Plant Archives Vol. 25, No. 2, 2025 pp. 1749-1757 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org

DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2025.v25.no.2.253

EFFECT OF NANO ZINC PARTICLES AND CONVENTIONAL ZINC FERTILIZERS ON ONION GROWTH AND YIELD UNDER DIFFERENT APPLICATION METHODS

Anita R. Ghandhe[1]*, Kishorkumar G.K.[2], Kavin Raj[3], M.S. Nagaraja[2], H.P. Hadimani[2] and Shankar Meti[5]

[1]Department of Nanotechnology, College of Horticulture, Bagalkot, UHS, Bagalkot - 587 104, Karnataka, India.
[2]Department of Vegetable Science, College of Horticulture Bagalkot, UHS, Bagalkot - 587 104, Karnataka, India.
[3]Department of Soil Science, College of Horticulture Bagalkot, UHS Bagalkot, Karnataka, India.
[4]Department of Soil Science, College of Agriculture, KSNUAHS Shivamogga, Karnataka, India.
[5]Department of Agronomy, UHS Bagalkot, Karnataka, India.
*Corresponding author E-mail : anita.ghandhe@gmail.com

(Date of Receiving-24-08-2025; Date of Acceptance-27-10-2025)

ABSTRACT

The present investigation demonstrated that both soil and foliar application of nano zinc oxide and conventional zinc sulphate at varying levels and methods significantly influenced onion crop growth. Detailed evaluation of the results showed a noticeable enhancement in vegetative parameters with the application of these zinc sources compared to the control. The improved growth performance may be attributed to better zinc availability and absorption, which stimulates physiological and metabolic activities essential for crop development. The maximum leaf length at 90 DAT (57.31cm) and harvest (52.80 cm) were recorded in treatment T_6 that received 0.5% foliar application of conventional zinc sulphate. Maximum bulb yields per plot (19.08 kg/plot) and bulb yield /ha (352.12q/ha) at harvest were recorded in treatment T_6 that received 0.5% foliar application of conventional zinc sulphate at 30 and 60 DAT compare to the all-other experiments. The highest number of marketable bulbs/plot (268.33 number of marketable bulbs/plot) of onion crop was recorded in treatment T_6 0.5% foliar application of conventional zinc sulphate at 30 and 60 DAT. At harvest maximum average weight of bulbs per plot (71.14 g/bulbs) was recorded in treatment T_6 0.5% foliar application of conventional zinc sulphate.

Key words : Nano, Zinc sulphate, Zinc Oxide, Onion, Soil application, Foliar application.

Introduction

Onion (*Allium cepa* L.) is one of the most significant commercial vegetable crops, cultivated extensively across the globe. The edible part of the onion is the bulb, a modified stem composed of thickened scale leaves. Onion is highly valued for its medicinal properties, as it is rich in vitamin B-complex, vitamin C, iron and calcium. Its characteristic pungency is attributed to the presence of allyl propyl disulphide. Research indicates that onion extract possesses antioxidant properties and may act as an anticancer agent (Block, 1985). Additionally, it has been found to reduce glucose levels by 25%. Maharashtra, Karnataka, Orissa, Uttar Pradesh, Tamil Nadu andhra Pradesh, Gujarat and Madhya Pradesh are the largest onion-growing states in the country, accounting for 87.84 per cent of area and 91.58 per cent of production. Dharwad, Chickmagalur, Bellary, Raichur, Chitradurga, Bijapur, Gulbarge, Belgaum, Shimoga and Kolar are the onion growing districts in Karnataka (Mia *et al*., 2020).

Excessive use of chemical fertilizers, limited application of organic manures and restricted incorporation of crop residues in conventional cropping systems have accelerated the depletion of micronutrients from the soil. In recent years, the maximum potential yield of crops has not been achieved in many cultivated areas due to micronutrient deficiencies, particularly zinc. Zinc is an essential micronutrient that plays crucial structural and catalytic roles in numerous proteins. To date, nearly 59 groups of zinc-containing enzymes have been identified. Zinc is primarily involved in tricarboxylic acid metabolism and the glycolytic pathway and it also contributes to the synthesis of chlorophyll, tryptophan, indole-3-acetic acid (IAA), auxins and ascorbic acid in plants. Insufficient zinc availability in the soil limits plant growth, reducing both crop yield and quality, which in turn leads to malnutrition in humans and livestock (Pal *et al*., 2016).

Zinc is vital for various enzymatic and physiological functions in plants. It catalyzes oxidation processes within plant cells, facilitates carbohydrate transformation, regulates sugar consumption, enhances energy production for chlorophyll synthesis, contributes to auxin formation and improves water absorption. Zinc is also a crucial micronutrient frequently found to be deficient in Indian soils and is known to influence multiple physiological and enzymatic activities in plants. Studies have shown a positive response to zinc application in improving the growth and yield of vegetable crops across various regions of India (Pal *et al*., 2016).

Zinc deficiency is more likely to occur at alkaline pH, as the solubility of zinc is less at alkaline pH than under mild acidic condition and zinc solubility is further decreased with increasing carbonate concentration in soil. Soil applications of zinc fertilizer on calcareous soil had low nutrient use efficiency and high fixation in soil and pollute the environment. In calcareous soil, application of micronutrients is more effective through foliar spray on the leaves as compared to soil application, because liquid fertilizers spray rapidly recovers deficiency symptoms of these micronutrients. Repeated usage of foliar spray cause scorching effect on leaves so the most appropriate strategy has been suggested as a soil application followed by foliar spray. The presence of calcareous soil in Karnataka northern region converts applied zinc to calcium zincate, necessitating a higher application rate. Therefore, better mechanism needs to manage the level of zinc applied to the soil or foliar without reduction in crop growth, yield and reduce the environmental pollution.

Nanotechnology's qualities and prospects, which have sparked a lot of interest in agriculture revolutions are characterized by increased reactivity, adhesion, bioavailability and its surface effects. The nanoscale particle that's are unique and distinct from others compared to those seen at a macro level. It has high surface area that improve the chemical reaction of particle in soil and supply nutrients to plants at nano scale level particularly micronutrients. Nano fertilizers are smaller than 100 nm, allowing for greater penetration into the plant roots. As a result, nano zinc fertilizers have been popular in recent years as a way to improve the nutrient use efficiency of zinc fertilizers. Nano fertilizers have been shown in studies to be an effective way to release essential nutrients in a controlled manner than that could help to prevent fertilizer pollution. The problem of zinc insufficiency in plants and humans in northern Karnataka can be solved by supplementing and biofortifying onion cultivated on soil deficient in zinc micronutrient. Therefore, keeping in mind the above-mentioned facts, the present experiment was carried out to find out the best suitable and comparison between nano zinc particles and conventional zinc fertilizer by different levels and methods of application to obtain better and higher yield and growth.

Materials and Methods

The experiment was conducted at College of Horticulture, University of Horticultural Sciences (UHS), Bagalkot during 2020-21 with a view to find the most suitable doses of zinc nano particles and methods of application. Nursery of the onion cultivar Bhima Red was transplanted in a well-prepared field on 7th December 2020. The experimental plot was ploughed and disked several times and well-rotten farm yard manure was incorporated into the soil well-ahead of the transplantation. Before fertilizer application soil samples were taken randomly from the area demarcated for the experiment and the soil was analyzed for nitrogen, phosphorous, potassium, calcium, calcium carbonate, magnesium, sulphur, zinc, pH, electric conductivity and organic carbon. It revealed that the specific field contained 211.0 kg N; 21.40 kg P; 290.3 kg K; 9.98 c mol (p+)/kg exchangeable calcium; 4.20 c mol (p+)/kg exchangeable magnesium; 5.02% calcium carbonate; 0.41 ppm Zinc; 10.75 ppm Sulphur, 0.49 per cent organic carbon whereas pH of the soil was about 8.17 and contains electric conductivity 0.39 dSm^{-1}. Zinc oxide nanoparticles, with a particle size ranging from 30 to 40 nm and comprising 80% zinc, were procured from VIT Vellore, Tamil Nadu. Zinc sulphate, urea, DAP and MOP were sourced from a local fertilizer shop. The zinc sulphate contained 21% zinc, urea had 46% nitrogen, DAP comprised 48% phosphorus along with 18% nitrogen and MOP contained 48% potassium. Zinc sulphate was incorporated with NPK fertilizers and applied to the soil during transplanting. Meanwhile, nano zinc oxide was mixed with water and applied to the designated soil treatment plot. According to the package of practices (POP) of the University of Horticultural Sciences, Bagalkot, the recommended fertilizer dose for onion is 150:100:80 kg/ha of N, P_2O_5 and K_2O, along with 25

Table 1 : Treatment details used in the experiment.

T_1	Soil application ZnO NPs 15g/ha days after transplanting
T_2	Soil application ZnO NPs 30g/ha days after transplanting
T_3	ZnO NPs as foliar application @ 20 ppm at 30 and 60 days after transplanting
T_4	ZnO NPs as foliar application @ 40 ppm at30 and 60 days after transplanting
T_5	Conventional $ZnSO_4$ @ 4 kg/ha as soil application
T_6	Foliar spray of Conventional $ZnSO_4$ 0.5% solution in 30 and 60 days after transplanting
T_7	Soil application ZnO NPs 7.5 g/ha and foliar spray 20ppm 30 days after transplanting
T_8	Soil application ZnO NPs 15 g/ha and foliar spray 20ppm 30 days after transplanting
T_9	Control

tons per hectare of FYM, applied across all treatments. One week after transplanting, a full dose of phosphorus and potassium, along with half the nitrogen dose, was applied, with the remaining half of the nitrogen dose administered 30 days later. The experiment was laid out in Randomized Block Design (RBD) having 9 treatments with 3 replications. The experimental plants were regularly observed and the data were recorded on the growth and yield parameters.

Results and Discussion

The findings of the present study indicated that varying levels and application methods of nano zinc oxide and conventional zinc sulphate exerted a significant influence on the growth performance of onion. Critical analysis of the data showed that there is increase in the crop growth due to application of zinc sulphate and zinc oxide nano particles.

Number of leaves per plant (cm)

The observations on the number of leaves per plant at 30 DAT indicated that the treatments imposed on onion resulted in a significant variation, with values ranging from 6.20 to 7.76 leaves per plant and an overall mean of 6.98 leaves per plant. The treatment T_5, which received a soil application of 4 kg conventional zinc sulphate at the time of transplanting, recorded the highest number of leaves (7.76 leaves per plant). This treatment was statistically on par with T_2 (7.25 leaves per plant), where 30 g nano zinc oxide was applied to the soil during transplanting. The data on the number of leaves per plant at 90 DAT showed a significant variation among the treatments. The treatment T_5, involving the soil application of 4 kg conventional zinc sulphate at transplanting, recorded a significantly higher number of leaves per plant (9.75), remaining statistically on par with all other treatments except T_9. The lowest number of leaves per plant was observed in T_9, which recorded 7.65 leaves per plant. The results presented in Table 2 indicate that treatment T_6, which involved a 0.5% foliar application of conventional zinc sulphate at 30 and 60 DAT, produced a significantly higher number of leaves per plant (11.62) compared to the other treatments. This performance was statistically comparable with treatments T_5 and T_4. The lowest number of leaves per plant was recorded in treatment T_9, with 8.60 leaves per plant. A significant variation in the number of leaves per plant at harvest was observed among the treatments. The highest number of leaves (10.52 per plant) was recorded in treatment T_6, which received a 0.5% foliar application of conventional zinc sulphate at 30 and 60 DAT. This treatment was statistically comparable with T_5 and T_4. The lowest number of leaves per plant was obtained in treatment T_9, which recorded 7.90 leaves per plant. The foliar application of zinc that are directly uptake by leaf that enhance the auxin production in crop it significantly increases the number of leaf and shoot height of crop. Above similar results were obtained in Manna., (2013) in onion crop, Pal *et al.* (2020) in chickpea, Nadergoli *et al.* (2011) common bean, Roy *et al.* (2014) in green gram and Anita *et al.* (2005) in cow pea.

Leaf length (cm)

Effect of different source, levels and methods of application of zinc on leaf length at different growth stages of onion was presented in Table 3. The data recorded for leaf length at 30 DAT indicated a significant difference among the treatments. The maximum leaf length (25.10 cm) was observed in treatment T_5, which received a soil application of 4 kg zinc sulphate per hectare at transplanting. This treatment was statistically comparable to T_2 (21.60 cm), where 30 g nano zinc oxide per hectare was applied to the soil at transplanting. The lowest leaf length was obtained in T_9 (19.77 cm). A similar trend was noticed at 60 DAT, where the treatments imposed showed significant influence on leaf length. The highest value (45.81 cm) was recorded in T_5 with soil application of zinc sulphate at 4 kg/ha during transplanting and was statistically at par with T_6 (42.80 cm), which received 0.5% foliar spray of conventional zinc sulphate at 30 and 60 DAT. The shortest leaves were found in the control treatment T_9 (33.83 cm). Significant variation in leaf length at 90 DAT was observed due to different sources, levels and methods of zinc application. Treatment T_6, involving a 0.5% foliar spray of conventional zinc

Table 2 : Effect of different source, levels and method of application of zinc on number of leaves per plant at different growth stages of onion.

Treatments	Number of leaves			
	30 DAT	60 DAT	90 DAT	At harvest
T_1- Soil application ZnO NPs 15g/ha days after transplanting	6.95^{b}	8.62^{ab}	9.75^{b}	9.00^{bc}
T_2-Soil application ZnO NPs 30g/ha days after transplanting	7.25^{ab}	8.91^{a}	9.90^{b}	9.18^{b}
T_3-ZnO NPs as foliar application @ 20 ppm at 30 and 60 days after transplanting	6.21^{c}	9.00^{a}	10.25^{b}	9.35^{b}
T_4-ZnO NPs as foliar application @ 40 ppm at 30 and 60 days after transplanting	6.20^{c}	9.10^{a}	10.69^{ab}	9.50^{ab}
T_5-Conventional $ZnSO_4$ @ 4 kg/ha as soil application	7.76^{a}	9.75^{a}	10.77^{ab}	9.85^{ab}
T_6- Foliar spray of Conventional $ZnSO_4$ 0.5% solution in 30 and 60 days after transplanting	6.21^{c}	9.57^{a}	11.62^{a}	10.52^{a}
T_7- Soil application ZnO NPs 7.5 g/ha and foliar spray 20ppm 30 days after transplanting	6.73^{bc}	9.30^{a}	10.15^{b}	9.11^{b}
T_8-Soil application ZnO NPs 15 g/ha and foliar spray 20ppm 30 days after transplanting	6.98^{b}	9.35^{a}	10.20^{b}	9.32^{b}
T_9-Control	6.20^{c}	7.65^{b}	8.60^{c}	7.90^{c}
SEm±	0.21	0.38	0.38	0.38
CD 5%	0.62	1.14	1.15	1.14

DAT – Days After Transplanting ZnONPs - Zinc oxide Nano Particles

sulphate at 30 and 60 DAT, recorded the maximum leaf length (57.31 cm), closely followed by treatments T5 and T_4. The minimum leaf length was noted in the control T_9 (36.34 cm). The measurements recorded at harvest (Table 9) revealed significant differences among treatments. The highest leaf length at harvest (52.80 cm) was recorded in T_6, which received 0.5% foliar application of conventional zinc sulphate at 30 and 60 DAT, followed by T_5 and T_4. The lowest leaf length was again observed in treatment T_9 (37.00 cm). Soil application of zinc sulphate at transplanting improved seedling establishment and promoted both root development and vegetative growth compared to foliar application. However, the maximum leaf length at 90 DAT and at harvest was observed under treatment T_6, which received 0.5% foliar application of zinc sulphate at 30 and 60 DAT, recording 57.31 cm and 52.80 cm, respectively. The enhancement in leaf length could be attributed to direct zinc uptake through foliage, which stimulates metabolic processes in onion plants. These findings are in accordance with the reports of Acharya *et al.* (2015) in onion, Rahman *et al.* (2020) in okra, Patel *et al.* (2019) in sunflower and Pahlavan *et al.* (2009) in wheat.

Neck thickness (mm)

The data on crop neck thickness at different growth stages by application of different source, levels and method of application of zinc was presented in Table 4. The neck thickness measured at 30 DAT showed no significant variation among the treatments. However, the highest neck thickness (8.01 mm) was recorded in T5, which received a soil application of conventional zinc sulphate at transplanting. The lowest values (7.21 mm) were observed in treatments T_4 and T_9. At 60 DAT, the different sources, levels and methods of zinc application had a significant influence on neck thickness. Treatment T_5, involving a soil application of 4 kg/ha zinc sulphate at transplanting, produced the highest neck thickness (14.51 mm) and it was statistically comparable with T_4, T_3, T_6, T_7 and T_8. The smallest neck thickness was found in T_9 (11.70 mm). A significant variation in neck thickness at 90 DAT was also observed among the treatments. Treatment T_6, with a 0.5% foliar spray of conventional zinc sulphate at 30 and 60 DAT, recorded the highest neck thickness (15.92 mm), statistically similar to T_4, T_3 and T_5. The lowest value was recorded in the control treatment T_9 (12.40 mm). The measurements recorded at harvest indicated no significant differences due to zinc source, level, or method of application. The maximum neck thickness (9.41 mm) was observed in T_6, which received a 0.5% foliar spray of conventional zinc sulphate at 30 and 60 DAT, while the minimum (8.46 mm) was recorded in the untreated control T_9. Foliar application of

Table 3 : Effect of different source, levels and method of application of zinc on leaf length at different growth stages of onion.

Treatments	Leaf length (cm)			
	30 DAT	60 DAT	90 DAT	At harvest
T_1- Soil application ZnO NPs 15g/ha days after transplanting	21.28[b]	37.13[de]	41.00[d]	38.00[e]
T_2-Soil application ZnO NPs 30g/ha days after transplanting	21.60[ab]	38.07[cde]	41.80[d]	40.60[bcde]
T_3-ZnO NPs as foliar application @ 20 ppm at 30 and 60 days after transplanting	20.00[b]	39.33[bc]	43.88[cd]	41.71[bcd]
T_4-ZnO NPs as foliar application @ 40 ppm at 30 and 60 days after transplanting	20.05[b]	40.80[bc]	47.70[bc]	42.46[bc]
T_5-Conventional $ZnSO_4$ @ 4 kg/ha as soil application	25.10[a]	45.81[a]	50.10[b]	44.70[b]
T_6- Foliar spray of Conventional $ZnSO_4$ 0.5% solution in 30 and 60 days after transplanting	19.99[b]	42.80[ab]	57.31[a]	52.80[a]
T_7- Soil application ZnO NPs 7.5 g/ha and foliar spray 20ppm 30 days after transplanting	21.22[b]	40.62[bcd]	42.10[cd]	38.00[de]
T_8-Soil application ZnO NPs 15 g/ha and foliar spray 20ppm 30 days after transplanting	21.45[b]	41.85[abc]	42.80[cd]	40.22[cde]
T_9-Control	19.97[b]	33.83[e]	36.34[e]	37.00[e]
SEm±	1.01	1.16	1.87	1.39
CD 5%	3.04	3.49	5.61	4.17

DAT – Days After Transplanting ZnONPs - Zinc oxide Nano Particles.

micronutrients increases the nutrient uptake by plant that leads to increase in crop growth results high neck thickness of onion crop.

Fresh and dry weight of bulb (g)

The data on fresh weight of bulb and dry weight of bulb was presented in Table 5. The fresh weight of bulbs per plant at 60 DAT differed significantly across treatments. The highest fresh bulb weight (26.88 g per bulb) was recorded in T_5, where zinc sulphate was applied to the soil at 4 kg/ha during transplanting. This treatment was statistically comparable with T_6 (24.65 g per bulb), which received a 0.5% foliar spray of conventional zinc sulphate at 30 and 60 DAT. The lowest fresh bulb weight was observed in the control treatment T_9 (13.20 g per bulb). Significant variation was also noted for bulb fresh weight at 90 DAT. Treatment T_6, with foliar application of 0.5% zinc sulphate at 30 and 60 DAT, recorded the highest bulb weight (57.32 g per bulb), surpassing all other treatments. The minimum fresh weight (34.14 g per bulb) was again recorded in T_9. The data at harvest indicated that zinc source, level and method of application significantly affected bulb fresh weight. The maximum value (71.14 g per bulb) was obtained in T_6, which received 0.5% foliar application of conventional zinc sulphate at 30 and 60 DAT. This was statistically on par with T_5 (67.60 g per bulb), where zinc sulphate was applied at transplanting. The lowest weight was registered in the control T_9 (50.99 g per bulb).

At 60 DAT, the dry weight of bulbs per plant showed significant differences due to various zinc sources, levels and methods of application. The highest dry weight (2.29 g per bulb) was obtained in T_5, which received a soil application of 4 kg/ha zinc sulphate at transplanting. This was statistically comparable with T_6 (2.48 g per bulb), where a 0.5% foliar spray of conventional zinc sulphate was applied at 30 and 60 DAT. The lowest dry bulb weight was recorded in the control treatment T_9 (1.56 g per bulb). A significant variation in dry bulb weight at 90 DAT was also observed among the treatments. Treatment T_6, with a 0.5% foliar application of conventional zinc sulphate at 30 and 60 DAT, recorded the highest dry weight (7.18 g per bulb), outperforming all other treatments. The lowest value was noted in T_9 (3.87 g per bulb). The dry bulb weight at harvest was significantly influenced by zinc application treatments. The maximum dry weight (7.64 g per bulb) was observed in T_6, followed closely by T_5 (7.07 g per bulb) and both were statistically comparable with T_4. The minimum dry weight (6.25 g per bulb) was once again recorded in the untreated control T_9.

Fresh and dry weight of bulb (Table 5) (Figs. 4 and 5) at 60, 90 and harvest significantly differed among the treatments. Significantly higher fresh (26.88 g/plant) and dry weight (2.29 g/plant) of bulb at 60 DAT were recorded in treatment T_5 soil application of zinc sulphate 4kg/ha

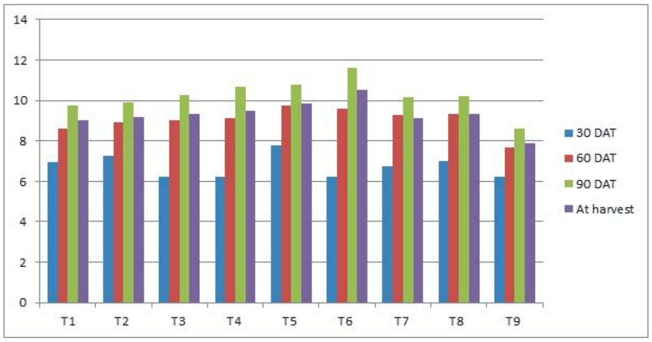

Fig. 1 : Effect of different source, levels and method of application of zinc on number of leaves per plant at different growth stages of onion.

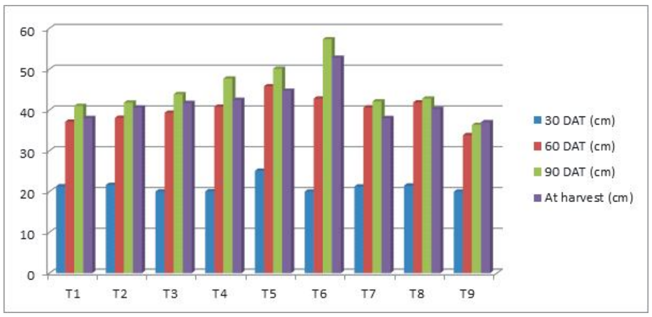

Fig. 2 : Effect of different source, levels and method of application of zinc on leaf length at different growth stages of onion.

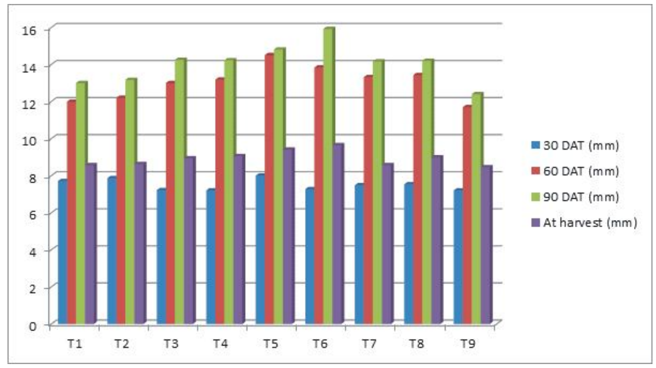

Fig. 3 : Effect of different source, levels and method of application of zinc on neck thickness at different growth stages of onion.

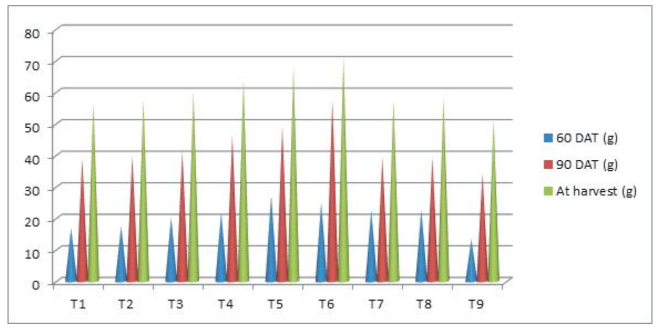

Fig. 4 : Effect of different source, levels and method of application of zinc on fresh weight of bulb at different growth stages of onion.

Table 4 : Effect of different source, levels and method of application of zinc on neck thickness at different growth stages of onion.

Treatments	Neck thickness (mm)			
	30 DAT	60 DAT	90 DAT	At harvest
T_1- Soil application ZnO NPs 15g/ha days after transplanting	7.71	11.99^{bc}	13.00^{cd}	8.57
T_2-Soil application ZnO NPs 30g/ha days after transplanting	7.87	12.21^{bc}	13.17^{bcd}	8.63
T_3-ZnO NPs as foliar application @ 20 ppm at 30 and 60 days after transplanting	7.22	13.00^{abc}	14.25^{abc}	8.94
T_4-ZnO NPs as foliar application @ 40 ppm at 30 and 60 days after transplanting	7.21	13.19^{abc}	14.23^{abc}	9.06
T_5-Conventional $ZnSO_4$ @ 4 kg/ha as soil application	8.01	14.51^{a}	14.81^{ab}	9.41
T_6- Foliar spray of Conventional $ZnSO_4$ 0.5% solution in 30 and 60 days after transplanting	7.27	13.84^{ab}	15.92^{a}	9.65
T_7- Soil application ZnO NPs 7.5 g/ha and foliar spray 20ppm 30 days after transplanting	7.49	13.32^{ab}	14.17^{bc}	8.57
T_8-Soil application ZnO NPs 15 g/ha and foliar spray 20ppm 30 days after transplanting	7.54	13.43^{ab}	14.20^{bc}	8.99
T_9-Control	7.21	11.70^{c}	12.40^{d}	8.46
SEm±	0.26	0.52	0.57	0.35
CD 5%	NS	1.54	1.72	NS

DAT – Days After Transplanting ZnONPs - Zinc oxide Nano Particles

Table 5 : Effect of different source, levels and method of application of zinc on fresh weight and oven dry weight of bulb at different growth stages of onion.

Treatments	Fresh weight of bulb (g)			Oven dry weight of bulb (g)		
	60 DAT	90 DAT	At harvest	60 DAT	90 DAT	At harvest
T_1- Soil application ZnO NPs 15g/ha days after transplanting	16.70[d]	38.76[de]	56.65[de]	1.62[de]	4.53[de]	6.08[cd]
T_2-Soil application ZnO NPs 30g/ha days after transplanting	17.40[d]	39.64[d]	57.51[d]	1.70[cde]	4.66[d]	6.18[cd]
T_3-ZnO NPs as foliar application @ 20 ppm at 30 and 60 days after transplanting	20.13[c]	41.19[cd]	59.98[cd]	1.73[cde]	4.88[c]	6.49[bcd]
T_4-ZnO NPs as foliar application @ 40 ppm at 30 and 60 days after transplanting	21.58[c]	46.39[bc]	64.10[bc]	1.81[bcde]	5.61[bc]	6.63[bc]
T_5-Conventional $ZnSO_4$ @ 4 kg/ha as soil application	26.88[a]	48.90[b]	67.60[ab]	2.29[a]	5.98[b]	7.07[ab]
T_6- Foliar spray of Conventional $ZnSO_4$ 0.5% solution in 30 and 60 days after transplanting	24.65[ab]	57.32[a]	71.14[a]	2.08[ab]	7.18[a]	7.64[a]
T_7- Soil application ZnO NPs 7.5 g/ha and foliar spray 20ppm 30 days after transplanting	22.39[bc]	39.30[de]	57.31[d]	1.88[bcd]	4.61[de]	6.16[cd]
T_8-Soil application ZnO NPs 15 g/ha and foliar spray 20ppm 30 days after transplanting	22.51[bc]	39.46[de]	58.00[d]	1.96[bc]	4.63[de]	6.25[cd]
T_9-Control	13.20[e]	34.14[e]	50.99[e]	1.56[e]	3.87[e]	5.99[d]
SEm±	0.87	1.86	1.91	0.10	0.18	0.22
CD 5%	2.62	5.58	5.72	0.29	0.55	0.65

DAT – Days After Transplanting ZnONPs - Zinc oxide Nano Particle.

compare to all other treatments because soil application initially increases the shoot and root growth that increase the photosynthesis products results in increase in bulb weight. Similar results were obtained in Manna (2013) in onion crop, Acharya *et al.* (2015) in onion crop and Rani (2015) in garlic crop.

Number of marketable bulbs

The number of marketable bulbs per plant recorded at harvest did not differ significantly among the treatments. However, the maximum number of marketable bulbs per plot (268.33) was observed in T_6, which received a 0.5% foliar spray of conventional zinc sulphate at 30 and 60 DAT, while the lowest count (248.50 bulbs per plot) was noted in the control treatment T_9.

Average weight of bulb at harvest

The average bulb weight per plant at harvest showed significant variation due to zinc application. The highest bulb weight (71.14 g per bulb) was recorded in T_6 with foliar application of 0.5% zinc sulphate at 30 and 60 DAT and this treatment was statistically comparable with T_5 (67.60 g per bulb), where conventional zinc sulphate was applied to the soil at transplanting. Treatment T_9 recorded the lowest bulb weight (50.99 g per bulb).

Total bulb yield per plot at harvest

The data in Table 6 clearly indicated that total bulb yield per plot was significantly affected by different sources, levels and methods of zinc application. Treatment T_6 produced the highest yield (19.08 kg per plot) and was statistically similar to T_5 (17.79 kg per plot). The minimum yield was obtained in T_9 (12.67 kg per plot).

Total bulb yield per hectare at harvest

The total bulb yield per hectare also exhibited significant differences among the treatments. The foliar application of 0.5% conventional zinc sulphate at 30 and 60 DAT (T_6) resulted in the maximum yield of 352.1 q per hectare, surpassing all other treatments. The lowest yield per hectare was observed in the control T_9 (248.63 q per hectare).

Soil and foliar application of zinc sulphate and nano zinc oxide had a significant effect on the yield and yield components of onion (Table 6). The highest total bulb yield (352.12 q/ha) was recorded under 0.5% foliar application of conventional zinc sulphate at 30 and 60 DAT, surpassing all other treatments. Similarly, the maximum average bulb weight per plot (71.14 g) and the highest number of marketable bulbs per plot (268.33) were observed under the same treatment. The increase in bulb

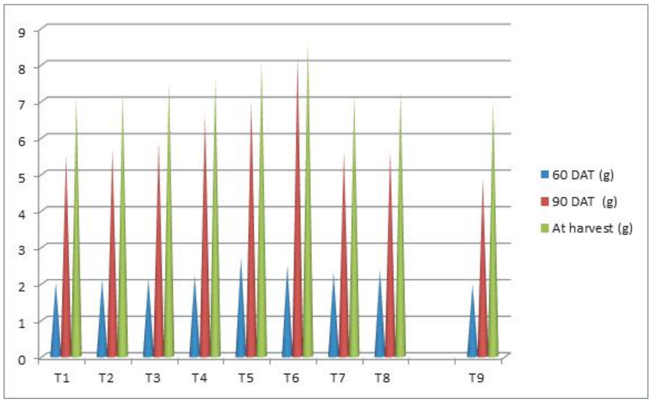

Fig. 5 : Effect of different source, levels and method of application of zinc on dry weight at different growth stages of onion.

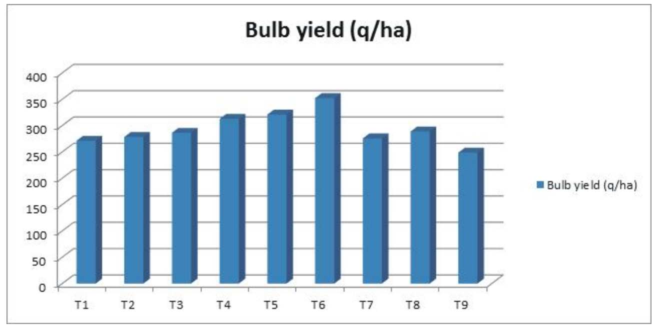

Fig. 6 : Effect of different source, levels and method of application of zinc on yield of onion.

in peanut (Prasad *et al.*, 2012) and paddy (Jangid *et al.*, 2018), where enhanced zinc uptake through foliar nano zinc application resulted in higher crop yields.

Table 6 : Effect of different source, levels and method of application of zinc on yield, yield attributes.

Treatments	Number of marketable bulbs/plot	Average bulb weight(g)	Total bulb yield/plot (kg)	Total bulb yield/ha (q/ha)
T_1- Soil application ZnO NPs 15g/ha days after transplanting	255.80	56.65[de]	14.49[de]	271.08[de]
T_2-Soil application ZnO NPs 30g/ha days after transplanting	257.60	57.51[d]	14.81[cd]	278.32[de]
T_3-ZnO NPs as foliar application @ 20 ppm at 30 and 60 days after transplanting	255.44	59.98[cd]	15.32[cd]	286.16[cd]
T_4-ZnO NPs as foliar application @ 40 ppm at 30 and 60 days after transplanting	258.67	64.10[bc]	16.58[bc]	312.76[bc]
T_5-Conventional $ZnSO_4$ @ 4 kg/ha as soil application	263.25	67.60[ab]	17.79[ab]	320.95[b]
T_6- Foliar spray of Conventional $ZnSO_4$ 0.5% solution in 30 and 60 days after transplanting	268.33	71.14[a]	19.08[a]	352.12[a]
T_7- Soil application ZnO NPs 7.5 g/ha and foliar spray 20ppm 30 days after transplanting	258.68	57.31[d]	14.82[cd]	275.66[de]
T_8-Soil application ZnO NPs 15 g/ha and foliar spray 20ppm 30 days after transplanting	260.30	58.00[d]	15.09[cd]	288.65[cd]
T_9-Control	248.50	50.99[e]	12.67[e]	248.63[e]
SEm±	8.20	1.91	0.69	8.99
CD 5%	NS	5.72	2.08	27.08

DAT – Days After Transplanting ZnONPs - Zinc oxide Nano Particle

weight and number of marketable bulbs contributed substantially to the overall yield improvement. Foliar application of zinc sulphate enhances zinc content in the leaves, stimulating crop growth and increasing the synthesis of photosynthetic products. These micronutrients play a crucial role in the translocation of photosynthates from source to sink, thereby improving bulb yield in onion. Comparable results have been reported by Anitha *et al.* (2005) in cowpea and Soni and Kushwaha (2020) in mungbean. Foliar application of nano zinc oxide at low concentrations also effectively increased bulb yield compared to the control, consistent with findings

Conclusion

The biofortification of zinc in the edible part of crop is alternate way to alleviate the zinc deficiency among the human society. The present study revealed that there was a significant difference on crop growth due to soil and foliar application of nano zinc oxide and conventional zinc sulphate by different levels and method of application in onion crop. Among various treatments 0.5% foliar application of conventional zinc sulphate at 30 and 60 DAT was found beneficial in enhancing the crop growth and yield factors in onion on a Northern Transition Zone of Karnataka.

Acknowledgement

The authors would like to express their heartfelt and sincere gratitude to the Department of Soil Science and Allied Chemistry, College of Horticulture, University of Horticultural Sciences, Bagalkot, for their valuable guidance and assistance throughout the course of this experiment.

References

Acharya, U., Sharma N., Rimal K., Venkatesan T., Saraswathi K. and Subramanian S. (2015). Response on growth, yield and quality parameters of multiplier onion (*Allium cepa* L. var. aggregatum Don.) var. CO (On) 5 with different doses and method of zinc and boron application. *Int. J. Agron. Agric. Res.*, **6(4)**, 59-67.

Anitha, S., Sreenivasan E. and Purushothaman S.M., (2005). Response of cowpea [*Vigna unguiculata* (L.) Walp.] to foliar nutrition of zinc and iron in the Oxisols of Kerala. *Legume Res.*, **28(4)**, 294 – 296.

Jangid, B., Srinivas A., Kumar M.R., Ramprakash T., Prasad T.N.V.K.V., Kumar A.K., Reddy S.N. and Dida V.K. (2019). Influence of zinc oxide nanoparticles foliar application on zinc uptake of rice (*Oryza sativa* L.) under different establishment methods. *Int. J. Chem Stud.*, **7**, 257-261.

Manna, D. (2013). Growth, yield and bulb quality of onion (*Allium cepa* L.) in response to foliar application of boron and zinc. *SAARC J. Agricult.*, **11(1)**, 149-153.

Miah M.S., Taheri R.H., Rabbani M.G. and Md. Karim M.R. (2020). Effects of different application methods of zinc and boron on growth and yield of onion. *Int. J. Biosci.*, **17(4)**, 126-133.

Nadergoli, M.S., Yarnia M. and Khoei F.R. (2011). Effect of zinc and manganese and their application method on yield and yield components of common bean (*Phaseolus vulgaris* L. CV. Khomein). *Middle East J. Sci. Res*., **8(5)**, 859-865.

Pahlavan Rad, M.R. and Pessarakli M. (2009). Response of wheat plants to zinc, iron, and manganese applications and uptake and concentration of zinc, iron and manganese in wheat grains. *Communications in Soil Science and plant Analysis*, **40(7-8)**, 1322-1332.

Pal, A.K., Lal M., Singh A.K. and Singh C.P. (2016). Response of onion to iron and zinc nutrition in an alluvial soil. *Annals Plant Soil Res.*, **18(3)**, 241-245.

Palacio-Márquez, A., Ramírez-Estrada C.A., Gutiérrez-Ruelas N.J., Sánchez E., Ojeda-Barrios D.L., Chávez-Mendoza C. and Sida-Arreola J.P. (2021). Efficiency of foliar application of zinc oxide nanoparticles versus zinc nitrate complexed with chitosan on nitrogen assimilation, photosynthetic activity and production of green beans (*Phaseolus vulgaris* L.). *Sci. Hortic*., **288**, 110297.

Patel, S.S., Kumar B.A., Singh M.D., Alagundagi S.C., Savalgi V.P. and Rabinal M.K. (2019). Foliar Application of Green Synthesized Zinc Sulphide and Zinc Oxide Nano Particles Enhances Growth, Root attributes, Yield and Oil Quality of Sunflower (*Helianthus Annuus* L.)

Prasad, T.N.V.K.V., Sudhakar P., Sreenivasulu Y., Latha P., Munaswamy V., Reddy K.R., Sreeprasad T.S., Sajanlal P.R. and Pradeep T. (2012). Effect of nanoscale zinc oxide particles on the germination, growth and yield of peanut. *J. Plant Nutr.*, **35(6)**, 905-927.

Rahman, M.H., Quddus M.A., Satter M.A., Ali M.R., Sarker M.H. and Trina T.N. (2020). Impact of foliar application of boron and zinc on growth, quality and seed yield of Okra. *J. Energy Nat. Resour.*, **9(1)**, 1-9.

Rani, P. (2015). Effect of foliar application of urea and micronutrients on garlic seed production (*Doctoral dissertation*, CCSHAU).

Roy, D.P., Narwal R.P., Malik R.S., Saha B.N. and Kumar S. (2014). Impact of zinc application methods on application of green gram (*Vigna radiata* L.) productivity and grain zinc fortification. *J. Environ. Biol*., **35**, 851-854.

Soni, J. and Kushwaha H.S. (2020). Effect of foliar spray of zinc and iron on productivity of mungbean (*Vigna radiate* (L.) Wilczek). *J. Pharmacogn. Phytochem.*, **9(1)**, 108-111.