Annals of Plant and Soil Research 24(1): 151-157 (2022)
https://doi.org/10.47815/apsr.2022.10141

Growth, yield and zinc accumulation in garlic (*Allium sativum* L.) as affected by zinc supply on zinc deficient soils

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Received: October, 2021; Revised accepted: November. 2021

ABSTRACT

Zinc deficiency in soils and plants is the worldwide problem causing considerable yield reduction and indirectly affects human health due to its lesser concentration in the crop produces grown on zinc deficient soils. Hence to know the effect of zinc supply on the growth, clove yield and Zn accumulation, four field experiments were conducted with varied levels of zinc sulphate (0, 5, 10, 25, 37.5 and 50 kg ha^{-1}) using garlic variety Ooty 1 as test crop on zinc deficient sandy loam soils during the Rabi season of 2018-19. Soils with deficient zinc availability showed better response to different levels of zinc sulphate and application of recommended NPK along with 10 kg zinc sulphate ha^{-1} was found sufficient and economical in increasing the clove yield of garlic by 20.6 per cent. The same treatment resulted in higher farm income with the benefit cost ratio of 3.28. Slight yield reduction (5-7%) at all the four farms was observed for the higher levels of zinc sulphate addition (37.5 and 50 kg ha^{-1}). The highest soil Zn availability, zinc accumulation and uptake by garlic crop were obtained with the addition of 50 kg zinc sulphate ha^{-1}. Although there was a higher variability in the garlic crop response to zinc levels at all the farms, zinc sulphate addition at different levels considerably improved the growth and yield of garlic and also increasing the zinc accumulation in cloves and plants on zinc deficient soils.

Key words: Garlic, zinc levels, growth, yield attributes, clove yield, zinc accumulation

INTRODUCTION

Garlic (*Allium stavium* L.) is the second most important spice crop next to onion and belongs to family *Alliaceae*. It is rich in protein and many nutrients like phosphorus, potassium, calcium and magnesium hence also finds a place in medicinal use for treating intestinal and heart diseases, high blood pressure, cholesterol and cancer (Salata *et al.* 2021). Balanced fertilizer application is essential for producing crops with better growth and yields especially on soils under intensive cultivation (Jitarwal *et al.,* 2018). Garlic is nutrient exhaustive crop and removes considerable amount of nitrogen, phosphorus, and sulphur besides the micronutrients from soil. Hence ensuring sufficient availability of these nutrients are of prime importance for growing garlic as they are the major and indispensable source of protein and nucleic acid molecules. Recently use of micronutrients in improving the crop yields and quality of crop produces are gaining momentum due to the increased awareness on their significance in human health. Among various micronutrients, zinc plays an important role in achieving higher yield and quality of crop produces in many crops (Chitdeshwari *et al.,* 2011; Yousuf *et al.,* 2016). Zinc deficiency in soils and plants is the widest abiotic stress observed worldwide resulting in substantial losses in crop yield and quality crop. The crop produces grown on Zn deficient soils have lesser Zn content, which in turn have direct impact on human health. Hence balanced fertilizer schedule must also include zinc addition and optimized based on crop requirement and soil fertility status (Yadav *et al.*, 2018). Studies have demonstrated that, supply of zinc increased the transport and accumulation of zinc in plants and its use efficiency by plants (Yousuf *et al.,* 2016; Yatsenko *et al.,* 2020). Some studies have shown that zinc fertilization increased the crop growth and yield in cereals, oilseeds and vegetables (Cakmak *et al.,* 2017). Zinc plays an active role in many metabolic and physiological processes of plants such as cell wall development, photosynthesis, respiration, chlorophyll formation and also involved in the catalytic functions of more than 300 enzymes (Alloway, 2008; Yadav *et al.,* 2018). It is very much essential for the synthesis of Indole acetic acid which regulates plant growth and also necessary for chlorophyll formation and starch synthesis (Zakiullah *et al.,* 2019; Yatsenko *et al.,* 2020). Garlic being a cash crop, increment in

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yield with balanced fertilization is one of the identified researchable issues hence the study was taken up to optimize the rate of zinc sulphate application for obtaining better growth, higher yield, quality of cloves, Zn availability and its uptake by garlic.

MATERIALS AND METHODS

Experimental site and soils

Four field experiments were conducted during 2018-2019 on the zinc deficient sandy loam soils at farmer's fields in Erode district using garlic variety Ooty 1 as test crop. The soils of the four experimental farms belongs to red sandy loam in texture, neutral in soil reaction (7.20 to 7.60), non saline (0.22 to 0.47 dS m^{-1}) and low in organic carbon status (2.40 to 4.60 g kg^{-1},). The soils were low in $KMnO_4$ nitrogen (172 to 220 kg ha^{-1}), medium in Olsen- phosphorus (13.6 to 15.7 kg ha^{-1}) and Neutral NH_4OAc-potassium (200 to 262 kg ha^{-1}) status. The DTPA Zn availability in all the farms was deficient (< 0.85 mg kg^{-1}) which varied from 0.44 to 0.78 mg kg^{-1} (Table 1)

Table 1: Characteristics of the experimental farm soils

Soil properties	Zinc deficient Farm sites			
	Kombaiyaru (L1)	Kombaiyaru (L2)	Chinnaulle palayam (L3)	Chinnaulle palayam (L4)
Latitude	N11.7003	N11.69689	N11.68591	N11.69755
Longitude	E077.23853	E077.23995	E077.24549	E077.23981
pH	7.20	7.60	7.45	7.50
Electrical conductivity (dS m^{-1})	0.29	0.22	0.25	0.47
Organic carbon (g kg^{-1})	4.20	4.60	3.10	2.40
$KMnO_4$ -Nitrogen (kg ha^{-1})	220	210	188	172
Olsen- Phosphorus (kg ha^{-1})	15.7	14.2	13.6	14.1
N NH_4OAc-Potassium (kg ha^{-1})	262	245	211	200
Available sulphur (mg kg^{-1})	35.5	40.5	38.5	30.3
DTPA Zn (mg kg^{-1})	0.48	0.64	0.78	0.44
Hot water soluble B (mg kg^{-1})	0.63	0.87	1.05	0.94
Soil texture	Sandy loam	Sandy loam	Sandy loam	Sandy loam

Experimental details

The farm soil was ploughed to fine tilth, ridges, furrows were formed at 30 cm spacing and healthy cloves were planted at a spacing of 15 cm x 10 cm. There were six zinc treatments viz., 0, 5, 10, 25, 37.5 and 50 kg zinc sulphate ha^{-1} which was applied basally and replicated four times in a randomized block design. The recommended major nutrient fertilizers viz., nitrogen phosphorus, and potassium (75:75:75 kg NPK ha^{-1}) were applied basally as complex fertilizer, urea and muriate of potash. Nitrogen alone was split applied basally (40 kg ha^{-1}) and on 45 days (35 kg ha^{-1}) after planting. The crop was grown to maturity and harvested after following necessary crop production and protection measures. The dry matter production was determined by uprooting the plants in all treatments, washed with water to remove the soil particles, shade dried then oven dried and weighed. The clove yield, growth and yield attributes such as plant height, single bulb weight, no. of cloves per bulb and bulb diameter were also recorded at harvest.

Soil and plant analysis

The post harvest soil samples were analyzed for pH, electrical conductivity (Jackson, 1973) and soil organic carbon content (Walkley and Black, 1934). The available N was determined by alkaline permanganate method (Subbiah and Asija, 1956), available P by Olsen method (Olsen *et al.,* 1954), available K by neutral N NH_4OAc method (Stanford and English, 1949) and DTPA Zn as outlined by Lindsay and Norwell (1978). The dried cloves and plant samples were digested with tri acid mixture (9:2:1 HNO_3: H_2SO_4: $HClO_4$) and analyzed for zinc concentration using the atomic absorption spectrophotometer (Model Avanta PM, Piper, 1950). The zinc accumulation in cloves and plants was computed by multiplying the zinc concentration in plants and weight of dry matter.

Statistical analysis

The results obtained were subjected to statistical analysis as suggested by Gomez and Gomez (1984). Wherever the treatment differences were found significant, critical differences (CD) were worked out at 5% level of significance with a mean separation by least significant difference and denoted by symbol (* ,** for 5% and 1% respectively). Non significant comparisons were indicated as NS.

RESULTS AND DISCUSSION

Growth and yield attributes

A significant linear response to added levels of zinc sulphate was observed with plant height of garlic in all the four farms (Table 2) upto10 kg zinc sulphate ha^{-1} in two farm sites (L_1& L_3) and up to 25 kg zinc sulphate ha^{-1} in another two locations (L_2& L_4). A slight reduction in the plant height at all the farms was noticed beyond 25 kg zinc sulphate ha^{-1}. Basal soil application of recommended NPK (75:75:75 kg ha^{-1}) along with 10 kg zinc sulphate ha^{-1} recorded the highest mean plant height (59.2 cm) and bulb diameter (4.82 cm) which was on par with the application of 25 kg zinc sulphate ha^{-1} (58.6 and 4.73 cm). The lowest mean plant height and bulb diameter was observed in NPK control (51.0 and 3.53cm). As regards the yield attributes, though basal soil application of 10 kg zinc sulphate ha^{-1} along with recommended NPK registered the maximum single bulb weight (18.1 g) and cloves per bulb (17 nos.), it was on par with the application of 25 and 37.5 kg zinc sulphate ha^{-1}. The values varied from 10.4 to 21.6 g for single bulb weight, 2.31 to 5.33 cm for bulb diameter and 10 to 19 for no. of cloves per bulb. The lowest values of all the yield attributes were associated with the NPK control (Table 3). The increased yield might be attributed to higher availability of zinc and its influence on enhanced enzymatic and photosynthetic activity with greater zinc translocation rate (Yadav *et al.* 2018; Zakiullah *et al.,* 2019; Yatsenko *et al.,* 2020). Bulb size and diameter are the most important factors closely related with yield per hectare, which also increased with the addition of zinc sulphate. Though basal application of 10 kg zinc sulphate ha^{-1} along with recommended NPK registered the maximum single bulb weight, bulb diameter and no. of cloves per bulb, it was on par with the application of 25 and 37.5 kg zinc sulphate ha^{-1}. Zinc application notably increased the number of cloves per bulb and weight of cloves which might be due to rapid transformation and storage of food materials which ultimately increased the bulb weight and yield.

Table 2: Effect of various levels of $ZnSO_4$ on the growth attributes of garlic

$ZnSO_4$ (kg ha^{-1})	Plant height (cm)					Bulb diameter (cm)				
	L1	L2	L3	L4	Mean	L1	L2	L3	L4	Mean
Control	51.7^{a}	46.0^{b}	51.1^{d}	55.3^{b}	51.0	3.64^{d}	3.73^{c}	2.31^{c}	3.10^{c}	3.20
5 .0	56.3^{a}	50.6^{ab}	54.0^{d}	57.7^{ab}	54.7	4.47^{c}	4.28^{bc}	3.07^{b}	3.67^{bc}	3.87
10.0	58.3^{a}	52.3^{ab}	55.3^{cd}	60.0^{ab}	56.5	5.32^{a}	4.67^{ab}	3.42^{ab}	4.00^{ab}	4.35
25.0	56.0^{a}	53.0^{ab}	58.7^{bc}	60.7^{a}	57.1	5.14^{ab}	4.83^{ab}	3.63^{ab}	4.10^{ab}	4.41
37.5	56.7^{a}	55.3^{a}	59.5^{ab}	61.6^{a}	58.3	4.73^{bc}	4.88^{ab}	3.76^{ab}	4.40^{ab}	4.44
50.0	55.0^{a}	56.7^{a}	63.0^{a}	62.0^{a}	59.2	4.58^{c}	5.33^{a}	3.88^{a}	4.67^{a}	4.62
SEd	4.17	3.29	1.77	2.15	1.19	0.23	0.31	0.3	0.33	0.13
CD (P=0.05)	9.30	7.34	3.95	4.79	2.54	0.51	0.69	0.67	0.74	0.28

Fresh bulb and Dry foliage Yield

Different levels of zinc sulphate significantly influenced the fresh bulb and dry foliage yield of garlic. The fresh bulb yield of garlic at all four farms was increased with increasing levels of zinc sulphate application gradually up to 10 kg ha^{-1} (7532 kg ha^{-1}) along with recommended NPK and the yield increase varied from 17.6 to 26.2 per cent (20.6%). Next to this, basal soil application of NPK+25 kg zinc sulphate ha^{-1} recorded the highest mean fresh bulb yield (7431 kg ha^{-1}) with the average yield increase of 18.8%. Higher levels of zinc sulphate (37.5 and 50 kg ha^{-1}) showed slight yield reduction (5-7%) in all the four farms. The lowest mean fresh bulb yield was observed in NPK control (6258 kg ha^{-1}). The beneficial effect of

Table 3: Effect of various levels of $ZnSO_4$ on the yield attributes of garlic

$ZnSO_4$ (kg ha^{-1})	Single bulb weight (g)					No. of cloves per bulb				
	L1	L2	L3	L4	Mean	L1	L2	L3	L4	Mean
Control	10.4^{c}	16.3^{c}	12.0^{c}	11.1^{c}	12.5	13.0^{b}	14.0^{d}	10.0^{b}	12.0^{d}	12.0
5 .0	12.5^{bc}	18.3^{bc}	13.2^{bc}	15.3^{b}	14.8	15.0^{ab}	15.0^{c}	13.0^{a}	15.0^{c}	15.0
10.0	18.4^{a}	21.6^{a}	15.9^{a}	16.4^{ab}	18.1	19.0^{a}	16.0^{bc}	15.0^{a}	16.0^{bc}	17.0
25.0	16.6^{ab}	21.2^{ab}	15.6^{a}	18.1^{a}	17.9	17.0^{ab}	17.0^{bc}	15.0^{a}	16.0^{bc}	16.0
37.5	16.1^{ab}	20.9^{ab}	15.0^{a}	17.5^{a}	17.4	16.0^{ab}	17.0^{b}	14.0^{a}	16.0^{b}	16.0
50.0	15.5^{ab}	20.6^{ab}	14.1^{ab}	17.1^{ab}	16.8	16.0^{ab}	18.0^{a}	11.0^{a}	19.0^{a}	16.0
SEd	1.90	1.23	0.75	0.92	0.64	1.46	0.59	1.11	0.66	0.53
CD (P=0.05)	4.24	2.74	1.67	2.05	1.35	3.26	1.32	2.48	1.47	1.13

zinc sulphate on the yield attributes was also due to the significant role of zinc in better absorption of water, nutrients, enhanced enzymatic and metabolic activities (Jitarwal *et al.,* 2018).

Similar to fresh bulb yield, the dry foliage yield at all the four farms were increased with the addition of zinc sulphate and maximum mean dry foliage yield was obtained by the application of recommended NPK + 10 kg zinc sulphate ha^{-1} (1252 kg ha^{-1}). This was followed by the basal soil application of NPK +25 kg zinc sulphate ha^{-1}, which recorded a mean dry foliage yield of 1156 kg ha^{-1}. Higher levels of zinc sulphate application resulted in the reduction in dry foliage yield. The lowest dry foliage yield was noted with NPK control (925 kg ha^{-1}).

The economics worked out for various zinc sulphate treatments to understand the profitability revealed that, application of 10 kg zinc sulphate ha^{-1} along with recommended NPK recorded the maximum benefit : cost ratio (3.28) followed by the basal application of 25 kg zinc sulphate ha^{-1} (3.20). The lowest net income and benefit: cost ratio was realized with no zinc sulphate applied NPK control (2.75). The results clearly indicated that application of zinc was beneficial for increasing the clove and foliage yield due to its favourable effect on enhanced photosynthetic activity, as a co factor in many plant enzymes and protein metabolisms. Similar beneficial effect of zinc on yield improvement of garlic was reported by Pramanik and Tripathy, (2017).

Table 4: Effect of various levels of $ZnSO_4$ on Zn content (mg kg^{-1}) in garlic

$ZnSO_4$ (kg ha^{-1})	Cloves					Leaves				
	L1	L2	L3	L4	Mean	L1	L2	L3	L4	Mean
Control	12.8^{d}	16.9^{d}	14.2^{e}	11.5^{c}	13.9	24.8^{f}	25.2^{d}	22.3^{e}	22.1^{e}	23.6
5 .0	14.6^{c}	18.0^{d}	17.7^{d}	13.1^{bc}	15.9	28.1^{e}	28.1^{d}	25.6^{de}	24.7^{de}	26.6
10.0	15.8^{c}	19.1^{cd}	20.6^{c}	13.5^{bc}	17.3	30.8^{d}	31.5^{c}	27.9^{cd}	27.4^{d}	29.4
25.0	18.3^{b}	21.8^{bc}	22.7^{b}	15.1^{b}	19.5	33.2^{c}	35.5^{b}	30.9^{bc}	31.7^{c}	32.8
37.5	20.3^{a}	24.2^{ab}	23.9^{a}	18.1^{a}	21.6	35.7^{b}	37.0^{b}	33.9^{ab}	35.8^{b}	35.6
50.0	21.9^{a}	26.9^{a}	26.0^{a}	19.9^{a}	23.7	39.2^{a}	40.8^{a}	37.8^{a}	40.4^{a}	39.6
SEd	0.77	1.4	0.84	0.87	0.62	0.93	1.39	2.09	1.80	0.84
CD (P=0.05)	1.72	3.12	1.87	1.94	1.31	2.07	3.10	4.66	4.01	1.79

Zinc accumulation and uptake

The results in Table 4 showed that the increasing levels of zinc sulphate increased the zinc content in cloves and foliage significantly and the values varied from 11.5 to 26 mg kg^{-1} and 22.1 to 40.8 mg kg^{-1} respectively. Higher mean zinc content in cloves (23.7 mg kg^{-1}) and foliage (39.6 mg kg^{-1}) was associated with the application of 50 kg zinc sulphate ha^{-1} along with recommended NPK in all the four farms. This was followed by the soil application of 37.5 kg zinc sulphate ha^{-1} + recommended NPK, which registered the mean zinc content of 21.6 mg kg^{-1} in cloves and 35.6 mg kg^{-1} in foliage. The lowest mean zinc content was recorded with NPK (13.9 and 23.6 mg kg^{-1} in cloves and foliage respectively).

Similar to zinc content, zinc uptake by garlic at all four farms were also influenced considerably by the addition of various levels of zinc sulphate and the highest zinc uptake in cloves and foliage was noticed with the addition of 50 kg zinc sulphate ha^{-1} (45.2 and 41.8 g ha^{-1}, respectively). The lowest zinc uptake was recorded with no zinc applied NPK control (22.5 and 21.9 g ha^{-1} in cloves and foliage, respectively). The maximum zinc content and uptake in cloves and foliage was associated with the application of recommended NPK + 50 kg zinc sulphate ha^{-1} in all the four farms (Table 5). This was closely followed by the soil application of 37.5 kg zinc sulphate ha^{-1} + recommended NPK which registered the next highest mean zinc content in cloves and foliage. The lowest mean zinc content was recorded with NPK control. The increased zinc accumulation was probably due to more zinc availability and its active translocation in to the plants which might have resulted in higher absorption and better metabolic activities. Further, sufficient zinc supply resulted in higher crop growth and zinc uptake. This was in agreement with the findings reported by Yousuf *et al.* (2016) and Alam *et al.* (2019).

Table 5: Effect of various levels of $ZnSO_4$ on Zn uptake (g ha^{-1}) in garlic

$ZnSO_4$ (kg ha^{-1})	Cloves					Leaves				
	L1	L2	L3	L4	Mean	L1	L2	L3	L4	Mean
Control	20.6^{c}	27.0^{b}	21.6^{c}	20.8^{d}	22.5	23.9^{c}	23.5^{c}	19.3^{c}	20.8^{c}	21.9
5 .0	25.3^{b}	33.5^{b}	29.7^{b}	25.3^{cd}	28.5	29.2^{b}	28.7^{b}	23.6^{c}	24.9^{c}	26.6
10.0	36.2^{a}	44.1^{a}	42.9^{a}	27.7^{c}	37.7	41.2^{a}	39.1^{a}	31.4^{b}	35.8^{b}	36.9
25.0	39.0^{a}	47.1^{a}	44.9^{a}	33.3^{b}	41.1	40.1^{a}	41.0^{a}	33.1^{ab}	37.7^{ab}	38.0
37.5	38.8^{a}	47.8^{a}	44.9^{a}	38.1^{a}	42.4	39.9^{a}	39.4^{a}	35.3^{ab}	39.6^{ab}	38.5
50.0	40.2^{a}	51.7^{a}	47.3^{a}	41.5^{a}	45.2	42.1^{a}	44.3^{a}	37.5^{a}	43.4^{a}	41.8
SEd	1.79	3.95	3.16	2.07	1.92	2.00	2.26	2.25	2.71	2.19
CD (P=0.05)	3.99	8.81	7.05	4.62	3.84	4.46	5.04	5.02	6.04	4.40

Soil zinc availability

Post harvest soil zinc availability was also increased with increasing levels of zinc sulphate application and the mean values varied from 0.56 to 1.80 mg kg^{-1}. However, a lower level of zinc sulphate addition (5-10 kg ha^{-1}) was not sufficient to sustain soil zinc availability in the post harvest soils of all the four farms (Fig.1).

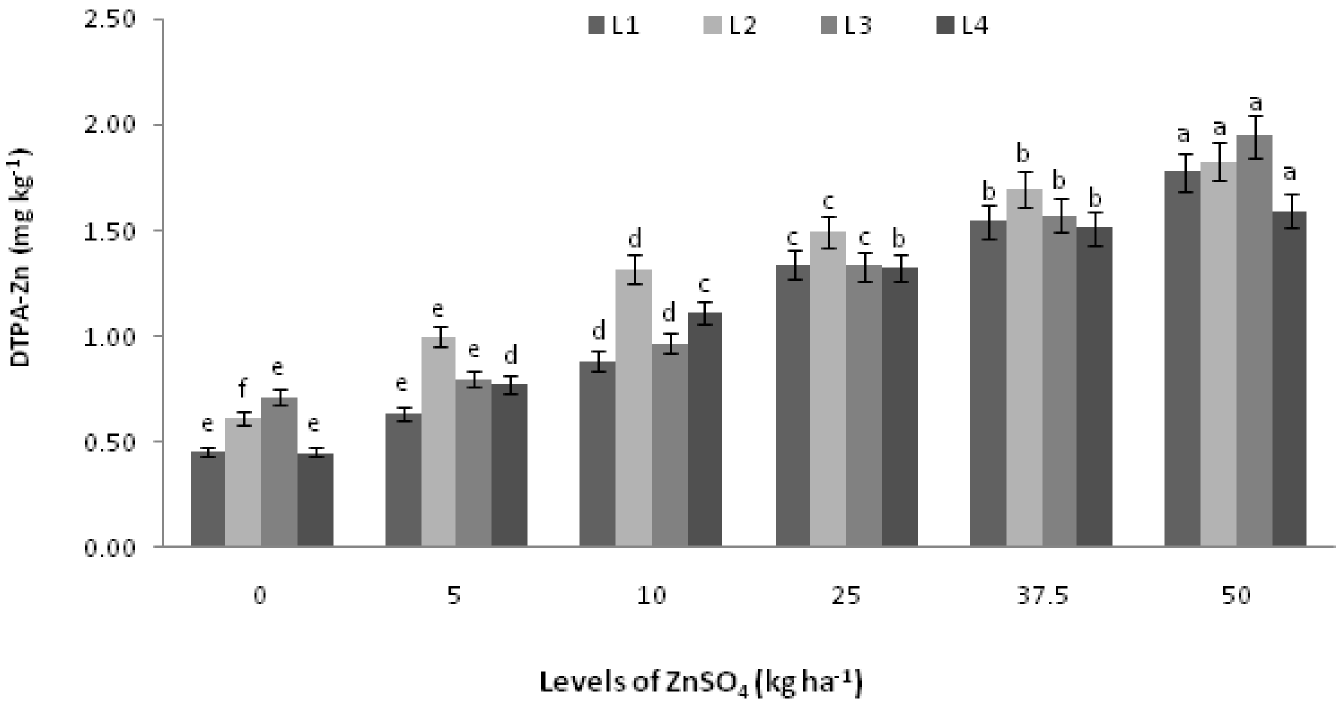

Fig.1: Effect of various levels of zinc sulphate on soil zinc availability. Error bars represent standard error (n=4) and bars having different letters are significantly different at 5% level

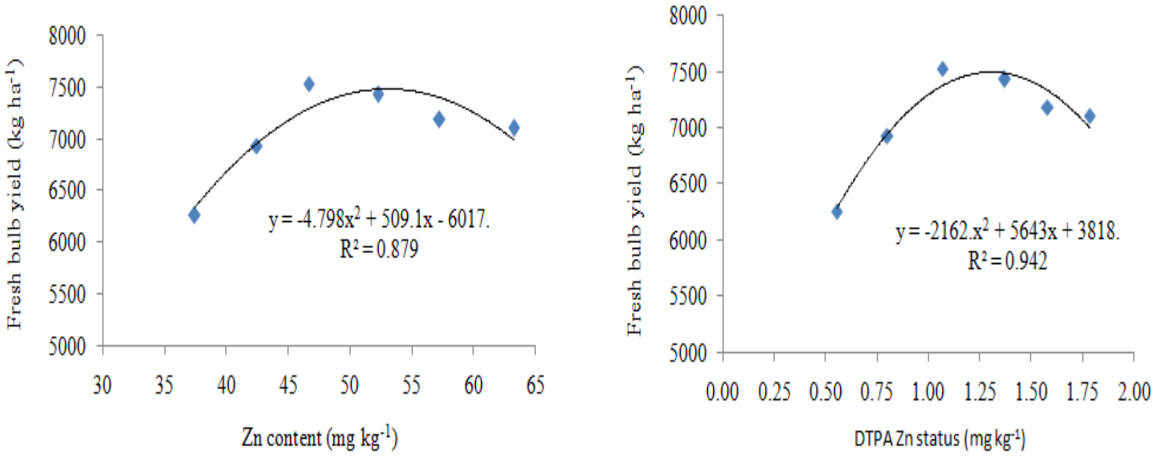

Fig.2: Relationship between the fresh bulb yield, Zn availability and Zn content in garlic

The relationship between fresh bulb yield with zinc content and availability showed significant positive correlation with each other. Soil zinc availability had highest correlation (R^2= 0.942) than the plant zinc content (R^2= 0.879) in increasing the fresh bulb yield of garlic (Fig.2.). Higher soil zinc status was recorded with the application of recommended NPK + 50 kg zinc sulphate ha^{-1} in all the four farms which might be due to sufficient supply of soluble zinc from the fertilizer source which was also reported by Suganya and Saravanan (2016) and Liu *et al.* (2019).

It can be concluded that soil application of 10 kg zinc sulphate ha^{-1} was found optimal and economical in increasing the garlic clove yield by 20.7% besides improving the growth and yield attributes on zinc deficient sandy loam soils. Increasing levels of zinc sulphate application increased the soil zinc status, its content an uptake by garlic plants however lower levels of zinc sulphate addition (5-10 kg) was not sufficient to sustain soil zinc availability.

ACKNOWLEDGEMENT

The work was jointly supported by IACR-AICRP on Micro and secondary nutrients and pollutant elements in soils and plants, IISS, Bhopal and Tamil Nadu Agricultural University, Coimbatore. The authors express their sincere thanks for providing funds and all support to take up the experiments and complete. We would also like to thank the farmers in the study area for providing their lands for testing the treatments and also for assisting in carrying out all farm activities.

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