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Research Article

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Growth and Productivity of Capsicum as Influenced by Mineral Nutrients and Nanomaterials under Polyhouse Conditions

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Abstract

Capsicum requires a significant quantity of primary nutrients; however, secondary nutrients are also necessary for high productivity. The application of metallic nutrients like zinc (Zn), iron (Fe) and magnesium (Mg) as nano-formulation has additional advantages as nanomaterials are the effective way to deliver metallic minerals to the plants. This research aims to evaluate the effectiveness of Zn, Fe and Mg as nano-mineral in combination with calcium (Ca), sulphur (S) and molybdenum (Mo) on growth and yield of capsicum (cv. Rani) with three replications in factorial randomized block design (FRBD). It was observed that application of nano-Mg or Fe in combination with wettable sulphur (WS) @ 1000 ppm each (N_3M_2 followed by N_2M_2) is significant for improving various plant growth attributes. Application of nano-Zn or Mg in combination with wettable $CaCl_2$ or WS @ 1000 ppm each (N_1M_1 followed by N_3M_1, N_1M_2 N_3M_2) is significant for improving various yield related attributes in capsicum. N_1M_1 (Rs. 13,64,247; and 3.29, respectively) followed by N_3M_1 (Rs. 12,91,542; and 3.11, respectively) and N_2M_2 (Rs. 11,36,212; and 2.73, respectively) could be the effective approach for improvement in economic yield and net return to the farmers through capsicum cultivation.

Keywords

Nanoformulation, Controlled delivery, High precision, Productivity, Economics

Introduction

Capsicum, also known as bell pepper, is grown as a perennial fruit vegetable crop in the tropics, but it is also cultivated as an annual crop in the sub-tropics [1]. Among various species of capsicum, the domesticated or cultivated species are *Capsicum annuum*, *Capsicum frutescens*, *Capsicum chinense*, *Capsicum baccatum* and *Capsicum pubescens* [2]. Although it is currently cultivated all over the world, capsicum is native to Central and Southern America [3]. Capsicum is well suited for year-round cultivation under protected conditions through manipulation of temperature and relative humidity. The ideally required climatic condition for capsicum is 25 - 30 °C and 18 - 20 °C of day and night temperature, respectively with a relative humidity of 50 - 60% for proper growth and development [4].

Capsicum is a heavy feeder nitrogen, phosphorus, and potassium; however, metallic nutrients like Zn, Fe, Ca, and Mg are also essential for high productivity. Plants require these minerals in smaller quantities than primary macronutrients [5]. A micronutrient with multiple uses, Zn is necessary for the synthesis of certain carbohydrates and chlorophyll. Additionally, it changes starches into sugars and activates the enzymes necessary to produce particular proteins. Auxin is produced by Zn, which in turn is essential for stem elongation and growth regulation [6]. Zn is essentially required for activities of hydrogenase and carbonic anhydrase enzymes and cytochrome synthesis [7] while its deficiency results in dark brown necrotic lesions between leaf veins which appears as patches in field but under stress condition the symptoms appear more rapidly [8]. This could be associated with the role of Zn in cell division, nucleic acid metabolism and control of programme cell death [9].

Fe is required for chlorophyll synthesis in plants and requisite for redox reactions in plant cells that is essential in photosynthesis process [10]. Fe is essential for growth and metabolism in plants [11]. The oxidized state of ferric ions (Fe) has low solubility in aerobic environment [12]. In plants, Fe is a critical determining factor of a wide range of cellular enzymes which are vital for photosynthesis and respiration [13]. In many crop plants, Fe deficiency results in reduced yields and nutritional value. Fe deficiency develops in soil which is too waterlogged or has been over fertilized. In the soil with excess of manganese element, somewhere interfere with Fe uptake of plants [14]. A soil pH greater than 6.5 may hinder the uptake or absorption of Fe [15].

Mg is the central atom of the green pigment in a plant, where photosynthesis takes place. Mg acts as activator of enzymes participating in photosynthesis, nucleic acid formation and synthesis of fats and oils [16]. In Mg deficient plant, older leaves show interveinal chlorosis as Mg is mobile element in plant body [17]. Mg deficiency always appear in some of the specific conditions like acidic soil with low CEC, tropical region with high rainfall leading to Mg leaching [18, 19], field with aluminum toxicity [20], heat stress [21] or unbalanced NPK fertilization leading to leaching of Mg [22].

Thus, the present study was conducted to evaluate the effectiveness of Ca, S and Mo minerals and nano form of Zn, Fe and Mg on growth and yield of capsicum grown under polyhouse.

Materials and Methods

Experimental site and unit

The current study was conducted in 2021 - 2022 at crop research center of ITM University, Gwalior, Madhya Pradesh. The investigation was carried out under naturally ventilated polyhouse supplemented with low pressure drip irrigation system.

Treatments and application

With three replications, the design of experiment was as FRBD. There were two factors viz., mineral nutrients (Ca, S, and Mo) and nanomaterials (nano-Fe, nano-Zn and nano-Mg), each of three levels, applied at the rate of 1000 ppm. In each replication, all the treatments were randomized separately. The nano-metals were chelated with EDTA and were available in composition of 12% (nano-Zn and nano-Fe) and 9.5% (nano-Mg). The details of various treatments are: N_1: nano-Zn, N_2: nano-Fe, N_3: nano-Mg, M_1: anhydrous $CaCl_2$, M_2: wettable S and M_3: ammonium molybdate tetrahydrate $[(NH_4)_6Mo_7O_{24}.4H_2O]$ as source of Mo, applied @ 1000 ppm each.

After preparation of land, the beds of height 30 cm and width 90 cm were prepared at spacing of 60 cm. The moisture level was properly maintained before transplanting and the neem cake was thoroughly mixed in soil @ 1 kg/sq. m. at the time of bed preparation.

Observations recorded

Plant growth parameters

The number of branches (primary, secondary, and tertiary branches) were counted from each plot at 45, 60, and 75 days after transplanting. The average values were estimated by adding the number of branches of each counted plant and by dividing them with plant count. Plant spread was measured by metric tape at 45, 60 and 75 days after transplanting. On each end (N-S and E-W) of plant stick was vertically incorporated in soil and then with the help of metric tape, the distance between two sticks was measured. The average values were estimated by adding spread of each selected plant and by dividing with plant count and the data was expressed in centimeter (cm).

Flowering and fruiting

This was further verified by the harvested fruit count and the number of flowers or fruits reported to be dropped or dried at the different observation periods. Total number of fruits harvested from each plant of a plot at different dates was counted and the sum was divided by plant counts to obtain the average number of fruits harvested. Percentage fruit set was also estimated by using following formula:

$$\text{Percentage fruit set (\%)} = \frac{\text{Total number of fruit harvested (per plant)}}{\text{Total number of flowers estimated (per plant)}} \times 100$$

Yield and related parameters

Total fruit diameter and length was measured and then divided by fruit count on each plant from each experimental unit. The value was expressed in cm. Total fruit weight was taken and then divided by number of fruits on each plant from each experimental unit. The value was expressed in gram (g). The economics of cultivation under different treatments was also estimated as net return (in rupee per hectare) and benefit: cost ratio.

Statistical analysis

The replicated data on various parameters were statistically analyzed by using OPSTAT software for two-way analysis of variances (ANOVA) and the hypothesis was validated at 5% level of significance for individual as well as interaction effect as suggested by Panse and Sukhatme [23].

Results and Discussion

Average number of branches per plant

The nanomaterials application has significant influence on the average count of branches per plant in capsicum estimated at 45, 60 and 75 DAT (days after transplanting) and among all the nano materials, the highest number of branches (3.83, 7.56 and 13.19, respectively) was counted in plants provided with nano-Mg @ 1000 ppm (N_1) and nano-Fe @ 1000 ppm (N_2) (3.78, 7.44 and 13.11, respectively) and lowest in nano-Zn @ 1000 ppm. There was significant influence of micronutrient application on branching in capsicum where application of S @ 1000 ppm (3.86, 7.47 and 13.17, respectively) and $CaCl_2$ @ 1000 ppm (3.47, 7.03 and 12.75, respectively) resulted in at par branch count. The interaction of nanomaterials and mineral nutrients had significantly influenced the average number of branches in capsicum at all growth stages and the highest branch count (4.17, 7.92, 13.58 respectively) was reported in N_3M_2 (nano-Mg and WS @ 1000 ppm each) which was at par with N_2M_2 (nano-Fe and WS @ 1000 ppm each) (4.08, 7.67 and 13.33, respectively) (Table 1).

The observations recorded on the number of branches in capsicum after application of variable nano materials and mineral nutrients confirms the similarity in trend as like that of number of leaves per plant. This could be described after considering the superiority of Mg and Fe over Zn as these elements might be responsible to induce the lateral growth of capsicum plants which could be in account of better translocation of photosynthates and chlorophyll pigments. Further, Mg is an essential constituent of chlorophyll pigment resulting in enhanced photosynthetic areas due to improvement in proliferation of leaves primordia [24, 25]. Mg is also in high demand by the ATP synthase and rubisco enzymes [26]. However, contribution of Mg to phloem-loading and long-distance transport of photo-assimilates and to the photoprotection of the photosynthetic apparatus which could be supportive to plant growth [27]. In addition, the nano-Mg is also involved in systemic stimulation against pathogens owing to increased synthesis of secondary metabolites and demonstrated the antimicrobial activity for various crop pathogens which could be accountable for better plant growth [28]. Nano-Fe had role in energy transfer, cellular metabolism, and cell division accounting for vigorous plant growth and its accumulation in the leaf tissues [29].

Further, the combined application of these nano materials with S had stimulatory impact on amino acids and protein synthesis favoring the increase in number of branches in capsicum. S is structural component of macromolecules and has influence on abiotic stress tolerance, augmenting the crop growth and productivity [30]. When these nanomaterials have been interacted with S in various combinations, the synthesis of amino acids like methionine and cysteine might be accelerated or enhanced resulting in synthesis of protein and better plant growth [31].

Table 1: Average number of branches in capsicum at 45, 60 and 75 days after transplanting (DAT).

Average number of branches at 45 DAT				
Treatments	**M_1**	**M_2**	**M_3**	**Mean N**
N_1	2.83^c	3.33^c	3.17^d	3.11^B
N_2	3.67^b	4.08^a	3.58^b	3.78^A
N_3	3.92^a	4.17^a	3.42^c	3.83^A
Mean M	3.47^B	3.86^A	3.39^B	-
Factors	**C.D.**	**SE(d)**	**SE(m) ±**	**P value**
Factor (N)	1.432	0.867	0.634	< 0.01**
Factor (M)	1.432	0.867	0.634	< 0.01**
Factor (N x M)	2.745	1.438	1.118	< 0.01**
Average number of branches at 60 DAT				
Treatments	**M_1**	**M_2**	**M_3**	**Mean N**
N_1	6.08^e	6.83^d	6.67^d	6.53^B
N_2	7.42^b	7.67^a	7.25^c	7.44^A
N_3	7.58^b	7.92^a	7.17^d	7.56^A
Mean M	7.03^B	7.47^A	7.03^B	-
Factors	**C.D.**	**SE(d)**	**SE(m) ±**	**P value**
Factor (N)	0.144	0.068	0.048	< 0.01**
Factor (M)	0.144	0.068	0.048	< 0.01**
Factor (N x M)	0.25	0.117	0.083	0.00024**
Average number of branches at 75 DAT				
Treatments	**M_1**	**M_2**	**M_3**	**Mean N**
N_1	11.92^d	12.58^c	12.17^c	12.22^B
N_2	13.08^c	13.33^b	12.92^c	13.11^A
N_3	13.25^b	13.58^a	12.75^c	13.19^A
Mean M	**12.75^B**	**13.17^A**	**12.61^B**	-
Factors	**C.D.**	**SE(d)**	**SE(m) ±**	**P value**
Factor (N)	0.132	0.062	0.044	< 0.01**
Factor (M)	0.132	0.062	0.044	< 0.01**
Factor (N x M)	0.228	0.107	0.075	0.00157**

Average plant spread

The nanomaterials application significantly influenced the average plant spread (N-S and E-W spread) in capsicum measured at 45, 60 and 75 DAT, and the variation was nearly at par to nano-Mg @ 1000 ppm (21.46 cm and 21.36 cm, 29.85 cm and 29.79 cm, 40.22 cm and 40.23 cm, respectively) and nano-Fe @ 1000 ppm (22.03 cm and 21.00 cm, 29.77 cm and 29.77 cm, 39.95 cm and 39.95 cm, respectively) followed by nano-Mg @ 1000 ppm. There was significant influence of micronutrient application on plant spread (N-S and E-W spread) of capsicum recorded at 45 days, 60 days and 75 days after transplanting where the highest average plant spread (22.79 cm and 21.27 cm, 29.97 cm and 29.90 cm, 40.31 cm and 40.23 cm, respectively) was measured after S @ 1000 ppm followed by the plants treated with $CaCl_2$ @ 1000 ppm (19.94 cm and 20.00 cm, 28.66 cm and 28.62 cm, 38.14 cm and 39.95 cm, respectively) and lowest in Mo @ 1000 ppm. The interaction between nanomaterials and micronutrients on the average plant spread (N-S and E-W spread) in capsicum was significant and the variation was nearly at par for N_3M_2, N_2M_2 and N_3M_1 while the lowest was recorded in N_1M_1 (Table 2 and table 3).

Plant spread is the function of the number of branches and the number of leaves in a plant and depends on the foliage development over the branches developed throughout the different growth stages. The spread of capsicum plants measured in N-S and E-W directions after applications of various nano materials and/or the minerals reflects a significant variation where nano Mg and nano Fe were reported to be at par which could be attributed with the common influence of these materials over the biomass of capsicum plants resulting in better plant growth and the biomass production [24]. Increase in photosynthetic pigments and IAA could be associated with increased peroxidase, polyphenol-oxidase and nitrate-reductase activities in the plant treated with nano Fe [32]. Further, Fe is associated with carbohydrate metabolism, maintaining homeostasis with improvement in Fe uptake which suggests that nanoscale zerovalent Fe can enhance CO_2 uptake by plant [33].

When nanomaterials have been interacting with S in various combinations, the synthesis of S containing amino acids might be enhanced, favoring the protein synthesis to improve differentiation of leaf primordia to increase leaf count in plant [31]. The limited Ca was secondary in comparison to S and other nano- materials which could be due to its limited role in plant growth.

Flowering and fruiting

The nanomaterials application has non-significantly influenced the fruit count and percentage of fruit set in capsicum. The total flower and fruit counts on the capsicum plants recorded at different phase of observation was reflected a signif-

Table 2: Average plant spread in N-S direction (cm) in capsicum at 45, 60 and 75 DAT.

Average plant spread (N-S) at 45 DAT				
Treatments	**M_1**	**M_2**	**M_3**	**Mean N**
N_1	17.725^a	19.642^a	18.583^a	18.65^B
N_2	20.767^a	21.767^a	20.575^a	21.036^A
N_3	21.333^a	22.792^a	20.275^a	21.467^A
Mean M	19.942^B	21.40^A	19.811^B	-
Factors	**C.D.**	**SE(d)**	**SE(m) ±**	**P value**
Factor (N)	0.747	0.35	0.247	< 0.01**
Factor (M)	0.747	0.35	0.247	0.00049**
Factor (N x M)	NS	0.606	0.428	0.21795
Average plant spread (N-S) at 60 DAT				
Treatments	**M_1**	**M_2**	**M_3**	**Mean N**
N_1	26.293^d	28.07^c	27.51^c	27.291^B
N_2	29.453^b	30.86^a	28.997^b	29.77^A
N_3	30.233^a	31.003^a	28.34^c	29.859^A
Mean M	28.66^B	29.978^A	28.282^B	-
Factors	**C.D.**	**SE(d)**	**SE(m) ±**	**P value**
Factor (N)	0.627	0.293	0.207	< 0.01**
Factor (M)	0.627	0.293	0.207	0.00007**
Factor (N x M)	1.086	0.508	0.359	0.00882**
Average plant spread (N-S) at 75 DAT				
Treatments	**M_1**	**M_2**	**M_3**	**Mean N**
N_1	34.62^c	38.467^b	37.933^b	37.007^B
N_2	39.637^b	40.993^a	39.243^b	39.958^A
N_3	40.32^a	41.483^a	38.877^b	40.227^A
Mean M	38.192^B	40.314^A	38.684^C	-
Factors	**C.D.**	**SE(d)**	**SE(m) ±**	**P value**
Factor (N)	1.004	0.47	0.332	< 0.01**
Factor (M)	1.004	0.47	0.332	0.00091**
Factor (N x M)	1.739	0.813	0.575	0.0096**

Table 3: Plant spread in E-W direction (cm) in capsicum at 45, 60 and 75 DAT.

Average plant spread (E-W) at 45 DAT				
Treatments	**M_1**	**M_2**	**M_3**	**Mean N**
N_1	17.985^a	19.635^a	18.935^a	18.852^B
N_2	20.833^a	21.642^a	20.552^a	21.009^A
N_3	21.192^a	22.533^a	20.377^a	21.367^A
Mean M	20.003^B	21.27^A	19.954^C	-
Factors	**C.D.**	**SE(d)**	**SE(m) ±**	**P value**
Factor (N)	0.789	0.369	0.261	0.00001^{**}
Factor (M)	0.789	0.369	0.261	0.00358^{**}
Factor (N x M)	NS	0.639	0.452	0.3187
Average plant spread (N-S) at 60 DAT				
Treatments	**M_1**	**M_2**	**M_3**	**Mean N**
N_1	26.342^d	28.068^c	27.477^c	27.296^B
N_2	29.51^b	30.693^a	29.118^b	29.774^A
N_3	30.01^a	30.942^a	28.437^b	29.796^A
Mean M	28.621^B	29.901^A	28.344^B	-
Factors	**C.D.**	**SE(d)**	**SE(m) ±**	**P value**
Factor (N)	0.665	0.311	0.22	$< 0.01^{**}$
Factor (M)	0.665	0.311	0.22	0.00028^{**}
Factor (N x M)	1.152	0.539	0.381	0.03534^{*}
Average plant spread (N-S) at 75 DAT				
Treatments	**M_1**	**M_2**	**M_3**	**Mean N**
N_1	34.608^c	38.48^b	37.933^b	37.008^B
N_2	39.642^a	40.993^a	39.243^b	39.959^A
N_3	40.325^a	41.5^a	38.877^b	40.234^A
Mean M	38.192^C	40.326^A	38.684^B	-
Factors	**C.D.**	**SE(d)**	**SE(m) ±**	**P value**
Factor (N)	1.001	0.468	0.331	$< 0.01^{**}$
Factor (M)	1.001	0.468	0.331	0.00084^{**}
Factor (N x M)	1.734	0.811	0.574	0.00905^{**}

icant variation among different treatments of micronutrients with the highest value due to application of $CaCl_2$ @ 1000 ppm (18.61 and 11.11, respectively) followed by S @ 1000 ppm (15.30 and 9.69, respectively) with the percentage fruit set of 60.60 and 64.58, respectively; however, it was highest after application of Mo @ 1000 ppm (70.05). The interaction effect of nanomaterials and micronutrients on total flower and fruit counts of the capsicum plants was significant and the highest value (19.60 and 11.58, respectively) was estimated after application of N_1M_1 (nano-Zn and $CaCl_2$) followed by N_3M_1 (nano-Mg and $CaCl_2$) (18.65 and 10.92, respectively); however, the fruit set reflected a non-significant variation due to interaction. (Table 4). The significance of S lies in the increase of fruit count per plant in capsicum might be associated with its role in signaling in stress management as well as normal metabolic process [34]. The role of Mo in fruit set has not been reported by any authors.

Although nanomaterials containing Zn, Fe and Mg had not resulted in significant variation for number of fruits per plant, their interaction with the minerals viz., Ca and S had resulted in the significant variation at later stage of observation. This confirms that application of nano-Zn, nano-Fe and nano-Mg has similar influence over the fruit set. However, the variation after application of these nanomaterials with Ca could be attributed to the strong interaction between nanomaterials and Ca ions (Ca-Zn, Ca-Fe, Ca-Mg interaction. The Ca-Zn interaction was reported to be more prominent over Ca-Mg while lowest in Ca-Fe which could be due to higher negative enthalpy of Ca-Zn interaction than others [35, 36].

Average fruit size and weight

The influence of mineral nutrients application on average fruit size (diameter and length of fruits) and the average fruit weight was significant. The highest value (7.577 cm, 11.559 cm, and 204.013 g, respectively) was observed due to $CaCl_2$ (M_1) followed by S (M_2) (7.392 cm, 10.952 cm, and 182.451 g, respectively). There was no significant influence of nanomaterials and mineral nutrients interaction on average fruit size (diameter and length of fruits) and the average fruit weight of capsicum fruits. The parameters related to the yield are directly correlated with the fruit set and retention and all the factors promoting the fruit set and fruit retention are accountable for improvement in fruit yield related attributes viz., number of fruits harvested, average fruit weight (length, diameter, or fruit weight) harvested from each plant. Although there was no significant variation in fruit count and fruit weight due to the spraying of the nano Zn or Mg or Fe, the role of these elements in yield and its contributing factors cannot be ignored (Table 5). This can be described on the basis of their significant role during interaction with the mineral nutrients (Ca, S or Mo) applied as combination in these treatments. The integrated approach of application of Ca with Zn has also been de-

Table 4: Total number of flowers per plant, harvested fruits per plant and percentage fruit set in capsicum.

Total number of flowers per plant				
Treatments	**M_1**	**M_2**	**M_3**	**Mean N**
N_1	19.60^a	16.17^d	11.42^i	15.73^A
N_2	17.58^c	14.50^f	13.58^g	15.22^B
N_3	18.65^b	15.25^e	12.50^h	15.47^B
Mean M	18.611^A	15.304^B	12.50^C	-
Factors	**C.D.**	**SE(d)**	**SE(m) ±**	**P value**
Factor (N)	0.244	0.114	0.081	0.00163^{**}
Factor (M)	0.244	0.114	0.081	$< 0.01^{**}$
Factor (N x M)	0.423	0.198	0.140	$< 0.01^{**}$
Total number of harvested fruits per plant				
Treatments	**M_1**	**M_2**	**M_3**	**Mean N**
N_1	11.58^a	10.17^b	7.83^d	9.86^A
N_2	10.83^a	9.25^c	9.17^c	9.75^A
N_3	10.92^a	9.67^b	8.67^c	9.75^A
Mean M	11.11^A	9.69^B	8.56^C	-
Factors	**C.D.**	**SE(d)**	**SE(m) ±**	**P value**
Factor (N)	NS	0.248	0.176	0.87602
Factor (M)	0.531	0.248	0.176	$< 0.01^{**}$
Factor (N x M)	0.92	0.43	0.304	0.01328^{*}
Percentage fruit set				
Treatments	**M_1**	**M_2**	**M_3**	**Mean N**
N_1	59.76^a	63.787^a	71.037^a	64.861^A
N_2	62.503^a	65.00^a	68.71^a	65.404^A
N_3	59.54^a	64.967^a	70.403^a	64.97^A
Mean M	60.60^B	64.584^B	70.05^A	-
Factors	**C.D.**	**SE(d)**	**SE(m) ±**	**P value**
Factor (N)	NS	1.733	1.226	0.94666
Factor (M)	3.706	1.733	1.226	0.00022^{**}
Factor (N x M)	NS	3.002	2.123	0.74427

scribed by Haleema et al. [37]. Similarly, the variation due to application of nanometals with Ca could be due to the positive interaction between nanomaterials with Ca ions [35, 36].

Further, Zn has its role in protein and nucleic acid metabolism regulating the cell division and improvement in fruit size and weight [38]. Higher yield due to the foliar application of Zn might also be associated with enrichment of Ca and P in leaves as confirmed by Xie et al. [39]. El-Desouky et al. [40] had also reported the maximum fruit size, count and weight related attributes after application of nano-Fe (100 mg/kg) in tomatoes grown under greenhouse conditions.

The positive response of Ca in flowering and fruiting could be related to its role as intracellular messenger and maintaining the ionic balance to counteract the toxic effects of other nutrients [41, 42]. Ca also improves the phosphorus uptake which could be associated with high yield per plant in capsicum after application of Ca [43]. Next to Ca, S had also resulted in improvement in flowering and fruiting or yield in capsicum as S is structural component of macromolecules and has influence on abiotic stress tolerance, augmenting the crop growth and productivity [30].

Economics of cultivation of capsicum

Net return and benefit cost ratio from capsicum cultivation after application of nanomaterials and micronutrients are presented in figure 1 and figure 2. The highest net return, and B:C ratio was reported in N_1M_1 (Rs. 13,64,247; and 3.29, respectively) followed by N_3M_1 (Rs. 12,91,542; and 3.11, respectively) and N_2M_2 (Rs. 11,36,212; and 2.73, respectively). These treatments have resulted in a significantly high B:C ratio due to high gross or net return and relatively low cost of cultivation. The high gross or net return might be associated with the greater yield in these treatments. Though, the treatments resulting in B:C ratio more than 1 should be considered beneficial in production economics but it should be greater than

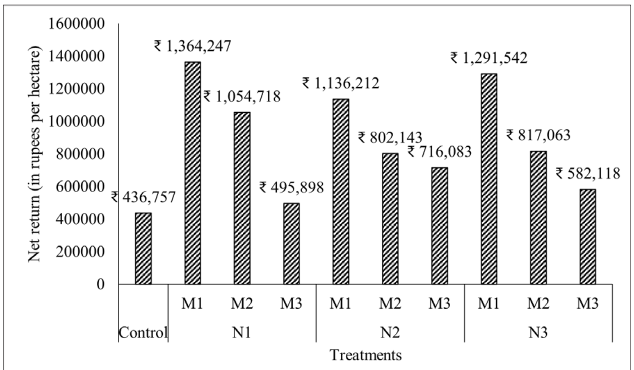

Figure 1: Net return (in rupees per hectare) from capsicum cultivation after application of nanomaterials and micronutrients.

Table 5: Yield and yield contributing traits in capsicum.

Average diameter of fruits (cm)				
Treatments	**M_1**	**M_2**	**M_3**	**Mean N**
N_1	7.397^a	7.333^a	6.16^a	6.963^A
N_2	7.36^a	7.267^a	6.73^a	7.119^A
N_3	7.973^a	7.577^a	6.75^a	7.433^A
Mean M	7.577^A	7.392^B	6.547^C	-
Factors	**C.D.**	**SE(d)**	**SE(m) ±**	**P value**
Factor (N)	NS	0.278	0.197	0.25693
Factor (M)	0.595	0.278	0.197	0.00433**
Factor (N x M)	NS	0.482	0.341	0.82865
Average length of the fruit (cm)				
Treatments	**M_1**	**M_2**	**M_3**	**Mean N**
N_1	11.613^a	11.177^a	9.55^a	10.78^A
N_2	11.06^a	10.207^a	9.647^a	10.304^A
N_3	12.003^a	11.473^a	9.77^a	11.082^A
Mean M	11.559^A	10.952^B	9.656^C	-
Factors	**C.D.**	**SE(d)**	**SE(m) ±**	**P value**
Factor (N)	NS	0.459	0.325	0.26214
Factor (M)	0.982	0.459	0.325	0.00245**
Factor (N x M)	NS	0.796	0.563	0.84774
Average weight (g) of the fruits				
Treatments	**M_1**	**M_2**	**M_3**	**Mean N**
N_1	207.223^a	195.403^a	158.39^a	187.006^A
N_2	193.71^a	177.907^a	167.283^a	179.633^A
N_3	211.107^a	174.043^a	155.343^a	180.164^A
Mean M	204.013^A	182.451^B	160.339^C	-
Factors	**C.D.**	**SE(d)**	**SE(m) ±**	**P value**
Factor (N)	NS	5.72	4.044	0.37809
Factor (M)	12.23	5.72	4.044	< 0.01**
Factor (N x M)	NS	9.907	7.005	0.13628

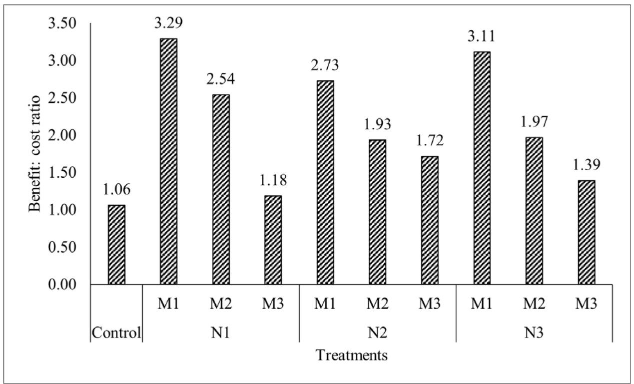

Figure 2: Benefit: cost ratio (on net return basis) from capsicum cultivation after application of nanomaterials and micronutrients.

B:C ratio of control to get accepted by the farming society. However, treatments having a B:C ratio of more than 1 with high net return can also be considered as a profitable option. The present findings of economic analysis can be confirmed by the result of work described by Kumar et al. [44].

Conclusion

On the basis of investigation, consisting of the application of Ca, S and Mo as minerals while Zn, Fe and Mg as nanomaterials in capsicum, the following conclusion are interpreted: (1) Application of nano-Mg or Fe in combination with WS @ 1000 ppm each (N_3M_2 followed by N_2M_2) is significant for improving various plant growth attributes. (2) Application of nano-Zn or Mg in combination with wettable $CaCl_2$ or wettable S @ 1000 ppm each (N_1M_1 followed by N_3M_1, N_1M_2, N_3M_2) is significant for improving various yield related attributes in capsicum and profitability. Though the present investigation was carried out under polyhouse, these treatments may also be suitable for cultivation of capsicum under open field conditions.

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Conflict of Interest

None.

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