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Response of pigeonpea (*Cajanus cajan*) to sole and combined modes of zinc fertilization

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Abstract
Present field experiment was conducted during kharif seasons of 2013-14 and 2014-15 at Mahatma Gandhi Chitrakoot Gramoday Vishwavidyalaya, Chitrakoot to study the different modes of zinc application on performance of pigeonpea (cv. ICPL-87119). The experiment was laid out in randomized block design (RBD) with fifteen treatments in three replications. The treatments involved the combinations of two levels each of soil zinc, farm yard manure and foliar zinc. The response of pigeonpea in terms of growth and yield attributes and properties of soil at harvest of crop were studied. The results revealed that, the combined application of soil zinc, FYM and/or foliar zinc significantly influenced the plant height, number of pods plant^{-1}, number of seeds pod^{-1}, yield, total biomass and test weight of pigeonpea. The soil available nutrients were found significantly higher under the treatments involving the application of FYM.

Keywords: biomass, foliar zinc, pigeonpea, plant height, yield

Introduction
Zinc has been the micronutrient needed by crops especially pulses in sufficiently large quantity. Unfortunately, in India, about 50% of soils are deficient in zinc inducing Zn deficiency in human and animal due to reduction in concentration of zinc in edible plant parts (Singh, 2011) [35]. Recent research revealed that one third of the world population under the risk of zinc malnutrition. Zinc plays an important role in metabolism both in plants as well as animals by acting as essential component of enzyme, RNA, electron carrier etc. The proteinases, peptidases, carbonic, dehydrogenase, anhydrase etc. are the examples metalloenzymes in which zinc is the integral part. Besides enzymes, zinc also associated with the proteins and plays an important role. The plants exhibited lower rate of protein synthesis and protein accumulation under zinc deficiency. Zinc also plays important role in physiological process of plants through synthesis of hormones essential for growth and reproduction. Zinc is an essential component of RNA polymeras and provides structural integrity to ribosomes (Taliee and Sayadian, 2000) [40]. The accumulation of zinc in edible parts of plant serves as zinc source for primary consumers. Soil is the only source for availability of zinc to plants and animals naturally but the intensive cropping system involving high yielding varieties have led to depletion of soil zinc. Zinc deficiency remained a major problem all over country. Zinc deficiency has increased from 44% to 48% and expected to further increase up to 63% by 2025 as most of the marginal soils are showing higher response to added zinc (Shukla *et al.*, 2014) [34]. Soil zinc deficiency can be overcome by application of zinc salts and organic manures. But the use efficiency of the soil zinc application is poor hence application of zinc through different and combined modes has been widely studied and adopted.
Pigeon pea [*Cajanus cajan* (L.) Millsp.] belongs to the genus *Cajanus*, subtribe *Cajaninae*, tribe *Phaseoleae*, and family abaceae. It is also known as redgram, tur, arhar, gandul (Spanish) and pois d'Angole (Sharma and Green, 1980) [31]. Pigeon pea is one of the important pulse crop of India, plays a vital role in daily diet, being widely consumed in the country. It is the second most important pulse crops of India after chickpea. It is one of the protein rich legume crops of semi arid and sub tropics. Zinc plays important role in determining the yield and quality of the pulse crop especially pigeonpea. Considering the importance of zinc to pigeonpea crop, depleting soil zinc status and limited efficiency of applied zinc fertilizers, the response of pigeonpea to different mode of zinc application was studied.

Materials and Methods
Experimental site
Present field experiment was conducted at the Student's Instructional Farm, Rajaula of

Mahatma Gandhi Chitrakoot Gramodaya Vishwavidyalaya (MGCGV), Chitrakoot, Satna, Madhya Pradesh which located at 24°31' North latitude and 81°15' East longitude and at an altitude of 306 meters above the mean sea level. It is situated in East tract of M.P., enjoying semi-arid and sub-tropical climate. The summers are hot desiccating winds (Loo) are regular feature and dry. May and June are the hottest months with mean monthly maximum temperature of 47°C and 38.4°C, respectively. December and January constitute the coolest months of the year. Mean monthly minimum temperature of 2°Cand 4°C, respectively. The mean annual rainfall ranges between 900 to 1000 mm distributed over a period of three months from the middle of June and the end of September.

Initial soil properties

The initial characteristics of the experimental soil are presented in Table 1. The soil of the experimental site is sandy loam texture with 56.2, 28.8 and 15.0 per cent of sand, silt and clay, respectively.

Table 1: Initial soil characteristics of experimental field (0-15 cm)

Soil Properties	Value
Sand (%)	56.2
Clay (%)	15
Silt (%)	28.8
pH (1:2)	7.49
EC (1:2) (dS m^{-1})	0.26
Organic carbon (%)	0.24
Available N (kg ha^{-1})	210
Available P (kg ha^{-1})	15.1
Available K (kg ha^{-1})	189
Available Fe (mg kg^{-1})	20.5
Available Mn (mg kg^{-1})	12.4
Available Zn (mg kg^{-1})	0.57
Available Cu (mg kg^{-1})	0.36

Initially, the soil was low in soil organic carbon (Walkley and Black easily oxidizable carbon) (0.24%), low in available N (210 kg ha^{-1}), medium in available P (15 kg ha^{-1}) and low in available K (189 kg ha^{-1}). The soil was normal in reaction (pH 7.49 and EC 0.26 dS m^{-1}) having DTPA extractable micronutrients in optimum range (Fe, Mn, Zn and Cu; 20.5, 12.4, 0.57 and 0.36 mg kg^{-1}, respectively).

Meteorological observations

The meteorological data recorded at Meteorological Observatory, Krishi Vigyan Kendra, Majgawa, Satana, M.P. during the experimental period has been presented in Fig. 1. The data revealed that the minimum and maximum temperature ranged 9-26 °C and 20-41 °C. The lowest and highest minimum and maximum temperature was observed in December and June; and January and May, respectively. Similarly, the mean relative humidity ranged 36-78% during the study period (2013-2015). The minimum and maximum relative humidity was observed in May and January month, respectively. The mean monthly rainfall data revealed that, it was ranged between 0-81 mm with highest in July month. The monsoon season (June-September) contributed 77% of total rainfall received during the study duration (Fig. 1).

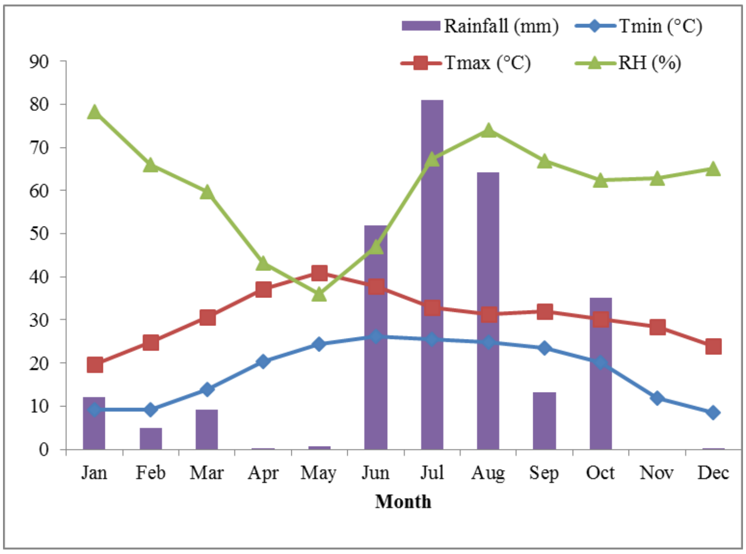

Fig 1: Meteorological observations during the study period (2013-15)

Treatment details

The experiment was conducted during *kharif* seasons of 2013-14 and 2014-15 in randomized block design (RBD) with 15 treatments in three replications. The experiment was carried out with plots of area 16 m^2 (4.0 m × 4.0 m). The treatments involved combination of two zinc levels (12.5 and 25 kg), two farm yard levels (0 and 5t) and foliar Zn application at two stages (flower initiation and pod development stage). The details of treatments have been presented in Table 2.

Table 2: Treatment details of the field experiment

Treatment	Description
T1	Control
T2	$ZnSO_4$@25 kg ha^{-1}
T3	$ZnSO_4$@25 kg ha^{-1} + FYM @ 5t ha^{-1}
T4	$ZnSO_4$@25 kg ha^{-1} + Foliar Zn@0.5% at FI
T5	$ZnSO_4$@25 kg ha^{-1} + Foliar Zn@0.5% at PD
T6	$ZnSO_4$@25 kg ha^{-1} + FYM @ 5t ha^{-1} + Foliar Zn@0.5% at FI
T7	$ZnSO_4$@25 kg ha^{-1} + FYM @ 5t ha^{-1} + Foliar Zn@0.5% at PD
T8	$ZnSO_4$@25 kg ha^{-1} + FYM @ 5t ha^{-1} + Foliar Zn@0.5% at FI and PD
T9	$ZnSO_4$@12.5 kg ha^{-1}
T10	$ZnSO_4$@12.5 kg ha^{-1} + FYM @ 5t ha^{-1}
T11	$ZnSO_4$@12.5 kg ha^{-1} + Foliar Zn@0.5% at FI
T12	$ZnSO_4$@12.5 kg ha^{-1} + Foliar Zn@0.5% at PD
T13	$ZnSO_4$@12.5 kg ha^{-1} + FYM @ 5t ha^{-1} + Foliar Zn@0.5% at FI
T14	$ZnSO_4$@12.5 kg ha^{-1} + FYM @ 5t ha^{-1} + Foliar Zn@0.5% at PD
T15	$ZnSO_4$@12.5 kg ha^{-1} + FYM @ 5t ha^{-1} + Foliar Zn@0.5% at FI and PD

FI-flower initiation; PD-pod development; FYM-farm yard manure

The commercial grade zinc sulphate ($ZnSO_4.7H_2O_4$) containing 21% Zn (active ingredient) was used as a source of zinc for soil application. Long duration (200 to 220 days) pigeonpea genotype ICPL 87119 was chosen as test crop. Sowing of pigeonpea was performed in first week of July in both the years. Seeds were sown at 3 cm depth at 15 cm plant and 60 cm row distance. Nutrients particularly, nitrogen, phosphorus and potassium were applied as basal dose as well as other agronomic management practice was as per recommended practices and was kept similar for all the treatments. The recommended dose of fertilizers viz., N, P_2O_5 and K_2O (20:40:30 kg ha^{-1}) were applied as basal dose at the time of sowing in the form of Urea, DAP and MOP; and FYM @ 5 tones ha^{-1} was applied two weeks before sowing for proper decomposition. The nutrient composition of FYM used has been presented in Table 3. Two foliar sprays @ 0.5% Zn were taken at flower initiation and pod development stage respectively. One hand weeding after three weeks of sowing was performed to keep the plots weed free and optimum plant population was maintained in the plots.

Table 3: Mean nutrient composition of farm yard manures used in the experiment

Nutrient	Value
Total Nitrogen (g kg^{-1})	8.6
Total Phosphorus (g kg^{-1})	4.4
Total Potassium (g kg^{-1})	10.7
Fe (g kg^{-1})	1.1
Mn (mg kg^{-1})	320
Cu (mg kg^{-1})	56
Zn (mg kg^{-1})	39

Growth parameters, yield attributes and yield observations

Data on plant height were recorded at 30, 60, 90 and 120 DAS of five randomly selected plants from each plot. At harvest five representative plants of each plot were collected and biometrical data were recorded and computed for pods $plant^{-1}$, seeds pod^{-1}, total plant dry weight (g $plant^{-1}$) and seed yield (g $plant^{-1}$). Similarly 1000 seed weight (g) were also computed for test weight. Biomass (kg ha^{-1}) and seed yield (kg ha^{-1}) were computed based on seed weight $plot^{-1}$ and computed for ha^{-1}. Dry weight of the plant shoots were recorded by drying samples in an oven at 60°C for 72 hours. Harvest index was estimated as per the formula suggested by Donald (1962) [8].

Soil sampling and analysis

The soil samples were collected at the end of cropping cycle from 0-15 cm depth at three randomly selected spots in each replication and composite samples were prepared. The soil was gently ground, well mixed and sieved through 2 mm mesh and utilized for laboratory analysis of various physicochemical properties. Soil pH and electrical conductivity was estimated in the 1:2 (soil: water) suspension using glass electrode pH meter as per method described by Jackson (1973) [13]. The organic carbon content was determined by Walkley and Black (1934) [45] method. Soil texture was determined with hydrometer as described by Bouyoucos (1927) [5]. Soil available nitrogen (Subbaiah and Asija, 1956) [38], phosphorus (Olsen *et al.*, 1954) [23] and potassium (Hanway and Heidel, 1952) were determined by following standard methods. The soil available micronutrients were determined on atomic absorption spectrophotometer (AAS) after extracting the soil with DTPA-extractant (Lindsay and Norvell, 1978) [19].

Statistical analysis

Analysis of variance (ANOVA) was performed for each trait for all seasons and the combined (Pooled) analysis over seasons after testing error variance homogeneity was carried out according to the procedure outlined by Gomez and Gomez (1984) [11]. Significant differences between the treatments were compared with the critical difference at (± 5%) probability by LSD.

Results and Discussions

Plant height

Plant height is one of the important morphological growth parameter influenced by the applied nutrients and growth regulators. The data pertaining to the plant height of pigeon pea at different growth stages *viz*. 30, 60, 90 and 120 days after sowing (DAS) as influenced by sole and combined mode of zinc nutrition have been presented in Table 4. The plant height of pigeon pea at 30 DAS found 4-14% higher under the treatments receiving different mode of Zinc application and their combination as compared to the control (no zinc application). The application of 12.5 kg $ZnSO_4$ either alone or in combination with FYM and/or foliar application registered 4-9% higher plant height at 30 DAS as compared to control. Similarly, the application of 25 kg $ZnSO_4$ either alone or in combination with FYM and/or foliar zinc increased plant height of pigeon pea by 6-14% over control (Table 4.). The application of 0.5% Zn as foliar spray at flower initiation and/or pod development stage in combination with different soil application (12.5 or 25 kg $ZnSO_4$) with or without FYM @ 5t ha^{-1} showed 6-13% higher plant height at 30 DAS over control. Similarly, zinc fertilization through soil (with or without foliar application) in combination with FYM @ 5t ha^{-1} increased plant height of pigeon pea by 8-14% as compared to the control. Among these treatments, the treatments involving application of soil zinc in combination with foliar zinc and FYM found most beneficial with respect to improvement in plant height of pigeon pea at 30 DAS. The plant height of pigeon pea at 60 DAS found 4-16% higher under the treatments receiving different mode of Zinc application and their combination as compared to the control (no zinc application). The application of 12.5 kg $ZnSO_4$ either alone or in combination with FYM and/or foliar application registered 4-13% higher plant height at 60 DAS as compared to control. Similarly, the application of 25 kg $ZnSO_4$ either alone or in combination with FYM and/or foliar zinc increased plant height of pigeon pea by 6-16% over control. The application of 0.5% Zn as foliar spray at flower initiation and/or pod development stage in combination with different soil application (12.5 or 25 kg $ZnSO_4$) with or without FYM @ 5t ha^{-1} showed 4-16% higher plant height at 60 DAS over control. Similarly, zinc fertilization through soil (with or without foliar application) in combination with FYM @ 5t ha^{-1} increased plant height of pigeon pea by 10-16% as compared to the control. Among these treatments, the treatments involving application of soil zinc in combination with foliar zinc and FYM found most beneficial with respect to improvement in plant height of pigeon pea at 60 DAS.

Table 4: Growth and yield attributes of pigeonpea under sole and combined mode of zinc nutrition (pooled data of 2 years).

Treatment	Plant height (cm)				Pods $plant^{-1}$	Seeds Pod^{-1}
	30 Das	60 Das	90 Das	120 Das		
T_1	41.4	91.3	161.2	194.5	46.8	3.77
T_2	43.9	96.9	168.3	207.6	48.6	3.85
T_3	47.1	104.0	178.5	217.3	53.0	3.96
T_4	44.7	98.8	171.5	211.7	49.4	3.88
T_5	44.2	98.5	171.1	208.7	48.7	3.83
T_6	46.1	105.5	179.7	220.5	53.2	3.97
T_7	46.3	104.8	177.4	218.9	53.9	3.89
T_8	46.6	106.2	180.4	222.5	53.8	3.98
T_9	43.0	96.1	165.7	199.5	47.2	3.78
T_{10}	44.8	100.4	174.4	214.1	52.4	3.92
T_{11}	44.1	96.4	170.6	207.0	49.8	3.82
T_{12}	43.8	95.5	166.7	206.1	49.0	3.77
T_{13}	44.6	102.2	174.9	215.8	52.8	3.94
T_{14}	44.9	100.5	174.0	214.9	52.7	3.90
T_{15}	45.3	103.4	177.1	218.3	54.1	3.93
SEm±	0.759	2.245	3.164	3.811	0.971	0.042
CD 5%	2.199	6.502	9.166	11.04	2.812	0.122

DAS-days after sowing

The plant height of pigeon pea at 90 DAS found 3-12% higher under the treatments receiving different mode of Zinc application and their combination as compared to the control (no zinc application) (Table 4.). The application of 12.5 kg $ZnSO_4$ either alone or in combination with FYM and/or foliar application registered 3-10% higher plant height at 90 DAS as compared to control. Similarly, the application of 25 kg $ZnSO_4$ either alone or in combination with FYM and/or foliar zinc increased plant height of pigeon pea by 4-12% over control. The application of 0.5% Zn as foliar spray at flower initiation and/or pod development stage in combination with different soil application (12.5 or 25 kg $ZnSO_4$) with or without FYM @ 5t ha^{-1} showed 3-12% higher plant height at 90 DAS over control. Similarly, zinc fertilization through soil (with or without foliar application) in combination with FYM @ 5t ha^{-1} increased plant height of pigeon pea by 8-12% as compared to the control. Among these treatments, the treatments involving application of soil zinc in combination with foliar zinc and FYM found most beneficial with respect to improvement in plant height of pigeon pea at 90 DAS. The plant height of pigeon pea at 120 DAS found 3-14% higher under the treatments receiving different mode of Zinc application and their combination as compared to the control (no zinc application). The application of 12.5 kg $ZnSO_4$ either alone or in combination with FYM and/or foliar application registered 3-12% higher plant height at 120 DAS as compared to control. Similarly, the application of 25 kg $ZnSO_4$ either alone or in combination with FYM and/or foliar zinc increased plant height of pigeon pea by 7-14% over control. The application of 0.5% Zn as foliar spray at flower initiation and/or pod development stage in combination with different soil application (12.5 or 25 kg $ZnSO_4$) with or without FYM @ 5t ha^{-1} showed 6-14% higher plant height at 120 DAS over control. Similarly, zinc fertilization through soil (with or without foliar application) in combination with FYM @ 5t ha^{-1} increased plant height of pigeon pea by 10-14% as compared to the control. Among these treatments, the treatments involving application of soil zinc in combination with foliar zinc and FYM found most beneficial with respect to improvement in plant height of pigeon pea at 120 DAS (Table 4.).

In general, the plant height responded to the combined application of soil zinc, foliar zinc and FYM, the beneficial effects of combined method of application of micronutrients especially zinc on growth of Pigeonpea might be due to more availability of zinc both during seedling and subsequent stages of plant growth which is known to increase photosynthates and 'N' fixation (Hegazy *et al.,* 1990). Similarly, the zinc have important role in chlorophyll formation, carbohydrate metabolism, synthesis of proteins and activation of oxidation process and enzymes (Sharma *et al.,* 2010) [32]. Similar results with respect to the higher plant height of culasterbean (Kuniya *et al.,* 2018) [17], mungbean (Tayyeba *et al.,* 2017) [41] and pigeonpea (Shah *et al.,* 2016; Thamke, 2017; Purushottam *et al.,* 2018) [30, 42, 25] under the soil zinc application have also been recorded. The importance of appropriate time of application (*i.e.* flowering and panicle initiation) of Zn could alter the physiological events of crop. Increase in plant height was mainly attributed due to higher shoot growth through cell elongation, cell differentiation and apical dominance promoted by Zinc. Zinc were also supposed to be involved in the hormone synthesis, hence indirectly related to translocation and metabolism of carbohydrate finally contributing to additional growth compared to control (Padma *et al.* 1989 and Deotale *et al.* 1998) [24, 7]. The favorable results might be due to promotion of bud and branch development by the auxins whereas Zn application ultimately increased the availability of other nutrients and accelerated the translocation of photo assimilates as well (Guhey, 1999) [12].

Number of pods, number of seeds and test weight

The number of pods per plant in pigeon pea at harvest was found 1-15% higher under the treatments receiving different mode of Zinc application and their combination as compared to the control (no zinc application) (Table 4). The application of 12.5 kg $ZnSO_4$ either alone or in combination with FYM and/or foliar application registered 1-15% higher pods in pigeon pea plant as compared to control. Similarly, the application of 25 kg $ZnSO_4$ either alone or in combination with FYM and/or foliar zinc increased 4-15% pods in pigeon pea plant over control. The application of 0.5% Zn as foliar spray at flower initiation and/or pod development stage in combination with different soil application (12.5 or 25 kg $ZnSO_4$) with or without FYM @ 5t ha^{-1} showed 4-14% higher pods per plant over control. Similarly, zinc fertilization through soil (with or without foliar application) in combination with FYM @ 5t ha^{-1} increased number of pods in pigeon pea plant by 12-15% as compared to the control. Among these treatments, the treatments involving application of soil zinc in combination with foliar zinc and FYM found most beneficial with respect to improvement in number of pods in pigeon pea.

The number of seeds per pod in pigeon pea found 0-6% higher under the treatments receiving different mode of Zinc application and their combination as compared to the control (no zinc application) (Table 4). The application of 12.5 or 25 kg $ZnSO_4$ either alone or in combination with foliar application had no significant effect on seeds per pod in pigeon pea. The zinc fertilization through soil (with or without foliar application) in combination with FYM @ 5t ha^{-1} increased seed per pod by 3-6% as compared to the control. Among these treatments, the treatments involving application of soil zinc in combination with foliar zinc and FYM found most beneficial with respect to improvement in number of seeds per pod in pigeon pea.

The test weight of pigeon pea found 0.2-5.0% higher under the treatments receiving different mode of Zinc application and their combination as compared to the control (no zinc application) (Table 5). The application of 12.5 kg $ZnSO_4$ either alone or in combination with FYM and/or foliar application registered 0.2-4.5% higher test weight as compared to control (Fig. 1). Similarly, the application of 25 kg $ZnSO_4$ either alone or in combination with FYM and/or foliar zinc increased test weight of pigeon pea by 0.6-5.0% over control. The application of 0.5% Zn as foliar spray at flower initiation and/or pod development stage in combination with different soil application (12.5 or 25 kg $ZnSO_4$) with or without FYM @ 5t ha^{-1} showed 1.0-5.0% higher test weight over control. Similarly, zinc fertilization through soil (with or without foliar application) in combination with FYM @ 5t ha^{-1} increased test weight of pigeon pea by 2.7-5.0% as compared to the control. Among these treatments, the treatments involving application of soil zinc in combination with foliar zinc and FYM found most beneficial with respect to improvement in test weight of pigeon pea (Table 5).

The increase in yield attributes due to application of zinc may be due to accumulative effect of growth characters and also yield attributes as it contain Zinc which is involved in IAA synthesis and also different metabolic process in plants. These might be due to the fact that IAA promotes the prevention of pod abscission and cell elongation at suppression of abscission of pod was the major determining factor of the seed yield. On the other hand, auxin indirectly controlled the ethylene activity, which accelerated the abscission. It also suppressed the cellulase activity, cell degrading enzyme which favored abscission process (Mote *et al.* 1975, Singh, 1986) [22, 36]. Zn also contributed significantly in reducing the pod abscission by preventing abscission layer formation when applied at podding stage. At the same time, it also increased the sink demand as well as the translocation of photosynthates from source to sink. This might be due to unloading of the current photosynthates being accumulated in the leaf and stem (Singh, 1986; Setia *et al.*, 1993; Guhey, 1999) [36, 29, 12].

The significant positive response of pigeon pea to zinc application has also been reported earlier by Umesh and Shankar (2013) [43], Shah *et al.* (2016) [30], Tayyeba *et al.* (2017) [41], Kuniya *et al.*, 2018) [17] and Purushottam *et al.* (2018) [25]. It can be concluded that the enhancement effect be attributed to the favorable influence of the Zn application to pigeon pea on nutrient metabolism, biological activity and growth parameters was very clear, hence applied zinc resulted in taller and higher enzyme activity which in turn encourage vegetative branches, pods /plant (Michail *et al.*, 2004) [21].

Table 5: Grain yield, Straw yield, harvest index and test weight of pigeon pea under sole and combined mode of zinc nutrition (pooled data of 2 years)

Treatment	Grain yield (q ha^{-1})	Straw yield (q ha^{-1})	HI	Test weight (g)
T_1	19.07	51.92	26.89	90.8
T_2	20.61	55.22	27.94	91.4
T_3	22.62	59.11	26.88	93.4
T_4	22.05	57.79	27.31	92.5
T_5	21.81	58.33	27.53	92.0
T_6	23.35	60.54	27.55	94.7
T_7	22.53	58.45	27.47	93.9
T_8	23.77	61.36	27.68	95.4
T_9	20.38	55.45	27.70	91.0
T_{10}	22.18	59.11	27.19	93.2
T_{11}	21.85	57.62	27.68	92.3
T_{12}	21.87	57.54	27.62	91.8
T_{13}	22.79	60.20	27.22	94.5
T_{14}	22.14	57.90	27.83	93.7
T_{15}	23.38	61.04	27.84	94.9
SEm±	0.17	1.19	0.403	0.428
CD 5%	0.50	3.44	1.167	1.241

Grain yield, straw yield and harvest index

Grain yield is the ultimate economic produce of the crop which is determined by grain weight, number of grains per unit land area as governed by the management practices and its native genetic potential. The grain yield of pigeon pea found 7-25% higher under the treatments receiving different mode of Zinc application and their combination as compared to the control (no zinc application) (Table 5). The application of 12.5 kg $ZnSO_4$ either alone or in combination with FYM and/or foliar application registered 7-23% higher grain yield as compared to control. Similarly, the application of 25 kg $ZnSO_4$ either alone or in combination with FYM and/or foliar zinc increased grain yield of pigeon pea by 8-25% over control. The application of 0.5% Zn as foliar spray at flower initiation and/or pod development stage in combination with different soil application (12.5 or 25 kg $ZnSO_4$) with or without FYM @ 5t ha^{-1} showed 15-25% higher grain yield over control. Similarly, zinc fertilization through soil (with or without foliar application) in combination with FYM @ 5t ha^{-1} increased grain yield of pigeon pea by 16-25% as compared to the control. Among these treatments, the treatments involving application of soil zinc in combination with foliar zinc and FYM found most beneficial with respect to improvement in grain yield of pigeon pea.

The straw yield of pigeon pea found 6-18% higher under the treatments receiving different mode of Zinc application and their combination as compared to the control (no zinc application). The application of 12.5 kg $ZnSO_4$ either alone or in combination with FYM and/or foliar application registered 6-17% higher straw yield as compared to control. Similarly, the application of 25 kg $ZnSO_4$ either alone or in combination with FYM and/or foliar zinc increased straw yield of pigeon pea by 7-18% over control. The application of 0.5% Zn as foliar spray at flower initiation and/or pod development stage in combination with different soil application (12.5 or 25 kg $ZnSO_4$) with or without FYM @ 5t ha-1 showed 11-18% higher straw yield over control. Similarly, zinc fertilization through soil (with or without foliar application) in combination with FYM @ 5t ha^{-1} increased straw yield of pigeon pea by 12-18% as compared to the control. Among these treatments, the treatments involving application of soil zinc in combination with foliar zinc and FYM found most beneficial with respect to improvement in straw yield of pigeon pea. The Harvest index in the pigeon pea ranged from 26.88 to 27.94 among the various treatments studied. The lowest and highest Harvest index of pigeon pea was found in the treatment T_3 and the treatments T_2, respectively. However the impact of treatments on harvest index of pigeon pea was not found significant. It has been observed that the FYM with application of chemical fertilizers had no marked difference on harvest index of pigeon pea (Table 5).

Zn is required for the biosynthesis of plant growth regulator (IAA) and for carbohydrate and N metabolism which leads to high yield and yield components (Taliee and Sayadian, 2000) [40]. Hundred grain weights is one of the most important yield components in pulse. Overcoming limitations to plant nutrient through the application of appropriate fertilisers increased assimilate production and photosynthesis efficiency at the seed filling stage (Ali, 2004) [1]. The positive response of the pigeon pea to zinc fertilization either through soil or foliar with and without FYM has already been reported by different researchers in diverse soils. The results of the present investigation are in close agreement with the results obtained by Shrikant babu *et al.* (2012) [33]; Umesh and Shankar (2013) [43], Shah *et al.* (2016) [30] and Purushottam *et al.* (2018) [25]. Similarly, the application of zinc either through soil or foliar mode also improved the yield of other pulses and crops *i.e.* chickpea (Valenciano, *et al.*, 2010) [44], Green gram (Srinivasarao, 2012) [37], Soybean (Chauhan, *et al.*, 2013) [6], Mungbean (Tayyeba, *et al.*, 2017) [41] and Cluster bean (Kuniya, *et al.*, 2018) [17].

The positive effects of zinc application to crop yield might be due to the Zn fertilizer (as $ZnSO_4$) decreases pH of soil and increases root absorption of minerals and improved Zn nutrition of plants improves biosynthesis of the plant growth regulator IAA, carbohydrate and N metabolism which lead to high yield and yield components. The enhanced plant nutrition increases photosynthesis efficiency, assimilation and production (Ali, 2004) [1]. Dry matter accumulation in the plant at progressive stages is a justified assessment of growth as a cumulative expression of different growth parameters. Further, it was observed that productivity of pigeon pea was not only dependent on accumulation of total amount of dry matter but its effective partitioning into economic sink seems to be key to increase the yield. Auxin is known to maintain the higher rate of photosynthesis which contributed to higher dry matter which was an indicator of current photosynthesis (Bangla, *et al.* 1983) [2]. The results of the present study revealed the higher accumulation of total biomass under the combined application of the $ZnSO_4$, foliar zinc and FYM.

Table 6: Effect of sole and combined mode of zinc application on soil properties at pigeonpea harvest (pooled data of 2 years)

Treatment	pH	EC	OC	N	P	K	Zn
T_1	7.51	0.316	0.24	200.1	13.9	197.6	0.54
T_2	7.53	0.309	0.24	207.1	9.5	199.9	0.83
T_3	7.47	0.281	0.37	223.0	14.6	227.7	0.95
T_4	7.54	0.318	0.25	199.1	10.5	198.0	0.82
T_5	7.52	0.316	0.23	206.3	10.7	195.6	0.86
T_6	7.46	0.268	0.38	218.6	15.7	217.4	0.95
T_7	7.47	0.266	0.35	223.4	14.2	218.5	0.98
T_8	7.49	0.278	0.36	220.9	15.6	215.7	0.99
T_9	7.53	0.316	0.25	205.1	10.7	195.9	0.73
T_{10}	7.48	0.282	0.35	221.8	15.7	222.2	0.91
T_{11}	7.53	0.297	0.26	202.4	11.8	196.2	0.78
T_{12}	7.54	0.286	0.27	203.5	11.9	195.9	0.81
T_{13}	7.46	0.265	0.33	220.9	16.0	228.8	0.91
T_{14}	7.45	0.273	0.35	219.5	15.1	235.5	0.91
T_{15}	7.52	0.285	0.35	223.0	15.7	223.3	0.93
SEm±	0.032	0.019	0.012	3.580	0.538	4.308	0.03
CD 5%	0.092	0.056	0.034	10.372	1.559	12.478	009

Values in kg ha^{-1} except pH, EC (dS m^{-1}), OC (%) and Zn (mg kg^{-1})

Soil organic carbon, macro and micronutrients

The data pertaining to the organic carbon in soil is presented in Table 6. The organic carbon in soil ranged from 0.23% in treatment T_5 to 0.38% in treatment T_6. The organic carbon percentage in treatments with 5t FYM (T_6, T_3, T_8, T_{15}, T_{10}, T_{14}, T_7 and T_{13}) were found significantly higher as compared to the treatments without application of the FYM. The highest soil available N was observed under the treatment receiving 25 kg $ZnSO_4$ with 5t FYM and the lowest was recorded for the treatment T_4. The treatments followed the similar trend that of organic carbon in soil, showing higher available N under the combined application of inorganic Zn and FYM. The soil available phosphorus (P) was observed significantly higher under the treatments receiving application of FYM @5 ton ha^{-1} over the treatments without application of FYM. Similarly, the treatments involving application of FYM significantly improved the soil available potassium over the treatments without application of FYM *i.e.* treatment T_2, T_4, T_{11}, T_{12}, T_9, and T_5 (Table 6). The pooled data of two years revealed that the treatments involving application of Zn along with FYM significantly improved the DTPA extractable Zn content in soil.

Application of FYM resulted in an increase OC of soil over the treatments without application of FYM and control. The observed increase in SOC might be due to the continuous buildup of carbon in soil due to external carbon inputs such as

FYM. Besides the regular applications of different organic manures, the root biomass and left over stubbles have also contributed to the increment in soil carbon. Jha, *et al.* (2014) [15] and Lakaria, *et al.* (2012a) [18] also observed significant increment in SOC with the application of FYM. Similarly, these treatments registered significant increment in soil available macro and micronutrients. The increment in soil nutrient availability upon application of FYM (Manna, *et al.*, 2007a; Tadesse, *et al.*, 2013; Ram, *et al.*, 2013) [20, 39, 26] have already been reported by many researchers. Results of this investigation are in good agreement with the earlier findings. Jagtap *et al.* (2007) [14] also observed increased DTPA-micronutrients (Fe, Zn, Cu and Mn) with the application of organic manures either alone or in combination with chemical fertilizers. This was probably due to the mineralization of added FYM which released the nutrients in soil solution. Also, the significant increase in soil available macro and micro nutrients content of soil was due to the increased mineralization of organic manure as well as SOC by active microorganisms. The increased availability of micronutrient cations with the application of organics might be due to release of micronutrients in readily available forms from soil. Also, the cations form relatively stable chelates with organic ligands, which decrease susceptibility to adsorption, fixation and/or precipitation (Bharadwaj and Omanwar, 1994) [3].

Conclusions

The pigeonpea crop responded positively to the various modes of zinc applications. The plant height, number of pods plant-1, number of seeds pod-1, seed yield, straw yield and test weight was found 3-16%, 1-15%, 0-6%, 7-25%, 6-18% and 0.2-5.0% higher under the different modes of zinc application. The harvest index of pigeon pea was not significantly influenced by either mode of zinc application. Similarly, the treatments involving the application of FYM showed slight to significant improvement in soil organic carbon, macro and micronutrients.

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References

1. Ali H. Interactive effects of seed inoculation and phosphorous application on growth and yield of chick pea (*cicer arietinum* L.). International Journal of Agriculture and Biology. 2004; 6(1):110-112.
2. Bangla DB, Deshmukh SN, Patil VA. Contribution of pod wall in grain development of Chickpea (*Cicer arientanum* L.) as influenced by growth promoter. Indian Journal plant physiology. 1983; 26:292-295.
3. Bharadwaj V, Omanwar PK. Long-term effects of continuous rotational cropping and fertilization on crop yields and soil properties. II. Effects on EC, pH, organic matter and available nutrients of soil. Journal of Indian Society of Soil Science. 1994; 42:387-392.
4. Bouyoucos GJ. Hydrometer method improved for making particle size analysis of soils. Journal of Agronomy. 1962; 54:464-465.
5. Bouyoucos GJ. The hydrometer as a new method for the mechanical analysis of soils. Soil Science. 1927; 23:343-353.
6. Chauhan S, Titov A, Tomar DS. Effect of potassium, sulphur and zinc on growth, yield and oil content in soybean (*Glycine max* L.) in vertisols of central India. Indian Journal of Applied Research, 2013; 3(6):489-491.
7. Deotale RD, Maske VG, Sorte NV, Chimurkar BS, Yerne AZ. Effect of GAaand NAA on morphological parameters of soybean. Journal Soils and crops. 1998; 8(1):91-94.
8. Donald CM. In search of yield. Journal of Australian Institute of Agricultural Sciences. 1962; 28:171-178.
9. Drinkwater LE, Letourneau DK, Workneh F, Vanbruggen AHC, Shennan C. Fundamental differences between conventional and organic tomato agroecosystems in California. Applied soil ecology. 1995; 5(4):1098-1112.
10. Falah S. Effect of plant densities and soil moisture in yield and yield component of chickpea cultivars. Master Thesis. Isfahan University, 2002.
11. Gomez KA, Gomez AA. Statistical Procedures for Agricultural Research, 2nd Edition. A Wiley Inter-Science Publication, New York (USA), 1984.
12. Guhey A. Physiological studies on chickpea in relation to drought tolerance. Ph.D. Thesis Submitted to Dept. of plant physiology, Institute of Agriculture Sciences, BHU, Varanasi, 1999.
13. Jckson ML. Soil Chemical Analysis. Prentice, Hall of India Pvt. Ltd., New Delhi, 1973.
14. Jagtap PB, Patil JD, Nimbalkar CA, Kadlag AD. Influence of integrated nutrient management on soil properties and release of nutrients in a saline-sodic soil. Journal of Indian Society of Soil Science. 2007; 55(2):147-156.
15. Jha P, Lakaria BL, Biswas AK, Saha R, Mahapatra P, Agrawal BK *et al*. Effects of carbon input on soil carbon stability and nitrogen dynamics. Agriculture, Ecosystems and Environment. 2014; 189:36-42.
16. Kumar J, Dhiman S. Moisture stress studies in different chick pea types. www.crop sience.org.au. 2004.
17. Kuniya Neeta, Chaudhary Neha, Patel Sweta. Effect of sulphur and zinc application on growth, yield attributes, yield and quality of summer clusterbean [*Cyamopsis tetragonoloba* (L.)] in light textured soil. International Journal of Chemical Studies. 2018; 6(1):1529-1532.
18. Lakaria BL, Singh M, Reddy KS, Biswas AK, Jha P, Choudhary RS *et al.* Carbon addition and storage under integrated nutrient management in soybean-wheat cropping sequence in a Vertisol of central India. National Academy of Science Letters. 2012a; 35(3):131-137.
19. Lindsay WL, Norvell WA. Development of a DTPA soil test for zinc, iron, manganese and copper. Journal of American Society of Soil Science. 1978; 42:421-428.
20. Manna MC, Swarup A, Wanjari RH, Ravankar HN. Long-term effects of NPK fertilizer and manure on soil fertility and a sorghum-wheat farming system. Australian Journal of Experimental Agriculture. 2007; 47:700-711.
21. Michail T, Walter T, Astrid W, Walter G, Dieter G, Maria SJ *et al*. A survey of foliar mineral nutrient concentrations of Pinus canariensis at field plots in Tenerife. Forest Ecology and Management. 2004; 189:49-55.
22. Mote UN, Patil AV, Wavhal KN. Effect of NAA (Planofix) sprays on flower drop and yield in important varieties of chillies. Research Journal of Mahatma Phule Agriculture University. 1975; 6(1):57-66.

23. Olsen SR, Cole GV, Watnable FS, Dean LA. Estimation of available P in soils by extraction with sodium bicarbonate USDA. CRIC, 1954, 939.
24. Padma M, Reddy SA, Babu RS. Effect of foliar sprays of molybdenum (Mo) and boron (B) on the vegetative growth and dry matter production of French bean (*Phaseolus vulgaris* L.) Journal Research Andra Pradesh Agriculture University. 1989; 17(1):87-89.
25. Purushottam B, Puhup K, Kumar CSK, Sodi B. Effect of irrigation scheduling and zinc application on chlorophyll content, zinc content, uptake and yield of chickpea (*Cicer arietinum* L.). Journal of Pharmacognosy and Phytochemistry. 2018; 7(1):1834-1837.
26. Ram B, Punia SS, Tetarwal JP, Meena DS, Tomar SS. Effect of organic and inorganic sources of nutrients on productivity, profitability and soil health in lentil (*Lens culinaris*) under Vertisols. Indian Journal of Agronomy. 2013; 58(4):564-569.
27. Reganold JP, Palmer AS, Lockhart JC, Macgregor AN. Soil quality and financial performance of biodynamic and conventional farms in New Zealand. Science. 1993; 260:344-349.
28. Richards LA. Diagnosis and improvement of saline and alkali soils. *Handbook No. 60* (ed.) USDA, Washington, D.C, 1954.
29. Setia N, Setia SRC, Malik CP. Alterations in growth and yield components of lentil in response to foliar application of Napthyl Acetic Acid (NAA). Indian Journal of Plant physiology. 1993; 36(1):47-52.
30. Shah KA, Gurjar R, Parmar HC, Sonani VV. Effect of sulphur and zinc fertilization on yield and quality of pigeonpea in sandy loam soil. Green Farming. 2016; 7(2):495-497.
31. Sharma D, Green JM. Pigeon pea. Pages 471-481 *in* Hybridization of crop plants (Fehr, Walter R. and Hadley, Henry H., eds.). Madison, WI, USA: American Society of Agronomy and Crop Science Society of America, 1980.
32. Sharma A, Nakul HT, Jelgeri BR, Surwenshi A. Effect of Micronutrients on Growth, Yield and Yield Components in Pigeonpea (*Cajanus cajan* L. Millsp.). Journal of Agricultural Sciences. 2010; 1(2):142-144.
33. Shrikantbabu PK, Goppalkar BG, Desai BK, Nagalikar VP, Katti P. Yield and yield components and economics of pigeon pea cultivation as influenced by organics manures and grased levels of zinc sulphate. Karnataka Journal Agriculture Science. 2012; 25(4):527-530.
34. Shukla AK, Tiwari PK. Progress report of AICRP on micro- and secondary nutrients and pollutant elements in soils and plants. ICAR-IISS, Bhopal, 2014.
35. Singh MV, Sampath KT. Micronutrient status in farms of India and their effect on health and productivity. Proceedings 10th NAAS Congress, held at Lucknow, 2011, 11-13.
36. Singh Amar. Fruit physiology and production (2nd ed.) Kalyani Pub. Delhi, 1986, 105-118.
37. Srinivasarao C. Impacts of participatory site specific potassium management in several crops in rainfed regions of Andhra Pradesh, India. International Potash Institute. e-ifc (Electronic International Fertilizer Correspondent). 2012; 30:7-25.
38. Subbiah BV, Asija GL. A rapid procedure for the estimation of available nitrogen in soils. Current Science. 1956; 25:259-260.
39. Tadesse T, Dechassa N, Bayu W, Gebeyehu S. Effects of farmyard manure and inorganic fertilizer application on soil physico-chemical properties and nutrient balance in rain fed lowland rice ecosystem. American Journal of Plant Sciences. 2013; 4:309-316.
40. Taliee A, Sayadan K. Effect of supplemental irrigation and plant nutrition chickpea (dry farming). Journal of Agronomy Sience. Journal Agronomy and Crop Science. 2000; 2:12-19.
41. Tayyeba S, Hamid USH, Ullah S, Javid M. Zinc effect on growth rate, chlorophyll, protein and mineral contents of hydroponically grown mung beans plant (*Vigna radiata*). Arabian Journal of Chemistry. 2017; 10:1802-1807.
42. Thamke Sumedh Sanjay. Studies on effect of graded levels of potassium and zinc on growth, yield, nutrient uptake and quality of pigeon pea. M.Sc. Ag Thesis Research Guide - Waikar, S.L. Department - Soil Science and Agricultural Chemistry, Vasantrao Naik arathwada Krishi Vidyapeeth, Parbhani (M.S.) India, 2017; 431402.
43. Umesh, MR, Shankar MA. Yield performance and profitability of pigeonpea (*Cajanus cajana* L.) varieties under different nutrient Supply levels in dryland alfisols of karnataka. Indian Journal of Dryland Agriculture Research and Development. 2013; 28(1):63-69.
44. Valenciano JB, Boto JA, Marcelo V. Response of chickpea (*Cicer arietinum* L.) yield to zinc, boron and molybdenum application under pot conditions. Spanish Journal of Agricultural Research. 2010; 8:797-807.
45. Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Science.1934; 37:29-38.
46. Wander MM, Traina SJ, Stinner BR, Peters SE. Organic and conventional management effects on biologically active soil organic matter pools. Soil Science Society of America Journal. 1994; 58:1130-1139.