



# **Influence of Iron Nutrition on Soil Properties, Uptake and Yield of Soybean Grown on Iron Deficient Inceptisol**

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## **Authors' contributions**

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## **ABSTRACT**

Iron (Fe) is an essential micronutrient for optimum growth and yield of crop. In calcareous soils availability of Fe is low, to correct Fe deficient soil application of Chelated Fe-EDTA is often recommended to avoid the possible nutritional disorder due to antagonistic effect of Fe with other cationic micronutrients. The present study was initiated with an objective to evaluate response of soybean crop to soil and foliar application of iron. The experiment was carried out at Agricultural Research Station, Kasbe Digraj, Dist: Sangli (MS) during kharif 2018-19. The experimental soil was alkaline, calcareous, clay in texture, low in available nitrogen, phosphorus, very high in available potassium and deficient in iron. The experiment was laid out in randomized block design with eight treatments and three replications. The treatments comprised of common application of NPK fertilizers in conjunction with 10 t FYM ha<sup>-1</sup>, soil application of FeSO<sub>4</sub> @ 10 and 20 kg ha<sup>-1</sup> with and without 0.2 per cent spray of chelated Fe. The results revealed that the soil pH and electrical conductivity did not differ due to different treatments however, the organic carbon content was found to be slightly improved over control. The free calcium carbonate percentage in soil also found to be statistically non-significant although it revealed slight decline from the initial value due to different iron nutrition treatments. General recommended dose of fertilizers +Soil application of FeSO<sub>4</sub> @ 20

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kg ha<sup>-1</sup> + two foliar sprays of chelated Fe @ 0.2 per cent at 30 and 50 DAS (T<sub>8</sub>) recorded significantly higher available N, P and DTPA Fe over control treatment whereas, available K, DTPA Zn, Mn and Cu were found to be statistically non-significant due to different treatment of iron nutrition along with NPK fertilizers and organic manure. Significantly highest total uptake of N, P, K, Fe, Mn, Cu and Zn by soybean was exhibited in T<sub>8</sub> which was either equivalent or statistically at par to GRDF + soil application of FeSO<sub>4</sub> @ 10 kg ha<sup>-1</sup> + two foliar sprays of chelated Fe @ 0.2% at 30 and 50 DAS (T<sub>7</sub>). In general, all the treatments of iron nutrition were statistically at par in context of soil nutrient and nutrient uptake by soybean crop. Significantly higher grain yield (2493 kg ha<sup>-1</sup>), straw yield (3779 kg ha<sup>-1</sup>) of soybean was recorded by T<sub>8</sub> which was closely followed by T<sub>7</sub>. All the treatments of iron nutrition irrespective of method of application recorded statistically at par grain yield of soybean nonetheless, soil application of FeSO<sub>4</sub> was found to be beneficial in correcting the initial deficient iron and zinc status in the soil. In a nutshell, it can be concluded that soil application of FeSO<sub>4</sub> @ 10 or 20 kg ha<sup>-1</sup> is adequate for obtaining optimum soybean yield and sustaining soil fertility in an iron deficient, slightly calcareous Inceptisol soil.

**Keywords:** Iron nutrition; soil properties; nutrient status; uptake; yield.

## 1. INTRODUCTION

Soybean (*Glycine max* L.) is leguminous crop and it belongs to family papilionaceae, sub family of leguminoaceae, originally a crop of China. Soybean is cultivated for more than 3000 years in South-Eastern Asia [1]. Soybean stands first in the world as edible oil and occupies important place in the economy. Globally legumes play a vital role in human nutrition as these are rich sources of protein, calories, certain minerals and vitamins. Among legumes, soybean is the largest source of protein and vegetable oil with poly-unsaturated fatty acids specially Omega 6 and Omega 3 [2]. Soybean is considering one of the most important oil crops. It is significant on worldwide level nourishment and mechanical yields due to high protein content with a dietary benefit industrial crops and nutritional value close to the value of animal protein. Soybean seeds contain about 20% oil, 35% carbohydrate and about 35-40% protein [3].

Soybean is cultivated on 124 million ha area in the world. India ranks fifth in area and production after USA, Brazil, China and Argentina. All world estimated area and production of soybean in *Kharif*- 2017 was 10.60 million ha and 8.00 million MT respectively [4]. The area under soybean cultivation is increasing due to some reason such as soybean is short duration crop (90-110 days), good market price with its higher productivity as compared to other pulses. It can be processed easily for different products viz., soy cheese, soy milk, soy protein, soy yogurt, soybean oil, soy nut. Soybean also used for making the soy ink, soy paint and soy molasses. It is a potential crop that can boost the food-processing industry in rural areas. Soybean

production is affected by many factors such as climatic and edaphic factors which severely affect its production; According to Dass *et al.* 2022, performance of soybean crop is highly affected by the availability of macronutrient and trace elements such as Fe, Zn and Mn. Besides, iron deficiency of Mn and Zn can also affect the production of soybean crop [5]. Deficiency of micronutrient and low availability of other essential nutrients or imbalance use of fertilizers emerged as the important constraint in soybean production. Hence a balanced nutrient application is must to increase the productivity of soybean crop. Among micronutrients, iron plays a vital role in basic biological processes such as photosynthesis, chlorophyll synthesis, respiration [6]. It is also an active cofactor of many enzymes that are necessary for plant hormone synthesis, such as ethylene, lipoxygenase, 1-aminocyclopropane acid-1-carboxylic oxidase [7], or abscisic acid (compounds that are active in many plant development pathways and their adaptive responses to fluctuating environment conditions). Iron deficiency is usually observed in soybean grown in calcareous or alkaline soils. In calcareous soil, iron availability is restricted due to conversion of ferrous to ferric and showed deficiency of Fe manifest into yellowish inter-venal paling of younger leaves (commonly referred as iron chlorosis) and soil conditions such as high soil pH found in large areas of the Great Plains may decrease the plant availability of some macro and micronutrients. This may be corrected through initially application at time of sowing and foliar fertilizer application of combination of starter and booster dose of fertilizer. Supplementary foliar application of N, P, K and micronutrients for deficient soils can help to enhance the crop yields under these

conditions. Foliar application of micronutrient in high pH saline soils is more beneficial in terms of growth and yield of crop [8]. Foliar application of micronutrient is more beneficial as compare to soil application as the application rate of nutrient is comparatively lesser, nutrient absorption is more moreover, when roots cannot provide necessary nutrients, foliar application is always a compatible alternative [9]. The foliar spray of micronutrient improved soybean yield, quality, resistant to pest and diseases and drought tolerance [10]. They further added that thought the plant need of micronutrient is very little but play important role in growth and development of plant. Soil application of fertilizers is the conventional way of supply nutrient to the plant but it poses loss of nutrient due to leaching and environmental anomalies like soil pollution. Foliar nutrition is thus better way to avoid leaching and quick translocation of nutrient to different plant parts [11]. The aim of present study was to investigate the effect of soil and foliar application of iron or combination of both on soil properties, uptake and yield of soybean grown on iron deficient soil.

## 2. MATERIALS AND METHODS

### 2.1 Experimental Site and Soils

The field experiment was conducted on slightly calcareous soil belonging to Sawargaon series of Isohyperthermic family of *Vertic haplustepts* at Agricultural Research Station, Kasbe Digraj, district Sangli, Maharashtra, (India) during *khari* season of the year 2018-19. This research station is geographical located at 16°53'49' N latitude and 74°31'09'E longitude and 580 m above sea level. The experimental soil (0-15 cm soil depth) had alkaline pH (8.15), electrical conductivity (EC) 0.18 dS m<sup>-1</sup>, calcium carbonate (CaCO<sub>3</sub>) 6.80 g kg<sup>-1</sup>, clayey in texture, bulk density (BD) 1.25 Mg m<sup>-3</sup> and organic carbon 4.50 g kg<sup>-1</sup>. The soil available nitrogen, phosphorus and potassium contents were 170, 7.50, 433 kg ha<sup>-1</sup> respectively, and soil DTPA iron, zinc, copper and manganese contents were 4.05, 0.35, 0.40 and 2.52 ppm respectively.

### 2.2 Sample Collection and Analytical Methods

The soil samples were collected from 0-15 cm depths from each plot at the time of sowing and at harvest of soybean. The soil samples were air dried and pulverized to pass through 0.5 mm sieve for organic carbon and 2 mm sieve for

general analysis. These soil samples (0-15 cm soil depth) were analyzed for various physical and chemical properties. The pH (1:2.5) and EC of soil were determined by pH meter and conductivity meter [12]. The organic carbon content of soil was determined by Walkley and Black method [13]. The CaCO<sub>3</sub> content of soil was determined by rapid titration method [14]. The soil samples were analyzed for available N by the alkaline permanganate method [15], available P (Olsen- P) by 0.5 M NaHCO<sub>3</sub> extraction [16], available K (NH<sub>4</sub>OAc) by 1N neutral NH<sub>4</sub>OAc extraction on flame photometer [17] and DTPA extractable micronutrients (Fe, Mn, Cu, Zn) [18]. The grain and straw samples were collected separately from each plot at the time of soybean harvest. The samples were oven dried at 60°C. The plant and grain samples were analyzed for total N by microkjeldahl method in H<sub>2</sub>SO<sub>4</sub>:H<sub>2</sub>O<sub>2</sub> (1:1) digestion [19], total P by vanadomolybdate yellow colour method in nitric acid H<sub>2</sub>SO<sub>4</sub>:HClO<sub>4</sub>:HNO<sub>3</sub> (1:4:10) digestion [12], total K on flame photometer in H<sub>2</sub>SO<sub>4</sub>:HClO<sub>4</sub>:HNO<sub>3</sub> (1:4:10) digestion and micronutrients viz., Fe, Mn, Cu, Zn by nitric perchloric acid digestion method [20].

### 2.3 Experimental Details

The field experiment was laid out in a randomized block design with eight treatments and three replications. The treatments were absolute control (T<sub>1</sub>), general recommended dose of fertilizer (GRDF) i.e.50:75:45 kg ha<sup>-1</sup> N:P<sub>2</sub>O<sub>5</sub>:K<sub>2</sub>O + 10 t ha<sup>-1</sup> FYM (T<sub>2</sub>), GRDF + soil application of FeSO<sub>4</sub> @ 10 kg ha<sup>-1</sup> (T<sub>3</sub>), GRDF + soil application of FeSO<sub>4</sub> @ 20 kg ha<sup>-1</sup> (T<sub>4</sub>), GRDF + FeSO<sub>4</sub> @ 10 kg ha<sup>-1</sup> + cow dung slurry @ 500 liters ha<sup>-1</sup> (T<sub>5</sub>), GRDF + two foliar sprays of chelated Fe @ 0.2% at 30 and 50 days after sowing (DAS) (T<sub>6</sub>), GRDF + soil application of FeSO<sub>4</sub> @ 10 kg ha<sup>-1</sup> + two foliar sprays of chelated Fe @ 0.2% at 30 and 50 DAS (T<sub>7</sub>) and GRDF + soil application of FeSO<sub>4</sub> @ 20 kg ha<sup>-1</sup> + two foliar sprays of chelated Fe @ 0.2% at 30 and 50 DAS (T<sub>8</sub>). The FYM containing 0.53 % N, 0.24 % P and 0.48 % K were applied fifteen days before sowing of soybean. The soybean crop was fertilized with 50 kg N, 75 kg P<sub>2</sub>O<sub>5</sub> and 45 kg K<sub>2</sub>O ha<sup>-1</sup> for treatment GRDF as a basal dose through urea, single super phosphate and muriate of potash to treatment T<sub>2</sub> to T<sub>8</sub> at the time of sowing. The treatments wise quantity of ferrous sulfate was incubated in well decomposed FYM for four days and then applied to treatment T<sub>3</sub>, T<sub>4</sub>, T<sub>7</sub> and T<sub>8</sub> at the time of sowing. The foliar sprays of chelated Fe at the

rate of 0.2 per cent at 30 and 50 DAS as were applied to treatments T<sub>6</sub>, T<sub>7</sub> and T<sub>8</sub>. The cow dung slurry (125 kg cow dung + 500 liters water) with FeSO<sub>4</sub> @ 10 kg ha<sup>-1</sup> were incubated for one week and applied to the treatment T<sub>5</sub> during first irrigation. The seeds of soybean variety *Phule Sangam* (KDS 726) were inoculated with *Rhizobium* and phosphate solubilizing bacteria @ 250 g per 10 kg of seeds and used for sowing. The soybean crop was sown in monsoon (*khariif*) season on 27/07/2018 with 30 cm row spacing and harvested on 3/11/2018. The gross experimental plot size was 5.4 x 3.6 m<sup>2</sup> and net plot size was 4.8 x 3.0 m<sup>2</sup>. The standard agronomic packages of practices were adopted in soybean crop. The statistical analysis was carried out and the treatment effect was compared at 5 % significance level [21].

### 3. RESULTS AND DISCUSSION

#### 3.1 Soil Properties

The treatments of iron nutrition through foliar, soil and combination of both applications did not show any significant change in soil properties such as pH, EC, organic carbon and calcium carbonate content after harvest of soybean crop. However, the data exhibited meager positive changes in these properties (Table 1). The soil pH and electrical conductivity did not differ within the treatments however, numerically less pH was observed in treatments receiving soil application of inorganic fertilizer along with organic manures. As compared to the initial soil pH value of 8.15, the lowest soil pH (8.07) was observed in T<sub>6</sub> and highest was found in the treatment T<sub>1</sub> (8.27).

In present investigation, the chemical fertilizers are coupled with organic fertilizer for better use efficiency. Decrease in soil pH by use of chemical fertilizer can be explained by leaching of basic cations such as potassium, calcium and magnesium from the soil. In general, use of livestock byproduct increases soil pH but again it depends upon soil properties, treatment amount and organic matter content. Similar results are also reported by Han *et al.*, [22]. The soil organic carbon content among the different treatments did not show specific trends but found to be statistically (5% level) significant when compared to unfertilized control. Significant highest OC (0.53%) was observed in treatment T<sub>8</sub> however it was statistically at par with all the other iron nutrition treatments. The treatments receiving chemical fertilizers in combination with FYM and Fe application through soil and foliar sprays in

general recorded higher OC content as compared to control. It indicated that the application of FYM and chemical fertilizers improves organic carbon content in soil. The OC content also corresponded to higher soybean yield perhaps signifying the role of below ground biomass towards contributing in improving soil organic carbon. The results are in agreement with findings of Singh *et al.* [23], Jagadeesha *et al.* [24]. The lowest calcium carbonate content in soil (6.15%) and (6.16%) was obtained in T<sub>7</sub> and T<sub>8</sub> respectively, as compared to initial calcium carbonate content (6.8%). The unfertilized control recorded highest calcium carbonate (6.51%) over rest of the treatments. The decrease in calcium carbonate content in soil might be due to neutralization of calcium carbonate due to application of FYM and due to excess soybean residue, which upon decomposition might have neutralized calcium carbonate. The results corresponded to the finding of Mairan *et al.* [25].

#### 3.2 Soil Available Nutrient Status

The fertilizer treatments significantly affected the soil available nutrient content (Table 2). Significantly highest available nitrogen was recorded by T<sub>8</sub> (209 kg ha<sup>-1</sup>) among the different NPK treatments with or without FYM and iron nutrition. However, it was statistically at par with all the other nutrient management treatments except unfertilized control.

The control treatment recorded lowest available nitrogen content (146 kg ha<sup>-1</sup>) which was substantially less than initial value of 170 kg ha<sup>-1</sup>. This could be due to uptake of existing available nitrogen for growth and development of soybean. The treatments, receiving NPK fertilizers along with FYM and Fe application through soil and foliar unveiled enhanced available nitrogen content which could be attributed to role of iron in biological nitrogen fixation in legume crop. The results are in corroboration with those of Mostafavi [26]. Similarly, available phosphorus was found to be significantly higher in T<sub>8</sub> (10.2 kg ha<sup>-1</sup>) over rest of the treatments. The available phosphorus content among the different NPK fertilizers along with FYM and Fe application through soil and foliar varied meagerly however, these treatments recorded higher available phosphorus content as compared to initial P status (7.5 kg ha<sup>-1</sup>). General recommended dose of fertilizer (GRDF) consisted of conjunct use of inorganic, organic and beneficial microbes which was commonly applied along with iron nutrition

treatments. Increase in soil available nitrogen and phosphorus indicated that plant did not utilize excess nutrient which could be since slow decomposing organic matter of manure that might have enabled the plant to use nutrient for longer time besides, the evident action of rhizobium and phosphorus solubilizing bacteria seed treatments further could have enhanced their availability in the soil (Bhandari *et al.* [27], Singh *et al.* [28]). Similar findings are also reported by Abbas *et al.*, [29]. The soil available potassium did not show any significant difference within the various nutrient management treatments. The probable reason for statistically non-significant differences may be because the initial K status was sufficient and thus as a results removal of K by plant had little influence on the residual K content (Rahman *et al.*, [30]). Nevertheless, the available K content was found to be highest in treatment receiving GRDF along with Fe application through soil and foliar. Numerically highest available K was recorded by treatment T<sub>8</sub> (470 kg ha<sup>-1</sup>) as compared to other treatments. Perhaps, increase in potassium content in soil might be due to application of inorganic K fertilizer, organic manure and iron-potassium synergistic effect. Similar results were also reported by Mortvedt *et al.* [31]. The iron nutrition treatments influenced the DTPA Fe content in soil substantially (Table 3). The treatment receiving FeSO<sub>4</sub> @ 20 kg ha<sup>-1</sup> + two foliar spray of chelated Fe @ 0.2% i.e.T<sub>8</sub> recorded significantly highest DTPA Fe content (4.71 mg kg<sup>-1</sup>) among the various treatments. Nonetheless, it was at par with all the treatments of soil application FeSO<sub>4</sub> @ 10 and 20 kg ha<sup>-1</sup> alone and along with two foliar spray of chelated Fe @ 0.2% at 30 & 50 DAS, soil application FeSO<sub>4</sub> @ 10 kg ha<sup>-1</sup> with cow + dung slurry @ 500 liters ha<sup>-1</sup> as well as soil application FeSO<sub>4</sub> @ 10 kg ha<sup>-1</sup> GRDF except control. These results are in close accordance with Farid [32]. In the present investigation the iron status of soil was observed to be improved from deficient (0.35 mg kg<sup>-1</sup>) to near sufficient (0.47 mg kg<sup>-1</sup>) after harvest of soybean crop in treatments receiving iron nutrition either through soil or foliar or both soil and foliar. This might be since soil applied iron forms a chelating agent with applied farmyard manure that helps in keeping micronutrient (Fe) soluble and consequently more available to the plants for longer period [33]. The DTPA Mn content in soil was not significantly influenced due to soil application and foliar spray of iron. The DTPA Mn content in soil at harvest was higher under T<sub>8</sub> (2.65 mg kg<sup>-1</sup>) than the other treatments. In general, the

treatments consisting NPK fertilizers coupled with organic fertilizer showed increase in DTPA Mn when compared to initial soil test value (2.52 mg kg<sup>-1</sup>). This improvement may be attributed to the release of native micronutrients contained in the FYM as a consequence of microbial decomposition [34]. Likewise, the DTPA Cu content in soil was not significantly influenced due to various treatments. The DTPA Cu content in soil at harvest was more under T<sub>8</sub> (0.49 mg kg<sup>-1</sup>) than other treatments. The increase in soil DTPA Cu content at harvest stage was observed in all the treatments receiving GRDF with Fe application through soil and foliar spray as compare to initial DTPA Cu content (0.35 mg kg<sup>-1</sup>). This might be due to FYM increased the Cu content by supplying complexing agents, which formed stable complexes with Cu micronutrients. These results are in conformity with those reported by Jalali *et al.* [35]. The DTPA Zn content in soil was found non-significant due to soil application and foliar spray of iron (Table 3). Soil Zn content was highest in T<sub>8</sub> (0.47 mg kg<sup>-1</sup>) as compared to other treatments. The increase in soil DTPA Zn content as compared to initial soil test Zn (0.35 mg kg<sup>-1</sup>) after harvest was observed in all the treatments receiving GRDF with Fe application either through soil and foliar spray. The higher availability of Zn in soil due to application of FYM could be ascribed to mineralization of manures, reduction in fixation and complexing properties of decomposition products of manures with micronutrients [36].

### 3.3 Total Macronutrient Uptake by Soybean Crop

The total N, P and K uptake by soybean crop exhibited significant differences among the treatments revealing the minimum necessity of Fe nutrition. The data in this context is presented in Table 4. Significantly highest N uptake to the tune of 133.68 kg ha<sup>-1</sup> by soybean was observed under the treatment T<sub>8</sub> over T<sub>5</sub> (116.59 kg ha<sup>-1</sup>), T<sub>3</sub> (114.21 kg ha<sup>-1</sup>), T<sub>2</sub> (111.05 kg ha<sup>-1</sup>) and T<sub>1</sub> (61.66 kg ha<sup>-1</sup>) however, it was at par with T<sub>7</sub> (123.81 kg ha<sup>-1</sup>) and T<sub>4</sub> (123.29 kg ha<sup>-1</sup>). This clearly indicated that the better total uptake of nitrogen corresponded to minimum soil application of FeSO<sub>4</sub> @ 20 kg ha<sup>-1</sup> along with or without foliar sprays of chelated Fe @ 0.2% for their growth and development. The increase in uptake of nitrogen may be attributed to higher uptake of N due to high dry matter production and its further translocation to grain and straw. Further, applied Fe helped in the uptake of other nutrients including N, through activation enzymes

in soil [37]. Similar results were also reported by Meena *et al* [38]. Significantly highest total uptake of phosphorus by soybean 24.32 kg ha<sup>-1</sup> was noticed recorded by T<sub>8</sub> which was at par with T<sub>7</sub> (21.72 kg ha<sup>-1</sup>), T<sub>4</sub> (21.03 kg ha<sup>-1</sup>) and T<sub>5</sub> (20.99 kg ha<sup>-1</sup>). The results in context to P uptake highlighted that soil application of FeSO<sub>4</sub> @ 10 and 20 kg ha<sup>-1</sup> along with two foliar sprays of chelated Fe @ 0.2% or soil application of FeSO<sub>4</sub> @ 20 kg ha<sup>-1</sup> without foliar application of chelated Fe exhibited higher P assimilation. This could be attributed to combine effect of soil and foliar Fe application in enhancing chlorophyll synthesis in leaves which might have led to increased photosynthetic rate and dry matter yield. Thus, higher uptake of P may be due to the increased dry matter production and synergistic effect between N and P. Similar observations were made by Kumar *et al.*, [39]. The total K uptake by soybean crop was found to be significant highest in treatment T<sub>8</sub> (67.79 kg ha<sup>-1</sup>) over treatment T<sub>2</sub> (55.66 kg ha<sup>-1</sup>), T<sub>3</sub> (57.41 kg ha<sup>-1</sup>), T<sub>5</sub> (59.97 kg ha<sup>-1</sup>) and T<sub>6</sub> (58.58 kg ha<sup>-1</sup>) however, it was at par with treatments T<sub>7</sub> (63.70 kg ha<sup>-1</sup>) and T<sub>4</sub> (62.64 kg ha<sup>-1</sup>). It is clearly indicated that the Fe applications, either as soil or foliar application increased the K uptake of soybean. The results are in agreement to that of Jawaharlal *et al.* [40] who reported that, soil and foliar application of FeSO<sub>4</sub> significantly increased the nitrogen and potassium uptake by onion.

### 3.4 Total Micronutrient Uptake by Soybean Crop

The data pertaining to total Fe, Zn, Mn, and Cu uptake is presented in Table 5. Alike macronutrient the micronutrient uptake by soybean crop displayed significant differences. Total iron uptake by soybean crop was observed to be significantly higher in T<sub>8</sub> (1579 g ha<sup>-1</sup>) over other treatments of iron nutrition such as T<sub>5</sub> (1254 g ha<sup>-1</sup>), T<sub>4</sub> (1303 g ha<sup>-1</sup>), T<sub>3</sub> (1230 g ha<sup>-1</sup>) however, it was at par with T<sub>7</sub> (1469 g ha<sup>-1</sup>) and T<sub>6</sub> (1362 g ha<sup>-1</sup>). Foliar application of chelated Fe alone or in combination with soil application of FeSO<sub>4</sub> was found to be vital for Fe uptake. The treatments receiving only soil application of FeSO<sub>4</sub> did not show significant Fe uptake. The increase in uptake of iron may be attributed to higher uptake of Fe due to high dry matter production and its further translocation to grain and straw. The results of present investigation are in accordance with findings of Sakal *et al.* [41] in rice and maize. In context to, Zn uptake the results revealed that all the treatments consisting soil application and/or foliar

application and/or combination treatment of iron nutrition showed higher uptake as compared to control (80 g ha<sup>-1</sup>). Amongst the different treatment of iron nutrition significantly highest uptake of Zn (204 g ha<sup>-1</sup>) by soybean was observed under the treatment T<sub>8</sub> followed by T<sub>7</sub> (187 g ha<sup>-1</sup>). However, all the other treatments were found to be statistically at par for Zn uptake except control. This indicated that total uptake of zinc increased with soil application of Fe and foliar sprays of chelated Fe @ 0.2% with GRDF. Zn reacts easily with organic chelating agents present in FYM, which can increase crop available Zn in the soil solution. The presence of chelating agents and complexation of Zn by organic matter can increase the availability of Zn in the soil solution. Enhanced availability of Zn might have increased its uptake and further translocation to grain and straw. Similar results were also reported by Patel *et al.* [42].

The Mn uptake by soybean crop unveiled identical trend to earlier micronutrient uptake. The treatments receiving soil application of FeSO<sub>4</sub> @ 20 kg ha<sup>-1</sup> along with two foliar sprays of chelated Fe @ 0.2% i.e. T<sub>8</sub> recorded highest Mn uptake (153 g ha<sup>-1</sup>) by T<sub>7</sub> (139 g ha<sup>-1</sup>) and T<sub>4</sub> (133 g ha<sup>-1</sup>) which was significantly superior over T<sub>2</sub> (118 g ha<sup>-1</sup>) and T<sub>1</sub> (61 g ha<sup>-1</sup>). However, it was statistically at par with other treatment of iron nutrition. The higher level of Fe may often result into relatively low availability of Mn, this can be considered as indicative of a mutual antagonism between these elements. The antagonism between them may get reflected either during uptake by the roots or during translocation from roots to the leaves or other above ground parts [43]. In the present investigation, higher level of Fe i.e. soil application of FeSO<sub>4</sub> @ 20 kg ha<sup>-1</sup> did not show any adverse effect on either availability of Mn or uptake of Mn by soybean crop which might be probably because the initial Fe content in soil is below critical level and the applied Fe levels might just enough to meet the demand of the crop. This could have led to unaffected translocation of Mn to soybean crop resulting in higher uptake in treatments consisting iron application. Furthermore, application of iron through soil along with organic matter might have increased the availability of micronutrients by forming complex with fulvic acids and thereby creating a favourable condition for microbial decomposition as well. Similarly, Kandoliya and Kunjadia, [44] reported increased Mn uptake by wheat crop in treatments receiving soil or foliar application of Fe and Zn. The results are also in

conformity to that of Moosavi and Ronaghi [45] who studied the effect of iron and Mn soil and foliar application on uptake by soybean and their relationship in calcareous soil. The Cu uptake by soybean crop also varied as per the level of iron nutrition the treatment receiving soil application of FeSO<sub>4</sub> in combination of chelated Fe foliar spray recorded higher Cu uptake. Significantly highest Cu uptake by soybean crop was observed in T<sub>8</sub> (99 g ha<sup>-1</sup>) over T<sub>3</sub> (78 g ha<sup>-1</sup>), T<sub>2</sub>

(73 g ha<sup>-1</sup>) and T<sub>1</sub> control (40 g ha<sup>-1</sup>) however, it was at par with rest of the treatment of iron nutrition. The increase in uptake of copper may be attributed increased solubility of Cu due to organic supplements and its further translocation to grain and straw of soybean. The findings are in conformity with Kandoliya and Kunjadia, [44] who reported higher Cu uptake by wheat crop due to soil or foliar application of Fe and Zn.

**Table 1. Effect of soil and foliar application of iron on soil chemical properties after harvest of soybean**

Treatments	pH (1:2.5)	EC (dS m <sup>-1</sup> )	Organic carbon (%)	CaCO <sub>3</sub> (g kg <sup>-1</sup> )
T <sub>1</sub>	8.27	0.20	0.41	6.51
T <sub>2</sub>	8.10	0.23	0.48	6.31
T <sub>3</sub>	8.13	0.23	0.52	6.25
T <sub>4</sub>	8.13	0.23	0.52	6.17
T <sub>5</sub>	8.13	0.24	0.49	6.15
T <sub>6</sub>	8.07	0.24	0.47	6.27
T <sub>7</sub>	8.13	0.23	0.51	6.15
T <sub>8</sub>	8.10	0.24	0.53	6.16
Initial values	<b>8.15</b>	<b>0.18</b>	<b>0.45</b>	<b>6.8</b>
SE±	0.06	0.01	0.01	0.09
CD at 5 %	NS	NS	0.05	NS

**Table 2. Effect of soil and foliar application of iron on soil available N, P and K after harvest of soybean**

Treatments	Available Nutrients		
	N	P	K
		(kg ha <sup>-1</sup> )	
T <sub>1</sub>	146	7.0	414
T <sub>2</sub>	192	9.2	459
T <sub>3</sub>	197	9.4	467
T <sub>4</sub>	201	9.6	463
T <sub>5</sub>	205	9.6	459
T <sub>6</sub>	197	9.2	467
T <sub>7</sub>	201	9.8	463
T <sub>8</sub>	209	10.2	470
Mean	<b>170</b>	<b>7.5</b>	<b>433</b>
SE±	9.76	0.45	16.93
CD at 5 %	29.62	1.38	NS

**Table 3. Effect of soil and foliar application of iron on soil DTPA micronutrient after harvest of soybean**

Treatments	Soil DTPA micronutrients			
	Fe	Mn	Cu	Zn
			(mg kg <sup>-1</sup> )	
T <sub>1</sub>	4.05	2.42	0.35	0.32
T <sub>2</sub>	4.52	2.48	0.38	0.38
T <sub>3</sub>	4.56	2.51	0.40	0.40
T <sub>4</sub>	4.65	2.58	0.41	0.42
T <sub>5</sub>	4.59	2.59	0.43	0.43
T <sub>6</sub>	4.54	2.55	0.42	0.42
T <sub>7</sub>	4.67	2.63	0.45	0.45
T <sub>8</sub>	4.71	2.65	0.49	0.47
Initial	<b>4.17</b>	<b>2.52</b>	<b>0.40</b>	<b>0.35</b>
SE±	0.19	0.15	0.07	0.04
CD at 5 %	0.59	NS	NS	NS

**Table 4. Effect of soil and foliar application of iron on total macronutrient uptake by soybean**

Treatments	Total macronutrient uptake		
	N uptake	P uptake	K uptake
		(kg ha <sup>-1</sup> )	
T <sub>1</sub>	61.7	11.3	33.3
T <sub>2</sub>	111.1	18.2	54.7
T <sub>3</sub>	114.2	18.4	57.4
T <sub>4</sub>	123.3	21.0	62.6
T <sub>5</sub>	117.9	20.1	60.0
T <sub>6</sub>	116.6	20.4	58.6
T <sub>7</sub>	123.8	21.7	63.7
T <sub>8</sub>	133.7	24.3	67.8
SE±	4.83	1.20	2.25
CD at 5 %	14.67	3.64	6.85

### 3.5 Grain Yield

The significantly higher grain yield (2493 kg ha<sup>-1</sup>) was observed with treatment receiving soil application of FeSO<sub>4</sub> @ 20 kg ha<sup>-1</sup> along with two foliar sprays of chelated Fe @ 0.2% (T<sub>8</sub>) over the rest of treatments which was estimated to be 14 per cent higher compared to T<sub>2</sub> and 81 per cent over T<sub>1</sub> (Table 6). Treatments receiving iron nutrition irrespective of method of application demonstrated increment in soybean grain yield as compared treatments without iron supplement could be due to quicker availability of iron to plants, soil applied FeSO<sub>4</sub> and FYM might have resulted increased concentration of plant available iron and formation of metalo-organic

complexes of higher extractability and helped in continuous supply of iron and this in turn increases chlorophyll content and accumulate more carbohydrates, which seems to be associated with increase in flowering and pod development ultimately increasing grain yield of soybean. While foliar application of iron might have resulted in direct absorption of the foliage sprayed with Fe solution. The results are in conformity to that of Sale *et al.* [46] who observed increased in soybean yields due to foliar nutrition of Fe and Zn. Similarly, Moosavi and Ronaghi [45] also reported substantial increase in soybean yield in response to foliar and soil iron nutrition.



**Table 5. Effect of soil and foliar application of iron on total micronutrient uptake by soybean**

Treatments	Total micronutrient uptake			
	Fe	Zn	Mn	Cu
			(g ha <sup>-1</sup> )	
T <sub>1</sub>	628	80	61	40
T <sub>2</sub>	1121	160	118	73
T <sub>3</sub>	1230	163	123	78
T <sub>4</sub>	1303	184	133	87
T <sub>5</sub>	1254	177	135	84
T <sub>6</sub>	1362	177	126	85
T <sub>7</sub>	1469	187	139	91
T <sub>8</sub>	1579	204	153	99
SE±	77.49	16.43	10.77	4.89
CD at 5 %	235.04	32.68	14.85	49.85

**Table 6. Effect of soil and foliar application of iron on grain, straw yield and yield contributing parameter of soybean**

Treatments	Grain yield	Straw yield
	(kg ha <sup>-1</sup> )	
T <sub>1</sub>	1372	2070
T <sub>2</sub>	2180	3305
T <sub>3</sub>	2212	3479
T <sub>4</sub>	2314	3633
T <sub>5</sub>	2237	3528
T <sub>6</sub>	2219	3520
T <sub>7</sub>	2324	3638
T <sub>8</sub>	2493	3779
SE±	70.0	152.0
CD at 5 %	212.0	462.0

### 3.6 Straw Yield

Soybean straw yield differed to grain yield in its statistical relation. The treatment T<sub>8</sub> recorded highest straw yield to the tune of 3779 kg ha<sup>-1</sup> which was significantly superior over T<sub>2</sub> (3305 kg ha<sup>-1</sup>) and T<sub>1</sub> (2070 kg ha<sup>-1</sup>). However, it was statistical at par with all the treatments receiving iron nutrition irrespective, of method of application. The per cent increase in straw yield under the treatment T<sub>8</sub> was 54% over the T<sub>1</sub> and 14% over the T<sub>2</sub>. The combine soil and foliar application of iron may be better availability of Fe and its uptake could be assigned as the proper reason for significant increase in dry matter production and its accumulation in soil application and foliar spray treatments.

Application of Fe improved the dry matter yield of pea [47].

### 4. CONCLUSIONS

The findings of the present study suggested that application of inorganic NPK fertilizer in conjunction with organic manure @ 10 t ha<sup>-1</sup> and soil application of FeSO<sub>4</sub> @ 20 kg ha<sup>-1</sup> coupled with two foliar sprays of chelated Fe @ 0.2% at 30 and 50 DAS to soybean was found to be pronounced in sustaining soil fertility rather, improving the status of iron from deficient to near sufficient in soil. Besides, this treatment recorded highest total macro and micronutrient uptake by soybean crop which correspondingly increased the grain and straw yield of soybean grown in

iron deficient soil. In general, the treatment receiving iron nutrition performed better as compared to treatment without iron supplement. Soil application of FeSO<sub>4</sub> @ 20 kg ha<sup>-1</sup> along with or without foliar spray of chelated Fe @ 0.2% is prominent in sustaining soil fertility, nutrient uptake and yield of soybean.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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