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Chavan NS
Department of Soil Science and Agricultural Chemistry, College of Agriculture Latur, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, India

Adsul PB
Assistant Professor, Department of Soil Science and Agricultural Chemistry, College of Agriculture Latur, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, India

Kadam DM
Department of Soil Science and Agricultural Chemistry, College of Agriculture Latur, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, India

Lingayat NR
Department of Soil Science and Agricultural Chemistry, College of Agriculture Latur, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, India

Jaybhaye BB
Department of Soil Science and Agricultural Chemistry, College of Agriculture Latur, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, India

Corresponding Author:
Chavan NS
Department of Soil Science and Agricultural Chemistry, College of Agriculture Latur, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, India

Effect of iron and zinc on growth, yield and quality of soybean (*Glycine max* L.) in Inceptisol

Chavan NS, Adsul PB, Kadam DM, Lingayat NR and Jaybhaye BB

Abstract
The present investigation entitled "Effect of iron and zinc on soil properties, nutrient uptake and yield of soybean (*Glycine max* L.) in Inceptisol" during *Kharif* season of year, 2021-2022 at Research farm Department of Soil Science and Agricultural Chemistry, College of Agriculture, Latur. The experiment was laidout in RBD with three replications and recommended variety of soybean MAUS-158 as a test crop along with nine treatments. The results in nutshell indicated that the growth, yield, quality, nutrient availability, nutrient uptake and soil nutrient balance were significantly influenced by application of iron and zinc with RDF of soybean. The growth parameters *viz.*, plant height, number of leaves plant^{-1}, leaf area, dry matter content, chlorophyll – a, chlorophyll – b and total chlorophyll content, number of nodules, fresh weight of nodules plant^{-1} and dry weight of nodules plant^{-1} significantly increased with application of RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$ and was found at par with treatment T9 (RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS) and treatment T4 (RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS).

Keywords: Iron, zinc, growth, yield, quality of soybean, *Glycine max* L.

Introduction

A wonder crop soybean (*Glycine max* L.) is a leguminous crop which belongs to family leguminaceae with sub family Papilionaceae. Soybean was introduced in India probably as soon as it was domesticated in China. Soybean is an important crop in human and animal nutrition because it is major source of edible vegetable oil and high protein containing food in the world. It contains about protein (40-42%), carbohydrates (23%) and cholesterol free oil (18-20%). Soybean protein is rich in valuable amino acid lysine (5%) which is deficient in most of the cereals. It also contains 60% polyunsaturated fatty acids (52.8% linolenic acid + 7.2% Linoleic acid). It has high caloric value releasing 432 calories from 100 gm edible protein as compared to 350 calories from cereals of same quantity. Soybean is a global crop that is known as golden bean and poor man's meat.

Micronutrient deficiencies in crop plants are widespread because of increased micronutrient demand from intensive cropping practices and adaptation of high-yielding crop cultivars, enhanced crop production on marginal soils that contain low levels of essential micronutrients, increased use of high analysis fertilizers with low amounts of micronutrients, decreased use of animal manures, composts and crop residues, use of soils low in micronutrient reserves, use of liming in acid soils, involvement of natural and anthropogenic factors that limit adequate supplies and create elemental imbalance in soil Fageria *et al.*, (2002) [3]. Shukla and Behera (2011) [10] reported that as much as 48, 12, 5, 4, 33, 13 and 41 percent soils in India are affected with deficiency of Zn, Fe, Mn, Cu, B, Mo and S, respectively.

Metal such as iron is very important for normal growth of soybean (Fageria *et al.*, 2002) [3]. It also plays an important role in the formation of some nodule proteins like nitrogenase and leghaemoglobin (Moran *et al.*, 1997) [6]. Zinc plays important role in activating the enzymatic systems, zinc is essential for synthesis of chlorophyll and carbohydrates. Zinc is considered as the most limiting factor in producing crop in different parts of the world. Zinc deficiency reduces nutritional value, yield and production of soybean crop. Among the micronutrients, Zn and Fe nutrition can affect the susceptibility of plants to drought.

Micronutrients play many complex roles in plant nutrition and plant production. While, most of the micronutrients participate in the functioning of enzyme systems, there is considerable variation in the specific functions of the various micronutrients in plant and microbial growth processes. For example, copper, iron, and molybdenum are capable of acting as electron carriers in the enzyme systems that brings about oxidation-reduction reaction in plants.

Such reactions are essential in photosynthesis and many other metabolic processes. Zinc and manganese involve in many plant enzyme system as bridges to connect the enzyme with the substrate upon which it is meant to act.

Materials and Methods

Field experiment entitled "Effect of iron and zinc on soil properties, nutrient uptake and yield of soybean (*Glycine max* L.) in Inceptisol" was conducted at Soil Science and Agricultural Chemistry Departmental Research Farm, College of Agriculture, Latur during *kharif* season 2021 on sorghum variety MAUS-158. The topography of experimental field was uniform and leveled. The experimental soil was slightly alkaline in nature. The total geographical area of Latur district is 7.37 mha. Geographically Latur district comes under Maharashtra state which is located between 180 05' to 180 75' North. The soils of Latur district belongs to order Vertisols, Inceptisol and Entisol derived from Deccan trap. RDF (30:60:30:20 kg NPKS ha^{-1}) supplied through Urea, SSP, MOP & Bensulf.

The experimental soil was clayey in texture, calcareous in nature, moderately alkaline reaction, low in content of organic carbon (5.60 g kg^{-1}), available nitrogen (216.12 kg ha^{-1}), available phosphorous (18.24 kg ha^{-1}), high in available potassium (453.15 kg ha^{-1}), available sulphur (27.55 kg ha^{-1}), DTPA zinc (1.14 kg ha^{-1}) and DTPA iron (7.7 kg ha^{-1}).The experiment was laid out in randomized block design with nine treatments and three replications, respectively.

Results and Discussion

Growth parameters

Effect of iron and zinc on plant height (cm) of soybean

The data in respect of plant height (cm) at 30, 45 and 60 DAS of soybean as influenced by application of iron and zinc in Table 1. The data showed that the application of iron and zinc significantly influenced plant height of soybean at all the stages of crop.

Data presented in Table 1 revealed that the plant height was found to be increased progressively at every growth stage of crop till maturity. Effect of different treatments on height of soybean was found to be significant due to application of different fertilizers through soil and foliar application. Application of RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$ (T7) recorded significantly higher plant height at all growth stages of crop which was at par with treatment (T9) RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS and treatment (T4) RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS and also found significantly superior over rest of the treatments at 30, 45 and 60 DAS. Similar results were also reported by Shinde *et al.* (2020) [1]. The result might be due to combine application of Zn and Fe along with RDF in soybean due to which improvement in nutrient uptake particularly iron and zinc that increased transformation of photosynthetic activity towards growing plant parts and resulting growth of plant.

Table 1: Effect of iron and zinc application on plant height (cm) of soybean at 30, 45 and 60 DAS

Treatments	30 DAS	45 DAS	60 DAS
T1: RDF (30 kg N:60 kg P_2O_5:30 kg K_2O:20 kg S ha^{-1})	20.3	32.60	45.53
T2:RDF + 0.5% Foliar spray of $FeSO_4$ at 30 and 45 DAS	23.26	37.60	50.74
T3:RDF + 0.5% Foliar spray of $ZnSO_4$ at 30 and 45 DAS	23.70	37.30	51.51
T4:RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS	22.23	39.26	52.51
T5:RDF + 25 kg ha^{-1} $FeSO_4$	23.73	38.16	51.17
T6:RDF + 25 kg ha^{-1} $ZnSO_4$	23.23	38.66	51.78
T7:RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$	29.06	45.10	55.58
T8:RDF+ Grade I micronutrients formulation @ 25 kg ha^{-1}	24.60	39.56	51.46
T9:RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS	24.10	41.76	54.76
SE±	1.39	1.76	1.29
CD at 5%	4.19	5.29	3.89

Number of functional leaves $plant^{-1}$

The data in respect of number of functional leaves at 30, 45 & 60 DAS of soybean as influenced by application of iron and zinc on number of functional leaves was presented in Table 2.

The number of leaves $plant^{-1}$ of soybean ranged between 17.62 to 21.30 at 30 DAS, 30.63 to 39.42 at 45 DAS and 45.86 to 59.34 at 60 DAS. The maximum number of leaves $plant^{-1}$ was recorded in treatment T7 **(**RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$) during 30DAS (21.30), 45DAS (39.42) and 60 DAS (59.34). The treatment T7 gives maximum number of leaves $plant^{-1}$ at 30 DAS was found at par with treatment T9 (RDF+ Grade II micronutrients formulation @ 0.5% foliar spray at 30 and 45 DAS) during 45 DAS (36.84) and 60 DAS (56.69), and with treatment T4 (RDF + 0.5% each foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS) during 45DAS (35.62) and 60 DAS (55.87) and with treatment T8 (RDF+ Grade I micronutrients formulation @ 25 kg ha^{-1}) during 60 DAS (54.76) and was found significantly superior over rest of the treatments. This increase in leaves $plant^{-1}$ might be due to combined application of RDF and micronutrient via soil and foliar spray which accelerate metabolic activities and resulted into maximum leaves. Similar results were also reported by Adsul *et al.* (2020) [1].

Table 2: Effect of iron and zinc application on number of leaves per plant of soybean at 30, 45 and 60 DAS

Treatments	30 DAS	45 DAS	60 DAS
T1:RDF (30 kg N:60 kg P_2O_5:30 kg K2O:20 kg S ha^{-1})	17.62	30.63	45.86
T2:RDF + 0.5% Foliar spray of $FeSO_4$ at 30 and 45 DAS	18.46	35.43	55.43
T3:RDF + 0.5% Foliar spray of $ZnSO_4$ at 30 and 45 DAS	17.50	33.47	52.72
T4:RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS	19.16	35.62	55.87
T5:RDF + 25 kg ha^{-1} $FeSO_4$	18.56	32.40	52.78
T6:RDF + 25 kg ha^{-1} $ZnSO_4$	18.73	34.30	53.83
T7:RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$	21.30	39.42	59.34
T8:RDF+ Grade I micronutrients formulation @ 25 kg ha^{-1}	18.53	35.32	54.76
T9:RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS	20.43	36.84	56.69
SE±	0.89	1.36	1.58
CD at 5%	NS	4.08	4.74

The number of leaves $plant^{-1}$ of soybean ranged between 17.62 to 21.30 at 30DAS, 30.63 to 39.42 at 45 DAS and 45.86 to 59.34 at 60 DAS. The maximum number of leaves $plant^{-1}$ was recorded in treatment T7 **(**RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$) during 30DAS (21.30), 45DAS (39.42) and 60DAS (59.34). The treatment T7 gives maximum number of leaves $plant^{-1}$ at 30DAS was found at par with treatment T9 (RDF+ Grade II micronutrients formulation @ 0.5% foliar spray at 30 and 45 DAS) during 45 DAS (36.84) and 60 DAS (56.69), and with treatment T4 (RDF + 0.5% each foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS) during 45DAS (35.62) and 60DAS (55.87) and with treatment T8 (RDF+ Grade I micronutrients formulation @ 25 kg ha^{-1}) during 60 DAS (54.76) and was found significantly superior over rest of the treatments. Whereas the minimum number of leaves $plant^{-1}$ was observed at 30(17.62), 45(30.63) and 60(45.86) DAS with treatment T1 (RDF).

Leaf area (cm2 $plant^{-1}$)

The data in respect to leaf area (cm2 $plant^{-1}$) at 30, 45 & 60 DAS of sorghum as influenced by different silicon and nitrogen levels are presented in Table 3. The leaf area (cm2 $plant^{-1}$) of soybean increased from 384.23 to 659.56 cm at 30DAS, 418.9 to 891.30 cm at 45 DAS and 706.23 to 1026.08 cm at 60 DAS.

The maximum leaf area (cm2 $plant^{-1}$) was recorded in treatment T7 **(**RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$) during 30DAS (659.56cm), 45DAS (891.30) and 60DAS (1026.08cm) and was found at par with treatment T9 (RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS) during 30 DAS (640.53 cm2 $plant^{-1}$), 45 DAS (840.63 cm2 $plant^{-1}$) and 60 DAS (982.56 cm2 $plant^{-1}$), treatment T4 (RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS) during 30 DAS (625.16 cm2 $plant^{-1}$) and 60 DAS (967.93 cm2 $plant^{-1}$), treatment T8 (RDF+ Grade I micronutrients formulation @ 25 kg ha^{-1}) during 60 DAS (946.60 cm2 $plant^{-1}$) and it was found significantly superior over rest of treatments. Similar results were also reported by Shinde *et al.*, (2020) [1]. The increase in leaf area (cm2 $plant^{-1}$) might be due to involvement of zinc and iron in chlorophyll formation, which helped to favour cell division, meristematic activity in apical tissue, expansion of cell and formation of new cell wall. The supply of micronutrient in the early growth phase of crop encourages early vigorous growth.

Table 3: Effect of iron and zinc application on dry matter content (g $plant^{-1}$) of soybean at 30, 45 and 60 DAS.

Treatments	30 DAS	45 DAS	60 DAS
T1: RDF (30 kg N:60 kg P_2O_5:30 kg K2O:20 kg S ha^{-1})	5.04	9.33	19.48
T2:RDF + 0.5% Foliar spray of $FeSO_4$ at 30 and 45 DAS	5.65	10.16	21.43
T3:RDF + 0.5% Foliar spray of $ZnSO_4$ at 30 and 45 DAS	5.58	10.37	22.43
T4:RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS	5.77	11.59	27.64
T5:RDF + 25 kg ha^{-1} $FeSO_4$	5.67	10.96	24.86
T6:RDF + 25 kg ha^{-1} $ZnSO_4$	5.68	10.97	22.96
T7:RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$	5.88	12.28	28.46
T8:RDF+ Grade I micronutrients formulation @ 25 kg ha^{-1}	5.67	11.00	26.40
T9:RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS	5.75	12.01	27.67
SE±	0.04	0.33	0.33
CD at 5%	0.12	0.99	1.00

Chlorophyll content

The data pertaining to chlorophyll content *i.e.* chlorophyll a, chlorophyll b and total chlorophyll analyzed at 45 DAS are presented in table 5.

The chlorophyll a varied from 3.63 to 5.62 mg g^{-1}, chlorophyll b varied from 2.37 to 4.21 mg g^{-1} and total chlorophyll content varied from 6.00 to 9.83 mg g^{-1}. The maximum chlorophyll a, chlorophyll b was recorded in treatment T7 (RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$) at 45 DAS (5.62 and 3.25 mg g^{-1}, respectively) which was at par with rest of the treatments except treatment T1 (RDF) which gives least chlorophyll a and chlorophyll b at 45 DAS (3.63 and 2.37 mg g^{-1}, respectively). The highest total chlorophyll (9.83 mg g^{-1}) was recorded with treatment T7 (RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$) at 45 DAS which was at par with treatment T9 (RDF+ Grade II micronutrients formulation @ 0.5% foliar spray at 30 and 45 DAS), T4 (RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS), T8 (RDF+ Grade I micronutrients formulation @ 25 kg ha^{-1}) and T6 (RDF + 25 kg ha- 1 $ZnSO_4$) at 45 DAS i.e. 9.65, 9.49, 9.01 and 8.60 mg g^{-1}, respectively. The similar results were found by Gowthami *et al.* (2018) [4]. The maximum chlorophyll content might be due to soil and foliar application of zinc and iron which is an essential elements for chlorophyll synthesis and imparts green colour to the plants.

Table 4: Effect of iron and zinc application on chlorophyll content (mg g^{-1}) of soybean at 45 DAS

Treatments	Chlorophyll-a	Chlorophyll-b	Total Chl
T1: RDF (30 kg N:60 kg P_2O_5:30 kg K2O:20 kg S ha^{-1})	3.63	2.37	6.00
T2: RDF + 0.5% Foliar spray of $FeSO_4$ at 30 and 45 DAS	5.02	3.32	8.34
T3: RDF + 0.5% Foliar spray of $ZnSO_4$ at 30 and 45 DAS	5.11	3.43	8.55
T4: RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS	5.46	4.03	9.49
T5:RDF + 25 kg ha^{-1} $FeSO_4$	5.19	3.25	8.44
T6:RDF + 25 kg ha^{-1} $ZnSO_4$	5.45	3.15	8.60
T7: RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$	5.62	4.21	9.83
T8: RDF+ Grade I micronutrients formulation @ 25 kg ha^{-1}	5.21	3.81	9.01
T9: RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS	5.57	4.08	9.65
SE±	0.31	0.36	0.41
CD at 5%	0.93	1.08	1.24

Nodulation

The data regarding number of nodules $plant^{-1}$, fresh weight of nodules (g $plant^{-1}$) and dry weight of nodules (g $plant^{-1}$) of soybean as affected by application of iron and zinc was recorded during flowering stage are presented in table 6. The number of nodules $plant^{-1}$ of soybean ranged from 34.84 to 43.90 at flowering stage, fresh weight of nodules ranged from 1.95 to 2.38 g $plant^{-1}$ and dry weight of nodules (g $plant^{-1}$) ranged from 0.72 to 1.70 g $plant^{-1}$.

The maximum number of nodules $plant^{-1}$ (43.90) was recorded in treatment T7 (RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$) during flowering stage and was found at par with treatment T9 (RDF+ Grade II micronutrients formulation @ 0.5% foliar spray at 30 and 45 DAS) during flowering stage (41.08 nodules $plant^{-1}$) and treatment T4 (RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS) during flowering stage (39.76 nodules $plant^{-1}$) and it was found significantly superior over rest of treatments. Whereas the minimum number of nodules $plant^{-1}$ (34.84) was observed at flowering stage with treatment T1 (RDF).

The highest fresh weight of nodules $plant^{-1}$ (2.38 g) was recorded in treatment T7 (RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$) during flowering stage and was found at par with treatment T9 (RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS) during flowering stage (2.35g), treatment T4 (RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS) during flowering stage (2.35g), T2 (RDF + 0.5% Foliar spray of $FeSO_4$ at 30 and 45 DAS) during flowering stage (2.19g), T8 (RDF+ Grade I micronutrients formulation @ 25 kg ha^{-1}), T6 (RDF + 25 kg ha^{-1} $ZnSO_4$) during flowering (2.16g) and T3 (RDF + 0.5% foliar spray of $ZnSO_4$ at 30 and 45 DAS) during flowering stage (1.99g) it was found significantly superior over other treatments.

The highest dry weight of nodules $plant^{-1}$ (1.70 g) was recorded in treatment T7 (RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$) during flowering stage and was found at par with treatment T9 (RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS) during flowering stage (1.57 g), treatment T4 (RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS) during flowering stage (1.31 g), T8 (RDF+ Grade I micronutrients formulation @ 25 kg ha^{-1}) during flowering stage (1.20 g) and T5 (RDF + 25 kg ha^{-1} $FeSO_4$) during flowering stage (1.18 g) it was found significantly superior over rest of treatments.

Similar beneficial effect on nodulation was also reported by Ravi *et al*. (2020) [1]. The increase in number of nodules $plant^{-1}$, fresh weight (g $plant^{-1}$) and dry weight (g $plant^{-1}$) of soybean might be due to significant role of iron and zinc and balanced nutrient management with RDF of soybean.

Table 5: Effect of iron and zinc application on nodulation of soybean at flowering stage.

Treatments	Nodules $plants^{-1}$	Fresh weight (g $plant^{-1}$)	Dry weight (g $plant^{-1}$)
T1: RDF (30 kg N:60 kg P_2O_5:30 kg K2O:20 kg S ha^{-1})	34.84	1.95	0.72
T2: RDF + 0.5% Foliar spray of $FeSO_4$ at 30 and 45 DAS	38.88	2.19	1.02
T3: RDF + 0.5% Foliar spray of $ZnSO_4$ at 30 and 45 DAS	35.63	1.99	0.75
T4: RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS	39.76	2.35	1.31
T5: RDF + 25 kg ha^{-1} $FeSO_4$	34.79	1.97	1.18
T6: RDF + 25 kg ha^{-1} $ZnSO_4$	38.06	1.98	0.78
T7: RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$	43.90	2.38	1.70
T8: RDF+ Grade I micronutrients formulation @ 25 kg ha^{-1}	38.51	2.16	1.20
T9: RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS	41.08	2.35	1.57
SE±	1.45	0.13	0.19
CD at 5%	4.36	0.39	0.57

Yield parameters Number of branches per plant

The data regarding number of branches $plant^{-1}$ of soybean as affected by application of iron and zinc was recorded during three growth stages at 30, 45 and 60 DAS are presented in table 7. The number of branches $plant^{-1}$ of soybean ranged between 3.20 to 4.66 at 30 DAS, 5.16 to 8.01 at 45 DAS and 6.83 to 8.68 at 60 DAS.

The maximum number of branches $plant^{-1}$ was recorded in treatment T7 (RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$) during 30DAS (4.66), 45DAS (8.01) and 60DAS (8.68) and was found at par with treatment T9 (RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS) during 30 DAS (4.50), 45 DAS (7.53) and 60 DAS (8.33), treatment T4 (RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS) during 30 DAS (4.26), 45DAS (7.31) and 60DAS (8.23), treatment T8 (RDF+ Grade I micronutrients formulation @ 25 kg ha^{-1}) during 30 DAS (4.06) and treatment T6 (RDF + 25 kg ha^{-1} $ZnSO_4$) during 30

DAS (3.90) and it was found significantly superior over rest of treatments.

The similar results were found with application of iron and zinc in Shinde *et al*. (2020) [1]. The increase in number of branches plant^{-1} might be due to significant role of iron and zinc in regulating the photosynthesis and balanced nutrient management with RDF of soybean.

Table 6: Effect of iron and zinc application on number of branches per plant of soybean at 30, 45 and 60 DAS.

Treatments	30 DAS	45 DAS	60 DAS
T1: RDF (30 kg N:60 kg P_2O_5:30 kg K_2O:20 kg S ha^{-1})	3.20	5.16	6.83
T2: RDF + 0.5% Foliar spray of $FeSO_4$ at 30 and 45 DAS	3.33	5.70	7.43
T3: RDF + 0.5% Foliar spray of $ZnSO_4$ at 30 and 45 DAS	3.45	6.41	7.23
T4: RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS	4.26	7.31	8.23
T5: RDF + 25 kg ha^{-1} $FeSO_4$	3.63	6.80	7.63
T6: RDF + 25 kg ha^{-1} $ZnSO_4$	3.90	7.22	8.12
T7: RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$	4.66	8.01	8.68
T8: RDF+ Grade I micronutrients formulation @ 25 kg ha^{-1}	4.06	6.67	7.87
T9: RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS	4.50	7.53	8.33
SE±	0.16	0.15	0.17
CD at 5%	0.50	0.46	0.51

Number of pods plant^{-1} and number of grains pod^{-1}

Data on mean number of pods per plant of soybean as influenced by various treatments are presented in table 8.. The data on number of pods per plant varied from 46.71 to 78.89 at the time of harvesting of crop. There was significant increase in number of pods plant^{-1} with all the treatments over T1 (RDF). Highest number of pods plant^{-1} recorded with treatment T7 (RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$) at harvest (78.89) which was found at par with treatment T9 (RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS) and T4 (RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS) having number of pods per plant 73.27 and 71.86, respectively.

The mean number of grains per pod ranged between 2.64 to 3.81. The maximum number of grains per pod was observed with treatment T7 (RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$) at harvest (3.81) which was found at par with treatment T9 (RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS), T4 (RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS), T8 (RDF+ Grade I micronutrients formulation @ 25 kg ha^{-1}) and T6 (RDF + 25 kg ha^{-1} $ZnSO_4$) having number of grains per pod 3.70, 3.68, 3.56 and 3.56, respectively.

These results are close agreement with those reported by Meshram *et al*, (2019) [5]. Increase in number of pods per plant and number of grains per pod might be due to increase in translocation of assimilates from source to sink. It might be due to influence of zinc on auxin metabolism, preferential accumulation of chlorophyll, protein synthesis, starch metabolism and activation of many enzymes.

Table 7: Effect of iron and zinc application on number of pods per plant and number of grains per pod of soybean at harvest.

Treatments	No. of pods plant^{-1}	No. of grains pod^{-1}
T1: RDF (30 kg N:60 kg P_2O_5:30 kg K2O:20 kg S ha^{-1})	46.71	2.64
T2: RDF + 0.5% Foliar spray of $FeSO_4$ at 30 and 45 DAS	69.03	2.81
T3: RDF + 0.5% Foliar spray of $ZnSO_4$ at 30 and 45 DAS	56.34	3.10
T4: RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS	71.86	3.68
T5: RDF + 25 kg ha^{-1} $FeSO_4$	63.1	3.26
T6: RDF + 25 kg ha^{-1} $ZnSO_4$	68.02	3.56
T7: RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$	78.89	3.81
T8: RDF+ Grade I micronutrients formulation @ 25 kg ha^{-1}	68.64	3.56
T9: RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS	73.27	3.70
SE±	2.38	0.13
CD at 5%	7.16	0.39

Seed yield

The data on seed yield of soybean as influenced by application of zinc and iron are presented in table 9. The seed yield of soybean ranged between 1890.11 kg ha^{-1} to 2280.65 kg ha^{-1}. The highest seed yield (2280.65 kg ha^{-1}) was recorded in treatment T7 (RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$) which was at par with treatment T9 (RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS) (2260.62 kg ha^{-1}) and T4 (RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS) (2235.60 kg ha^{-1}) and significantly superior over rest of the treatments.

Similar results were reported with Chaube *et al.* (2002) [2]. The increase in yield might be due to cumulative effect of iron and zinc in increasing growth contributing characters which have been clearly exhibited on the final produce i.e. seed yield ha^{-1}.

Straw yield

The data on straw yield of soybean as influenced by application of zinc and iron are presented in table 9. The straw yield of soybean ranged between 2990.22 kg ha^{-1} to 3967.42 kg ha^{-1}. The highest straw yield (3967.42 kg ha^{-1}) was recorded in treatment T7 (RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$) which was at par with treatment T9 (RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS) (3930.09 kg ha^{-1}) and T4 (RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS) (3907.13 kg ha^{-1}) and significantly superior over rest of the treatments.

Whereas the lowest straw yield (2990.22 kg ha^{-1}) was recorded in treatment T1 (RDF).
Similar results were reported by Raghuwanshi *et al*. (2017) [8]. The increase in yield might be due to cumulative effect of iron and zinc in increasing growth contributing characters like number of leaves and dry matter content which have been clearly exhibited on the final produce i.e. straw yield ha^{-1}.

Table 8: Effect of iron and zinc application on seed yield & straw yield of soybean.

Treatments	Seed yield (kg ha^{-1})	Straw yield (kg ha^{-1})
T1: RDF (30 kg N:60 kg P_2O_5:30 kg K2O:20 kg S ha^{-1})	1890.11	2990.22
T2: RDF + 0.5% Foliar spray of $FeSO_4$ at 30 and 45 DAS	2184	3621.98
T3: RDF + 0.5% Foliar spray of $ZnSO_4$ at 30 and 45 DAS	2062.21	3466.16
T4: RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS	2235.6	3907.13
T5: RDF + 25 kg ha^{-1} $FeSO_4$	2050.85	3395.54
T6: RDF + 25 kg ha^{-1} $ZnSO_4$	2162.42	3606.32
T7: RDF + 25 kg ha-1 $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$	2280.65	3967.42
T8: RDF+ Grade I micronutrients formulation @ 25 kg ha^{-1}	2188.45	3746.85
T9: RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS	2260.62	3930.09
SE±	29.51	51.077
CD	88.48	153.13

Quality parameters Seed index (100 seeds weight g)

The data on seed index of soybean as influenced by application of iron and zinc are presented in table 4.11 and depicted in fig. 4.11. The seed index of soybean ranged between 10.39 to 13.19 g. The highest seed index (13.19 g) was recorded in treatment T7 (RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$) which was at par with treatment T9 (RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS), T4 (RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS),T8 (RDF+ Grade I micronutrients formulation @ 25 kg ha^{-1}), T6 (RDF + 25 kg ha^{-1} $ZnSO_4$) and T2 (RDF + 0.5% Foliar spray of $FeSO_4$ at 30 and 45 DAS) with seed index (g) 12.71, 12.47, 12.32, 11.81 and 11.52, respectively.
Similar beneficial effect on test weight of soybean reported by Raghavendra *et al.* (2020) [7]. The increase in seed index might be due to application of zinc which helps in activation of many enzymes, nucleic acid synthesis and normal crop growth and development.

Table 9: Effect of iron and zinc application on seed index i.e. 100 seeds weight (g) of soybean.

Treatments	Seed Index (g)
T1: RDF (30 kg N:60 kg P_2O_5:30 kg K2O:20 kg S ha^{-1})	10.39
T2: RDF + 0.5% Foliar spray of $FeSO_4$ at 30 and 45 DAS	11.52
T3: RDF + 0.5% Foliar spray of $ZnSO_4$ at 30 and 45 DAS	11.03
T4: RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS	12.47
T5: RDF + 25 kg ha^{-1} $FeSO_4$	10.79
T6: RDF + 25 kg ha^{-1} $ZnSO_4$	11.81
T7: RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$	13.19
T8: RDF+ Grade I micronutrients formulation @ 25 kg ha^{-1}	12.32
T9: RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS	12.71
SE±	0.56
CD at 5%	1.68

Protein content and protein yield

The data on protein content and protein yield of soybean are presented in table 12. Both the characters were significantly influenced by different treatments. The protein content and protein yield varied between 35.13% to 35.97% and 648.65 kg ha^{-1} to 821.90 kg ha^{-1}, respectively. From the data it was observed that the treatment (T7) soil application of RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$ recorded maximum protein content (35.97%) which was numerically superior over rest of the treatments followed by treatment T9 (RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS) (35.70%) and T4 (RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS) (35.68%). Whereas, maximum protein yield (821.90 kg ha^{-1}) obtained in treatment T7 (RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$) which was found at par with treatment T9 (RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS) (808.62 kg ha^{-1}) and T4 (RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS) (799.22 kg ha^{-1}) and significantly superior over rest of treatments.
These results are in agreement with result of Sonune *et al.* (2001) [11]. The increase in protein content might be due to iron and zinc which are two important elements in enzymes structure involved in amino acids are the base of protein synthesis, protein content increased with the application of these micronutrients.

Table 10: Effect of iron and zinc application on protein content (%) and protein yield (kg ha^{-1}) of soybean.

Treatments	Protein content (%)	Protein yield (kg ha^{-1})
T1: RDF (30 kg N:60 kg P_2O_5:30 kg K2O:20 kg S ha^{-1})	35.13	648.65
T2: RDF + 0.5% Foliar spray of $FeSO_4$ at 30 and 45 DAS	35.25	765.29
T3: RDF + 0.5% Foliar spray of $ZnSO_4$ at 30 and 45 DAS	35.37	727.66
T4: RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS	35.68	799.22
T5: RDF + 25 kg ha^{-1} $FeSO_4$	35.43	719.91
T6: RDF + 25 kg ha^{-1} $ZnSO_4$	35.31	759.56
T7: RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$	35.97	821.90
T8: RDF+ Grade I micronutrients formulation @ 25 kg ha^{-1}	35.5	768.08
T9: RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS	35.70	808.62
SE±	0.29	11.24
CD at 5%	NS	33.70

Oil content and oil yield

The data on oil content and oil yield of soybean are presented in table 13. There was no significant increase in oil content due to application of various treatments. The oil content and oil yield varied between 17.49 to 19.26 percent and 330.71 to 439.25 kg ha^{-1}, respectively. From the data it was evident that the soil application of RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$ recorded maximum oil content (19.26%) which was numerically higher over rest of the treatments followed by treatment T9 (RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS) (19.10%) and T4 (RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS) (19.05%). Whereas, maximum oil yield (439.25 kg ha^{-1}) obtained in treatment T7 (RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$) and found at par with treatment T9 (RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS) (431.77 kg ha^{-1}) and T4 (RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS) (425.88 kg ha^{-1}).

These results are inline with result of Sonune *et al.* (2001) [11]. Many researchers reported that micronutrient elements because of supplying plant need to these elements leads to increase of seed oil percentage. Due to enzymatic activity increased photosynthesis and translocation of assimilates to seed. The available soil zinc and iron status (0.60 mg Zn kg^{-1}) and (4.70 mg Fe kg^{-1}) is above critical level hence there was non significant response in terms of oil content observed in the treatments.

Table 11: Effect of iron and zinc application on oil content (%) and oil yield (kg ha^{-1}) of soybean.

Treatments	Oil content (%)	Oil yield (kg ha^{-1})
T1: RDF (30 kg N:60 kg P_2O_5:30 kg K2O:20 kg S ha^{-1})	17.49	330.7171
T2: RDF + 0.5% Foliar spray of $FeSO_4$ at 30 and 45 DAS	18.24	398.4574
T3: RDF + 0.5% Foliar spray of $ZnSO_4$ at 30 and 45 DAS	18.28	377.5369
T4: RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS	19.05	425.8804
T5: RDF + 25 kg ha^{-1} $FeSO_4$	18.30	375.3243
T6: RDF + 25 kg ha^{-1} $ZnSO_4$	18.32	396.1661
T7: RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$	19.26	439.2573
T8: RDF+ Grade I micronutrients formulation @ 25 kg ha^{-1}	18.34	401.3516
T9: RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS	19.10	431.7759
SE±	0.34	10.68
CD at 5%	NS	32.02

Conclusion

Soybean crop fertilized with application of RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$ improved growth parameters like plant height, number of leaves plant^{-1}, leaf area, dry matter content, chlorophyll – a, chlorophyll – b and total chlorophyll content, number of nodules, fresh weight of nodules plant^{-1} and dry weight of nodules plant^{-1} and was found at par with treatment T9 (RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS) and treatment T4 (RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS).

Significantly higher number of branches plant^{-1} at 60 DAS, number of pods plant^{-1}, number of grains pod^{-1}, seed yield plot^{-1}, seed yield ha^{-1}, straw yield plot^{-1} and straw yield ha^{-1} with application of RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$ (T7) and was found at par with treatments T9 (RDF+ Grade II micronutrients formulation @ 0.5% Foliar spray at 30 and 45 DAS) and T4 (RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS).

The improvement in quality parameters were recorded with application of RDF + 25 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} $ZnSO_4$ (T7) *i.e.* seed index, protein content, protein yield, oil content and oil yield followed by treatments T9 (RDF+ Grade II micronutrients formulation

@ 0.5% Foliar spray at 30 and 45 DAS) and T4 (RDF + 0.5% each Foliar spray of $FeSO_4$ and $ZnSO_4$ at 30 and 45 DAS).Combined application of silicon and nitrogen significantly increased the growth parameters of sorghum crop than the separate application of silicon and nitrogen. Treatment S1N120 is significantly superior over rest of the treatments in case of growth parameters of sorghum crop.

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