

vOriginal Research Article

Zinc–Fortification of vegetable pea through Zinc and ZSB Solubiliser

ABSTRACT

The investigation was carried out in the pot experiment during 2021-2022 at the Department of Soil Science, College of Agriculture, JNKVV, Jabalpur, to study **Zinc Fortification of vegetable pea through Zinc and ZSB Solubiliser. There were fourteen treatments viz.** T₁-Absolute control, T₂-RDF (30 N, 60 P₂O₅, and 30 K₂O kg ha⁻¹), T₃-(T₂ + Soil application of 25 kg ZnSO₄·7H₂O ha⁻¹), T₄-(T₂ + Seed treatment ZnSO₄·7H₂O @3g kg⁻¹ of seed), T₅-(T₂ + Foliar application @ 0.5% ZnSO₄·7H₂O, at flowering and pod formation stage), T₆-(T₃+T₅), T₇-(T₄+ T₅), T₈-(T₃+ T₄+T₅), T₉-(T₂+ Soil application of 2 L⁻¹ Acre (liquid ZSB), T₁₀-(T₂+Seed treatment (Liquid ZSB) @10 ml kg⁻¹ of seed), T₁₁-(T₂+Foliar application of 2 L⁻¹ Acre (liquid ZSB) at flowering and pod formation stage), T₁₂-(T₉+T₁₁), T₁₃-(T₁₀+T₁₁), T₁₄-(T₉+T₁₀+T₁₁). The treatments were replicated three times in a completely randomized design (CRD). The vegetable pea (PSM -3) was grown in rabi season. Results revealed that the treatment 100% of RDF + Foliar application @ 0.5% ZnSO₄·7H₂O, at flowering and pod formation stage maintained the soil health in terms of pH, EC, organic carbon and available nutrients (N, P and K) and Zn in soil which were better than control.

Key words: Zinc fortification, Vegetable Pea, Zinc and ZSB

1. INTRODUCTION

Vegetable pea (*Pisum sativum* L.), is one of the most nutritious leguminous crops and it fixes nitrogen in the soil and legumes are an excellent source of protein, complex carbohydrates, vitamins and minerals in the diets of many millions of people, particularly in developing countries. Its cultivation maintains soil fertility through biological nitrogen fixation and thus play a vital role in fostering sustainable agriculture [1]. India is one of the top five pea producing countries of the world [2] with with an area of 564 million hectares and produces 5694 million tonnes of grain with productivity of 1009 kg ha⁻¹. However, in the state of Madhya Pradesh, it is grown in an area of 1.07 lakh ha with production of 10.37 lakh mt and productivity of 1031 kg

ha⁻¹.

Zinc is an essential micronutrient for the plant as it is required concentration range of 10⁻⁶ g/g of plant fresh weight to complete their life cycle, and its absence is not fulfilled by other micronutrients. It is fourth most important yield limiting nutrient in agricultural crops. Plants absorb most of the Zn from the soil, but unfortunately Indian soils are poor in zinc (49 to 63%) [3]. Zinc deficiency is also responsible for 16% of all deep respiratory infections in human beings worldwide [4]. The Zn deficiency is strongly related to severity of the novel COVID-19 infestation. It is estimated that deficiencies of zinc are found in > 50 % people of the world. The deficiency of zinc has increased from 44% to 48% and it is expected to further increase up to 63% by 2025 [5]. This deficiency can be corrected by variety of ways, among which bio-fortification is the most common technique.

Agronomic bio-fortification has proved to be an effective and fast solution for increasing Zn concentration in the edible parts of several crops, particularly crop. Thus, bringing agricultural and nutrition science together for reducing malnutrition by increasing levels of zinc in staple foods at no additional cost to consumers. Bio-fortification *via* foliar Zn application has been shown to be effective in increasing grain Zn concentration in crops grown in either Zn sufficient or Zn-deficient soils. Secondly, soil Zn application was not effective in increasing grain Zn concentration, but increased grain yield. The aim of bio-fortification is to produce plants that have an augmented content of bioavailable nutrients in their edible parts. Zn and ZSB which have some optimistic relations leading to increased crop yield and reduced environmental threats. Zinc solubilizing bacteria alone or with organic materials may increase the bioavailability of native and applied zinc to the plant's improving the yield and quality of crop [6].

MATERIAL AND METHODS

The investigation was carried out in the Department of Soil Science, College of Agriculture, JNKVV, Jabalpur during 2021-2022. Jabalpur is situated at 23° 10" N latitude and 79° 57" E longitude at 393 meters above the mean sea level. In winter season i.e., from November to February the temperature ranges from 4 to 33°C and the relative humidity varies from 70 to 90%. Dry and warm weather usually persists during the month of March to June. The

temperature may rise as high as 44°C during these summer months. Monsoon season extends from mid-June to mid-September. The temperature during this period varies between 25°C and 35°C and the relative humidity ranges from 70 to 80%. The total annual rainfall varies from 1200 to 1500 mm.

Jabalpur is located in the “Kymore Plateau and Satpura hills” agro-climatic zone of Madhya Pradesh. The tropic of cancer passes through the middle of the district. It has sub-tropical climate characterized by hot dry summers and cool dry winter. The average maximum temperature during the month of May June varies between 42.5 to 46.4 °C and these are the hottest months of the year, while the average minimum temperature varies between 4.2 to 8.7 °C during December-January, which are the coldest months of the year. The average annual seasonal rainfall of this region is about 1200 mm which is mostly received between June to September and a little rainfall of 75 to 175 mm is received between October to May. The average humidity of the region is about 73% and average evaporation is 3.93 mm day⁻¹.

The soil of the experimental field is categorized as Vertisols, and they are from the Kheri series of fine montmorillonite and the Hyperthermic family of Typic Haplusterts, which is known as “black cotton soil.” The soil parameters of the experimental site are listed below.

Experimental procedures and details

Collection of materials

Zinc Sulphate Heptahydrate ($\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$) Zinc Solubilising Bacterial Strain *Pseudomonas aurigenosa* was taken from MRPC JNKVV Jabalpur. The zinc content in materials was determined by using Atomic Absorption Spectrophotometer. The soil was analyzed for available zinc by extracted by 0.005 M DTPA (Di ethylene Tri amine Penta Acetic Acid pH 7.3), 0.01 M CaCl_2 and 0.1 M tri ethanol amine (TEA) and determined by Atomic Absorption Spectrophotometer Lindsay and Norvell [7].

Pot experiment

A pot experiment was conducted at Department of Soil Science, JNKVV, Jabalpur with vegetable Pea (PSM-3). All the necessary cultural practices were carried out when needed. About 5 kg soil was placed in clean earthen Pot and Zinc and ZSB fourteen combinations were tested according to a 3x3x2 Factorial Complete Randomized Design. Samples were collected

from all treatments and analyzed for available zinc. There were *viz.*, zinc and zinc solubilizing bacteria (*Pseudomonas aeruginosa*) on growth, dry matter production and Zn composition of vegetable pea.

Treatment details

The treatments were used in Pot study, with two replications. A pot experiment comprised of fourteen treatment *viz.*, T₁ Absolute control, T₂ RDF (30 N, 60 P₂O₅, and 30 K₂O kg ha⁻¹) T₃ (T₂ + Soil application of 25 kg ZnSO₄·7H₂O ha⁻¹, T₄ (T₂ + Seed treatment ZnSO₄·7H₂O @3g kg⁻¹ of seed), T₅ (T₂ + Foliar application @ 0.5% ZnSO₄·7H₂O, at flowering and pod formation stage), T₆ (T₃+T₅), T₇ (T₄+ T₅), T₈ (T₃+ T₄+T₅), T₉ (T₂+ Soil application of 2 L⁻¹ Acre (liquid ZSB), T₁₀ (T₂+Seed treatment (Liquid ZSB) @10 ml kg⁻¹ of seed), T₁₁ (T₂+Foliar application of 2 L⁻¹ Acre (liquid ZSB) at flowering and pod formation stage), T₁₂ (T₉+T₁₁), T₁₃ (T₁₀+T₁₁), T₁₄ (T₉+T₁₀+T₁₁). The experiment was conducted to study the effect of Fortification of Zinc and zinc solubilizer with three replications.

Pots were arranged according to Factorial completely randomized design. The basal dose of 30 N: 60 P₂O₅: 30 K₂O kg ha⁻¹ was applied to vegetable Pea crop at the time of sowing. 10 Seeds were sown on dated December 17, 2021 per pot and 5 plants were maintained for observation and analyzed for yield and attributes of vegetable Pea. The vegetable Pea crop was harvested in month of 07th March, 2022. Growth parameters of wheat were also recorded at critical stages of crop. Plant samples were taken when they were fully mature, then processed and tested for zinc using an Atomic Absorption Spectrophotometer. At the end of the experiment, soil samples from each pot were taken to examine changes in soil properties.

Input application

Zinc and ZSB (*Pseudomonas aeruginosa*) application

During pot experiment the doses of various materials were added according to their per hectare doses which is equivalent to 2.26 x 10⁶ kg and then their amount was calculated for 5 kg soil.

Fertilizer application

In all treatments recommended doses of fertilizer 30kg N, 60kg P₂O₅ and 30 kg K₂O ha⁻¹ was applied (Table 1) in the forms of urea, single super phosphate (SSP) and muriate of potash (MOP), respectively. Amount of fertilizer required for each pot was calculated for 5 kg soil, considering weight of soil for 1 ha land is equivalent to 2.26 x 10⁶ kg.

Table 1: Amount of fertilizer applied in a pot

| Fertilizer | mg pot ⁻¹ |
|-------------------------|----------------------|
| Urea | 464 |
| Single Super Phosphate | 668 |
| Muriate of Potash (Mop) | 119 |

Observations were taken

The pH of soil sample was determined in 1:2 (soil: water) suspension using a combined electrode (glass and calomel electrodes) by digital pH meter. The electrical conductivity (EC) was determined in the supernatant liquid of the same extracts with the help of a conductivity bridge and expressed in dS m⁻¹ at 25°C. Organic carbon content in soil was determined by wet oxidation method as outlined by Walkley and Black [8].

The alkaline permanganate method was adopted to measure the amount of available nitrogen in a soil sample, Subbiah and Asija [9]. 5 gm soil sample was taken and mixed with alkaline permanganate and distilled. Organic matter was oxidized by KMnO₄ in the presence of NaOH releasing ammonia which was absorbed in 2% boric acid containing methyl red bromocresol green mixed indicator and converted to ammonium borate. This ammonium borate was titrated against standard sulphuric acid. The available P in soil was extracted using the Olsen's reagent (0.5 M NaHCO₃ for the neutral soil), Olsen et al. [10]. The intensity of the blue colour developed was determined by a spectrophotometer at 660 nm wave length. Available potassium was determined by extracting the soil sample with 1 N ammonium acetate (pH 7.0) and K content in the extracts was measured by a Flame Photometer Jackson ML [11].

The soil available Zn was extracted by 0.005 M DTPA (Di ethylene amine Penta Acetic Acid pH 7.3), 0.01 M CaCl₂ and 0.1 M tri ethanol amine (TEA) and determined by Atomic Absorption Spectrophotometer, Lindsay and Norvell [7]. Standard statistical procedures were employed for analysis and interpretation of data by Gomez and Gomez [12].

RESULT AND DISCUSSION

Effect of different treatments on soil physico-chemical properties

Data on soil physico-chemical properties (pH, electrical conductivity, organic carbon) of vegetable pea as influenced by different treatments are presented in Table 2.

Soil reaction (pH)

Data pertaining to effect of different treatments on pH of are presented in Table 1 The pH of soil ranged from 7.27 to 7.63. When compared to the control. The maximum pH of soil was 7.63 due to treatment of T₈ (T₃ + T₄ + T₅) which was higher than the control (7.27). T₆ (T₃ + T₅), T₁₁ (T₂ + Foliar application of 2 L⁻¹ Acre (liquid ZSB).at flowering and pod formation stage), T₁₄ (T₉ + T₁₀ + T₁₁) , T₅ (T₂ + Foliar application @ 0.5% ZnSO₄.7H₂O, at flowering and pod formation stage) , T₇ (T₄ + T₅) , T₄ (T₂ + Seed treatment ZnSO₄.7H₂O @ 3 g kg⁻¹ of seed) , T₉ (T₂ + Soil application of 2 L⁻¹ Acre (liquid ZSB) , T₁₀ (T₂ + Seed treatment (Liquid ZSB) @ 10 ml kg⁻¹ of seed) , T₂ (RDF (30 N, 60 P₂O₅, and 30 K₂O kg ha⁻¹) and T₃ (T₂ + Soil application of 25 kg ZnSO₄.7H₂O ha⁻¹) had the greatest influence on the soil pH of 7.60 , 7.57 , 7.50 , 7.50 , 7.43 , 7.40 , 7.40 , 7.30 and 7.23 respectively. Similar findings given by Batoo et al. [13] who showed significant reduction rhizospheric pH with ZnSB₂₄ and ZnSB₂₅ inoculation by 14% and 12%, respectively. Similar results were reported by David et al. [14] also reported that growth Parameters Pea (*Pisum sativum* L.) and soil properties, increased significantly with the application of 100% recommended dose of fertilizers EC (dSm⁻¹) increase in fertilizer levels. Singh et al. [15] conducted an experiment with four levels of zinc (control, 0.02%, 0.04%, 0.08%) applied as foliar spray at pre-flowering and past podding stage. The zinc application resulted in non-significant increase in pH in soil at harvest.

Electrical conductivity

Data on electrical conductivity of soil varied due to different treatments. It was also evident from the data that soil EC under control pot varied from (0.15 dSm⁻¹). When compared to the control, all of the treatments performed much better. The maximum EC was 0.19 dSm⁻¹ due to treatment of T₈ (T₃+ T₄+T₅) which was 0.6 % higher than the control (0.15 dSm⁻¹). T₁₂ (T₉+T₁₁), T₁₁ (T₂+Foliar application of 2 L⁻¹ Acre (liquid ZSB).at flowering and pod formation stage), T₇ (T₄+T₅), T₅ (T₂ + Foliar application @ 0.5% ZnSO₄.7H₂O, at flowering and pod formation stage), T₁₄ (T₉+T₁₀+T₁₁), T₁₃ (T₁₀+T₁₁), T₁₀ (T₂+Seed treatment (Liquid ZSB) @ 10 ml kg⁻¹ of seed), T₉ (T₂+Soil application of 2 L⁻¹ Acre (liquid ZSB), T₆ (T₃ + T₅), T₄ (T₂ + Seed treatment ZnSO₄.7H₂O @ 3 g kg⁻¹ of seed), T₃ (T₂+Soil application of 25 kg ZnSO₄.7H₂O ha⁻¹) and T₂ (RDF (30 N, 60 P₂O₅, and 30 K₂O kg ha⁻¹) had the greatest influence on the Electrical conductivity of 0.18, 0.17, 0.17, 0.17, 0.17, 0.16, 0.16, 0.16, 0.16, 0.16, 0.16 and 0.16 dSm⁻¹ respectively, with responses of 0.5 %. Similar results were reported by Borah et al. [16] studied the effect of foliar application of zinc by using five different treatments of zinc in four replications, on the quality of garden pea (*Pisum sativum L.*) and the soil properties, for which It can be suggested that the one with 0.75% zinc application turns out to be the optimum treatment, towards improving the soil characters. David et al. [14] also reported that growth Parameters Pea (*Pisum sativum L.*) and soil properties, increased significantly with the application of 100% recommended dose of fertilizers EC (dSm⁻¹) increase in fertilizer levels.

Organic carbon

The organic carbon content of post-harvest soil as influenced by different treatments Data on organic carbon content under control plot varied from (5.33 g kg⁻¹). When compared to the control, all of the treatments performed much better the except. The maximum organic carbon was 8.53 g kg⁻¹ due to treatment of T₆ which was 60 % higher than the control (5.33 g kg⁻¹). T₁₄ (T₉+T₁₀+T₁₁), T₇ (T₄+T₅), T₁₃ (T₁₀+T₁₁), T₅ (T₂+Foliar application @ 0.5% ZnSO₄.7H₂O, at flowering and pod formation stage), T₈ (T₃+T₄+T₅), T₁₂ (T₉+T₁₁), T₁₀ (T₂+Seed treatment (Liquid ZSB) @10 ml kg⁻¹ of seed), T₉ (T₂ + Soil application of 2 L⁻¹ Acre (liquid ZSB), T₂ (RDF (30 N, 60 P₂O₅, and 30 K₂O kg ha⁻¹), T₄ (T₂ + Seed treatment ZnSO₄.7H₂O @ 3g kg⁻¹ of seed) and T₃ (T₂ + Soil application of 25 kg ZnSO₄.7H₂O ha⁻¹) had the greatest influence on the organic carbon of 8.47, 8.23, 7.97, 7.80, 7.47, 6.57, 6.67, 6.33, 6.27, and 5.60 g kg⁻¹ respectively, with responses of 58.75, 54.38, 49.38, 46.25, 45, 40, 23.13, 25, 18.75, 17.50 and 5

% . Kumar et al. [17] application of zinc sulphate @ 40 kg ha⁻¹ and FYM @ 350 q ha⁻¹ significantly increased organic carbon (OC) content in soil (0.184%). Desai et al. [18] also reported that the acidic pH shown by all the bacterial isolates gives a clue that the solubilization could be due to production of organic acids and higher the production of the same, higher is the available zinc in culture broth reported that higher availability of Zn directly proportional to acidic pH of the culture broth. However, in some potent strains other mechanisms may be active and this aspect is being accentuated.

Effect of different treatments on available nutrients and DTPA extractable Zn

Data on available nutrients and DTPA extractable Zn of vegetable pea as influenced by different treatments are presented in Table 3.

Available nitrogen

Data on available nitrogen content in post-harvest soil as affected by treatments. In control plot, content of available nitrogen (kg ha⁻¹) varied from 185.76 to 240.78 kg ha⁻¹. All the treatments performed significantly better as compared to that of control. Due to application of T₅ (T₂ + Foliar application @ 0.5% ZnSO₄.7H₂O, at flowering and pod formation stage), the maximum content of available nitrogen 240.78 kg ha⁻¹ was registered which was 29.62% better over the control (185.76 kg ha⁻¹). This was followed by the influence from T₂ RDF (30 N, 60 P₂O₅, and 30 K₂O kg ha⁻¹), T₆ (T₃+T₅), T₇ (T₄+T₅), T₈ (T₃+T₄+T₅), T₁₃ (T₁₀+T₁₁) and T₁₄ (T₉+T₁₀+T₁₁) for the available nitrogen content of 227.19, 224.15, 224.09, 217.36, 216.20 and 216.80 kg ha⁻¹ along with response 22.31, 20.67, 20.64, 217.36, 16.39 and 16.71%, respectively. The reason for this can be attributed to the fact that with the application of zinc, the nodule count and root growth increases Singh and Bhatt [19] and also the leghaemoglobin content and rhizobium activity which in turn increases the nitrogen fixing capacity, and therefore the nitrogen content of the soil Shukla and Yadav, 1982 and Ghoneim [20] Similar results were reported by Singh et al. [15] found that the plots which were fertilized with Zn @ 0.08% nitrogen content in the soil.

Available potassium

Data on available phosphorus content in soil as affected by different treatments. In control plot, available phosphorus varied from 22.37 to 30.13 kg ha⁻¹. All the treatments performed significantly better as compared to that of control. Due to application of T₁₁ (T₂+Foliar application of 2 L⁻¹ Acre (liquid ZSB).at flowering and pod formation stage), the

maximum content of available P 30.13 kg ha⁻¹ was registered which was 25.75 % better over the control (22.37kg ha⁻¹). This was followed by the influence from T₃ (T₂ + Soil application of 25 kg ZnSO₄·7H₂O ha⁻¹), T₆ (T₃+T₅), T₅ (T₄+ T₅), T₁₀ (T₂+Seed treatment (Liquid ZSB) @10 ml kg⁻¹ of seed), T₈ (T₃+ T₄+T₅), T₇ (T₄+T₅), T₁₃ (T₁₀+T₁₁) and T₂ RDF (30 N, 60 P₂O₅ and 30 K₂O kg ha⁻¹) for the available nitrogen content of 29.57, 28.98, 27.49, 27.36, 26.95, 25.39, 25.63, 25.00, and 24.05 kg ha⁻¹ along with response 24.35, 22.79, 22.79, 18.6, 18.24, 16.99, 14.74, 10.52, 6.98 and 6.98%, respectively. This reason for this can be attributed to the fact that the inorganic phosphorous in the soil decreases with zinc application were reported by Menser and Sidle and Ghoneim [21] and as zinc and phosphorous have antagonistic effect on soil and each other's uptake and distribution in the plant were suggested by Mousavi [22] therefore it influences the same. Similar results were also reported by Safaya et al. [23], Stoyanova et al. [24], Doncheva Singh et al. [25] and Ladumor et al. [26].

Available potassium

Data on available potassium content in soil as affected by different treatments. Available potassium content varied from 175.56 to 256.03 kg ha⁻¹. All the treatments responded significantly better as compared to that from control.

The highest content of 256.03 kg ha⁻¹ was obtained due to T₇ (T₄+ T₅) with 31.43 % response over that of control (175.56 kg ha⁻¹). This was followed by the effects from T₈ (T₃+ T₄+T₅), T₁₃ (T₁₀+T₁₁), T₄ (T₂ + Seed treatment ZnSO₄·7H₂O @3 g kg⁻¹ of seed), T₉ (T₂+ Soil application of 2 L⁻¹ Acre liquid ZSB), T₅ (T₂ + Foliar application @ 0.5% ZnSO₄·7H₂O, at flowering and pod formation stage), T₁₁ (T₂ + Foliar application of 2 L⁻¹ Acre (liquid ZSB).at flowering and pod formation stage), T₆ (T₃+T₅), T₂ (RDF (30 N, 60 P₂O₅, and 30 K₂O kg ha⁻¹) and T₃ (T₂ + Soil application of 25 kg ZnSO₄·7H₂O ha⁻¹) presenting the available content of the nutrient of 255.68, 239.45, 231.75, 228.63, 228.60, 228.22, 223.87, 223.71 and 217.72 and kg ha⁻¹ having with percentage response of 31.34, 26.68, 24.24, 23.21, 23.20, 23.07, 21.58, 21.52 and 19.36 respectively. Similar results were reported by Nishith et al. [27] The result of experiments showed that the pea cv.PSM-3' recorded significantly Available potassium, in soil at harvest stage increased due to the application of these nutrient in soil.

Available zinc

Data on available zinc content in soil as affected by different treatments. Available Zinc content varied from 0.76 to 1.55 mg kg⁻¹. All the treatments responded significantly better as compared to that from control.

The highest content of 1.55 mg kg⁻¹ was obtained due to T₁₃ (T₁₀+T₁₁) with 104.17% response over that of control (0.76 mg kg⁻¹). This was followed by the effects from T₁₄ (T₉+T₁₀+T₁₁), T₇ (T₄+ T₅), T₉ (T₂+ Soil application of 2 L⁻¹ Acre liquid ZSB), T₈ (T₃+ T₄+T₅), T₁₀ (T₂+Seed treatment (Liquid ZSB) @10 ml kg⁻¹ of seed), T₅ (T₂ + Foliar application @ 0.5% ZnSO₄.7H₂O, at flowering and pod formation stage), T₆ (T₃+T₅), T₁₂ (T₉+T₁₁), T₄ (T₂ + Seed treatment ZnSO₄.7H₂O @3 g kg⁻¹ of seed), T₁₁ (T₂+Foliar application of 2 L⁻¹ Acre (liquid ZSB).at flowering and pod formation stage), T₂ (RDF (30 N, 60 P₂O₅, and 30 K₂O kg ha⁻¹), presenting the available content of the nutrient of 1.48, 1.43,1.42 ,1.40, 1.30, 1.25, 1.22, 1.14, 0.89 and 0.87 mg kg⁻¹ having with percentage response of 94.96, 88.04, 87.23, 84.30, 71.49, 64.97, 60.76, 50.17, 48.25, 17.07 and 14.91 respectively. Similar results were reported by Kumar et al. [17] application of zinc sulphate @ 40 kg ha⁻¹ and FYM @ 350 q ha⁻¹ significantly increased zinc content in soil (1.63 ppm) Borah et al. [16] studied the effect of foliar application of zinc by using five different treatments of zinc in four replications, on the quality of garden pea (*Pisum sativum L.*) and the soil properties, for which It can be suggested that the one with 0.75% zinc application turns out to be the optimum treatment, towards improving the quality of garden pea and soil characters. Nishith et al. [27]. The result of experiments showed that the pea cv. PSM-3' recorded significantly available zinc in soil at harvest stage increased due to the application of these nutrient in soil.

Table 2: Effect of different treatments on soil physico-chemical properties

| Treatment | | pH | EC (dSm ⁻¹) | OC (g kg ⁻¹) |
|-----------------|---|-------|----------------------------|-----------------------------|
| T ₁ | Absolute control | 7.27 | 0.15 | 5.33 |
| T ₂ | RDF (30 N, 60 P ₂ O ₅ , and 30 K ₂ O kg ha ⁻¹) | 7.3 | 0.16 | 6.33 |
| T ₃ | T ₂ + Soil application of 25 kg ZnSO ₄ ·7H ₂ O ha ⁻¹ | 7.23 | 0.16 | 5.6 |
| T ₄ | T ₂ + Seed treatment ZnSO ₄ ·7H ₂ O @3g kg ⁻¹ of seed | 7.4 | 0.16 | 6.27 |
| T ₅ | T ₂ + Foliar application @ 0.5% ZnSO ₄ ·7H ₂ O, at flowering and pod formation stage | 7.5 | 0.17 | 7.8 |
| T ₆ | T ₃ +T ₅ | 7.6 | 0.16 | 8.53 |
| T ₇ | T ₄ + T ₅ | 7.43 | 0.17 | 8.23 |
| T ₈ | T ₃ + T ₄ +T ₅ | 7.63 | 0.19 | 7.73 |
| T ₉ | T ₂ + Soil application of 2 L ⁻¹ Acre (liquid ZSB). | 7.4 | 0.16 | 6.67 |
| T ₁₀ | T ₂ +Seed treatment (Liquid ZSB) @10 ml kg ⁻¹ of seed | 7.4 | 0.16 | 6.57 |
| T ₁₁ | T ₂ +Foliar application of 2 L ⁻¹ Acre (liquid ZSB) at flowering and pod formation stage | 7.57 | 0.17 | 7.13 |
| T ₁₂ | T ₉ +T ₁₁ | 7.37 | 0.18 | 7.47 |
| T ₁₃ | T ₁₀ +T ₁₁ | 7.27 | 0.16 | 7.97 |
| T ₁₄ | T ₉ +T ₁₀ +T ₁₁ | 7.5 | 0.17 | 8.47 |
| | S.E(m)± | 0.087 | 0.007 | 0.526 |
| | C.D (P=0.05%) | NS | Ns | 1.576 |

Table 3: Effect of different treatments on available nutrients and DTPA extractable Zn

| Treatment | | Available nutrients (kg ha ⁻¹) | | | DTPA extractable Zn (mg kg ⁻¹) |
|-----------------|---|---|-------|--------|--|
| | | N | P | K | Zn |
| T ₁ | Absolute control | 185.76 | 22.37 | 175.56 | 0.76 |
| T ₂ | RDF (30 N, 60 P ₂ O ₅ , and 30 K ₂ O kg ha ⁻¹) | 227.19 | 24.72 | 223.71 | 0.87 |
| T ₃ | T ₂ + Soil application of 25 kg ZnSO ₄ .7H ₂ O ha ⁻¹ | 211.55 | 29.57 | 217.72 | 1.01 |
| T ₄ | T ₂ + Seed treatment ZnSO ₄ .7H ₂ O @3g kg ⁻¹ of seed | 208.50 | 25.63 | 231.75 | 1.13 |
| T ₅ | T ₂ + Foliar application @ 0.5% ZnSO ₄ .7H ₂ O, at flowering and pod formation stage | 240.78 | 27.49 | 228.60 | 1.25 |
| T ₆ | T ₃ +T ₅ | 224.15 | 28.98 | 223.87 | 1.22 |
| T ₇ | T ₄ + T ₅ | 224.09 | 22.08 | 256.03 | 1.43 |
| T ₈ | T ₃ + T ₄ +T ₅ | 217.36 | 22.35 | 255.68 | 1.40 |
| T ₉ | T ₂ + Soil application of 2 L ⁻¹ Acre (liquid ZSB). | 187.57 | 23.38 | 228.63 | 1.42 |
| T ₁₀ | T ₂ +Seed treatment (Liquid ZSB) @10 ml kg ⁻¹ of seed | 199.23 | 27.36 | 202.27 | 1.30 |
| T ₁₁ | T ₂ +Foliar application of 2 L ⁻¹ Acre (liquid ZSB) at flowering and pod formation stage | 204.09 | 30.13 | 228.22 | 0.89 |
| T ₁₂ | T ₉ +T ₁₁ | 195.00 | 26.24 | 207.55 | 1.14 |
| T ₁₃ | T ₁₀ +T ₁₁ | 216.20 | 25.00 | 239.45 | 1.55 |
| T ₁₄ | T ₉ +T ₁₀ +T ₁₁ | 216.80 | 22.12 | 209.82 | 1.48 |
| | S.E(m)± | 6.970 | 1.336 | 10.155 | 0.039 |
| | C.D (P=0.05%) | 20.896 | 4.005 | 30.444 | 0.117 |

CONCLUSIONS

- Treatment 100% of RDF + Foliar application @ 0.5% ZnSO₄.7H₂O, at flowering and pod formation stage also maintained the soil health in terms of pH EC and organic carbon and availability nutrients and Zn in soil which were better than control.

REFERENCES

1. Negi S, Kumar P, Kumar J, Singh A, Dubey RC. Indigenous nitrogen fixing microbes engineer rhizosphere and enhance nutrient availability and plant growth. In Rhizosphere Engineering 2022 Jan 1 (pp. 19-43). Academic Press.
2. Rawat DK, Verma C, Singh AK, Kumar A and Prasad J. (2021). Effect of varieties and micronutrient applications on growth and qualitative characters of chickpea (*Cicer arietinum* L.).

3. Suganya, A., Saravanan, A. and Manivannan, N., 2020. Role of zinc nutrition for increasing zinc availability, uptake, yield, and quality of maize (*Zea mays* L.) grains: An overview. *Commun. Soil Sci. Plant Anal*, 51(15), pp.2001-2021.
4. Xu Y, Hao Z, Li Y, Li H, Wang L, Zang Z, Liao X, Zhang R. Distribution of selenium and zinc in soil-crop system and their relationship with environmental factors. *Chemosphere*. 2020 Mar 1;242:125289.
5. Shukla AK, Behera SK, Pakhre A, Chaudhari SK. Micronutrients in soils, plants, animals and humans. *Indian Journal of Fertilisers*. 2018 Apr;14(3):30-54.
6. Ibrahim EA, Ramadan WA. Effect of zinc foliar spray alone and combined with humic acid or/and chitosan on growth, nutrient elements content and yield of dry bean (*Phaseolus vulgaris* L.) plants sown at different dates. *Scientia horticulturae*. 2015 Mar 5;184:101-5.
7. Lindsay WL and Norvell WA. 1978. Development of a DTPA soil test for zinc, iron, manganese, and copper. *Soil Science Society of America journal* 42(3):421-428.
8. Walkley A and Black IA. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil science* 37(1): 29-38.
9. Subbiah B V and Asija G L. 1956. A rapid procedure for the determination of available nitrogen in soils. 25 . 259-260
10. Olsen SR. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. United States Department of Agriculture; Washington.
11. Jackson M L. 1978. Pentice Hall of India Pvt. Ltd. New Delhi. pp. 498
12. Gomez KA and Gomez AA. Statistical procedures for agricultural research- Hand Book. John Willy & Sons, New York; 1984.
13. Batool S, Asghar HN, Shehzad MA, Yasin S, Sohaib M, Nawaz F and Uzair, M. (2021). Zinc-solubilizing bacteria-mediated enzymatic and physiological regulations confer zinc biofortification in chickpea (*Cicer arietinum* L.). *Journal of Soil Science and Plant Nutrition*, 21(3), 2456-2471.
14. Chethan KV, David AA., Thomas T, Swaroop N, Rao S and Hassan, A. (2018). Effect of different levels of NPK and Zn on physico-chemical properties of soil growth parameters and yield by pea (*Pisum sativum* L.) Cv. Rachana. *Journal of Pharmacognosy and Phytochemistry*, 7(3), 2212-2215.
15. Singh, AK and Bhatt, BP. (2013). Effect of foliar application of zinc on growth and seed yield of late-sown lentil (*Lens culinaris*). *Indian Journal of Agricultural Sciences*, 83(6), 622-626.
16. Borah L, Saikia J and Basumatary A. 2021. Consequences of foliar zinc application on soil properties and quality of garden pea (*Pisum sativum* L.) in Assam condition.
17. Kumar A, Suri VK , Choudhary AK, Yadav A, Kapoor R , Sandal S and Dass, A. 2015. Growth behavior, nutrient harvest index, and soil fertility in okra-pea cropping system as influenced by AM fungi, applied phosphorus, and irrigation regimes in Himalayan acidic Alfisol. *Communications in Soil Science and Plant Analysis*, 46(17), 2212-2233.

18. Desai S, Kumar P, Sultana U, Pinisetty S and Reddy G. 2012. Potential microbial candidate strains for management of nutrient requirements of crops. *African Journal of Microbiology Research*, 6(17):3924-3931.
19. Singh, AK and Bhatt, BP. (2013). Effect of foliar application of zinc on growth and seed yield of late-sown lentil (*Lens culinaris*). *Indian Journal of Agricultural Sciences*, 83(6), 622-626.
20. Ghoneim AM. Effect of Different Methods of Zn Application on Rice Growth, Yield and Nutrients Dynamics in Plant and Soil. *J. Agric. Ecol. Res. Int* 2016;6(2):1-9.
21. Menser HA, Sidle RC. Effect of zinc levels on phosphorous and zinc content in sand-cultured soybeans. *J. Plant Nutr* 1985;8:89-97.
22. Mousavi SR. Zinc in Crop Production and Interaction with Phosphorus. *Aust. J. Basic Appl. Sci* 2011;5(9):1503-1509.
23. Safaya NM. Phosphorus-zinc interaction in Zinc application methods in relation to absorption rates of phosphorus, zinc, copper, manganese, and iron in corn. *J. Soil Sci. Soc. Am* 1976;40:719-722.
24. Stoyanova Z, Doncheva S. The effect of zinc supply and succinate treatment on plant growth and mineral uptake in pea plant. *Brazilian Journal of Plant Physiology*. 2002;14:111-6.
25. Dandona L, Dandona R, Kumar GA, Shukla DK, Paul VK, Balakrishnan K, Prabhakaran D, Tandon N, Salvi S, Dash AP, Nandakumar A. Nations within a nation: variations in epidemiological transition across the states of India, 1990–2016 in the Global Burden of Disease Study. *The Lancet*. 2017 Dec 2;390(10111):2437-60.
26. Ladumor RG, Gudadhe NN, Onte S, Narwade AV, Karmakar N, Thanki JD. Evaluation of Maize for Different Methods and Levels of Zinc Application. *Maydica* 2019;64(3):1-14.
27. Gupta N, Sharma RP, Tiwari RJ, Bhargav KS. Response of pea (*Pisum sativum* L.) varieties to different fertility levels. *Research on Crops*. 2016;17(1):90-4.

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