Study the effect of seed inoculation of zinc solubilizing bacteria and zinc fertilization on total uptake of n, p, k and micronutrients by soybean (Glycine max L.) and nutrient use efficiency

Prashanth Madi B, SR Shelke and AG Durgude

DOI: https://doi.org/10.22271/chemi.2020.v8.i1y.8512

Abstract
The present study entitled, to study the effect of seed inoculation of Zinc solubilizing bacteria and zinc fertilization on total uptake of N, P, K and Micronutrients by soybean and nutrient use efficiency, was carried out during the year 2016-17 at the Department of Soil Science and Agricultural Chemistry, Post Graduate Institute, M.P.K.V. Rahuri. The experiment was contained 11 treatments with 3 replications with randomized block design (RBD). Different sources of zinc, ZnSO4 and ZnO were applied along with recommended dose of fertilizer and ZnSB (Zinc solubilizing bacteria, The ZnSO4 and ZnO are applied at different levels 100 percent, 75 percent, 50 percent, and 25 percent. The total uptake of nitrogen was found significantly highest (174.39 kgha-1) in treatment of T4 (100% RDF + 100%RD of Zn through ZnSO4+ ZnSB). The total uptake of phosphorus was found significantly highest (16.81 kg ha-1) in treatment of T4 (100% RDF + 100%RD of Zn through ZnSO4+ ZnSB). The total uptake of potassium was found significantly highest (110.30 kg ha-1) in treatment of T4 (100% RDF + 100%RD of Zn through ZnSO4+ ZnSB). The results showed non-significant difference in total uptake of micronutrients.

Keywords: seed inoculation, zinc solubilizing bacteria, zinc, fertilization, total uptake, Glycine max L.

1. Introduction
Soybean (Glycine max L.) is an important pulse as well as oilseed crop. Soybean is an excellent source of crude protein and oil. It contains 43.2% crude protein and 19.5% oil. Crude protein of soybean contains lysine (8.4%) and all other essential amino acids. It also contains 26% carbohydrate, 45% minerals and 2% phospholipids (Halwankar et al. 1992) [6]. It is source of vitamin A, B and D. Soybean oil is enriched with vitamin A and lecithin and resembles butter ghee. Soy protein is superior to most of the plant protein by virtue of its high biological value (78.41), protein efficiency ratio (2.47 %) and its essential amino acids pattern resemble to those of cow milk. Soybean therefore has a potential to combat protein calorie malnutrition, in developing countries like India. Soybean flour is used for making bread, biscuits and other foods for diabetic patients. Soybean seed is also used in manufacturing many food products like macaroni, bean curd, soya sauce, green bean, baked bean and soy milk. Soybean flour is also used for innumerable other products like plastics, paints, glue, linoleum and glycerin. All other plant proteins produce uric acid on digestion (acidic condition) however; soy protein has an alkalizing effect. It is also used as green manure, hay and silage crop. Zinc is one of the most important micronutrients. It plays vital role in the plant life. It has vital role in transformation of carbohydrates, regulation of consumption of sugar and increase source of energy for the production of chlorophyll. Zinc is also required for maintenance of auxin in an active state. The zinc is essential for the synthesis of tryptophan a precursor of auxin. The basic function of zinc in plants relate to metabolism of carbohydrate, protein and phosphate, auxin and ribosome formation. Zinc also indirectly regulates water relations in plants. Lack of auxin due to zinc deficiency results in the failure of cell walls to grow thereby causing high uptake by plants (Price et al. 1972) [12]. Zinc plays an important role in oilseed and legume crops for increasing yield, nodule development and nitrogen fixation (Bhanavase and Patil, 1993) [2].
Zinc deficiencies are generally corrected by applying zinc sulphate or zinc oxide as micronutrient fertilizers. However, very scanty information is available regarding comparative efficacy of these important Zn fertilizers along with zinc solubilizers to field crops in general and legumes in particular.

2. Materials and Methods

2.1 Collection of soil sample
Before sowing of soybean, the composite representative soil sample was prepared by taking ten soil samples (0 to 22.5 cm) from experimental field for monitoring initial fertility status of experimental plot.

2.2 Collection of plant samples of soybean
Soybean samples at 30 DAS and 60 DAS and straw and grain samples after harvest from each treatment were collected for analysis, dried and stored well by labeling for subsequent analysis.

2.3 Field operations
All cultural practices for soybean crop were followed timely so as to maintain required growth.

Field experimental details

Table 1: Experimental details

| 1. Location | PGI Research Farm, MPKV, Rahuri |
| 2. Year of start | 2016-17 |
| 3. Crop | Soybean |
| 4. Soil type | Medium deep black soil (Inceptisol) |
| 5. Season | Kharif |
| 6. Variety | Phule Agrani |
| 7. Treatments | 11 |
| 8. Replications | 3 |
| 9. Design | Randomized Block Design |
| 10. Plot size | Gross plot: 3.60 m x 3.20 m |
| | Net plot: 3.00 m x 2.80 m |
| 11. Spacing | 30 cm X 10 cm |

Table 2: Treatment details

| T1 | Absolute control |
| T2 | ZnSB alone |
| T3 | 100% RDF alone |
| T4 | 100% RDF + 100% RD of Zn through ZnSO\textsubscript{4} + ZnSB |
| T5 | 100% RDF + 75%RD of Zn through ZnSO\textsubscript{4} + ZnSB |
| T6 | 100% RDF + 50%RD of Zn through ZnSO\textsubscript{4} + ZnSB |
| T7 | 100% RDF + 25%RD of Zn through ZnSO\textsubscript{4} + ZnSB |
| T8 | 100% RDF + 100% RD of Zn through ZnO + ZnSB |
| T9 | 100% RDF + 75%RD of Zn through ZnO + ZnSB |
| T10 | 100% RDF + 50%RD of Zn through ZnO + ZnSB |
| T11 | 100% RDF + 25%RD of Zn through ZnO + ZnSB |

Note: - Seed treatment of ZnSB @ 5% to seed was given at the time of sowing and 5% through drenching at 30 DAS. 2) GRDF at 50:75:45 kg ha\textsuperscript{-1} + 5 t ha\textsuperscript{-1} FYM was common to all except T1 and T2. 3) 100 % RD of ZnSO\textsubscript{4} is 20 kg ha\textsuperscript{-1} (4.2 kg Zinc ha\textsuperscript{-1}).

2.6 Seed
The seed of the soybean (cv. Phule agrani) was procured from the Department of Soil Science and Agril. Chemistry, MPKV, Rahuri.

2.7 Collection of plant samples of soybean
Soybean samples at 30 DAS and 60 DAS and straw and grain samples after harvest from each treatment were collected for analysis, dried and stored well by labeling for subsequent analysis.

2.8 Details of the field operations
The details of field operations which were carried out during the period of field experimentation on soybean are presented in table 1.

2.9 Growth studies
2.9.1 Plant height
Height of plant generally indicates the growth of a crops. The observations on plant height of soybean were recorded from the 30\textsuperscript{th} days and 60\textsuperscript{th} days. It was measured in cm from the ground level up to the base of the terminal leaf bud on the main stem.

2.9.2 Number of pods per plant
The total number of pods from selected five sampled soybean plants was counted. The mean number of pods per plant was calculated.

2.9.3 Grain and straw yield per hectare
The grain yield per hectare (q ha\textsuperscript{-1}) was recorded after threshing of all plants from the net plot. The grain yield in quintals per hectare was worked out from the yield of grains per net plot.

The straw yield per net plot was obtained by subtracting seed yield from biological yield of respective net plot. Then straw yield per hectare was worked out from the straw yield per net plot.

2.9.4 Chemical studies
2.9.4.1 NPK content in plants (Nutrient concentration).
The total NPK concentration in plants was estimated at harvest by using standard methods of analysis as given in table 1.

2.9.4.2 NPK uptake
The uptake of nitrogen, phosphorus and potassium by plant was calculated by multiplying per cent nitrogen, phosphorus and potassium content in plant with their respective dry matter yield.

3. Results and Discussions
Nutrient concentration (NPK) at 30 DAS.
The data regarding the nutrient concentration in soybean plants are presented in table 3. The data revealed that the nutrient concentration was significantly influenced by zinc application through zinc sulphate and zinc oxide (Table 3). Further, it can be seen from table 3, that the application of Zinc @ 20, 15, 10.5 kg ha\textsuperscript{-1} either through zinc sulphate or zinc oxide were at par in respect of nitrogen, phosphorus and potassium concentration in soybean plants at 30 DAS and significantly superior over no zinc application. Numerically, however the nitrogen concentration was more in 10 kg Znha\textsuperscript{-1} through zinc oxide (1.66 %) followed by 15 kg Znha\textsuperscript{-1} and 20 kg Znha\textsuperscript{-1} through zinc oxide (1.64 % and 1.55 %).

~ 1723 ~
The numerical values of phosphorus and potassium concentration were more in the treatment, where 20 kg Zn ha\(^{-1}\) through zinc sulphate was applied (0.07 and 0.18 %). The magnitude of nutrient concentration in soybean at 30 DAS was not distinguishable to differentiate the effect due to levels of zinc and their sources. However, the significant lower nutrient concentrations were observed in treatment where no Zn was applied. These observation indicate that the application of zinc either through zinc sulphate or zinc oxide had positive role to enhance the nutrient concentration. The results are in confirmation with those reported by Kumar and Singh (1980). The increased nutrient concentrations in soybean at 30 DAS can be attributed to the synergism between the native phosphorus and added zinc resulted in increased availability of phosphorus. The added zinc to soybean might have stimulated the symbiotic process in soybean rhizosphere due to increased activities of micro-organisms which, in turn, increased the nitrogen concentration in plant.

**Table 3:** Concentration of nutrient in soybean plant at 30 DAS as influenced by application of Zn solubilizer and fertilizer to soybean on Inceptisol.

| Treatments                      | Concentration of nutrients (%) |
|--------------------------------|--------------------------------|
|                                | N    | P    | K    |
| T\(_1\): Absolute control      | 1.45 | 0.05 | 0.12 |
| T\(_2\): ZnSB alone            | 1.49 | 0.06 | 0.14 |
| T\(_3\): 100% RDF alone        | 1.41 | 0.06 | 0.15 |
| T\(_4\): 100% RDF + 100% RD of Zn through ZnSO\(_4\)+ ZnSB | 1.48 | 0.07 | 0.18 |
| T\(_5\): 100% RDF + 75% RD of Zn through ZnSO\(_4\)+ ZnSB | 1.54 | 0.06 | 0.13 |
| T\(_6\): 100% RDF + 50% RD of Zn through ZnSO\(_4\)+ ZnSB | 1.49 | 0.06 | 0.13 |
| T\(_7\): 100% RDF + 25% RD of Zn through ZnSO\(_4\)+ ZnSB | 1.59 | 0.07 | 0.13 |
| T\(_8\): 100% RDF + 100% RD of Zn through ZnO+ ZnSB | 1.55 | 0.07 | 0.14 |
| T\(_9\): 100% RDF + 75% RD of Zn through ZnO+ ZnSB | 1.64 | 0.06 | 0.13 |
| T\(_10\): 100% RDF + 50% RD of Zn through ZnO+ ZnSB | 1.66 | 0.05 | 0.14 |
| T\(_11\): 100% RDF + 25% RD of Zn through ZnO+ ZnSB | 1.58 | 0.06 | 0.13 |
| SEm (±)                         | 0.02 | 0.002 | 0.01 |
| CD at 5%                        | 0.07 | 0.006 | NS |

**Micronutrient concentration**

The data pertaining to micronutrient concentration of soybean plants at 30 DAS as influenced by zinc application through zinc sulphate and zinc oxide are presented in table 4. On critical observation of the data presented in table 4 revealed that the application of zinc through zinc sulphate and zinc oxide increased the concentration of iron, manganese, zinc and copper in soybean plant at 30 DAS. The magnitude of increase in iron and manganese concentration in soybean plants due to the graded levels of zinc irrespective of their sources was more or less similar. Whereas, the concentration of copper at 20 kg ha\(^{-1}\) zinc application through ZnO (25.70 mgkg\(^{-1}\)) and ZnSO\(_4\) (24.80 mgkg\(^{-1}\)) was significantly higher than 10 kg ha\(^{-1}\) zinc application through ZnO (23.40 mgkg\(^{-1}\)) and ZnSO\(_4\) (25.20 mgkg\(^{-1}\)). The treatments of 20 kg ha\(^{-1}\) zinc application to ZnSO\(_4\) and ZnO were intermediate in influencing the copper concentration as compared to their higher and lower level of zinc application. The higher zinc concentration showed an antagonistic effect on copper content of soybean plants might be probably due to the reduction of copper concentration in soybean plants at higher levels of zinc application. The iron content of soybean plants at 30 DAS stage was increased with an increase in zinc application. The application of ZnSO\(_4\) as a source of Zinc @ 20 kg ha\(^{-1}\) recorded the highest (166.0 mgkg\(^{-1}\)) iron content in soybean at 30 DAS over rest of the treatments. This observation was indicative of the fact that the application of zinc @ 15 kg ha\(^{-1}\) either through ZnSO\(_4\) or ZnO was in the safe limit as far as iron concentration of soybean is concerned at 30 DAS.

The manganese concentration in soybean was increased numerically with an increase in the levels of zinc. Application of zinc@ 10 kg ha\(^{-1}\) through zinc sulphate resulted in higher concentration of manganese (46.60 mgkg\(^{-1}\)); which was par with 15 kg ha\(^{-1}\) ZnSO\(_4\) (44.30) and 5 and 10 kg ZnO (46.30). Further, it is of interest to know that the zinc concentration in soybean was also significantly increased with an increase in the levels of zinc. Maximum zinc concentration (40.80 mgkg\(^{-1}\)) was seen at 20 kg Znha\(^{-1}\) application through zinc oxide was on par with the application of 10 kg Znha\(^{-1}\) through ZnO. These results are in accordance with the results of Gupta and Singh (1986).

**Table 4:** Concentration of micronutrient in soybean plant at 30 DAS as influenced by application of Zn solubilizer and fertilizer to soybean on Inceptisol.

| Treatments                      | Concentration of micronutrients (mgkg\(^{-1}\)) |
|--------------------------------|-----------------------------------------------|
|                                | Fe    | Mn    | Zn    | Cu    |
| T\(_1\): Absolute control      | 154   | 40.70 | 32.20 | 22.20 |
| T\(_2\): ZnSB alone            | 156   | 41.20 | 32.10 | 22.70 |
| T\(_3\): 100% RDF alone        | 160   | 40.00 | 34.40 | 21.20 |
| T\(_4\): 100% RDF + 100% RD of Zn through ZnSO\(_4\)+ ZnSB | 166   | 43.00 | 35.20 | 24.80 |
| T\(_5\): 100% RDF + 75% RD of Zn through ZnSO\(_4\)+ ZnSB | 164   | 44.30 | 32.10 | 24.30 |
| T\(_6\): 100% RDF + 50% RD of Zn through ZnSO\(_4\)+ ZnSB | 160   | 46.60 | 31.60 | 25.20 |
| T\(_7\): 100% RDF + 25% RD of Zn through ZnSO\(_4\)+ ZnSB | 158   | 46.30 | 38.00 | 25.40 |
| T\(_8\): 100% RDF + 100% RD of Zn through ZnO+ ZnSB | 165   | 46.30 | 40.80 | 25.70 |
| T\(_9\): 100% RDF + 75% RD of Zn through ZnO+ ZnSB | 162   | 41.00 | 34.70 | 23.80 |
| T\(_10\): 100% RDF + 50% RD of Zn through ZnO+ ZnSB | 164   | 42.60 | 39.50 | 23.40 |
| T\(_11\): 100% RDF + 25% RD of Zn through ZnO+ ZnSB | 160   | 42.20 | 37.10 | 22.20 |
Nutrient concentration of NPK at 60 DAS.

The data regarding the nutrient concentration in soybean plants are presented in Table 5. A close look to the data revealed that the nutrient concentration significantly influenced by zinc application through zinc sulphate and zinc oxide.

Further, it can be seen from Table 5, that the application of Zinc @ 20, 15, 10.5 kg ha\(^{-1}\) either through zinc sulphate or zinc oxide were at par in respect of nitrogen, phosphorus and potassium concentration in soybean plants at flowering stage and significantly superior over no zinc application. Numerically, however, the nitrogen concentration was more in 5 kg Znha\(^{-1}\) through zinc sulphate (1.98 %) which was on par with 10 kg Znha\(^{-1}\) (1.97 %) through ZnSO\(_4\) followed by 15 kg Znha\(^{-1}\) and 20 kg Znha\(^{-1}\) through ZnSO\(_4\) (1.96 %).

The numerical values of phosphorus concentration was more in the treatment, where 20 kg Znha\(^{-1}\) through zinc sulphate was applied (0.10 %) followed by 10 kg ZnO (0.09 %) and ZnSB alone (0.09), however, the nutrient concentration of potassium in soybean at 60 DAS was found non-significant. However numerically higher potassium concentration in 10 kg ZnSO\(_4\) and 5 kg ZnO.

The magnitude of nutrient concentration in soybean at 60 DAS was not distinguishable to differentiate the effect due to levels of zinc and their sources. However, the significant lower nutrient concentrations were observed in treatment where no Zn was applied. These observation indicate that the application of zinc either through zinc sulphate or zinc oxide had positive role to enhance the nutrient concentration. The results are in confirmation with those reported by Kumar and Singh (1980)\(^{[10]}\).

The increased nutrient concentrations in soybean at 60 DAS can be attributed to the synergism between the native phosphorus and added zinc resulted in increased availability of phosphorus. The added zinc to soybean might have stimulated the symbiotic process in soybean rhizosphere due to increased activities of micro organisms which, inturn increased the nitrogen concentration in plant.

| Treatments | Concentration of nutrients (%) |
|------------|-------------------------------|
|            | N    | P    | K    |
| T\(_0\): Absolute control | 1.72 | 0.08 | 0.18 |
| T\(_1\): ZnSB alone | 1.80 | 0.09 | 0.19 |
| T\(_2\): 100% RDF alone | 1.88 | 0.08 | 0.18 |
| T\(_3\): 100% RDF + 100% RD of Zn through ZnSO\(_4\) + ZnSB | 1.88 | 0.10 | 0.19 |
| T\(_4\): 100% RDF + 75% RD of Zn through ZnSO\(_4\) + ZnSB | 1.96 | 0.07 | 0.19 |
| T\(_5\): 100% RDF + 50% RD of Zn through ZnSO\(_4\) + ZnSB | 1.97 | 0.06 | 0.20 |
| T\(_6\): 100% RDF + 25% RD of Zn through ZnSO\(_4\) + ZnSB | 1.98 | 0.07 | 0.18 |
| T\(_7\): 100% RDF + 100% RD of Zn through ZnO + ZnSB | 1.93 | 0.08 | 0.19 |
| T\(_8\): 100% RDF + 75% RD of Zn through ZnO + ZnSB | 1.93 | 0.07 | 0.18 |
| T\(_9\): 100% RDF + 50% RD of Zn through ZnO + ZnSB | 1.90 | 0.09 | 0.18 |
| T\(_10\): 100% RDF + 25% RD of Zn through ZnO + ZnSB | 1.91 | 0.08 | 0.20 |
| SEm (±) | 0.04 | 0.002 | 0.008 |
| CD at 5% | 0.07 | 0.006 | NS |

Micronutrient concentration

The data pertaining to micronutrient concentration of soybean plants at 60 DAS as influenced by zinc application through zinc sulphate and zinc oxide are presented in Table 6. On critical observation of the data presented in Table 6 revealed that the application of zinc through zinc sulphate and zinc oxide increased the concentration of iron, manganese, zinc and copper in soybean plant at 60 DAS. The magnitude of increase in iron and manganese concentration in soybean plants due to the graded levels of zinc irrespective of their sources was more or less similar. Whereas, the concentration of copper at 20 kg ha\(^{-1}\) zinc application through ZnO (27.20 mg kg\(^{-1}\)) and ZnSO\(_4\) (26.70 mg kg\(^{-1}\)) was significantly lower than due to 10 kg ha\(^{-1}\) zinc application through ZnO (27.70 mg kg\(^{-1}\)) and ZnSO\(_4\) (26.80 mg kg\(^{-1}\)). The treatments of 20 kg ha\(^{-1}\) zinc application through ZnSO\(_4\) and ZnO were intermediate in influencing the copper concentration as compared to their higher and lower level of zinc application. The higher zinc concentration showed an antagonistic effect on copper content of soybean plants might be probably due to the reduction of copper concentration in soybean plants at higher levels of zinc application.

The iron content of soybean plants at 60 DAS stage was increased with an increase in zinc application. The application of ZnSO\(_4\) as a source of Zinc @ 20 kg ha\(^{-1}\) recorded the highest (170.0 mg kg\(^{-1}\)) iron content in soybean at 60 DAS over rest of the treatments. however, the result showed non-significant results. This observation was indicative of the fact that the application of zinc @ 20 kg ha\(^{-1}\) either through ZnSO\(_4\) or ZnO was in the safe limit as far as iron concentration of soybean is concerned at 60 DAS.

The manganese concentration in soybean was increased numerically with an increase in the levels of zinc. Application of zinc @ 20 kg ha\(^{-1}\) through zinc oxide resulted in higher concentration of manganese (49.40 mg kg\(^{-1}\)). Which was at par with application of Zn @ 5 kg ha\(^{-1}\) through ZnSO\(_4\) and 10 kg ha\(^{-1}\) ZnSO\(_4\).

Further, it will of interest to know that the zinc concentration in soybean was also significantly increased with an increase in the levels of zinc. Maximum zinc concentration (42.0 mg kg\(^{-1}\)) was seen at 20 kg Znha\(^{-1}\) application through zinc oxide. These results are in accordance with the results of Gupta and Singh (1986)\(^{[5]}\). Which was on par with 20 kg ha\(^{-1}\) Zn application through ZnSO\(_4\) (41.0) and 15 kg ha\(^{-1}\) Zn application through ZnSO\(_4\) and 15 and 10 kg ha\(^{-1}\) ZnO.
Table 6: Concentration of micronutrient in soybean plant at 60 DAS as influenced by application of Zn solubilizer and fertilizer to soybean on Inceptisol.

| Treatments          | Concentration of micronutrients (mg kg⁻¹) |
|---------------------|------------------------------------------|
|                     | Fe  | Mn  | Zn  | Cu  |
| T₁: Absolute control| 160 | 42  | 32  | 24.30 |
| T₂: ZnSB alone      | 162 | 43.2| 35  | 25.50 |
| T₃: 100% RDF alone  | 164 | 42.10 | 34  | 22.70 |
| T₄: 100% RDF + 100% RD of Zn through ZnSO₄ + ZnSB | 170 | 44.40 | 41  | 26.70 |
| T₅: 100% RDF + 75% RD of Zn through ZnSO₄ + ZnSB | 167 | 45.30 | 40  | 26.90 |
| T₆: 100% RDF + 50% RD of Zn through ZnSO₄ + ZnSB | 168 | 48.10 | 38  | 26.80 |
| T₇: 100% RDF + 25% RD of Zn through ZnSO₄ + ZnSB | 164 | 48.20 | 31  | 28.30 |
| T₈: 100% RDF + 100% RD of Zn through ZnO + ZnSB | 166 | 49.40 | 42  | 27.20 |
| T₉: 100% RDF + 75% RD of Zn through ZnO + ZnSB | 162 | 43.30 | 40  | 25.60 |
| T₁₀: 100% RDF + 50% RD of Zn through ZnO + ZnSB | 160 | 44.80 | 43  | 27.70 |
| T₁₁: 100% RDF + 25% RD of Zn through ZnO + ZnSB | 162 | 43.40 | 36  | 23.80 |
| SEm (±)             | 2.39| 1.20| 1.01| 1.05 |
| CD at 5%            | NS  | 3.54| 3.00| 3.10 |

Nutrient uptake (NPK)
The data regarding the nutrient uptake (NPK) by soybean at harvest as influenced by zinc application through zinc sulphate and zinc oxide are presented in table 7 and graphically depicted through fig.
The data revealed that application of zinc to soybean had significant effect on the uptake of nitrogen, phosphorus and potassium by soybean at harvest which were on par due to application of zinc @ 15 and 10 kg ha⁻¹ through zinc sulphate and zinc oxide. It is interesting to note that the application of zinc sulphate @ 20 kg ha⁻¹ as a source of zinc to soybean recorded significantly highest nitrogen uptake (174.39 kg ha⁻¹), however this treatment is on par with the 20 kg Znha⁻¹ through ZnO (164.21 kg ha⁻¹), phosphorus uptake (16.81 kg ha⁻¹) and potassium uptake (110.30 kg ha⁻¹). It can be seen from the data presented in table 7 that the higher levels of zinc application were not much effective over theirlower levels either through zinc sulphate or zinc oxide.

Table 7: Total uptake of nutrients as influenced by application of Zn solubilizer and fertilizer to soybean on Inceptisol.

| Treatments          | Total uptake of nutrients (kg ha⁻¹) |
|---------------------|-----------------------------------|
|                     | N   | P   | K    |
| T₁: Absolute control| 99.26| 8.20| 57.18 |
| T₂: ZnSB alone      | 99.28| 9.06| 59.54 |
| T₃: 100% RDF alone  | 158.38| 14.52| 98.94 |
| T₄: 100% RDF + 100% RD of Zn through ZnSO₄+ ZnSB | 174.39| 16.81| 110.30 |
| T₅: 100% RDF + 75% RD of Zn through ZnSO₄ + ZnSB | 159.81| 14.85| 101.04 |
| T₆: 100% RDF + 50% RD of Zn through ZnSO₄ + ZnSB | 151.65| 13.66| 100.73 |
| T₇: 100% RDF + 25% RD of Zn through ZnSO₄ + ZnSB | 149.08| 12.10| 93.70 |
| T₈: 100% RDF + 100% RD of Zn through ZnO+ ZnSB | 164.21| 15.30| 103.54 |
| T₉: 100% RDF + 75% RD of Zn through ZnO + ZnSB | 151.52| 12.97| 97.43 |
| T₁₀: 100% RDF + 50% RD of Zn through ZnO + ZnSB | 144.05| 11.75| 96.59 |
| T₁₁: 100% RDF + 25% RD of Zn through ZnO + ZnSB | 140.82| 11.43| 87.15 |
| SEm (±)             | 4.75| 0.86| 4.34 |
| CD at 5%            | 14.02| 2.56| 12.83 |

Micronutrient uptake
The data regarding the micronutrient uptake by soybean are presented in table 8. It can be seen that uptake of all the micronutrients was significantly influenced by zinc application through zinc sulphate and zinc oxide.
The increased levels of zinc application recorded the linear increase in the uptake of manganese, zinc and copper. The decreased uptake of iron by soybean due to graded levels of application could be attributed to antagonistic relation of Zn with iron.
The uptake of iron was significantly highest in application of zinc through 20 kg ha⁻¹ ZnSO₄ (1604.27), however which was on par with T₅, T₆, T₈, T₉.

The uptake of manganese was significantly highest in application of zinc through 20 kg ha⁻¹ ZnSO₄ (1988.1), however which was on par with T₃, T₄, T₆, T₈, T₉. The uptake of zinc was significantly highest in application of zinc through 20 kg ha⁻¹ ZnSO₄ (334.83), however which was on par with T₄, T₅, T₆, T₇, T₈, T₉. The uptake of copper was significantly highest in application of zinc through 20 kg ha⁻¹ ZnO (116.18), however which was on par with T₄. Similar observation was reported by Duraisamy et al. (1988) [4]. These observations are also in close agreement with the results reported by Brown and Tiffin (1962) [3] who observed iron deficiency in corn and millets due to application of zinc.
Table 8: Total uptake of micronutrient as influenced by Zinc solubilizer and zinc fertilizer on nutrient uptake, yield and quality of soybean on Inceptisol.

| Treatments | Total uptake of micronutrient at harvest (gha⁻¹) |
|------------|--------------------------------------------------|
|            | Fe     | Mn     | Zn     | Cu     |
| T1: Absolute control     | 1005.12 | 734.12 | 197.14 | 68.42  |
| T2: ZnSB alone           | 992.56  | 737.45 | 198.67 | 68.07  |
| T3: 100% RDF alone       | 1489.86 | 1125.86| 303.04 | 103.76 |
| T4: 100% RDF + 100%RD of Zn through ZnSO₄ + ZnSB | 1604.27 | 1198.11| 325.08 | 111.13 |
| T5: 100% RDF + 75%RD of Zn through ZnSO₄ + ZnSB | 1543.23 | 1156.47| 313.28 | 106.93 |
| T6: 100% RDF + 50%RD of Zn through ZnSO₄ + ZnSB | 1504.19 | 1122.16| 304.62 | 103.39 |
| T7: 100% RDF + 25%RD of Zn through ZnSO₄ + ZnSB | 1364.15 | 1069.96| 286.33 | 99.02  |
| T8: 100% RDF + 100%RD of Zn through ZnO + ZnSB  | 1574.01 | 1190.47| 334.83 | 116.18 |
| T9: 100% RDF + 75%RD of Zn through ZnO + ZnSB  | 1500.20 | 1119.85| 314.13 | 106.41 |
| T10: 100% RDF + 50%RD of Zn through ZnO + ZnSB | 1463.26 | 1113.64| 308.30 | 105.59 |
| T11: 100% RDF + 25%RD of Zn through ZnO + ZnSB | 1381.00 | 1017.46| 286.19 | 94.91  |
| SEm (±)                | 37.82  | 30.49  | 8.51   | 2.57   |
| CD at 5%                | 112.36 | 90.59  | 25.29  | 7.64   |

4. Conclusion
It is concluded that 100% RD of Zn through ZnSO₄ @ 20 kg ha⁻¹ along with general recommended dose of fertilizer (50:75:45 N: P₂O₅: K₂O kg ha⁻¹ + 10 tha⁻¹ FYM) with the 5% ZnSB treatment to seed at the time of sowing as well as drenching at 30 DAS to soybean was found beneficial for increasing total uptake of N, P, K, and micronutrients, agronomic efficiency in soybean on Inceptisol.

5. Acknowledgements
It is a great pleasure for me to express my deep sense of gratitude towards those innumerable people who have aided me towards the completion of my thesis.
6. References
1. Bahl GS, Baddesha HS, Pasricha NS, Aulakh MS. Sulphur and zinc nutrition of groundnut grown on Tolewal loamy sand soil: Indian Jounal of Agricultural Science. 1986; 56(6):429-434.
2. Bhanavase DB, Patil PL. Nodulation and nitrogen fixation as influenced by micronutrients. Journal of Maharashtra agricultural University. 1993; 18(2):167-174.
3. Brown JC, Tiffin LO. Zinc deficiency and Fe chlorosis dependence on plant species and nutrient element balance in Tulare Clay Agronomy Journal. 1962; 54:356-358.
4. Duraisamy P, Kothingarman GV, Chellamuthu S. Effect of amendments and zinc on the availability, content and uptake of zinc and iron by rice bhavani in sodic soil. Madras Agricultural Journal. 1988; 75(3):119-124.
5. Gupta VK, Singh B. Differential susceptibility of soybean cultivars to zinc stress. Legume Research. 1986; 9(2):85-90.
6. Halwankar GB, Raut VM, Taware SP, Patil VP. Production component study in soybean. Journal of Maharashtra agricultural university. 1992; 7(3):396-398
7. Hulagar BF, Dangarwala RT. Effect of zinc, copper and phosphorus fertilization on the uptake of Fe, Mn and Mo by hybrid maize. Madras Agricultural Journal. 1982; 69(1):11-16.
8. Jha AN, Chandel AS. Response of soybean to zinc application. Indian Journal of Agronomy. 1987; 32(4):354-358.
9. Joshi RC, Khandilkar GS, Patil ND. Response of soybean (Glycine max L.) to zinc. Indian Journal of agricultural Chemistry. 1974; 7(2):161-168.
10. Kumar V, Singh M. Sulphur and zinc interaction in relation to yield, uptake and utilization of sulphur in soybean. Soil Science. 1980; 130(1):19-25.
11. Patel GR, Dangarwala RT. Effect of varying Zn and Fe status on the utilization of Fe, Mn and Zn by rice. Indian Journal Agricultural Chemistry. 1983; 16(1):139-145.
12. Price VM, Elseccsy MA, Safaya MM. Zinc deficiency and its control. American Society of Soil Science. 1972; 28(5):319.
13. Tripathy SK, Patra AK, Samu RC. Effect of micronutrients on nodulation, growth, yield and nutrient uptake of summer groundnut. Annals of Agricultural Research. 1999; 20(4):439-442.