eurasian Journal of Agricultural & Environmental Science.* **1**(1): 51-57.

Boorboori, M., Asli, D.E. and Tehrani, M. 2012. The effect of dose and different methods of iron, zinc, manganese and copper application on yield components, morphological traits and grain protein percentage of barley plant (*Hordeum vulgare* L.) in greenhouse conditions. *Advances in Environmental Biology.* 740-747.

Bouis, H. E. and Welch, R. M. 2010. Biofortification-A sustainable agricultural strategy for reducing micronutrient malnutrition in the global south. *Crop Science*. **50**: 20-32.

Brand, J.D., Tang, C.T. and Graham, R.D. 2000. The effects of nutrient supply, predominantly addition of iron, and rhizobial inoculation on the tolerance of Lupinus pilosus genotypes to a calcareous soil. *Plant and Soil*. **224**(2): 207-215.

Bray, R.H. and Kurtz, L.T. (1945) Determination of total, organic, and available forms of phosphorus in soil. *Soil Science*. **59:** 39-45.

Brennan, R.F., Bolland, M.D.A. and Siddique, K.H.M. 2001. Responses of cool-season grain legumes and wheat to soil-applied zinc. *Journal of Plant Nutrition*. **24**(4-5): 727-741.

Broadley, M., White, P., Hammond, J., Zelko, I. and Lux, A. 2007. Zinc in plants. *New Phytologist.* **173**(4): 677–702.

Burchi, F., Fanzo, J., Frison, E. 2011. The role of food and nutrition system approaches in tackling hidden hunger. *International Journal of Environmental Research and Public Health.* **8**: 358- 373.

Cakmak, I. 2000. Role of zinc in protecting plant cells from reactive oxygen species. *NewPhytologist.* **146**: 185–205.

Cakmak, I. 2002. Plant nutrition research: Priorities to meet human needs for food in sustainable ways. *Plant and soil*. **247**: 3-24.

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

Cakmak, I. and Kutman, U.Á. 2018. Agronomic biofortification of cereals with zinc: a review. *European journal of soil science*. **69**(1): 172-180.

Cakmak, I., Kalayci, M., Ekiz, H., Braun, H. J., Kilin, Y. and Yilmaz, A. 1999. Zinc deficiency as a practical problem in plant and human nutrition in Turkey: A NATO-Science for Stability Project. *Field Crops Research.* **60**:175-188

Cakmak, I., Kalayci, M., Kaya, Y., Torun, A.A., Aydin, N., Wang, Y., Arisoy, Z., Erdem, H., Yazici, A., Gokmen, O., Ozturk, L. and Horst, W.J. 2010b. Biofortification and localization of zinc in wheat grain. *Journal of Agricultural and Food Chemistry*. **58**: 9092-9102

Cakmak, I., Pfeiffer, W. H. and McClafferty, B. 2010a. Biofortification of durum wheat with zinc and iron. *Cereal Chemistry.* **87:** 10-20.

Cakmak, I., Torun, A., Millet, E., Feldman, M., Fahima, T., Korol, A.B., Nevo, E., Braun, H.J. and Ozkan, H. 2004. *Triticum dicoccoides*: an important genetic resource for increasing zinc and iron concentration in modern cultivated wheat. *Soil Science and Plant Nutrition*. **50**: 1047-1054.

Cakmak, I., Torun, B., Erenoglu, B., Ozturk, L., Marschner, H., Kalayci, M., Ekiz, H. and Yilmaz, A. 1998. Morphological and physiological difference in cereals in response to zinc deficiency. *Euphytica.* **100**: 349-357.

Casida, L.E.J., Klein, D.A. and Santoro, T. 1964. Soil dehydrogenase activity. *Soil Science*. **98**: 371-376

Chakraborti, M., Prasanna, B. M., Hossain, F. and Singh, Anju. M. 2011. Evaluation of single cross quality protein maize (QPM) hybrids for kernel iron and zinc concentrations. *Indian Journal of Genetics*. **71**(4): 312-31.

Chaudhry, R.A., D.M. Malik, T. Amin, G. Haque and S. Sabir. 1992. Rice response to micronutrients. Proceedings of the 3rd National Congress of Soil Science Lahore, Mar. 20-22. *Soil Science Society of Pakistan*: 242-350.

Chauhan, S., Titov, A. and Tomar, D. S. 2013. Effect of potassium, sulphur and zinc on growth, yield and oil content in soybean (*Glycine max* L.) in vertisols of central India. *Indian Journal of Applied Research*. **3**(6): 489-491.

Chereskin, B.M. and Castelfranco, P.A. 1982. Effects of iron and oxygen on chlorophyll biosynthesis: II. Observations on the biosynthetic pathway in isolated etiochloroplasts. *Plant Physiology*. **69**(1): 112-116.

Chitdeshwari, T. and Krishnaswamini, R. 1998. Effect of zinc and zinc rich organic manures on the available micronutrient status in rice soil. *Advances in Plant Science*. **11**:211-219.

Chitra, U., Vimala, V., Singh, U. and Geervani, P. 1995. Variability in phytic acid content and protein digestibility of grain legumes. *Plant Foods for Human Nutrition*. **47**(2): 163-172.

Clemens, S. 2001. Molecular mechanisms of plant metal tolerance and homeostasis. *Planta*. **212**(4): 475-486.

Clemens, S., 2014. Zn and Fe biofortification: the right chemical environment for human bioavailability. *Plant Science*. **225**: 52-57.

Darwesh, D. A. 2011. Effect of soil and foliar application of iron chelate on nutrient balance in lentil (*Lens esculenta* L.) by using modified DRIS equation. *Mesopotamia Journal of Agriculture*. **39**(3): 39-49.

Dastane, N. G. 1972. A practical manual for water use research in agriculture, Navbharat Prakashans, Poona-4, India.

Datt, N., Dubey, Y.P. and Chaudhary, R. 2013. Studies on impact of organic, inorganic and integrated use of nutrients on symbiotic parameters, yield, and quality of French-bean (*Phaseolus vulgaris* L.) vis-à-vis soil properties of an acid Alfisol. *African Journal of Agricultural Research*. **8**(22): 2645-2654.

Deotale, R.D., Maske, V.G., Sorte, N.V., Chimurkar, B.S. and Yerne, A.Z. 1998. Effect of GA3 and NAA on morphological parameters of soybean. *Journal of Soils and Crops*. **8**(1): 91-94.

Dhaliwal S.S., Sadana U.S., Khurana, M.P.S., Dhadli, H.S. and Manchanda, J.S. 2009. Biofortification of wheat grains with zinc and iron in Typic Ustocherpt soils of Punjab. *Indian Journal of Fertilizaers.* **5**: 13-16 and 19-20.

Dhaliwal, S.S., Sadana, U.S., Khurana, M.P.S., Dhadli, H.S. and Manchanda, J.S. 2010. Enrichment of rice grains with zinc and iron through ferti-fortification. *Indian Journal of Fertilisers*. **6**(7): 28-35.

Dhaliwal, S.S., Sadana, U.S., Manchanda, J.S., Khurana, M.P.S. and Shukla, A.K. 2013. Differential response of maize cultivars to iron applied through ferti-fortification. *Indian Journal of Fertilisers*. **9**(8): 52-57.

Dhaliwal, S.S., Sharma, V., Shukla, A.K., Kaur, J., Verma, V., Kaur, M., Singh, P., Kaur, L., Verma, G., Singh, J. and Gaber, A. 2022. Biofortification of Soybean (Glycine max L.) through $FeSO_4.7H_2O$ to Enhance Yield, Iron Nutrition and Economic Outcomes in Sandy Loam Soils of India. *Agriculture*. **12**(5): 586.

Dhanashree, Pable, P., and Deshmukh, P.W. 2010. Effect of sulphur and zinc on yield and quality of soybean. *Asian Journal of Soil Science*. **5**(2): 315-317.

Dhull, S.K., Goyal, S., Krishan, K.K. and Mool, C.M. 2004. Microbial biomass carbon and microbial activities of soils receiving chemical fertilizers and organic amendments. *Archives of Agronomy and Soil Science.* **50**: 641-647.

Dobermann, A. 2005. Nitrogen use efficiency-State of the art. In: IFA International Workshop on 'Enhanced-Efficiency of Fertilizers', 28-30 June, Frankfurt, Germany, pp. 1-18

Dube, B.K., Sharma, C.P. and Chatterjee, C. 2001. Response of Pigeonpea to Applied Zinc in Ustifluvent Soils of Western Uttar Pradesh. *Journal of Indian Society of Soil Science.* **49**(3): 471-475.

Duraisamy, V.P. and Mani, A.K. 2001. Effects of zinc and iron on yield, content, uptake and soil fertility under samai in a red loamy sandy soil. *Mysore Journal of Agriculture Science*. **35**(4): 297-301.

Durgude, A.G., Kadam, S.R. and Pharande, A.L. 2014. Effect of soil and foliar application of ferrous sulphate and zinc sulphate on nutrient availability in soil and yield of Bt cotton. *Asian Journal of Soil Science*. **9**(1):82-86.

Ebrahim, Mohsen, K.H. and Aly, Magda M. 2004. Physiological response of wheat to foliar application of zinc and inoculation with some bacterial fertilizers. *Journal of Plant Nutrition.* **27**(10): 1859-1874.

Erdal, I., Yilmaz, A., Taban, S., Eker, S. E. L. İ. M., Torun, B. and Cakmak, I. 2002. Phytic acid and phosphorus concentrations in seeds of wheat cultivars grown with and without zinc fertilization. *Journal of Plant Nutrition*. **25**(1): 113-127.

Fageria, N.K. 2001. Screening method of lowland rice genotypes for zinc uptake efficiency. *Scientia Agricola.* **58**: 623-626.

Fageria, N.K., Santos, A.B.D. and Cobucci, T. 2011. Zinc nutrition of lowland rice. *Communications in Soil Science and Plant Analysis.* **42**: 1719-1727.

Fageria, N.K., Slaton, N.A. and Baligar, V.C. 2003. Nutrient management for improving lowland rice productivity and sustainability. *Advances in Agronomy.* **80**: 63-152.

Farhan, H.N. and Al-Dulaemi, T.M.B. 2011. The effect of foliar application of some microelements on growth and productivity of Wheat (*Triticum aestivum* L.) in Jordan. *Journal of Ahriculture Science*. **7**(1): 105-118.

Garvin, D.F., Welch, R.M. and Finley, J.W. 2006. Historical shifts in the seed mineral micronutrient concentration of US hard red winter wheat germplasm. *Journal of the Science of Food and Agriculture*. **86**(13): 2213-2220.

Ghasemian, V., Ghalavand, A., Zadeh, A.S. and Pirzad, A. 2010. The effect of iron, zinc and manganese on quality and quantity of soybean seed. *Journal Phytologist.* **2**(11): 73-79.

Ghatak, R., Jana, P.K., Sounda, G., Ghosh, R.K. and Bandopadhyay, P. 2005. Responses of transplanted rice to Zn fertilization at farmers’ field on red and laterite soils of West Bengal. *Journal of Interacademicia.* **9**(2): 231-234.

Ghoneim, A.M. 2016. Effect of different methods of Zn application on rice growth, yield and nutrients dynamics in plant and soil. *Journal of Agriculture and Ecology Research International*. **6**(2): 1-9.

Gogorcena, Y., Abadia, J. and Abadia, A. 2005. A new technique for screening iron-efficient genotypes in peach rootstocks: elicitation of root ferric chelate reductase by manipulation of external iron concentrations. *Journal of Plant Nutrition.* **27**: 1701-1715.

Gomaa, M.A., Radwan, F.I., Kandil, E.E. and El-Zweek, S.M. 2015. Effect of some macro and micronutrients application methods on productivity and quality of wheat (Triticum aestivum L.). *Middle East Journal Agricultural Research*. **4**(1): 1-11.

Gomez, K.A. and Gomez, A.A., 1984. *Statistical procedures for agricultural research*. John wiley & sons.

Gomez-Becerra, H.F., Erdem, H., Yazici, A., Tutus, Y., Torun, B., Ozturk, L., Cakmak, I. 2010. Grain concentrations of protein and mineral nutrients in a large collection of spelt wheat grown under different environments. *Journal of Cereal Science.* **52**: 342-34.

Goudar, G., Mudenoor, M.G. and Savalgi, V.P. 2008. Effect of micronutrient supplemented Bradyrhizobium biofertilizers on nodulation, dry matter production and yield of soybean (*Glycine max* (L.) Merrill). *Legume Research-An International Journal*. **31**(1): 20-25.

Goverdhan, M. 2017. Influence of iron and zinc management on dry matter production and nutrient removal by rice (*Oryza sativa* L.) and soil fertility status under aerobic cultivation. *Chem Science Review Letters*. **6**(24): 2627-2635.

Graham, R.D. 1984. Breeding for nutritional characters in cereals. **In**: Thinker, P.B. and Lauchli, A. (eds). *Advance in plant nutrition. Praeger. New York*. pp. 57-102.

Graham, R.D., Ascher, J.S. and Hynes, S.C. 1992. Selecting zinc-efficient cereal genotypes for soils of low zinc status. *Plant and Soil.* **146**: 241-250.

Graham, R.D., Senadhira, D. and Ortiz-Monasterio, I. 1997. A strategy for breeding staple-food crops with high micro-nutrient density. *Soil Science and Plant Nutrition.* **43**: 1153-1157.

Graham, R.D., Welch, R.M., Bouis. H.E. 2001. Addressing micronutrient malnutrition through enhancing the nutritional quality of staple foods: Principles, perspectives and knowledge gaps. *Advances in Agronomy*. **70**: 77-142.

Green, V.S., Stott, D.E. and Diack, M. 2006. Assay for fluorescein diacetate hydrolytic activity: optimization for soil samples. *Soil Biology and Biochemistry*. **38**(4) :693-701.

Guhey, A. 1999. Physiological studies on chickpea in relation to drought tolerance. Ph.D. Thesis Submitted to Dept. of plant physiology, Institute of Agriculture Sciences, BHU, Varanasi.

Gupta, P.K., Sharma, N.N., Acharya, H.K., Gupta, S.K. and Mali, G.C. 2003. Response of mung bean to zinc and iron on vertisols in south-eastern plain of Rajasthan. *Advances in Arid Legumes Research*. 259-262.

Habbasha, S.F., Mohamed, M.H., E.M. Abd El-Lateef, Mekki, B.B. and Ibrahim, M.E. 2013. Effect of combined zinc and nitrogen on yield, chemical constituents and nitrogen use efficiency of some chickpea cultivars under sandy soil conditions. *World Journal Agricultural Science.* **9**(4): 354-360.

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

Habib, M. 2012. Effect of supplementary nutrition with Fe, Zn chelates and urea on wheat quality and quantity. *African Journal of Biotechnology.* **11**(11): 2661-65.

Hafeez, B.M.K.Y., Khanif, Y.M. and Saleem, M. 2013. Role of zinc in plant nutrition-a review. *American journal of experimental Agriculture*. **3**(2): 374.

Hafeez, M.B., Ramzan, Y., Khan, S., Ibrar, D., Bashir, S., Zahra, N., Rashid, N., Nadeem, M., ur Rahman, S., Shair, H. and Ahmad, J. 2021. Application of zinc and iron-based fertilizers improves the growth attributes, productivity, and grain quality of two wheat (*Triticum aestivum*) cultivars. *Frontiers in Nutrition*. **8**.

Hanumanthappa, D., Vasudevan, S.N., Shakuntala, J.B., Muniswamy, N.M. and Macha, S.I., 2018. Enrichment of Iron and zinc content in pigeonpea genotypes through agronomic biofortification to mitigate malnutrition. *International Journal of Current Microbiology and Applied. Sciences*. **7**: 4334-4342.

Hao, B., Ma, J., Jiang, L., Wang, X., Bai, Y., Zhou, C., Ren, S., Li, C. and Wang, Z. 2021. Effects of foliar application of micronutrients on concentration and bioavailability of zinc and iron in wheat landraces and cultivars. *Scientific reports*. **11**(1): 1-10.

Havlin, J.L., Beaton, J.D., Tisdale, S.L. and W. L. Nelson. 1999. Soil Fertility and Fertilizers: An Introduction to Nutrient Management. *Prentice-Hall, Inc., London*.: 406-425.

Hazra, G.C. and Mandal, B. 1995. Zinc absorption in soils in relation to soil properties. *Indian Journal of Agricultural Sciences*. **65**: 659-664.

Heidarian, A. R., Kord, H., Mostafav, I K., Lak, A. P. and Mashhadi, F. A. 2011. Investigating Fe and Zn foliar application on yield and its components of soybean (*Glycine max* (L.) Merr.) at different growth stages. *Journal of Agricultural Biotechnology Sustainable Development.* **3**(9): 189-197.

Hemantaranjan, A. and Garg, O.K. 1988. Iron and zinc fertilization with reference to the grain quality of *Triticum aestivum* L. *Journal of Plant Nutrition*. **11**(6-11): 1439-1450.

Hossain, M.A., Jahiruddin, M. and Khatun, F. 2011. Response of maize varieties to zinc fertilization. *Bangladesh Journal of Agricultural Research*. **36**(3): 437-447.

Hotz, C. and Brown. K.H. (eds). 2004. Assessment of the Risk of Zinc Deficiency in Populations and Options for its Control. ***In**: Food and Nutrition Bulletin***.** **25**(2): 91-204.

Hugar, A.B. and Kurdikeri, M.B. 2000. Effect of application methods and levels of zinc and molybdenum on field performance and seed yield in soybean. *Karnataka. Journal Agriculture Science.* **13**(2): 439-441.

Hussain, N., Khan, M.A. and Javed, M.A. 2005. Effect of foliar application of plant micronutrients mixture on growth and yield of wheat (*Triticum aestivum* L.). *Pakistan Journal of Biological Sciences.* **8**: 1096-1099.

Hussain, S., Maqsood, M.A. and Rahmatullah, M. 2010. Increasing grain zinc and yield of wheat for the developing world: A Review. *Emirates Journal of Food and Agriculture*: 326-339.

Ismail Khan, M. and Tariq, M. 2018. Influence of Iron and Zinc on Nodulations in Mung Bean Crop. *The Journal of Agriculture and Natural Resources Sciences*. **5**(1): 1-6.

Jackson, M.L. 1973. Soil chemical analysis. Prentice Hall of India Pvt. Ltd., New Delhi, India.

Jain, N.K. and Dahama, A.K. 2006. Direct and residual effects of phosphorus and zinc fertilization on productivity of wheat (*Triticum aestivum*)-pearl millet (*Pennisetum glaucum*) cropping system. *Indian Journal of Agronomy*. **51**(3): 161-169.

Jalilvand, S., Roozbahani, A. and Hasanpour, J. 2014. Effect of foliar application of Iron on morphophysiological traits of wheat under drought stress. *Bulletin of Environment, Pharmacology and life science.* **3**: 167-177.

Janakiraman, N., Venkataravana, P. and Seenapa, C. 2005. Effect of iron, zinc and boron on yield and seed quality of groundnut (*Arachis hypogaea* L.). *Mysore Journal of Agricultural Sciences.* **39**(2): 286-288.

Jat, G., Sharma, S. K., Meena, R. H., Choudhary, R., Choudhary, R. S. and Yadav, S. K. 2021. Studies on effect of zinc application on quality and yield of soybean (Glycine max L.) under Typic Haplustepts soil. *Indian Journal of Pure Applied Bioscience*. **9**(1): 188-193.

Jat, S.L., Shivay, Y.S. and Parihar, C.M. 2011. Dual purpose summer legumes and zinc fertilization for improving productivity and zinc utilization in aromatic hybrid rice (*Oryza sativa*). *Indian Journal of Agronomy.* **56**(4): 328-333.

Jedidi, N., Hassen, A., Van Cleemput, O. and M'Hiri, A. 2004. Microbial biomass in a soil amended with different types of organic wastes. *Waste Managementand Research.* **22**: 93-99.

Jin, Z., Wang, M., Wu, J. and Shi, C. 2008. Impacts of combination of foliar iron and boron application on iron biofortification and nutritional quality of rice grain. *Journal of Plant Nutrition.* **31**: 1599-1611.

Johnson, F. and Giulivi, C. 2005. Superoxide dismutases and their impact upon human health. *Molecular Aspects of Medicine*. **26**(4-5): 340-352.

Joshi, A.K., Crassa, J., Arun, B., Chand, R., Trethowan, R., Vargas, M. and Ortiz-Monsterio. I. 2010. Genotype x environment interaction for zinc and iron concentration of wheat grain in eastern Gangetic plains of India. *Field Crops Research.***116**: 268-77.

Kabeya, M.J. and Shankar, A.G. 2011. Effect of different levels of zinc on growth and uptake ability in rice zinc contrast lines (*Oryza Sativa* L.). *Asian Journal of Plant Science and Research*. **3**:112-116.

Kamble, B.M., Meena, R. and Gajbhiye, P.N. 2021. Effect of Iron Nutrition on Growth, Quality and Yield of Soybean (*Glycine Max* L.) Grown on Problematic Inceptisol.

Kanase, N., Jadhao, S.M., Konde, N.M. and Patil, J.D. 2008. Response of soybean to application of zinc. *Agricultural Science Digest.* **28**(1): 63-64.

Kandoliya, R.U., Talaviya, B.P. and Kunjadia, B.B. 2018. Effect soil and foliar application of zinc and iron on growth of wheat plant in calcareous soil of Saurashtra region. *European Journal of Biotechnology and Bioscience*. **6**(5): 86-90.

Karkle, E.N.L., and Beleia, A. 2010. Effect of soaking and cooking on phytate concentration, minerals, and texture of food-type soybeans. *Food Science and Technology*. **30:** 1056-1060.

Keram, K.S. 2013. Impact of zinc application on its translocation into various plant parts of wheat and its effect on chemical composition and quality of grain. *Scientific Research and Essays*. **8**(45): 2218-2226.

Keram, K.S., Sharma, B.L., Kewat, M.L. and Sharma, G.D. 2014. Effect of zinc fertilization on growth, yield and quality of wheat grown under Agro-climatic condition of Kymore Plateau of Madhya Pradesh, India. *The Bioscan*. **9**(4): 1479-1483.

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

Khan, M.U., Qasim, M., Subban, M., Ahmad, R. and Ali, L. 2003. Effect of zinc application by different methods on the chemical composition and grain quality of rice. *Pakistan Journal of Applied Sci*ences. **3**(7): 530-536.

Khattak, S.G., Dominy, P.J. and Ahmad, W. 2015. Effect of Zn as soil addition and foliar application on yield and protein content of wheat in alkaline soil. *Journal of National Science Foundation of Sri Lanka.* **43**(4): 303-312.

Khorgamy, A. and Farina, A. 2009. Effect of phosphorus and zinc fertilisation on yield and yield components of chick pea cultivars. *African Crop Science Conference Proceedings.* **9**: 205-208.

Khoshgoftarmanesh, A.H., Shariatmadari, H., Karimian, K.M. and Khajehpour, M.R. 2004. Zinc efficiency of wheat cultivars grown on a saline calcareous soil. *Journal of Plant Nutrition.* **27**(11): 1953-62.

Kobraee, S., NoorMohamadi, G., HeidariSharifabad, H., DarvishKajori, F. and Delkhosh, B. 2011a. Influence of micronutrient fertilizer on soybean nutrient composition. *Indian Journal of Science and Technology*. **4**(7): 763-769.

Kobraee, S., Normohamadi, G., Heidarisharifabad, H. and Delkhush, B. 2011c. The important micronutrient fertilizer on soybean nutrient composition. *India Journal Science and Technology.* **4**: 26-29.

Kobraee, S., Shamsi, K. and Ekhtiari, S. 2011b. Soybean nodulation and chlorophyll concentration (SPAD value) affected by some of micronutrients. *Annals of Biological Research.* **2**(2): 414-422.

Kobraee, S., Shamsi, K. and Rasekhi, B. 2011. Effect of micronutrients application on yield and yield components of soybean. *Annals of Biological Research.* **2**(2): 476-482.

Kulhare, P.S., Chaudhary, M.K., Uike, Y., Sharma, G.D. and Thakur, R.K. 2014. Direct and residual effect of Zn alone and incubated with cow dung on growth characters, Zn content, uptake and quality of soybean [*Glycine max* (L.) merrill]–wheat (*Triticum aestivum* L.) in a vertisol. *Soybean Research*. **12**: 63-74.

Kumar, A. 2013. Effect of zinc, iron and manganese levels on growth, yield and quality of rice (*Oryza sativa* L.). Ph. D. Thesis, Agronomy, Institute of Agricultural Sciences, BHU, Varanasi. UP, India.

Kumar, M. 2011.Will rising CO_2 affect Zn and Fe bioavailability in food grains*?* *Current Science*. **101**(4): 467.

Kumar, M., Jha, A.K., Hazarika, S. and Verma, B.C. 2016. Micronutrients (B, Zn, Mo) for Improving Crop Production on Acidic Soils of Northeast India. *The National Academyof Sciences.* **39**(2): 85-89.

Kumar, V., Dwivedi, V.N. and Tiwari, D.D. 2009. Effect of phosphorus and iron on yield and mineral nutrition in chickpea. *Annals of Plant Soil Research*. **11**:16-18.

Kumar, V., Kumar, D., Singh, Y.V. and Raj, R. 2015. Effect of iron fertilization on dry-matter production, yield and economics of aerobic rice (Oryza sativa). *Indian Journal of Agronomy*. **60**(4): 547-553.

Kumar, V., Rani, A., Rajpal, S., Srivastava, G., Ramesh, A. and Joshi, O. P. 2005. Phytic acid in Indian soybean: genotypic variability and influence of growing location. *Journal of the Science of Food and Agriculture*. **85**(9): 1523-1526.

Kumar. V., Dwivedi, V.N. and Tiwari, D.D. 2009. Effect of phosphorus and iron on yield and mineral nutrition in chickpea. *Annals of plant and Soil research*. **11**: 16-18

Kumawat, R.N. and Rathore, P. S. 2006. Effects of sulphur and iron nutrition on the morpho-biochmical characteristics of summer mungbean in western Rajasthan. *Journal of Arid Legumes*. **3**(1): 19-26.

Kumawat, R.N., Rathore, P.S. and Pareek, N. 2008. Response of mungbean to S and Fe nutrition grown on calcareous soil of Western Rajasthan. *Indian Journal of Pulses Research*. **19**: 228-230.

Kumawat, R.N., Rathore, P.S., Nathawat, N.S. and Mahatma, M. 2006. Effect of sulfur and iron on enzymatic activity and chlorophyll content of mungbean. *Journal of plant nutrition*. **29**(8): 1451-1467.

Ladha, J.K., Pathak, H., Kruprik, T.J., Six, J. and Van Kessel, C. 2005. Efficiency of fertilizer nitrogen in cereal production: Retrospect and prospects. *Advances in Agronomy*. **87**:85-156.

Leite, C. M., Da, S., César, F. R., Guimarães, G. G., Almeida, E. and Muraoka, T. 2020. Low efficiency of Zn uptake and translocation in plants provide poor micronutrient enrichment in rice and soybean grains. *Journal of Plant Nutrition*. **43**(1): 79-91.

Leopold, A.C. and Kriedemann, P.E. 1975. Plant growth and development, 2nd ed.

Liu, N., Zhang, Y., Wang, B., Xue. Y., Yu, P., Zhang, Q. and Wang, Z. 2014. Is grain zinc concentration in wheat limited by source? *Australian Journal of Crop Science.* **8**(11): 1534-1541.

Lizarazo, M. L., Jorda, J. P. S. and Juarez, M. 2005. Effect of humic amendments on inorganic N, dehydrogenase and alkaline phosphates activities of a Mediterranean soil. *Biololgy Fertilty of Soil*. **42**: 172-177.

Lott, J.N.A., Ockenden, I., Raboy, V. and Battern, G.D. 2000. Phytic acid and phosphorus in crop seeds and foods: A global estimate. *Seed Science Research.* **10**:11-33.

Lu, X., Tian, X., Cui, J., Zhao, A., Yang, X. and Mai, W. 2011. Effects of combined phosphorus-zinc fertilization on grain zinc nutritional quality of wheat grown on potentially zinc-deficient calcareous soil. *Soil Science.* **176**(12): 684-690.

Mahmoudi, H., Labidi, N., Ksouri, R., Gharsalli, M., and Abdelly, C. 2007. Differential tolerance to iron deficiency of chickpea varieties and Fe resupply effects. *Comptes Rendus Biologies.* **330**: 237-246.

Majumdar, B., Venkatesh, M.S., Lal, B., Kumar, K. and Singh, C.D. 2001. Effect of phosphorus and zinc nutrition on groundnut in an acid haplustalf of Meghalaya. *Annals Agricultural Research News Series.* **22**(2): 354-359.

Mandal, B., Hazra, G.C. and Mandal, L.N. 2000. Soil management influence on zinc desorption for rice and maize nutrition. *Soil Science Society of America* Journal. **64**: 1699-1705.

Maurya, B.M., Dekate, J. and Upadhyay, V.B. 2010. Integrated nutrient management in rice wheat cropping system. *JNKVV Research. Journal*. **44**:39-43.

Meena, M., Jat, G., Meena, R.H., Choudhary, R., Jain, D., Doodhwal, K., Jat, H. and Yadav, S.K. 2022. Effect of Phospho Enriched Compost and Zinc on Productivity and Nutrient Uptake of Blackgram (*Vigna mungo* L.) in Subhumid Southern Hills and Aravalli Region of Rajasthan. *Legume Research: An International Journal*. **45**(2).

Meena, M.C., Patel, K.P. and Rathod, D.D. 2006. Effect of Zn and Fe enriched FYM on mustard yield and micronutrient availability in loamy sand soil (Typic Haplustept) of Anand. *Journal of the Indian Society of Soil Science*. **54**(4): 495-499.

Mirvat, E.G., Mohamed, M.H. and Tawfik, M.M. 2006. Effect of phosphorus fertilizers and foliar spraying with zinc on growth, yield and quality of groundnut under reclained sandy soils. *Journal Applied Science Research.* **2**(8): 491-496.

Mohamed, M.E.F., Zeinab, M.M. and Zeinab, A.S. 2011. Micronutrients (Fe, Mn, Zn) foliar spray for increasing salinity tolerance in wheat (*Triticum aestivum* L). *African Journal of Plant Science*. **5** (5): 314-322.

Moosavi, A.A. and Ronaghi, A. 2011. Influence of foliar and soil applications of iron and manganese on soybean dry matter yield and iron-manganese relationship in a calcareous soil. *Australian Journal of Crop Science.***5**: 1550-1556.

Morgounov, A., Becerra H.F.G., Abugalieva, A., Dzhunusova, M., Yessimbekova, M., Muminjanov, H., Zelenskiy, Y., Ozturk, L. and Cakmak, I. 2007. Iron and zinc grain density in common wheat grown in Central Asia. *Euphytica.* **155**: 193-203.

Mostafavi, K., 2012. Grain yield and yield components of soybean upon application of different micronutrient foliar fertilizers at different growth stages. *International Journal of Agricultural Research and Review.* **2**(4): 389-394.

Moussavi-Nik, S.M. and Kiani, Z. 2012. Considering interaction effects of micro nutrition's elements (Fe, Zn, Mn) on qualitative yield of wheat varieties. *Annals of Biological Research*. **3**(3): 1467-1472.

Muhammad, A., Shah, P., Hatam, M. and Jan, M.T. 2003. Comparative growth and vegetative development of land races and improved varieties of soybean. *Pakistan Journal of Agronomy*. **2**(4): 214-216.

Mundra, S.L. and Bhati, D.S. 1991. Effect of iron, manganese and Rhizobium inoculation on nutrient content and uptake by cowpea (*Vigna unguiculata*). *Indian Journal of Agronomy*. **36**: 294-296.

Muthal, Y.C., Deshmukh, S.L., Sagvekar, V.V. and Shinde, J.B. 2016. Response of foliar application of macro and micronutrients on growth, yield on quality of Kharif greengram (*Vigna radiata* L.). *International Journal of Tropical Agriculture*. **34**(7): 2137-2141.

Nadergoli, M.S., Yarnia, M. and Khoei, F.R. 2011. Effect of zinc and manganese and their application method on yield and yield components of common bean

(*Phaseolus vulgaris* L. CV. Khomein). *Middle East Journal of Scientific Research*. **8**(5): 859-865.

Naik, S.K. and Das, D.K. 2007. Effect of split application of zinc on yield of rice (*Oryza sativa* L.) in an inceptisol. *Archives of Agronomy and Soil Science*. **53**(3): 305-313.

Nandanwar, S.B., Nandanwar, V.B., Jadhao, V.O. and Mangre, P.N. 2007. Quality of soybean and fertility status of soil as influenced by NP Zn fertilization and PSB with FYM. *Crop production*. **4**: 77-78.

Narahari, S., Rao, K.P. and Bahadur, V. 2018. Effect of Zinc (Zn) and Boron (B) on Growth, Yield and Quality of Cape Goose Berry (*Physalis peruviana* L.). *International Journal of current Microbiology and Applied Sciences*. **7**(9): 817-823.

Nasri, M., Khalatbari, M. and Farahani, H.A. 2011. Zn-foliar application influence on quality and quantity features in Phaseolous vulgaris under different levels of N and K fertilizers. *Advances in Environmental Biology*. 839-847

Nayyar, V.K. and Takkar, P.N. 1989. Combating iron deficiency in rice grown in sandy soils of Punjab. In *International Symposium on Managing Sandy Soils. CAZRI, Jodhpur*: 379-384.

Nayyar, V.K., Arora, C.L. and Kataki, P.K. 2001. Management of soil micronutrient deficiencies in the rice-wheat cropping system. *Journal of Crop Production.* **4**(1): 87-131.

Nayyar, V.K., Takkar, P.N., Bansal, R.L., Singh, S.P., Kaur, N.P. and Sadana, U.S. 1990. Micronutrients in soils and crops of Punjab. *Research Bulletin, Department of Soils, Punjab Agricultural University (PAU), Ludhiana, Punjab, India.* 146 p.

Naz, S., Yousaf, B., Tahir, M.A., Qadir, A. and Yousaf, A. 2015. Iron and zinc bio-fortification strategies in wheat crop by exogenous application of micronutrients. *Food Science and Quality Management*. **35**: 49-54.

Oberleas, D. and Harland, B.F. 2005. Diagnosis of zinc deficiency in population studies. *Trace Elem. Elec.***22**:282-287.

Oberleas, D., Muhrer, M.E., Dell, O.B.L. and Kinter, L.D. 1961. Effect of phytic acid on zinc availability in rats and swine. *Journal of Animal Science.***20**: 1945.

Obrador, A., Novillo, J. and Alvarez, J.M. 2003. Mobility and availability to plants of two zinc sources applied to a calcareous soil. *Soil Science Society ofAmerica Journal*. **67**: 564-572.

Oteiza, P.I. and Mackenzie, G.G. 2005. Zinc, oxidant-triggered cell signaling, and human health. *Molecular aspects of medicine*. **26**(4-5): 245-255.

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

Pable D and Patil D B. 2011. Effect of sulphur and zinc on nutrient uptake and yield of soybean *var*. JS-335 crop on vertisoil. *International Journal of Agriculture Science*. **7** (1): 129-132.

Pal, V., Singh, G. and Dhaliwal, S.S. 2019. Agronomic biofortification of chickpea with zinc and iron through application of zinc and urea. *Communications in Soil Science and Plant Analysis*. **50**(15): 1864-1877.

Pande, P.K., Ravankar, H.W., Laharia, G.S., Ganwande, R.P. and Padole, V.R. 1993. Effect of iron on yield and uptake of nutrients in groundnut. *PKV Research Journal*. **17**: 135-137.

Pandey, N and Gupta, B. 2012. Improving seed yield of black gram (*Vigna Mungo* var DPU-88-31) through foliar fertilization of zinc during the reproductive phase. *Journal Plant Nutrition*. **35**: 1683-1692.

Patel, M.M., Patel, I.C., Patel, P.H., Patel, A.G., Acharya, S. and Tikka, S.B.S. 2009. Impact of foliar nutrition of zinc and iron on the productivity of cowpea (*Vigna unguiculata* L.) under rain fed conditions. *Journal of Arid Legumes*. **6**(1): 49-51.

Pathak, G.C., Gupta, B. and Pandey, N. 2012. Improving reproductive efficiency of chickpea by foliar application of zinc. *Brazilian Journal of Plant Physiology*. **24**: 173-180.

Peleg, Z., Saranga, Y., Yazici, A., Fahima, T., Ozturk, L. and Cakmak, I. 2008. Grain zinc, iron and protein concentrations and zinc-efficiency in wild emmer wheat under contrasting irrigation regimes. *Plant and Soil*. **306**(1): 57-67.

Piper, C. S. 1966. Soil and Plant analysis. International Science Publication. New York 47-49.

Pooladvand, S., Ghorbanliand., M. and Farzami, S. M. 2012. Effect of various levels of iron on morphological, biochemical, and physiological properties of *Glycine max* var. Pershing. *Iranian Journal of Plant Physiology*. **2**(4): 531-53

Pooniya, V. and Shivay, Y.S. 2011. Effect of green manuring and zinc fertilization on productivity and nutrient uptake in Basmati rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system. *Indian Journal of Agronomy*. **56**(1): 28- 34.

Pooniya, V. and Shivay, Y.S. 2012. Summer green-manuring crops and zinc fertilization on productivity and economics of *basmati rice* (*Oryza sativa* L.). *Archives of Agronomy and Soil Science*. **58**(6): 593-616.

Pooniya, V. and Shivay, Y.S. 2013. Enrichment of basmati rice grain and straw with zinc and nitrogen through ferti-fortification and summer green manuring under Indo-Gangetic plains of India. *Journal of Plant Nutrition*. **36**(1): 91-117.

Pooniya, V., Shivay, Y.S., Rana, A., Nain, L. and Prasanna, R. 2012. Enhancing soil nutrient dynamics and productivity of *Basmati rice* through residue incorporation and zinc fertilization. *European Journal of Agronomy*. **41**: 28-37.

Potarzycki, J., Grzebisz, W. 2009. Effect of zinc foliar application on grain yield of maize and its yielding components. *Plant, Soil and Environment*. **55**(12): 519-527

Prasad, R. 2005. Rice-wheat cropping system. *Advances in Agronomy*: **86**: 255-339

Prasad, R. 2006. Zinc in soils and in plants, human & animal nutrition. *Indian Journal of Fertilizers*. **2**(9): 103-119

Prasad, R., Shivay, Y. S., Kumar, D., & Sharma, S. N. 2006. Learning by doing exercises in soil fertility-A practical manual for soil fertility (p. 68). New Delhi: Division of Agronomy, Indian Agricultural Research Institute.

Prasad, R., Singh, R.K., Rani, A. and Singh, D.K. 2000. Partial factor productivity of nitrogen and its use efficiency in rice and wheat. *Fertilizer News*. **45**(5): 63-65.

Pushnik, J.C. and Miller, G.W. 1989. Iron regulation of chloroplast photosynthetic function: mediation of PS I development. *Journal of Plant Nutrition*. **12**(4): 407-421.

Qaim, M., Stein, A.J.s and Meenakshi, J.V. 2007. Economics of biofortification. *Agricultural Economics*. **37**: 119-133.

Quary, F. X., Leenhardt, F. and Remesy, C. 2006. Genetic variability and stability of grain Mg, Zn and Fe concentration in bread wheat. *European Journal of Agronomy*. **25** (2):177-185.

Quddus, M. A., Rashid, M. H., Hossain, M. A., Naser, H. M. 2011. Effect of zinc and boron on yield and yield contributing characters of mungbean in low Ganges

River floodplain soil at Madaripur, *Bangladesh. Bangladesh Journal of Agricultural Research*. **36**(1): 75-85.

Raboy, V., Dickinson, D. B. and Below, F. E. 1984. Variation in seed total phosphorus, phytic acid, zinc, calcium, magnesium, and protein among lines of *Glycine max* and G. soja 1. *Crop Science*. **24**(3): 431-434.

Rahevar, H.D., Patel, P.P., Patel, B.T., Joshi, S.K., Vaghela, S.J. 2015. Effect of FYM, iron and zinc on growth and yield of summer Groundnut (*Arachis hypogaea*L.) under North Gujarat agro-climatic conditions. *Indian Journal of Agricultural Research*. **49** (3): 294-296

Rai, S., Singh, P.K., Mankotia, S., Swain, J. and Satbhai, S.B. 2021. Iron homeostasis in plants and its crosstalk with copper, zinc, and manganese. *Plant Stress* **1**:100008.

Ram, H., Sohu, V. S, Singh, K., Cakmak, I., Buttar, G. S., Sodhi, G.P.S., Gill, H. S., Bhagat, I., Singh, P., Dhaliwal, S. S. and Mavi, G. S. 2011. Agronomic fortification of rice and wheat grains for improving human health. Paper presented in 3rd International zinc symposium on improving crop production and human health at Hyderabad, October 10-14, 2011.

Ramesh P., Panwar, N. R., Singh, A. B. and Ramana, S. 2008. Effect of organic manure on productivity, soil fertility and economics of soybean (*Glycine max*)-duram wheat (*Triticum duram*) cropping system under organic farming in vertisols. *Indian Journal of Agriculture Science*. **78** (12): 1033-1037.

Ramesh, N., Baradhan, G. and Ganapathy, M. 2007. Effect of foliar nutrition on reproductive efficiency and grain yield of rice fallow pulses. *Plant Archives*. **7**(2): 665-667.

Ranjbar. G. A, and Bahmaniar, M. A. 2007. Effects of soil and foliar application of Zn fertilizer on yield and growth characteristics of bread wheat cultivars. *Asian Journal of Plant Science*. **6**(6): 1000-05.

Rattan, R.K. and Sharma, P.D. 2004. Main micronutrients available and their method of use. In: *IFA International Symposium on Micronutrients*, February, 23-25, New Delhi, India

Ravi, S., Channal, H. T., Hebsur, N. S., Patil, B. N. and Dharmatti, P. R. 2008. Effect of sulphur, zinc and iron nutrition on growth, yield, nutrient uptake and quality of safflower. *Karnataka Journal Agricultural Sciences*. **21**(3): 382-385.

Rawashdeh, H.M. and Sala, F. 2014. Influence of iron foliar fertilization on some growth and physiological parameters of wheat at two growth stages. *Romania Scientific papers. Series A. Agron*. **57**: 306-309.

Reddy, S.R. 2004. Principles of crop production growth regulators and growth analysis, 2nd edition, K0alyani Publishers, Ludhiana, India.

Rengel, Z. and Graham, R.D. 1996. Uptake of zinc from chelate-buffered nutrient solutions by wheat genotypes differing in zinc efficiency. *Journal ofExperimental Botany*.**47***:* 217-219.

Revathy, M., Jriahnasamy, R. and Chitdeshwari, T. 1997. Chelated micronutrients on the yield and nutrient uptake by groundnut. *Madras Agricultural Journal*. **84**(11-12): 659-662.

Richards, L.A., 1954. Diagnosis and Improvement of. *Saline and Alkali Soils. Handbook*. **60**:129-134.

Rouse, T. I. and Davis, D.P. 2004. Exploring a vision: Integrating knowledge for food and health: A workshop summary. Washington DC: National Academies Press.

Rout, G.R. and Sahoo, S. 2015. Role of iron in plant growth and metabolism. *Reviews in Agricultural Science*. **3**: 1-24.

Sadasivam, S. and Manickam, A. (1996) Biochemical Methods. 3rd edition. New Age International publisher. pp 194-195

Safyan, N., Naderidarbaghshahi, M.R. and Bahari, B. 2012. The effect of microelements spraying on growth, qualitative and quantitative grain corn in Iran. *International Research journal of Applied and Basic Sciences.***3**: 2780-2784.

Sahrawat, K. L, Rego, T. J., Wani, S. P. and Pardhasaradhi, G. 2008. Sulphur, boron, and zinc fertilization effects on grain and straw quality of maize and sorghum grown in semi-arid tropical region of India. *Journal of Plant* Nutrition. **31**(9): 1578-1584

Sahu, S., Lidder, R.S. and Singh, P.K. 2008. Effect of micronutrient and biofertilizars on growth, yield and nutrient uptake by chickea (*Cicer aeritinum* L.) in vertisols of Madhya Pradesh. *Advances in plant sciences*. **21**: 501-503.

Sai Divya, B., Singh, R. and Khan, W. 2021. Effect of foliar application of iron and zinc on yield and economics of finger millet (*Eleusine coracana*. L). *The Pharma Innovation Journal*. **10**(4): 897-899

Sale, R.B., Nazirkar, R.B., Ritu, S.T. and Nilam, B.K. 2017. Effect of foliar spray of zinc, iron and seed priming with molybdenum on growth and yield attributes and quality of soybean in the rainfed condition of vertisol. *International Journal of Chemical Studies*. **6**: 828-831.

Salih, H. O. 2013. Effect of foliar fertilization of Fe, B and Zn on nutrient concentration and seed protein of Cowpea (*Vigna unguiculata*). *Journal of Agriculture and Veterinary Science*. **6**(3): 42-46.

Sangwan, P. S. and M. Raj. 2004. Effect of zinc nutrition on yield of chickpea (*Cicer arietinum* L.) under dryland conditions. *Indian Journal of Dryland Agriculture Research and Development*. **19**(1): 01-03.

Sarkar, A. K. and Singh, S. 2003. Crop response of secondary and micronutrient in acidic soil of India. *Fertilizer News*. **48**: 47-54.

Saxena, S.C. and Chandel, A.S. 1997. Effect of micronutrients on yields, nitrogen fixation by soybean (*Glycine max*) and organic carbon balance in soil. *Indian Journal of Agronomy*. **42**(2): 329-332.

Seifi-Nadergholi, M., Yarnia, M. and Rahimzade, K.F. 2011. Effect of Fe and Mn and their application method on yield and yield components of common bean (*Phaseolus vulgaris*L. CV. Khomein). *Middle-East Journal of Scientific Research*. **8**: 859-865.

Sharma, A., Kumar, A. and M. P. Potdar. 2009. Response of pigeonpea to conjunctive use of organic and inorganic source of fertilizers under rainfed conditions. *Karnataka Journal of Agriculture Science*. **22**(1): 8-10.

Sharma, P.D. 2008. Nutrient management challenges and options. *Journal of the Indian Society of Soil Science.* **55** (4): 395-403.

Sharma., A., Nakul, H. T., Jalgeri, B. R. and Surwenshi, A. 2010. Effect of micronutrients on growth, yield and yield components in pigeon pea (*Cajanus cajan* L. Millsp.). *Research Journal of Agricultural Science*. **1**:142-144

Shivay, Y. S., Prasad, R. and Pal, M. 2014. Effect of variety and zinc application on yield, profitability, protein content and zinc and nitrogen uptake by chickpea (*Cicer arietinum). Indian Journal of Agronomy*. **59**(2): 317-321.

Shivay, Y.S. and Prasad, R. 2012. Zinc-coated urea improves productivity and quality of basmati rice (*Oryza sativa* L.) under zinc stress condition. *Journal of Plant Nutrition*. **35**(6): 928-951.

Shivay, Y.S., Kumar, D. and Prasad, R. 2008b. Effect of zinc-enriched urea on productivity, zinc uptake and efficiency of an aromatic rice-wheat cropping system. *Nutrient Cycling in Agroecosystems*. **81**(3): 229-243.

Shivay, Y.S., Kumar, D., Ahlawat, I.P.S. and Prasad, R. 2007. Relative efficiency of zinc oxide and zinc sulphate coated urea for rice. *Indian Journal of Fertilizers*. **3**(2): 51-56.

Shivay, Y.S., Kumar, D., Prasad, R. and Ahlawat, I.P.S. 2008a. Relative yield and zinc uptake by rice from zinc sulphate and zinc oxide coatings onto urea. *Nutrient Cycling in Agroecosystems*. **80**(2): 181-188.

Shivay, Y.S., Pooniya, V., Pal, M., Ghasal, P.C., Bana, R. and Jat, S.L. 2019. Coated urea materials for improving yields, profitability, and nutrient use efficiencies of aromatic rice. *Global Challenges*.**3**(12): 1900013.

Shivay, Y.S., Prasad, R. and Rahal, A. 2008b. Relative efficiency of zinc oxide and zinc sulphate-enriched urea for spring wheat. *Nutrient Cycling in Agroecosystems*. **82(**3): 259-264.

Shivay, Y.S., Prasad, R. and Rahal, A. 2010. Genotypic variation for productivity, zinc utilization efficiencies, and kernel quality in aromatic rice under low available zinc conditions. *Journal of Plant Nutrition*. **33**: 1835-1848.

Shivay, Y.S., Prasad, R., Kaur, R. and Pal, M. 2016. Relative efficiency of zinc sulphate and chelated zinc on zinc biofortification of rice grains and zinc use-efficiency in Basmati rice. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences.* **86**(4): 973-984.

Shivay, Y.S., Prasad, R., Singh, R. and Pal, M. 2015. Relative Efficiency of Zinc-Coated Urea and Soil and Foliar Application of Zinc Sulphate on Yield, Nitrogen, Phosphorus, Potassium, Zinc and Iron Biofortification in Grains and Uptake by Basmati Rice (*Oryza sativa* L.). *Journal of Agricultural Science.***7**(2): 161-173.

Shukla, S.K. and Warsi, A.S. 2000. Effect of sulphur and macronutrients on growth, nutrient content and yield of wheat (*Triticum aestivum*). *Indian Journal of Agriculture Research.* **34**(3): 203-205.

Shukla, V. and Shukla, I.C. 1994. Effect of Fe, Mo, Zn and P on symbiotic nitrogen fixation of chickpea. *Indian Journal of Agriculture Chemistry*. **32**:118-123.

Shukla, V. and Shukla, I.C. 1994. Effect of Fe, Mo, Zn and P on symbiotic nitrogen fixation of chickpea. *Indian Journal of Agriculture Chemistry*. **32**:118-123.

Shukla, V., and I. C. Shukla. 1999. Effect of Fe, Mo, Zn and P on symbiotic nitrogen fixation of chick pea (*Cicer arietinum* L.*). Indian Journal of Agricultural Chemistry*. **32**(3): 118-123.

Singh, G., Sekhon, H. S. and Kaur H. 2012. Effect of farmyard manure, vermicompost and chemical nutrients on growth and yield of chickpea (*Cicer arietinum* L.). *International Journal of Agriculture Research*. **7**(2): 93-99.

Singh, M., Chaudhary, S.R., Sharma, S.R. and Rathore, M.S. 2004. Effect of some micronutrients on content and uptake by chickpea (*Cicer arietinum*). *Agriculture Science Digest*. **24**(4): 268-270.

Singh, S.K., Saxena, H.K. and Das, T.K. 1998. The effect of kind of micronutrients and their method of application on mungbean (*Vigna radiata* (L.) Wilczek) under zaid condition. *Annals of Agriculture Research.* **19**(4): 454-457.

Singh, T. and Tiwari, K. N. 1992. Effect of zinc application on yield and nutrient content in chickpea. *Maharashtra Agriculture. Journal*. **79**: 87-91.

Slaton, N. A., Norman, R.J. and Wilson, C.E. 2005b. Effect of zinc source and application time on zinc uptake and grain yield of flooded-irrigated rice. *Agronomy Journal.* **97**: 272-278.

Slaton, N.A., Gbur, E.E., Wilson, C.E. and Norman, R.J. 2005a. Rice response to granular zinc sources varying in water-soluble zinc. *Soil Science Society of America Journal*. **69**: 443-452.

Smolen, S. 2012. Foliar Nutrition: Current State of Knowledge and Opportunities. In: A. K. Srivastava (Ed.), *Advances in Citrus Nutrition*, DOI 10.1007/978-94-007-4171-3-4, Springer Science + Business Media. 41-58.

Soni, J. and Kushwaha, H.S. 2020. Effect of foliar spray of zinc and iron on productivity of mungbean (*Vigna radiata* (L.) Wilczeck). *Journal of Pharmacognosy and Phytochemistry.* **9**(1): 108-111.

Sonune, B.A., Naphade, P.S. and Kankal, D.S. 2001. Effect of zinc and sulphur on protein and oil content of soybean. *Agricultural Science Digest.* **21**(4): 259-260.

Souza, J.A., Moraes, L.A.C. and Moreira, A. 2019. Zinc and amino acids on wheat-soybean intercropping under no-till management. *Journal of Plant Nutrition*. **42**(16): 1992-2002.

Stein, A.J. and Qaim, M. 2007. The human and economic cost of hidden hunger. *Food*

Stein, A.J., Nestel, P., Meenakshi, J.V., Qaim, M., Sachdev, H.P. and Bhutta, Z.A. 2007. Plant breeding to control zinc deficiency in India: how cost-effective is biofortification? *Public Health Nutrition*. **10**: 492-501.

Stoltzfus, R. J. and Dreyfuss, M. L. 1998. Guidelines for the use of iron supplements to prevent and treat iron deficiency Anemia.International Nutritional Anemia Consultative Group (INACG). ILSI Press. Washington DC, USA.

Subbiah, B.V. and Asija, G.L. 1956. A rapid procedure for the estimation of available nitrogen in soils. *Current Science*. **25**(8): 259-260.

Sunder, P., Barad, A.V., Singh, A.K., Khadda, B.S. and Daleep, K. 2017. Effects of foliar application of $FeSO_4$ and $ZnSO_4$ on leaf tissue nutrients of gerbera (*Gerbera jamesonii*) varieties under protected condition. *Indian Journal of Agricultural Sciences.* **87**(1): 102-106.

Swami, S. and Shekhawat, K. 2009. Influence of zinc under different moisture regimes on yield and nutrient uptake of rice in *Inceptisol*. *AgriculturalScience Digest*. **29**(2): 36-38.

Tabassum, S., Khamparia, R.S. and Singh, S. 2013. Effect of zinc and organic manures on yield attributes and yield of rice. *BIOINFOLET-A Quarterly Journal of Life Sciences.* **10**(3a): 879-881.

Tayade, M., Badge, S. and Nikam, B. 2018. Foliar application of zinc and iron as influenced on flowering and quality parameters of Tuberose. *International Journal of Current Microbiology and Applied sciences*. **7**(1): 2239-2243.

Tayyeba, S., Hamid, U., Shah H., Ullah, S. and Javid M. 2017. Zinc effect on growth rate, chlorophyll, protein and mineral contents of hydroponically grown mungbeans plant (*Vigna radiata*). Arab Journal of Chemistry. **10**: 1802-1807.

Tejada, M., Gonzalez, J. L., García-Martínez, A.M. and Parrado, J. 2008. Effects of different green manures on soil biological properties and maize yield. *Bioresource technology*. **99**(6): 1758-1767.

Thakare, R. and Bhoyar, S. 2012. Dynamics of soil biological fertility as influenced by organic and inorganic inputs under soybean in vertisols. *Asian Journal of Soil Science*. **7**(1): 18-22.

Thavarajah, D., Thavarajah, P., Sarker, A. and Vandenberg, A. 2009. Lentils (*Lens culinaris* Medikus Subspecies culinaris): a whole food for increased iron and zinc intake. *Journal of Agricultural and Food Chemistry*. **57**(12): 5413-5419.

Thenua, O.V.S., Singh, K., Raj, V. and Singh, J. 2014. Effect of sulphur and zinc application on growth and productivity of soybean (*Glycine Max* (L.) Merrill) in northern plain zone of India. *Annals of Agricultural Research New Series*. **35**(2):183-187.

Trivedi, A.K., Hemantaranjan, A. and Pandey, S.K. 2011. Iron and sulphur application may improve growth and yield of soybean. *Indian Journal of plant physiology*. **16**(3/4): 309-313.

Umamaheswari, P. and Singh, C.P. 2002. Influence of irrigation levels and micronutrients (Fe and Zn) on yield and yield attributes of Rajmash (*Phaseolus vulgaris* L.). *Legume Research.***25**(2): 121-123.

Upadhyay, R.G. 2002. Response of growth regulators on flower drop, fruit setting, biochemical constituents and yield of chickpea under mid hill conditions of H.P. *Legume Research.***25**(3): 211-214.

Vaghar, M.S., Sayfzadeh, S., Zakerin, H.R., Kobraee, S. and Valadabadi, S.A., 2020. Foliar application of iron, zinc, and manganese nano-chelates improves physiological indicators and soybean yield under water deficit stress. *Journal of Plant Nutrition*. **43**(18): 2740-2756.

Valenciano, J.B., Frade, M. M. and Marcelo, V. 2009. Response of chickpea (*Cicer arietinum L*.) to soil zinc application. *Spanish Journal of Agricultural Research*. **7**(4): 952-956.

Vance, E.D., Brookes, P.C. and Jenkinson, D.S. 1987. An extraction method for measuring soil microbial biomass carbon. *Soil Biology and Biochemistry*. **19**: 703-704.

Walkley, A.J. and Black, I. A. 1934. An examination of the Degtjareff method for determination of soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science*. **37**: 29-38.

Watson, D.J. 1947. Comparative physiological studies on the growth of field crops: I. Variation in net assimilation rate and leaf area between species and varieties, and within and between years. *Annals of botany*. **11**(41): 41-76.

Welch, R. M. and Graham, R. D. 2004. Breeding for micronutrients in staple food crops from a human nutrition perspective. *Journal of Experimental Botany*. **55:** 353-364.

Wen, Y. X., Xiao-hong, T., Xin-chun, L., Gale, W. J. and Cao, Y. X. 2011. Foliar Zn fertilization improves the zinc nutritional value of wheat grain. *African Journal of Biotechnology*. **10**(66): 14778-85.

Wessells, K.R. and Brown, K.H. 2012. Estimating the global prevalence of zinc deficiency: results based on zinc availability in national food supplies and the prevalence of stunting. *PloS one*. **7**(11): p.e50568.

White, P. J. and Broadley, M. R. 2005. Biofortifying crops with essential mineral elements. *Trends in Plant Science.***10**: 586-592.

White, P. J. and Broadley, M. R. 2009. Biofortification of crops with seven mineral elements often lacking inhuman diets-iron, zinc, copper, calcium, magnesium, selenium and iodine. *New Phytologist.* **182**: 49-84.

White, P.J. and Broadley, M.R. 2011. Physiological limits to zinc biofortification of edible crops. *Frontiers in plant science*. **2**: 80.

WHO 2002. The World Health Report 2002; Reducing Risks, Promoting Healthy Life. World Health Organization, Geneva, Switzerland. 1-168.

Wise, A. 1995. Phytate and zinc bioavailability. *International Journal of Food Science and Nutrition.* **46**: 56-63.

Witham, F.H., Blaydes, D.F. and Devlin, R.M. 1971. Chlorophyll absorption spectrum and quantitative determination. In: Experiments in Plant Physiology, New York: Von Nostra and Ren FOLD Company: 55–56.

Wright, A. L. and Hons, F. M. 2005. Soil carbon and nitrogen storage in aggregates from different tillage and crop regimes. *Soil Science Society of America Journal*. **69**: 141-147.

Yadav, G. S., Dinesh, K. and Subhash, B. 2013. Enhancing iron density and uptake in grain and straw of aerobic rice through mulching and rhizo-foliar fertilization of iron. *Global Journal of Agricultural Research and Reviews.* **8**(44): 5447-5454.

Yadav, P.S., Kameriya, P.R. and Rathore, S. 2002. Effect of phosphorus and iron fertilization on yield, protein content and nutrient uptake in mungbean on loamy sand soil. *Journal of the Indian Society of Soil* Science. **50**(2): 225-226.

Yadi, R., Dastan, S. and Yasari, E. 2012. Role of zinc fertilizer on grain yield and some qualities parameters in Iranian rice genotypes. *Annals of Biological Research*. **3**(9): 4519-4527.

Yang, X.W., Tian, X.H., Lu, X.C., Cao, Y.X. and Chen, Z.H. 2011. Impacts of phosphorus and zinc levels on phosphorus and zinc nutrition and phytic acid concentration in wheat (*Triticum aestivum* L.). *Journal of the Science of Food and Agriculture*: **91**(13): 2322-2328.

Yasari, E. and Vahedi, A. 2012. Micronutrients impact on soybean (*Glycine max* (Merrill) qualitative and quantitative traits. *International Journal of Biology*. **2**: 112-118.

Yaseen, M., Hussain, T. Hakeem A. and Ahmad, S. 1999. To study the effect of integrated nutrient use including zinc for rice. *Pakistan Journal Biology Science*. **2**: 614-616.

Zayed, B.A., Salem, A.K.M. and El Sharkawy, H.M. 2011. Effect of different micronutrient treatments on rice (*Oriza sativa* L.) growth and yield under saline soil conditions. *World Journal of Agricultural Sciences*. **7**(2): 179-184.

Zeidan, M.S., Mohamed, M.F. and Hamouda, H.A. 2010. Effect of foliar fertilization of Fe, Mn and Zn on wheat yield and quality in low sandy soils fertility. *World Journal of Agriculture and Soil science*. **6**(6): 696-699.

Zhang, Y. Q., Sun, Y. X., Ye, Y-L, Karim, M. R., Xue, Y. F., Yan, P., Meng, Q. F., Cui, Z. L., Cakmak, I., Zhang, F. S. and Zou, C. Q. 2011. Zinc biofortification of wheat through fertilizer applications in different locations of China. *Field Crop Research*. **125**: 1-7.

Zhang, Y., Song, Q., Jan, Y., Tang, J., Zhao, R., Zhang, Y., He, Z., Zou, C. and Ortiz-Monasterio, I. 2010. Mineral element concentrations in grains of Chinese wheat cultivars. *Euphytica*. **174**: 303-13.

Zhao, F. J., Su, Y. H., Dunham, S. J., Rakszegi, M., Bedo, Z., McGrath, S. P., Shewry, P. R. 2009. Variation in mineral micronutrient concentrations in grain of wheat lines of diverse origin. *Journal of Cereal Science*. **49**: 290-295.

Ziaeian, A.H. and Malakouti, M. J. 2001. Effects of Fe, Mn, Zn and Cu fertilization on the yield and grain quality of wheat in the calcareous soils of Iran. In *Plant nutrition* (pp. 840-841). Springer, Dordrecht.

ANNEXURE I

Table 1 Weather data for the experimental year 2018 and 2019 at Medziphema

Parameters	***Temperature (ºC)***				***Relative humidity (%)***				***Sunshine hours***		***Rainfall (mm)***	
	Minimum		***Maximum***		***Minimum***		***Maximum***					
Month	***2018***	***2019***	***2018***	***2019***	***2018***	***2019***	***2018***	***2019***	***2018***	***2019***	***2018***	***2019***
July	23.80	23.80	35.80	36.40	71.71	71.77	91.65	93.48	3.10	3.10	239.50	271.30
August	23.70	23.50	36.80	37.70	71.39	72.52	94.23	92.65	3.80	4.90	302.80	274.30
September	22.70	22.10	35.30	36.40	66.70	72.10	93.60	93.80	5.30	4.10	115.70	173.50
October	17.70	18.10	33.90	33.30	66.71	72.87	95.68	95.35	6.00	5.90	64.00	244.80
November	10.20	11.30	31.20	32.00	53.50	64.20	96.73	97.40	7.00	7.00	13.30	52.90
December	8.10	7.30	27.90	28.00	55.84	62.16	96.45	97.03	6.30	6.10	50.00	0.90

ANNEXURE II

Table 2 Cost of cultivation for all treatments on ha^{-1} basis (Fixed cost)

Sl. No.	***Particulars***	***Units***	***Rate (₹)***	***Cost (ha^{-1})***
1	**Land preparation**			
a.	Ploughing by tractor	1	2500	2500
b.	Harrowing	2	1500	3000
c.	Seed bed preparation	12	220	2640
2	Manure and fertilizer application	5	220	1100
3	Seed cost	70	80	5600
4	Sowing	10	220	2200
5	Thinning	6	220	1320
6	Weeding & intercultural operation	12	220	2640
7	Chemical spray for insect pest	2	220	440
8	**Manures and fertilizers**			
a.	Urea	43	12	516
b.	SSP	375	15.8	5925
c.	MOP	66	25	1650
d.	FYM	10	500	5000
9	Biofertilzers	5	120	600
10	Chlorpyriphos	8	80	640
11	Harvesting	12	220	2640
12	Threshing & cleaning	8	220	1760
13	Miscelaneous			2000
14	Total (fixed cost)			**42,171**
	Interest on working capital	for 6 months	12% per annum	2530.26
Grand total				***44,701.26***

ANNEXURE III

Table 3 Cost of zinc application (variable) on ha^{-1} basis

Symbol	***Treatments***	***No. of units***	***Cost Zn (Zn rate* cost per unit)***	***Interest of Zn cost***	***Total***
Z_0	Control	0	0	0	0
Z_1	Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$	23.80	3570	214.20	3784.20
Z_2	Soil application of Zn @ 5 kg ha^{-1} through ZnO	6.25	1250	75	1325
Z_3	Soil application of Zn @ 5 kg ha^{-1} through $ZnSO_4.7H_2O$ + Two foliar spray application of $ZnSO_4$ @ 0.25% at pre-flowering and pod formation stages	26.80	4020	241.20	4261.20
Z_4	Soil application of Zn @ 5 kg ha^{-1} through ZnO + Two foliar spray application ZnO @ 0.25% at pre-flowering and pod formation stages	9.25	1850	111	1961
Z_5	Three (3) foliar spray applications of $ZnSO_4.7H_2O$ @ 0.5% at maximum vegetative stage, pre-flowering and pod formation stage.	9	1350	81	1431
Z_6	Three (3) foliar spray applications of ZnO @ 0.5% at maximum vegetative stage, pre-flowering and pod formation stage.	9	1800	108	1908Ā
	Foliar spraying one ha (manday)	2.50	550	33	583
	Soil application of micronutrient (manday)	2	440	26.40	466.40
		Avg.	*1647.78*	*98.87*	***1746.64***

Labour wages: Rs.220; Soybean grain: Rs. 70/-; $ZnSO_4.7H_2O$: Rs.150; ZnO: Rs.200