Original Research Article

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

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^{-1}, soil application of $FeSO_4$ @ 10 and 20 kg ha^{-1} 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. GRDF +Soil application of $FeSO_4$ @ 20 kg ha^{-1} + two foliar sprays of chelated Fe @ 0.2 per cent at 30 and 50 DAS (T_8) 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_8 which was either equivalent or statistically at par to GRDF + soil application of $FeSO_4$ @ 10 kg ha^{-1} + two foliar sprays of chelated Fe @ 0.2% at 30 and 50 DAS (T_7). 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 (24.93 q ha^{-1}), straw yield (37.79 q ha^{-1}) of soybean was recorded by T_8 which was closely followed by T_7. All the treatments of iron nutrition irrespective of method of application recorded statistically at par grain yield of soybean nonetheless, soil application of $FeSO_4$ 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 $FeSO_4$ @ 10 or 20 kg ha^{-1} 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 papillionaceae, 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 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 [3]. 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 Turner 1991, performance of this crop is highly affected by the availability of trace elements such as Molybdenum and Iron. Besides, iron deficiency of Mn and Zn can also affect the production of soybean crop [4]. 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 is vital being structural component of porphyrin molecules, cytochromes, heams, hematin, ferrichrome and leghaemoglobin. These substances are involved in oxidation-reduction reactions in respiration and photosynthesis. It is also an important part of the enzymes, including amino levlinic acid synthetase and co-proporphyrin ogenoxidase, which is essential for nitrogen fixation in nitrogen fixing microorganisms. Iron in chloroplasts reflects the presence of cytochromes for performing various photosynthetic reduction processes and of ferrodoxin as an electron acceptor. The ferrodoxins are Fe-S proteins and are the first stable redox compound of the photosynthetic electron transport chain. 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 [5]. 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 [6]. The foliar spray of micronutrient improved soybean yield, quality, resistant to pest and diseases and drought tolerance [7]. 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 [8].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 MATERIAL AND METHODS

2.1Experimental 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 *kharif* season of the year 2018-19. The experimental soil (0-15 cm soil depth) had alkaline pH, electrical conductivity (EC) 0.18 dS m^{-1}, calcium carbonate ($CaCO_3$) 6.80 g kg^{-1}, clayey in texture, bulk density (BD) 1.25 Mg m^{-3} and organic carbon 4.50 g kg^{-1}. The soil available nitrogen, and potassium contents were 170, 7.50, 433 kg ha^{-1} 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 [9]. The organic carbon content of soil was determined by Walkley and Black method [10]. The $CaCO_3$ content of soil was determined by rapid titration method [11]. The soil samples were analysed for available N by the alkaline permanganate method [12], available P (Olsen- P) by 0.5 M $NaHCO_3$ extraction [13], available K (NH_4OAc) by 1N neutral NH_4OAc extraction on flame photometer [14] and DTPA extractable micronutrients (Fe, Mn, Cu, Zn) [15]. The grain and straw samples were collected separately from each plot at the time of soybean harvest. The samples were oven dried at 60^0C. The plant and grain samples were analyzed for total N by microkjeldahl method in H_2SO_4:H_2O_2 (1:1) digestion [16], total P by vanadomolybdate yellow colour method in nitric acid H_2SO_4:$HClO_4$:HNO_3 (1:4:10) digestion [9], total K on flame photometer in H_2SO_4:$HClO_4$:HNO_3 (1:4:10) digestion and micronutrients *viz.*, Fe, Mn, Cu, Zn by nitric perchloric acid digestion method [17].

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_1), general recommended dose of fertilizer (GRDF) *i.e.*50:75:45 kg ha^{-1} N:P_2O_5:K_2O + 10 t ha^{-1} FYM (T_2), GRDF + soil application of $FeSO_4$ @ 10 kg ha^{-1} (T_3), GRDF + soil application of $FeSO_4$ @ 20 kg ha^{-1} (T_4), GRDF + $FeSO_4$ @ 10 kg ha^{-1} + cow dung slurry @ 500 liters ha^{-1} (T_5), GRDF + two foliar sprays of chelated Fe @ 0.2% at 30 and 50 days after sowing (DAS) (T_6), GRDF + soil application of $FeSO_4$ @ 10 kg ha^{-1} + two foliar sprays of chelated Fe @ 0.2% at 30 and 50 DAS (T_7) and GRDF + soil application of $FeSO_4$ @ 20 kg ha^{-1} + two foliar sprays of chelated

Fe @ 0.2% at 30 and 50 DAS (T_8) . The FYM were applied fifteen days before sowing of soybean. The soybean crop was fertilized with 50 kg N, 75 kg P_2O_5 $ha^{-1}$and 45 K_2O for treatment GRDF as a basal dose of N, P_2O_5 and K_2O was applied through urea, single super phosphate and muriate of potash to treatment T_2 to T_8 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 $T_{3,}$ $T_{4,}$ T_7 and T_8 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 $T_{6,}$ T_7 and $T_{8.}$ The cow dung slurry (125 kg cow dung + 500 liters water) with $FeSO_4$ @ 10 kg ha^{-1} were incubated for one week and applied to the treatment T_5 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 (*kharif*) season with 30 cm row spacing. The standard agronomic packages of practices were adopted in soybean crop. The statistical analysis was carried out. [18].

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 is soil properties such 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_6 and highest was found in the treatment T_1 (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 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.,* [19]. The soil organic carbon content among the different treatments did not show specific trends but found to be statistically significant when compared to unfertilized control. Significant highest OC (0.53%) was observed in treatment T_8 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.* [20] , Jagadeesha *et al.* [21] . The lowest calcium carbonate content in soil (6.15%) and (6.16%) was obtained in T_7 and T_8 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 neutralize calcium carbonate. The results corresponded to the finding of Mairan *et al.* [22].

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_8 (209 kg ha^{-1}) 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^{-1}) which was substantially less than initial value of 170 kg ha^{-1}. 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 Mostafavi [23] . Similarly, available phosphorus was found to be significantly higher in T_8 (10.2 kg ha^{-1}) over rest of the treatments. The available phosphorus content among the different of 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^{-1}). 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 might have enabled the plant to use nutrient for longer time besides, the evident action of rhizobium and PSB seed treatments further could have enhanced their availability in the soil (Bhandari *et al.* [24], Singh *et al.* [25]). Similar findings are also reported by Abbas *et al.,* [26] . 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*., [27]). 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_8 (470 kg ha^{-1}) 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.* [28] . The iron nutrition treatments influenced the DTPA Fe content in soil substantially (table 3). The treatment receiving $FeSO_4$ @ 20 kg ha^{-1} + two foliar spray of chelated Fe @ 0.2% i.e.T_8 recorded significantly highest DTPA Fe content (4.71 mg kg^{-1}) among the various treatments. Nonetheless, it was at par with all the treatments of soil application $FeSO_4$ @ 10 and 20 kg ha^{-1} alone and along with two foliar spray of chelated Fe @ 0.2% at 30 & 50 DAS, soil application $FeSO_4$ @ 10 kg ha^{1} with cow + dung slurry @ 500 liters ha^{-1} as well as soil application $FeSO_4$ @ 10 kg ha^{-1} GRDF except control. These results are in close accordance with Farid Hellal [29]. In the present investigation the iron status of soil was observed to be improved from deficient to near sufficient 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[30]. 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_8 (2.65 mg kg^{-1}) 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^{-1}). This improvement may be attributed to the release of native micronutrients contained in the FYM as a consequence of microbial decomposition [31] . 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_8 (0.49 mg kg^{-1}) 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^{-1}). 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.* [32]. 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_8 (0.47 mg kg^{-1}) as compared to other treatments. The increase in soil DTPA Zn content as compared to initial soil test Zn (0.35 mg kg^{-1}) 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[33] .

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^{-1} by soybean was observed under the treatment T_8 over T_5 (116.59 kg ha^{-1}), T_3 (114.21 kg ha^{-1}), T_2 (111.05 kg ha^{-1}) and T1 (61.66 kg ha^{-1}) however, it was at par with T_7 (123.81 kg ha^{-1}) and T_4 (123.29 kg ha^{-1}). This clearly indicated that the better total uptake of nitrogen corresponded to minimum soil application of $FeSO_4$ @ 20 kg ha^{-1} 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 [34]. Similar results were also reported by Meena *et al* [35]. Significantly highest total uptake of phosphorus by soybean 24.32 kg ha^{-1} was noticed recorded by T_8 which was at par with T_7 (21.72 kg ha^{-1}), T_4 (21.03 kg ha^{-1}) and T_5 (20.99 kg ha^{-1}). The results in context to P uptake highlighted that soil application of $FeSO_4$ @ 10 and 20 kg ha^{-1} along with two foliar sprays of chelated Fe @ 0.2% or soil application of $FeSO_4$ @ 20 kg ha^{-1} 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.*, [36] . The total K uptake by soybean crop was found to be significant highest in treatment T_8 (67.79 kg ha^{-1}) over treatment T_2 (55.66 kg ha^{-1}), T_3 (57.41 kg ha^{-1}), T_5 (59.97 kg ha^{-1}) and T_6 (58.58 kg ha^{-1}) however, it was at par with treatments T_7 (63.70 kg ha^{-1}) and T_4 (62.64 kg ha^{-1}). 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.* [37] who reported that, soil and foliar application of $FeSO_4$ 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_8 (1579 g ha^{-1}) over other treatments of iron nutrition such as T_5 (1254 g ha^{-1}), T_4 (1303 g ha^{-1}), T_3 (1230 g ha^{-1}) however, it was at par with T_7 (1469 g ha^{-1}) and T_6 (1362 g ha^{-1}). Foliar application of chelated Fe alone or in combination with soil application of $FeSO_4$ was found to be vital for Fe uptake. The treatments receiving only soil application of $FeSO_4$ 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.* [38] 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^{-1}). Amongst the different treatment of iron nutrition significantly highest uptake of Zn (204 g ha^{-1}) by soybean was observed under the treatment T_8 followed by T_7 (187 g ha^{-1}). 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 cheated 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.* [39].

The Mn uptake by soybean crop unveiled identical trend to earlier micronutrient uptake. The treatments receiving soil application of $FeSO_4$ @ 20 kg ha^{-1} along with two foliar sprays of chelated Fe @ 0.2% i.e. T_8 recorded highest Mn uptake (153 g ha^{-1}) by T_7 (139 g ha^{-1}) and T_4 (133 g ha^{-1}) which was significantly superior over T_2 (118 g ha^{-1}) and T_1 (61 g ha-^{1}). 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 (Van Der Vorm and Van Diest, [40]). In the present investigation, higher level of Fe i.e. soil application of $FeSO_4$ @ 20 kg ha^{-1} 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, [41] 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 [42] 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 $FeSO_4$ in combination of chelated Fe foliar spray recorded higher Cu uptake. Significantly highest Cu uptake by soybean crop was observed in T_8 (99 g ha^{-1}) over T_3 (78 g ha^{-1}), T_2 (73 g ha^{-1}) and T_1 control (40 g ha^{-1}) 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, [41] who reported higher Cu uptake by wheat crop due to soil or foliar application of Fe and Zn.

3.5 Grain yield: The significantly higher grain yield (24.93 q ha^{-1}) was observed with treatment receiving soil application of $FeSO_4$ @ 20 kg ha^{-1} along with two foliar sprays of chelated Fe @ 0.2% (T_8) over the rest of treatments which was estimated to be 14 per cent higher compared to T_2 and 81 per cent over T_1 (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 $FeSO_4$ 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.* [42] who observed increased in soybean yields due to foliar nutrition of Fe and Zn. Similarly, Moosavi and Ronaghi [43] also reported substantial increase in soybean yield in response to foliar and soil iron nutrition.

3.6 Straw yield: Soybean straw yield differed to grain yield in its statistical relation. The treatment T_8 recorded highest straw yield to the tune of 37.79 q ha^{-1} which was significantly superior over T_2 (33.05 q ha^{-1}) and T_1 (20.70 q ha^{-1}). 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_8 was 54% over the T_1 and 14% over the T_2. 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 (Rehman and Shah [44].

4. CONCLUSIONS

The findings of the present study suggested that application of inorganic NPK fertilizer in conjunction with organic manure @ 10 t ha^{-1} and soil application of $FeSO_4$ @ 20 kg ha^{-1} 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 $FeSO_4$ @ 20 kg ha^{-1} along with or without foliar spray of chelated Fe @ 0.2% is prominent in sustaining soil fertility, nutrient uptake and yield of soybean.

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

Treatments	**pH (1:2.5)**	**EC ($dS\ m^{-1}$)**	**Organic carbon (%)**	**$CaCO_3$ ($g\ kg^{-1}$)**
T_1	8.27	0.20	0.41	6.51
T_2	8.10	0.23	0.48	6.31
T_3	8.13	0.23	0.52	6.25
T_4	8.13	0.23	0.52	6.17
T_5	8.13	0.24	0.49	6.15
T_6	8.07	0.24	0.47	6.27
T_7	8.13	0.23	0.51	6.15
T_8	8.10	0.24	0.53	6.16
Initial values	**8.15**	**0.18**	**0.45**	**6.8**
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^{-1}) -----------------		
T_1	146	7.0	414
T_2	192	9.2	459
T_3	197	9.4	467
T_4	201	9.6	463
T_5	205	9.6	459
T_6	197	9.2	467
T_7	201	9.8	463
T_8	209	10.2	470
Mean	**170**	**7.5**	**433**
SE$\pm$	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^{-1}) -------------------------			
T_1	4.05	2.42	0.35	0.32
T_2	4.52	2.48	0.38	0.38
T_3	4.56	2.51	0.40	0.40
T_4	4.65	2.58	0.41	0.42
T_5	4.59	2.59	0.43	0.43
T_6	4.54	2.55	0.42	0.42
T_7	4.67	2.63	0.45	0.45
T_8	4.71	2.65	0.49	0.47
Mean	**4.17**	**2.52**	**0.40**	**0.35**
SE$\pm$	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^{-1}) ------------------		
T_1	61.7	11.3	33.3

T_2	111.1	18.2	54.7
T_3	114.2	18.4	57.4
T_4	123.3	21.0	62.6
T_5	117.9	20.1	60.0
T_6	116.6	20.4	58.6
T_7	123.8	21.7	63.7
T_8	133.7	24.3	67.8
SE±	4.83	1.20	2.25
CD at 5 %	14.67	3.64	6.85

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^{-1}) ------------------------			
T_1	628	80	61	40
T_2	1121	160	118	73
T_3	1230	163	123	78
T_4	1303	184	133	87
T_5	1254	177	135	84
T_6	1362	177	126	85
T_7	1469	187	139	91
T_8	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
	(q ha^{-1})	
T_1	13.72	20.70
T_2	21.80	33.05
T_3	22.12	34.79

T_4	23.14	36.33
T_5	22.37	35.28
T_6	22.19	35.20
T_7	23.24	36.38
T_8	24.93	37.79
SE$\pm$	0.70	1.52
CD at 5 %	2.12	4.62