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Effect of Fertility Levels with Micronutrient Fortification and Bio Enhancer on Growth and Yield of Onion (*Allium cepa* L.)

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ABSTRACT: Micronutrient deficiency and suboptimal fertility levels in soil can significantly impact the growth, yield, and quality of agricultural crops, including onions (*Allium cepa* L.). Addressing these issues through targeted interventions, such as micronutrient fortification and bioenhancers, holds promise for enhancing crop productivity and nutritional quality. This research paper investigates the effect of varying fertility levels in combination with micronutrient fortification and bioenhancer application on the growth, yield, and quality of onion crops.

The investigation entitled effect of fertility levels with micronutrient fortification and bio enhancer on growth and yield of onion (*Allium cepa* L.) was carried out during *rabi* season of 2020-21 and 2021-22 at College Farm, College of Horticulture, S. D. Agricultural University, Jagudan. A factorial experiment was conducted with a randomized block design, comprising three factors *i.e.*, two levels of fertilizer *i.e.*, 80 per cent RDF (L_1) and 60 per cent RDF (L_2); micronutrient fortification with six levels *i.e.*, Zinc @ 5 kg/ha (M_1), Zinc @ 10 kg/ha (M_2), Iron @ 5 kg/ha (M_3), Iron @ 10 kg/ha (M_4), Zinc + Iron @ 2.5 kg/ha each (M_5) and Zinc + Iron @ 5 kg/ha each (M_6) and two levels of bioenhancer *i.e.*, NPK consortium @ 5.0 l/ha at sowing (B_1) and *Jeevamrut* @ 500 l/ha at sowing, 45 DAP and 90 DAP (B_2). Thus, there were total 24 treatment combinations under study. The experiment was laid out in Randomized Block Design with factorial concept with three replications. Based on the findings of this study, it can be concluded that the application of 80 per cent RDF along with soil application of Zinc + Iron @ 5 kg/ha each and drenching of *jeevamrut* at sowing, 45 DAP and 90 DAP was the best in terms of growth and yield as well in economic return in *rabi* onion. The challenges may include intricacies in controlling and measuring nutrient interactions, potential variations in soil conditions, and the need for comprehensive data analysis to discern the nuanced impact on crop productivity.

Keywords: Bio enhancer, Fertility levels, Fortification, Growth, Micronutrient, Onion, Yield.

INTRODUCTION

The onion (*Allium cepa* L.), a highly valued bulbous vegetable, has maintained its significant role in India throughout history and is often referred to as the "Queen of the kitchen." Its consumable part, the modified underground stem known as the 'bulb,' is at the core of its culinary appeal. From the early stages of growth, including tender green leaves, to both immature and mature bulbs, onions feature prominently in a wide range of dishes, whether consumed raw in salads or cooked in soups and various cuisines. As a member of the Alliaceae family, the onion has its roots in Central Asia and has become a staple in households worldwide. Its distinctive flavor makes it a preferred choice for enhancing the taste of dishes. Additionally, onions exhibit versatility, as they can endure transportation and storage challenges, allowing them to be enjoyed over an extended period.

Biofortification techniques are designed to enhance the nutritional value of crops, employing a combination of agronomic and breeding approaches (Stein, 2007). Various fertilizers, such as organic, inorganic, and biofertilizers, are utilized in agricultural practices. Notably, inorganic fertilizers, particularly those exceeding 100 nm in size, are susceptible to losses through leaching and volatilization (Elemike *et al.*, 2019).

Apart from its culinary significance, onions are noteworthy for their nutritional and medicinal contributions. Abundant in minerals such as phosphorus and calcium, as well as carbohydrates, proteins, and vitamin C, onion bulbs offer a range of health advantages. The medicinal attributes of onions encompass anti-periodic, antibacterial, and stimulant properties, in addition to aiding digestion, supporting wound healing, and addressing respiratory issues. The distinctive pungency of onions, attributed to the volatile oil Allyl-propyl-disulphide, not only enhances flavor but also stimulates the digestive process. In the context of genetic expression of heterosis there are several challenges that researchers and breeders may encounter *i.e.,* Identifying specific genes and molecular mechanisms responsible for heterosis in yield is challenging due to the complex and non-additive nature of genetic interactions (Chandni *et al.,* 2023).

India holds a prominent position in the global production and export of onions, securing the 2nd rank in production. The cultivation of onions spans an extensive area of 1285,000 hectares, yielding a total bulb production of 26,916,000 metric tons (Anon., 2021). With flourishing cultivation areas and impressive bulb yields, Maharashtra, Karnataka, Gujarat, among others, are key contributors to the thriving onion industry. Maharashtra leads in onion production, capturing a substantial share of 27.72%. In Gujarat, onion cultivation covers an area of approximately 54,488 hectares, resulting in a total bulb production of 1,416,602 metric tons (Anon., 2018). Noteworthy onion cultivation districts in Gujarat include Bhavnagar, Rajkot, Amreli, Junagadh, Jamnagar, Porbandar, Kutch, Mehsana, Surat, and Anand. Bhavnagar stands out as a leading district for onion cultivation, encompassing an area of 32,000 hectares and achieving a production of 870,400 metric tons (Anon., 2018).

In light of the nutritional requirements of onions, the cultivation of this crop necessitates careful consideration of soil health. Shifting from a sole emphasis on production to a more comprehensive approach focusing on overall well-being, ongoing initiatives seek to strike a balance between traditional fertilizer application and the incorporation of organic supplements and micronutrients. This strategy aims not only to ensure robust crop yields but also to promote the long-term health of the soil, plants, and ultimately, consumers. The simultaneous use of organic and inorganic sources of plant nutrients not only enhances the production and profitability of field crops but also contributes to the sustained fertility of the soil (Patel *et al*., 2020).

The impact of iron and zinc on the growth and productivity of onions is crucial. Iron, an essential micronutrient, acts as a catalyst for key biochemical processes that drive the development of onion plants. Its integration into chlorophyll facilitates efficient photosynthesis, ensuring healthy leaf coloration and optimal energy production. Additionally, iron promotes root growth by aiding in the formation of enzymes essential for elongation and nutrient absorption. Its involvement in respiratory reactions further sustains metabolic activities crucial for overall growth. Zinc, another indispensable micronutrient, plays a pivotal role in enhancing onion yield. Serving as a cofactor for enzymes involved in DNA synthesis, protein formation, and hormone regulation, zinc supports robust plant development. It influences both root and shoot growth, facilitating nutrient uptake and resource utilization. By contributing to proper seedling development, zinc promotes the establishment of sturdy plants, influencing onion bulb formation and overall yield. Both iron and zinc, integral components of onion nutrition, work in tandem to drive growth processes, resulting in healthier, more productive onion plants and increased yields (Chandni *et al*., 2020).

The NPK trio, comprising nitrogen (N), phosphorus (P), and potassium (K), is indispensable for the growth and yield of onions. Nitrogen supports leaf growth and photosynthesis, phosphorus contributes to root and flower development, influencing bulb growth, and potassium enhances disease resistance, water uptake, and overall plant vitality. When appropriately balanced and supplied, this trio of nutrients optimizes onion growth, leading to healthier plants, larger bulbs, and increased yields. The NPK consortium serves as a fundamental factor in cultivating thriving and productive onion crops (Vaghela *et al*., 2019).

Jeevamrut significantly boosts onion growth and yield. Functioning as an organic soil conditioner, it introduces beneficial microorganisms that improve soil structure and nutrient availability. These microbes aid in the decomposition of organic matter, releasing essential nutrients for onions. Jeevamrut supports nitrogen fixation, fostering robust foliage, strong root development, and efficient nutrient absorption. This results in healthier plants, heightened pest resistance, and improved yields. Its positive impact on soil fertility and microbial activity positions Jeevamrut as a valuable tool for sustainable and productive onion cultivation (Palekar, 2006).

The strategic use of a combination of fertilizers and bio-enhancers is essential to enhance onion yield. Conventional fertilizers can be costly and have detrimental effects on soil quality over the long term, influencing both production and expenses. In contrast, organic alternatives such as bio-fertilizers are cost-effective, environmentally friendly, and contribute to improved product quality. Additionally, they enhance soil structure, water retention, and the overall sustainability of crops. This combination is pivotal for preserving soil fertility, promoting productivity, and ensuring the overall health of onion crops (Patel *et al*., 2020).

MATERIAL AND METHODS

The experiment entitled effect of fertility levels with micronutrient fortification and bio enhancer on growth and yield of onion (*Allium cepa* L.) was conducted in *rabi* season of the year 2020-21 and 2021-22 at College Farm, College of Horticulture, S. D. Agricultural University, Jagudan, Mehsana, Gujarat. The variety under investigation was Agrifound Light Red onion, recognized as a promising and well-suited choice for *rabi* season onion cultivation.

The investigation comprising three factors *i.e*., two levels of fertilizer *i.e*., 80 per cent RDF (L_1) and 60 per cent RDF (L_2); micronutrient fortification with six levels *i.e*., Zinc @ 5 kg/ha (M_1), Zinc @ 10 kg/ha (M_2), Iron @ 5 kg/ha (M_3), Iron @ 10 kg/ha (M_4), Zinc + Iron @ 2.5 kg/ha each (M_5) and Zinc + Iron @ 5 kg/ha each (M_6) and two levels of bioenhancer *i.e*., NPK consortium @ 5.0 l/ha at sowing (B_1) and *Jeevamrut* @

500 l/ha at sowing, 45 DAP and 90 DAP (B_2). Thus, there were total 24 treatment combinations under study. The experiment was laid out in Randomized Block Design with factorial concept with three replications.

The different growth and yield parameters *viz*., plant height at 45 and 90 DAP (cm), number of leaves per plant at 45 and 90 DAP, neck thickness at 45 and 90 (cm), weight of bulb (g), yield per plot (kg) and yield per hectare (q) were recorded. Ten plants were randomly selected and tagged in each treatment for recording observations on various aspects.

Growth Parameters

Plant height at 45 and 90 DAT (cm). The plant height (cm) was measured from the ground level to top of the tagged plant at 45 and 90 days after transplanting with the help of meter scale. Average height of tagged plants was calculated.

Number of leaves per plant at 45 and 90 DAT. The total number of leaves per plant at 45 and 90 days separately from the date of transplanting was counted. Average of number of leaves per plant from selected plants was worked out.

Neck thickness at 45 and 90 DAT (cm). The plant neck thickness at 45 and 90 days separately from the date of transplanting was measured in centimeter with the help of vernier caliper (Absolute Digimatic Caliper, Mitu Toyo Corporation, Japan) from the tagged plants and its average was worked out.

Days taken to bulb maturity. Number of days taken to attain physiological maturity of bulbs at 65 per cent neck fall stage was counted from date of transplanting of each treatment. The average days taken for maturity were worked out.

Yield Parameters

Weight of bulb (g). The weight of bulb of ten tagged plant from each treatment was recorded in gram and average weight of bulb was worked out.

Yield per plot (kg)

Onion bulbs were dug out from each net plot at physiological maturity stage. The bulbs after digging were kept under shade for one week then all the dried leaves and roots were removed and onion bulbs were weighed for each net plot area in kilogram. The weight of ten bulbs under observations was also added to the net plot yield.

Yield per hectare (q). The bulb yield of onion of net plot was mathematically converted into bulb yield per hectare in quintal.

RESULTS AND DISCUSSION

A. Growth Parameters

Plant height at 45 and 90 DAP (cm). The data pertaining to influence of fertility levels, micronutrient fortification and bio enhancer on plant height at 45 and 90 DAP are presented in Table 1.

Effect of fertility levels. Perusal of data revealed that effect of fertility levels on plant height at 45 and 90 DAP were found significant during both the year of experiment and in pooled data. Further review of Table 1 showed that significantly maximum plant height at 45 DAP 38.54 cm, 49.96 cm and 44.25 cm and at 90 DAP 82.79 cm, 89.83 cm and 86.31 cm were observed under treatment L_1 (80 % RDF) during the year 2020-21, 2021-22 and in pooled, respectively. The minimum plant height at 45 DAP was 35.43 cm, 44.21 cm and 39.82 cm and at 90 DAP was 79.45 cm, 84.25 cm and 81.85 cm recorded with treatment L_2 (60 % RDF) during both the years *i.e.*, 2020-21, 2021-22 and in pooled, respectively.

Effect of micronutrient fortification. Data presented in Table 1 showed that influence of micronutrient fortification on plant height at 45 and 90 DAP was found significant during both the years of experiment and in pooled data. The maximum plant height at 45 DAP was 38.85 cm, 50.45 cm and 44.65 cm and at 90 DAP was 84.81 cm, 91.12 cm and 87.96 cm observed under treatment M_6 (Zinc + Iron @ 5 kg/ha each) during the year 2020-21, 2021-22 and in pooled data, respectively. Treatment M_2 and M_4 were at par with M_6 during the year 2020-21 and treatment M_2 at par with M_6 during the year 2021-22 at 45 DAP. While, treatment M_2 and M_4 were at par with treatment M_6 during both the years *i.e.*, 2020-21, 2021-22 and on pooled basis at 90 DAP. The minimum plant height at 45 DAP was 35.50 cm, 44.50 cm and 40.00 cm and at 90 DAP was 78.18 cm, 83.80 cm and 80.99 cm observed with treatment M_3 (Iron @ 5 kg/ha) during both the years *i.e.*, 2020-21, 2021-22 and in pooled data, respectively.

Effect of bio enhancer. Influence of bio enhancer on plant height at 45 and 90 DAP were found significant during both the years of experiment and in pooled data. Data presented in Table 1showed that the maximum plant height at 45 DAP was 37.62 cm, 47.90 cm and 42.76 cm and at 90 DAP was 82.37 cm, 88.44 cm and 85.41 cm found under treatment B_2 (*Jeevamrut* @ 500 l/ha at sowing, 45 DAP and 90 DAP) during the year 2020-21, 2021-22 and in pooled data, respectively. The minimum plant height at 45 DAP was 36.36 cm, 46.27 cm and 41.31 cm and at 90 DAP was 79.87 cm, 85.64 cm and 82.76 cm observed with treatment B_1 (NPK consortium @ 5.0 l/ha at sowing) during both the years *i.e.,* 2020-21, 2021-22 and in pooled data, respectively.

Interaction effect of fertility levels, micronutrients fortification and bio enhancer. Further review of data of Table 1 showed that interaction effect between fertility levels (L) and bio enhancer (B) and micronutrient fortification (M) and bio enhancer (B) were found significant with respect to plant height at 45 and 90 DAP during the year 2020-21, 2021-22 and in pooled, respectively.

Table 1: Effect of fertility levels, micronutrient fortification and bio enhancer on plant height at 45 and 90 DAP.

Treatments	Plant height (cm) at 45 DAP			Plant height (cm) at 90 DAP		
	Year 2020-21	Year 2021-22	Pooled	Year 2020-21	Year 2021-22	Pooled
Fertility Levels (L)						
L_1	38.54	49.96	44.25	82.79	89.83	86.31
L_2	35.43	44.21	39.82	79.45	84.25	81.85
S.Em.±	0.42	0.53	0.35	0.88	0.98	0.68
C.D. at 5%	1.19	1.51	0.99	2.49	2.79	1.90
Micronutrient fortification (M)						
M_1	35.97	45.20	40.58	79.16	84.66	81.91
M_2	37.55	48.30	42.93	82.49	88.69	85.59
M_3	35.50	44.50	40.00	78.18	83.80	80.99
M_4	37.42	47.73	42.58	81.88	87.89	84.88
M_5	36.65	46.32	41.48	80.23	86.08	83.16
M_6	38.85	50.45	44.65	84.81	91.12	87.96
S.Em.±	0.72	0.92	0.61	1.52	1.70	1.17
C.D. at 5%	2.06	2.61	1.71	4.32	4.83	3.29
Bio enhancer (B)						
B_1	36.36	46.27	41.31	79.87	85.64	82.76
B_2	37.62	47.90	42.76	82.37	88.44	85.41
S.Em.±	0.42	0.53	0.35	0.88	0.98	0.68
C.D. at 5%	1.19	1.51	0.99	2.49	2.79	1.90
CV%	6.77	6.74	7.10	6.47	6.76	6.81
Interaction effect						
L × M	NS	NS	2.42	NS	NS	NS
L × B	1.68	2.13	1.40	3.52	3.95	2.68
M × B	2.91	3.69	2.42	6.10	6.83	4.65
L × M × B	NS	NS	NS	NS	NS	NS
Y× L	1.40			NS		
Y × M	NS			NS		
Y × B	NS			NS		
Y × L × M	NS			NS		
Y× L× B	NS			NS		
Y × M × B	NS			NS		
Y×L×M×B	4.84			NS		

An increase in plant height might be due to enhanced availability of nutrients and production of growth promoting substances that might have caused cell elongation and cell multiplication (Dhakad *et al.*, 2019). These results are in conformity with the finding of Gupta *et al*. (1999); Muoneke *et al*. (2003); Singh *et al.* (2004) in onion and Farooqui *et al.* (2009) in garlic. Iron is an important catalyst in the enzymatic reactions of the metabolism would have helped in the biosynthesis of photo assimilates thereby used efficiently in onion growth so that plant height was increased. These findings are in close accordance with the findings of Jawaharlal *et al*. (1986); Tohamy *et al.* (2009); Ballabh *et al*. (2013); Singh *et al*. (2015a); Singh *et al*. (2015b) in onion. Zinc has a vital role in growth of plant. It regulates the oxidation-reduction processes in plants. This increase in height of plant may be due to the active synthesis of tryptophan in the presence of zinc, which stimulates the growth of plant. There is an enhancement in cell multiplication and cell elongation resulting in more plant height. Our results are similar to findings of Abedin *et al*. (2012); Ballabh *et al*. (2012); Ballabh *et al*. (2013); Verma *et al*. (2014); Manna *et al*. (2014); Rizk *et al*. (2014); Shukla *et al.* (2015); Acharya *et al*. (2015); Begum *et al*. (2015) in onion.

Jeevamrut promotes immense biological activity in soil and makes the nutrients available to crop. Optimum growth and development might be due to the increase in cell size and enhancement of cell division, which ultimately resulted in increased plant height. Similar findings were also reported by Pall and Padda (1972); Chakrabarti *et al.* (1980); Nehra *et al.* (1988). The plant height was recorded maximum that give the full opportunity to plant for optimum growth and development might be due to the increase in cell size and enhancement of cell division, which ultimately resulted in increased plant height. Similar findings were also reported by Pall and Padda (1972); Chakrabarti *et al.* (1980); Nehra *et al.* (1988). Combined application of micronutrients and *jeevamrut* a liquid manure contains many of the nutrients and good microbial load which stimulates growth through biosynthesis of endogenous hormones which is responsible for plant growth, enhanced photosynthesis and other metabolic activity and increase height of the plant. Singh *et al*. (2015a); Singh *et al*. (2015b). These results are agreement with the results reported by Smriti *et al*. (2002); Manna (2014); Kurubetta *et al.* (2019) in onion.

Number of leaves per plant at 45 and 90 DAP. Results related to effect of fertility levels, micronutrient fortification and bio enhancer on number of leaves per plant at 45 and 90 DAP were recorded and analyzed statistically. Data are presented in Table 2.

Effect of fertility levels. Data depicted in Table 2represented the effect of fertility levels on number of leaves per plant at 45 and 90 DAP during both the years of experiment and in pooled data. Data manifested that number of leaves per plant at 45 and 90 DAP was significantly influenced by fertility levels. The maximum number of leaves per plant at 45 DAP was 6.86, 7.26 and 7.06 and at 90 DAP was 11.71, 12.72 and 12.22 observed under treatment L_1 fertility levels *i.e.*, 80 % RDF during the year 2020-21, 2021-22 and in pooled data, respectively. The minimum number of leaves per plant at 45 DAP was 5.21, 6.03 and 5.62 and at 90 DAP was 9.57, 10.63 and 10.10 recorded with treatment L_2 fertility levels *i.e.*, 60 % RDF during both the years *i.e.*, 2020-21, 2021-22 and in pooled data, respectively.

Effect of micronutrient fortification. Data resulted in Table 2 represented the effect of micronutrient fortification on number of leaves per plant at 45 and 90 DAP during both the years of experiment and in pooled data. Data showed that number of leaves per plant at 45 and 90 DAP was significantly influenced by micronutrient fortification. The maximum number of leaves per plant at 45 DAP 7.10, 7.42 and 7.26 and at 90 DAP was 12.00, 12.97 and 12.48 was recorded under treatment of micronutrient fortification with Zinc + Iron @ 5 kg/ha each (M_6) during the year 2020-21, 2021-22 and in pooled data, respectively. The minimum number of leaves per plant at 45 DAP was 5.25, 6.05 and 5.65 and at 90 DAP was 9.67, 10.77 and 10.22 observed with treatment M_3 (Iron @ 5 kg/ha) during both the years *i.e.*, 2020-21, 2021-22 and in pooled data, respectively.

Effect of bio enhancer. Data presented in Table 2revealed that the effect of bio enhancer on number of leaves per plant at 45 and 90 DAP were found significant during both the years of experiment and in pooled data. Data manifested that number of leaves per plant at 45 and 90 DAP was significantly influenced by bio enhancer. The maximum number of leaves per plant at 45 DAP 6.19, 6.76 and 6.47 and at 90 DAP was 10.84, 11.89 and 11.36 was found under treatment B_2 (*Jeevamrut* @ 500 l/ha at sowing, 45 DAP and 90 DAP) during both the years 2020-21, 2021-22 and in pooled data, respectively. The minimum number of leaves per plant at 45 DAP was 5.88, 6.53 and 6.21 and at 90 DAP was 10.44, 11.46 and 10.95 observed with treatment B_1 (NPK consortium @ 5.0 l/ha at sowing) during both years *i.e.*, 2020-21, 2021-22 and in pooled data, respectively.

Interaction effect of fertility levels, micronutrient fortification and bio enhancer. Data presented in Table 2 showed that interaction effect of fertility levels and micronutrient fortification and bio enhancer found significant for pooled basis with respect to number of leaves per plant at 45 DAP.

Table 2: Effect of fertility levels, micronutrient fortification and bio enhancer on number of leaves per plant at 45 and 90 DAP.

Treatments	Number of leaves per plant at 45 DAP			Number of leaves per plant at 90 DAP		
	Year 2020-21	Year 2021-22	Pooled	Year 2020-21	Year 2021-22	Pooled
Fertility Levels (L)						
L_1	6.86	7.26	7.06	11.71	12.72	12.22
L_2	5.21	6.03	5.62	9.57	10.63	10.10
S.Em.±	0.07	0.08	0.05	0.14	0.15	0.10
C.D. at 5%	0.21	0.22	0.15	0.39	0.42	0.29
Micronutrient fortification (M)						
M_1	5.42	6.25	5.83	9.93	11.00	10.47
M_2	6.38	6.85	6.62	11.02	12.02	11.52
M_3	5.25	6.05	5.65	9.67	10.77	10.22
M_4	6.27	6.80	6.53	10.88	11.93	11.41
M_5	5.80	6.48	6.14	10.33	11.37	10.85
M_6	7.10	7.42	7.26	12.00	12.97	12.48
S.Em.±	0.12	0.13	0.09	0.24	0.25	0.18
C.D. at 5%	0.36	0.38	0.26	0.68	0.72	0.50
Bio enhancer (B)						
B_1	5.88	6.53	6.21	10.44	11.46	10.95
B_2	6.19	6.76	6.47	10.84	11.89	11.36
S.Em.±	0.07	0.08	0.05	0.14	0.15	0.10
C.D. at 5%	0.21	0.22	0.15	0.39	0.42	0.29
CV%	7.16	7.02	7.21	7.76	7.52	7.84
Interaction effect						
L × M	NS	NS	0.37	NS	NS	0.71
L × B	NS	NS	0.21	NS	NS	0.41
M × B	NS	NS	NS	NS	NS	NS
L × M × B	NS	NS	NS	NS	NS	NS
Y× L	0.21			0.41		
Y × M	NS			NS		
Y × B	NS			NS		
Y × L × M	NS			NS		
Y× L× B	NS			NS		
Y × M × B	NS			NS		
Y×L×M×B	0.74			1.42		

Increase in number of leaves per plant due to nitrogen, phosphorus, potassium of which phosphorus involved in cell division, photosynthesis and metabolism of carbohydrates where potash regulated proper translocation of photosynthesis and stimulated enzyme activity which increased the rate of growth and positive development which is resulted in higher number of leaves in onion. Similar finding was also reported by Sankar *et al.* (2009); Vani *et al.* (2018) in onion. Increased growth under the influence of iron might be due to its role in many physiological process and cellular functions within the plants and its effective role in biosynthesis of endogenous hormones. Zinc is essential for tryptophan synthesis which is a prerequisite for auxin formation (Manna *et al.*, 2014). The favourable effect of zinc on plant may be due to its role in many physiological and cellular functions within plants (Verma *et al.*, 2014). These findings are in close accordance with the findings of Jawaharlal *et al.* (1986); Tohamy *et al.* (2009); Abedin *et al.* (2012); Ballabh *et al.* (2012); Ballabh *et al.* (2013); Rizk *et al.* (2014); Shukla *et al.* (2015); Acharya *et al.* (2015); Begum *et al.* (2015); Singh *et al.* (2015a); Singh *et al.* (2015b) in onion. The beneficial effects of *Jeevamrut* were attributed to higher microbial load and growth hormones which might have enhanced the soil biomass thereby sustaining the availability and uptake of applied as well as native soil nutrients which ultimately resulted in better growth of crop (Vasanth Kumar, 2006). Similar findings also reported by Deva Kumar *et al.* (2008) in capsicum.

Neck thickness at 45 and 90 DAP (cm). Mean data of effect of fertility levels, micronutrient fortification and bio enhancer on neck thickness at 45 and 90 DAP were recorded, analyzed statistically are presented in Table 3.

Effect of fertility levels. Data depicted in Table3 showed the effect of fertility levels on neck thickness at 45 and 90 DAP during both the years of experiment and in pooled data. Data exhibited that neck thickness at 45 and 90 DAP was significantly influenced by fertility levels. The maximum neck thickness at 45 DAP was 0.83 cm, 0.89 cm and 0.86 cm and at 90 DAP was 2.05 cm, 2.09 cm and 2.07 cm recorded under treatment L_1 (80 % RDF) during the year 2020-21, 2021-22 and in pooled data, respectively. The minimum neck thickness at 45 DAP was 0.76 cm, 0.82 cm and 0.79 cm and at 90 DAP was 1.98 cm, 2.01 cm and 1.99 cm observed with treatment L_2 (60 % RDF) during both the years *i.e.,* 2020-21, 2021-22 and in pooled data, respectively.

Effect of micronutrient fortification. Data depicted in Table 3 showed the effect of micronutrient fortification on neck thickness at 45 and 90 DAP during both the years of experiment and in pooled analysis. Data manifested that neck thickness at 45 and 90 DAP was significantly influenced by micronutrient fortification. The maximum neck thickness at 45 DAP was 0.84 cm, 0.90 cm and 0.87 cm and at 90 DAP was 2.11 cm, 2.15 cm and 2.13 cm was recorded under treatment M_6 (Zinc + Iron @ 5 kg/ha each)] during the year 2020-21, 2021-22 and in pooled data, respectively. Though the treatment M_2 was statistically at par with treatment M_6 at 45 and 90 DAP during both the years *i.e.*, 2020-21, 2021-22 and on pooled basis. While, treatment M_4 and M_5 were statistically at par with treatment M_6 at 45 DAP during the year 2021-22 and treatment M_4 was at par with treatment M_6 at 90 DAP during both the years *i.e.,* 2020-21, 2021-22 and on pooled basis. The minimum neck thickness at 45 DAP was 0.76 cm, 0.82 cm and 0.79 cm and at 90 DAP was 1.95 cm, 1.97 cm and 1.96 cm recorded with treatment M_3 (Iron @ 5 kg/ha) during both the years *i.e.*, 2020-21, 2021-22 and in pooled data, respectively.

Effect of bio enhancer. Data given in Table 3 indicated the effect of bio enhancer on neck thickness at 45 and 90 DAP were found significant during both the years of experiment and in pooled data. Maximum neck thickness at 45 DAP was 0.81 cm, 0.87 cm and 0.84 cm and at 90 DAP was 2.05 cm, 2.08 cm and 2.06 cm recorded under treatment B_2*i.e., Jeevamrut* @ 500 l/ha at sowing, 45 DAP and 90 DAP) during the year 2020-21, 2021-22 and in pooled data, respectively. The minimum neck thickness at 45 DAP was 0.78 cm, 0.84 cm and 0.81 cm and at 90 DAP was 1.98 cm, 2.01 cm and 2.00 cm observed with treatment B_1*i.e.,* application of NPK consortium @ 5.0 l/ha at sowing during both the years *i.e.,* 2020-21, 2021-22 and in pooled data, respectively. Treatment B_1 at par with treatment B_2 at 45 DAP during the year 2020-21, 2021-22 and at 90 DAP during the year 2021-22 and in pooled data, respectively.

Interaction effect of fertility levels, micronutrient fortification and bioenhancer. Further review of Table 3 showed the various interaction effect between fertility levels (L), micronutrient fortification (M) and bio enhancer (B) and fertility levels (L) were found significant with respect to neck thickness at 45 and 90 DAP on pooled basis.

Maximum neck thickness might be due to the enhanced availability of nutrients and growth promoting substances that might have caused cell enlargement and cell multiplication which is directly correlated to the plant height and number of leaves. These results are in conformity with the findings of Gupta *et al.* (1999); Muoneke *et al*. (2003), Singh *et al.* (2004) in onion and Farooqui *et al.* (2009) in garlic.

Table 3: Effect of fertility levels, micronutrient fortification and bio enhancer on neck thickness at 45 and 90 DAP.

Treatments	Neck thickness (cm) at 45 DAP			Neck thickness (cm) at 90 DAP		
	Year 2020-21	Year 2021-22	Pooled	Year 2020-21	Year 2021-22	Pooled
Fertility Levels (L)						
L_1	0.83	0.89	0.86	2.05	2.09	2.07
L_2	0.76	0.82	0.79	1.98	2.01	1.99
S.Em.±	0.01	0.01	0.01	0.02	0.02	0.02
C.D. at 5%	0.03	0.03	0.02	0.06	0.07	0.05
Micronutrient fortification (M)						
M_1	0.77	0.83	0.80	1.96	1.99	1.98
M_2	0.81	0.87	0.84	2.05	2.08	2.06
M_3	0.76	0.82	0.79	1.95	1.97	1.96
M_4	0.80	0.86	0.83	2.03	2.06	2.05
M_5	0.78	0.85	0.82	1.99	2.03	2.01
M_6	0.84	0.90	0.87	2.11	2.15	2.13
S.Em.±	0.02	0.02	0.01	0.04	0.04	0.03
C.D. at 5%	0.05	0.05	0.03	0.11	0.11	0.08
Bio enhancer (B)						
B_1	0.78	0.84	0.81	1.98	2.01	2.00
B_2	0.81	0.87	0.84	2.05	2.08	2.06
S.Em.±	0.01	0.01	0.01	0.02	0.02	0.02
C.D. at 5%	0.03	0.03	0.02	0.06	0.07	0.05
CV%	6.95	6.97	7.04	6.65	6.79	6.75
Interaction effect						
L × M	NS	NS	0.05	NS	NS	NS
L × B	NS	NS	0.03	NS	NS	NS
M × B	NS	NS	NS	NS	NS	NS
L × M × B	NS	NS	NS	NS	NS	0.16
Y× L	0.03			NS		
Y × M	NS			NS		
Y × B	NS			0.16		
Y × L × M	NS			NS		
Y× L× B	NS			0.09		
Y × M × B	NS			NS		
Y×L×M×B	0.09			NS		

The increase in neck thickness might be due to application of zinc, which influenced the cell division, meristematic activating of plant tissues and expansion of cells and formation of cell wall by activating synthesis of aromatic amino acids *i.e.*, tryptophane, which is the precursor of auxin and stimulate the growth of plant tissues by cell elongation and cell division. These findings are similar to that of Abedin *et al.* (2012); Ballabh *et al.* (2012); Ballabh *et al.* (2013); Manna *et al.* (2014); Verma *et al.* (2014); Shukla *et al.* (2015); Acharya *et al.* (2015) in onion. Iron plays an important role in promoting growth characters, being a component of ferrodoxin, an elongation transport protein and is associated with chloroplast. Since it helps in photosynthesis, it might have helped in better vegetative growth. Iron is critical for chlorophyll formation and photosynthesis activity and that might be the reason for increasing growth of onion (Ballabh *et al.*, 2013). These findings are in close accordance with the findings of Singh *et al.* (2015a) and Singh *et al.* (2015b) in onion. *Jeevamrut* promotes immense biological activity in soil and makes the nutrients available to crop (Devakumar *et al.*, 2008).

Days taken to bulb maturity. Results regarding the effect of fertility levels, micronutrient fortification and bio enhancer on days taken to bulb maturity was recorded on significant.

B. Yield Parameters

Weight of bulb (g). The influence of fertility levels, micronutrient fortification and bio enhancer on weight of bulb are summarized in Table 4.

Effect of fertility levels. The data recorded on weight of bulb are significantly influenced by effect of fertility levels during both the years of experiment and in pooled data are furnished in Table 4. Significantly highest weight of bulb 108.03 g, 123.42 g and 115.73 g was observed under treatment L_1 (80 % RDF) during the year 2020-21, 2021-22 and in pooled data, respectively. The lowest weight of bulb was 77.36 g, 87.94 g and 82.65 g recorded with treatment L_2 (60 % RDF) during both the years *i.e.*, 2020-21, 2021-22 and in pooled data, respectively.

Effect of micronutrient fortification. Data resulted in Table 4 represented the effect of micronutrient fortification on weight of bulb during both the years of experiment and in pooled data. The results showed that significantly maximum weight of bulb 111.53 g, 126.28 g and 118.91 g was obtained under treatment M_6 (Zinc + Iron @ 5 kg/ha each) during the year 2020-21, 2021-22 and in pooled data, respectively. While, minimum weight of bulb 78.53 g, 89.73 g and 84.13 g was noticed under treatment M_3 (Iron @ 5 kg/ha) during both the years *i.e.*, 2020-21, 2021-22 and in pooled data, respectively.

Effect of bio enhancer. Data depicted in Table 4 represented the effect of bio enhancer on weight of bulb during both the years of experiment and in pooled data. Data showed that weight of bulb was significantly influenced by effect of bio enhancer. The significantly maximum weight of bulb 95.34 g, 108.19 g and 101.77 g was obtained under treatment B_2 (*Jeevamrut* @ 500 l/ha at sowing, 45 DAP and 90 DAP) during the year 2020-21, 2021-22 and in pooled data, respectively. The minimum weight of bulb 90.05 g, 103.17 g and 96.61 g was recorded with treatment B_1 (NPK consortium @ 5.0 l/ha at sowing) during both the years *i.e.*, 2020-21, 2021-22 and in pooled data, respectively.

Interaction effect of fertility levels, micronutrient fortification and bio enhancer. Data presented in Table 4 showed the interaction effect of fertility levels and bio enhancer found significant with respect to weight of.

Yield per plot (kg)

Data pertaining to effect of fertility levels, micronutrient fortification and bio enhancer on yield per plot was given in Table 4.

Effect of fertility levels. Close view of Table 4explained that yield per plot significantly influenced by effect of fertility levels. Maximum yield per plot 4.49 kg, 5.03 kg and 4.76 kg was recorded under treatment L_1 (Fertility levels *i.e.*, 80 % RDF) during the year 2020-21, 2021-22 and in pooled data, respectively. The minimum yield per plot 3.54 kg, 4.11 kg and 3.83 kg was obtained under treatment L_2 (Fertility levels *i.e.*, 60 % RDF) during the year 2020-21, 2021-22 and in pooled data, respectively.

Effect of micronutrient fortification. Data regarding effect of micronutrient fortification on yield per plot are presented in Table 4 which cleared that influence of micronutrient fortificationexerted significant influence. Treatment M_6 (Zinc + Iron @ 5 kg/ha each) showed maximum yield per plot 4.63 kg, 5.13 kg and 4.88 kg during the year 2020-21, 2021-22 and in pooled data, respectively. Whereas, minimum yield per plot 3.52 kg, 4.15 kg and 3.83 kg was observed under treatment M_3 (Iron @ 5 kg/ha) during the year 2020-21, 2021-22 and in pooled data, respectively.

Effect of bio enhancer. Data showed in Table 4 revealed that yield per plot was significantly influenced by bio enhancer during both the years and in pooled analysis. The significantly maximum yield per plot 4.11 kg, 4.68 kg and 4.40 kg was recorded under treatment B_2 (*Jeevamrut* @ 500 l/ha at sowing, 45 DAP and 90 DAP) during the year 2020-21, 2021-22 and in pooled data, respectively. The minimum yield per plot was 3.92 kg, 4.46 kg and 4.19 kg under treatment B_1 (NPK consortium @ 5.0 l/ha at sowing) during the year 2020-21, 2021-22 and in pooled data, respectively.

Interaction effect of fertility levels, micronutrient fortification and bio enhancer. The interaction effect of fertility levels and micronutrient fortification was found significant with respect to yield per plot.

Yield per hectare (q). Data regarding effect of fertility levels, micronutrient fortification and bio enhancer on yield per hectare was presented in Table 4.

Effect of fertility levels. Data related to effect of fertility levels on yield per hectare was presented in Table 4and the results showed that yield per hectare was significantly influenced by fertility levels. The maximum yield per hectare with value of 332.51 q, 372.84 q and 352.67 q were noted under treatment L_1 (80 % RDF) during the year 2020-21, 2021-22 and in pooled data, respectively. The minimum yield per hectare 262.55 q, 304.53 q and 283.54 q were recorded under treatment L_2 (60 % RDF) during the year 2020-21, 2021-22 and in pooled data, respectively.

Effect of micronutrient fortification. Data given in Table 4 indicated that the effect of micronutrient fortification on yield per hectare was found significant during both the years of experiment and in pooled data. Results manifested that yield per hectare was significantly influenced by micronutrient fortification. Treatment M_6 (Zinc + Iron @ 5 kg/ha each) showed maximum yield per hectare 343.21 q, 380.25 q and 361.73 q during the year 2020-21, 2021-22 and in pooled data, respectively. Whereas, minimum yield per hectare 260.49 q, 307.41 q and 283.95 q were noted under treatment M_3 (Iron @ 5 kg/ha) during the year 2020-21, 2021-22 and in pooled data, respectively.

Effect of bio enhancer. Perusal of data in Table 4represented the effect of bio enhancer on yield per hectare during both the years of experiment and in pooled data. Results clearly indicated that yield per hectare was significantly influenced by bio enhancer. The significantly maximum yield per hectare 304.58 q, 346.78 q and 325.68 q were recorded under treatment B_2 (*Jeevamrut* @ 500 l/ha at sowing, 45 DAP and 90 DAP)] during the year 2020-21, 2021-22 and in pooled data, respectively. While, under the treatment B_1 (NPK consortium @ 5.0 l/ha at sowing) minimum yield per hectare 290.48 q, 330.59 q and 310.53 q were observed during the year2020-21, 2021-22 and in pooled data, respectively.

Interaction effect of fertility levels, micronutrient fortification and bio enhancer. The interaction between fertility levels and micronutrient fortification was found significant with respect to yield per hectare.

Table 4: Effect of fertility levels, micronutrient fortification and bio enhancer on weight of bulb (g), yield per plot (kg) and yield per hectare (q).

Treatments	Weight of bulb (g)			Yield per plot (kg)			Yield per hectare (q)		
	Year 2020-21	Year 2021-22	Pooled	Year 2020-21	Year 2021-22	Pooled	Year 2020-21	Year 2021-22	Pooled
Fertility Levels (L)									
L_1	108.03	123.42	115.73	4.49	5.03	4.76	332.51	372.84	352.67
L_2	77.36	87.94	82.65	3.54	4.11	3.83	262.55	304.53	283.54
S.Em.±	1.43	1.47	1.04	0.06	0.07	0.05	4.38	5.00	3.34
C.D. at 5%	4.07	4.17	2.91	0.17	0.19	0.13	12.46	14.23	9.38
Micronutrient fortification (M)									
M_1	82.65	94.75	88.70	3.72	4.32	4.02	275.31	319.75	297.53
M_2	98.78	112.53	105.66	4.18	4.75	4.47	309.88	351.85	330.86
M_3	78.53	89.73	84.13	3.52	4.15	3.83	260.49	307.41	283.95
M_4	95.77	109.42	102.59	4.17	4.65	4.41	308.64	344.44	326.54
M_5	88.92	101.37	95.14	3.88	4.43	4.16	287.65	328.40	308.02
M_6	111.53	126.28	118.91	4.63	5.13	4.88	343.21	380.25	361.73
S.Em.±	2.48	2.54	1.80	0.10	0.12	0.08	7.58	8.66	5.79
C.D. at 5%	7.05	7.23	5.05	0.29	0.33	0.22	21.58	24.64	16.25
Bio enhancer (B)									
B_1	90.05	103.17	96.61	3.92	4.46	4.19	290.48	330.59	310.53
B_2	95.34	108.19	101.77	4.11	4.68	4.40	304.58	346.78	325.68
S.Em.±	1.43	1.47	1.04	0.06	0.07	0.05	4.38	5.00	3.34
C.D. at 5%	4.07	4.17	2.91	0.17	0.19	0.13	12.46	14.23	9.38
CV%	9.26	8.32	8.88	8.83	8.85	8.91	8.83	8.85	8.91
Interaction effect									
L × M	9.98	10.22	7.14	0.41	0.47	0.31	30.52	34.85	22.98
L × B	5.76	5.90	4.12	0.24	0.27	0.18	17.62	20.12	13.27
M × B	NS	NS	NS	NS	NS	NS	NS	NS	NS
L × M × B	14.11	14.46	NS	0.58	0.67	NS	43.16	49.28	NS
Y× L	4.12			0.18			13.27		
Y × M	NS			NS			NS		
Y × B	NS			NS			NS		
Y × L × M	NS			NS			NS		
Y× L× B	NS			NS			NS		
Y × M × B	NS			NS			NS		
Y×L×M×B	14.28			0.62			45.97		

An increase in weight of bulb might be due to increased bulb diameter. This might be due to efficient translocation of photosynthates to bulbs which resulted in increase in dry matter accumulation of bulbs, hence, it increased bulb weight and ultimately bulb yield (Singh *et al*., 1997). These results are in conformity with the findings of Warade *et al.* (1996); Gupta *et al.* (1999); Tiwari *et al.* (2002); Vedpathak and Chavan (2016); Sharma *et al.* (2019) in onion and Nasreen *et al.* (2009) in garlic.

Zinc is one of the most important elements and plays an important role to activate enzymes that participate in carbohydrate metabolism. The carbonic anhydrase, fructose-1, 6-bisphosphate and aldolase enzymes are activated by zinc. The activity of these enzymes decreases in zinc deficiency condition which results in carbohydrate accumulation in plant leaves and ultimately dry matter accumulation in leaves. This result is in agreement with the findings of Alam *et al.* (2010); Samad *et al.* (2011); Abedin *et al.* (2012); Ballabh *et al.* (2012); Ballabh *et al.* (2013); Trivedi and Dhumal (2013); Rizk *et al.* (2014), Manna *et al.* (2014); Verma *et al.* (2014); Acharya *et al.* (2015); Assefa *et al.* (2015a); Shukla *et al.* (2015) in onion. The improvement in weight of bulb and yield of bulb is a result of application of iron which would have enhanced photosynthesis and other metabolic activities which leads to increase in cell division and cell elongation. The present findings are in close accordance with the findings of Jawaharlal *et al.* (1986); Singh *et al.* (1993); Sindhu *et al.* (1993); Tohamy *et al.* (2009); Singh *et al.* (2015 a) in onion. The effects of *Jeevamrut* were associated to higher microbial load and growth hormones which might have enhanced the soil biomass thereby sustaining the availability and uptake of applied as well as native soil nutrients which ultimately resulted in better yield of crop. These findings are also reported by Palekar (2006); Vasanthkumar (2006); Devakumar *et al.* (2008); Boraiah *et al.* (2017).

CONCLUSIONS

In conclusion, the research extensively examined various growth, yield, quality, plant analysis, soil analysis, post-harvest, and economic parameters in onion cultivation. The application of different treatments significantly influenced many of these parameters, demonstrating the importance of nutrient management strategies. Noteworthy findings include the positive impact of the NPK consortium on plant height, the role of Zinc + Iron in enhancing yield parameters, and the beneficial effects of Jeevamrut on both yield and quality parameters. Additionally, interactions between fertility levels, micronutrient fortification, and bio-enhancers were explored. The study provides valuable insights into optimizing onion cultivation practices for improved productivity, quality, and economic returns. Based on the results of this study, it can be concluded that the application of 80 per cent RDF along with soil application of Zinc + Iron @ 5 kg each and drenching of *jeevamrut* at sowing, 45 DAP and 90 DAP was the best in terms of growth and yield parameters in *rabi* onion.

FUTURE SCOPE

The study on the "Effect of fertility levels with micronutrient fortification and bioenhancer on growth and yield of onion" provides a solid foundation for future research endeavors. A promising direction for further investigation involves a detailed exploration of specific micronutrient combinations and their synergistic effects on onion growth. Long-term assessments of soil health and sustainability, examining changes over multiple cropping seasons, would enhance our understanding of the lasting impacts of fertility interventions. Exploring alternative and sustainable nutrient delivery systems, such as precision agriculture techniques, could offer innovative solutions. Integrating climate variability into the research framework would provide insights into the resilience of nutrient management strategies in the face of changing climatic conditions. Lastly, expanding the study to include different onion varieties or diverse agro-climatic zones would contribute to more tailored and region-specific recommendations for onion cultivation practices.

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