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RESEARCH ARTICLE

# Boosting quality and yield of garlic (*Allium sativum* L.): The synergy of microbiome and chemical fertilizers

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## Abstract

The replacement of chemical fertilizers with organic alternatives has demonstrated significant benefits for enhancing soil fertility and crop yield. However, limited research exists on sustainable fertilization strategies for garlic-based cropping pattern. This study aimed to investigate the changes in microbial community composition under various fertilization treatments during the garlic-growing season. An experiment was carried out at SKUAST-K, Wadura, Faculty of Agriculture during the year 2021 to study the impact of various Integrated Nutrient Management (INM) modules on soil properties and various quality parameters of garlic (*Allium sativum* L.). The study evaluated various soil properties, including texture, bulk density, particle density, pH, electrical conductivity (EC), organic carbon (OC) and primary nutrient uptake. The soil was characterized as silty loam, with the highest particle density and bulk density observed at 2.47 mg $m^{-3}$ and 1.30 mg $m^{-3}$, respectively. An improvement in soil fertility conditions was seen as a result of integrated nutrient management. The application of combined organic and inorganic fertilizer affected the amount of nitrogen, phosphorus and potassium that was absorbed by garlic. The data revealed that pH decreased with increase in organic manure, whereas EC and OC increased with increase in the level of fertilizers. The increasing trend was observed in micronutrient cations, namely Zn, Cu, Mn and Fe, with increase in level of organic and inorganic fertilizers. The highest uptake of nitrogen, phosphorus and potassium found in bulbs was 28.17, 8.57 and 24.70 kg $ha^{-1}$ all treatments were combined. The maximum biomass of garlic was recorded in $T_7$ {75 % RDF + Vermicompost (10 t $ha^{-1}$) + Biofertilizer [(PSB (200 mL) + KSB (200 mL) + *Azotobacter* (200 mL)]}, which ranged from 4.37 to 10.30 t $ha^{-1}$. The maximum bulb yield was recorded in $T_7$, which varied from 3.60 to 8.24 t $ha^{-1}$.

**Keywords:** biofertilizer; bulb yield; integrated nutrient management; quality; vermicompost

## Introduction

Plants' genetic makeup influences the amount of nutrition required by them for their growth and development to some degree (1). The availability and uptake of nutrients are influenced by a combination of physical, chemical and biological factors. Manures were the main source of nutrients used in production before chemical fertilizers were developed (2). Apart from providing soil with nutrients, manure enhances soil health by augmenting soil organic matter and stimulating the population of beneficial organisms. Manure addition to a field helps to increase the soil's water-holding capacity and structure, which lowers soil erosion (3). Garlic (*Allium sativum* L.) is the most commonly cultivated genus of *Allium*, after the Alliaceae family of onions. It is native to Central Asia and is considered to be its secondary Centre of origin in the Mediterranean region. It is one of the world's leading *Allium* vegetable crops, produced in terms of production and economic value. It is known as a desirable spice worldwide and is among the most significant commercially cultivated, profitable, bulbous and therapeutic crops. India is known as the home of spices and produces a wide range of spices, including black pepper, ginger, garlic, turmeric, chilli and a number of tree and seed spices. The bulb of garlic is antirheumatic, restorative, secondary hyperhidrosis, expectorant, mucolytic, laxative, antispasmodic, constringent, antiparalytic, antileprotic, purgative, antipyretic, demulcent, enteric, substitute and emmenagogue. Compared to other bulbous crops, garlic has a higher nutritive value. It has high levels of fat, vitamin C and sulfur in addition to being a rich source of minerals (0.3 %), proteins, carbs (29 %) and essential oils (0.1-0.4 %) (4).

The application of organic manures and biofertilizers has been shown to enhance the physical, chemical and biological properties of soil. However, organic manures alone may not be able to fulfil the nutritional requirements of high-yielding cultivars, there fore a need to supplement the nutrients by integrating organic with inorganic and biofertilizers. Excessive volumes of inorganic fertilizers are applied to vegetable crops in order to increase output (5). The overuse of chemical fertilizers led to a shortage of nutrients other than those that were applied and a decrease in the amount of organic carbon in the soil. Additionally, according to Arisha and Bardisi (6), using just inorganic fertilizers is bad for the environment and human health. Organic manure can serve as a viable alternative to mineral fertilizers. It has been demonstrated to increase soil biomass and improve soil structure (7-9). In light of these findings, the difficulty is in combining chemical fertilizers with varying grades of organic manure to maximize the availability of nutrients for garlic, resulting in improved bulb quality and yield. In consideration of this, the current study was conducted to confirm how nutrient management affects soil characteristics and nutrient uptake of garlic.

## Materials and Methods

An experiment was conducted during the year 2021 in a RCBD (Randomized Complete Block Design) with three replications consisting of 12 treatments at the Faculty of Agriculture Farm, Wadura, using garlic (*Allium sativum* L.) as a test crop. Large-sized cloves were chosen for planting and the plot was maintained at 3 m × 2 m with a 15 cm × 10 cm spacing. Table 1 lists the treatment details.

### Location and climate

The field experiment was set up in the northern region of Kashmir valley, situated at 34°34' N latitude and 74°40' E longitude having altitude of 1584 m above mean sea level. According to the climatic point of view, the trial was located in the temperate region with mid-altitude. The climate of the valley is very warm during summers, followed by cold winters. Most of the precipitation is received in winter, mainly during December to March (Fig. 1). The entire dosage of P and K was administered at the time of planting, while 50 % of the nitrogen was applied as the basal at the time of planting and the remaining 50 % in two equal splits between 30 and 45 days later. Biofertilizers and all organic manures (FYM, VC) were administered at a baseline dosage. Harvesting occurs when the tops of the garlic crop went from yellow to light brown, indicating drying.

### Collection and analysis of soil samples

The soil samples were collected from randomly chosen spots (0-15 cm) before sowing and treatment-wise after harvesting of the crop. These samples were shade dried and after that samples were processed and analyzed for various physical and chemical properties as per the standard procedures. The mechanical analysis of soil samples was carried out by the hydrometer method (10). The micronutrient cations, namely Zn, Fe, Mn and Cu, were measured in soil samples by using DTPA extractant (11).

### Nutrient uptake, yield and quality parameters

The nutrient uptake was calculated using the formula given below:

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \text{Nutrient content (\%)} \times \text{Dry plant biomass}$$

Biomass yield (t ha$^{-1}$) was recorded by weighing the plant along with the bulb after the harvest of the crop. The bulb yield (t ha$^{-1}$) was recorded on 10 randomly selected bulbs from each treatment. Bulb yield per hectare was

**Table 1.** Treatment details used in the investigation

| Treatments | Treatment details |
|---|---|
| T1 | RDF: N (100 kg ha$^{-1}$): $P_2O_5$(60 kg ha$^{-1}$): $K_2O$ (60 kg ha$^{-1}$): FYM (30 t) ha$^{-1}$ |
| T2 | 75 % RDF+FYM (30 t ha$^{-1}$) |
| T3 | 100 % RDF+ Vermicompost (7.5 t ha$^{-1}$) |
| T4 | 75 % RDF+ Vermicompost (10 t ha$^{-1}$) |
| T5 | 100 % RDF+ {Biofertilizer (PSB (200 mL) + KSB (200 mL) + Azotobacter (200 mL)} |
| T6 | 75 % RDF+ {Biofertilizer (PSB (200 mL) + KSB (200 mL) + Azotobacter (200 mL)} |
| T7 | 75 % RDF+ Vermicompost (10 t ha$^{-1}$) + {Biofertilizer (PSB (200 mL) + KSB (200 mL) + Azotobacter (200 mL)} |
| T8 | 75 % RDF+ FYM (30 t ha$^{-1}$) + {Biofertilizer (PSB (200 mL) + KSB (200 mL) + Azotobacter (200 mL)} |
| T9 | 50 % RDF+ FYM (30 t ha$^{-1}$) |
| T10 | 50 % RDF+ Vermicompost (15 t ha$^{-1}$) |
| T11 | 50 % RDF + FYM (15 t ha$^{-1}$) + Vermicompost (7.5 t ha$^{-1}$) |
| T12 | 50 % RDF + FYM (15 t ha$^{-1}$) + Vermicompost (7.5 t ha$^{-1}$) + {Biofertilizer (PSB) (200 mL) + KSB (200 mL) + Azotobacter (200 mL)} |

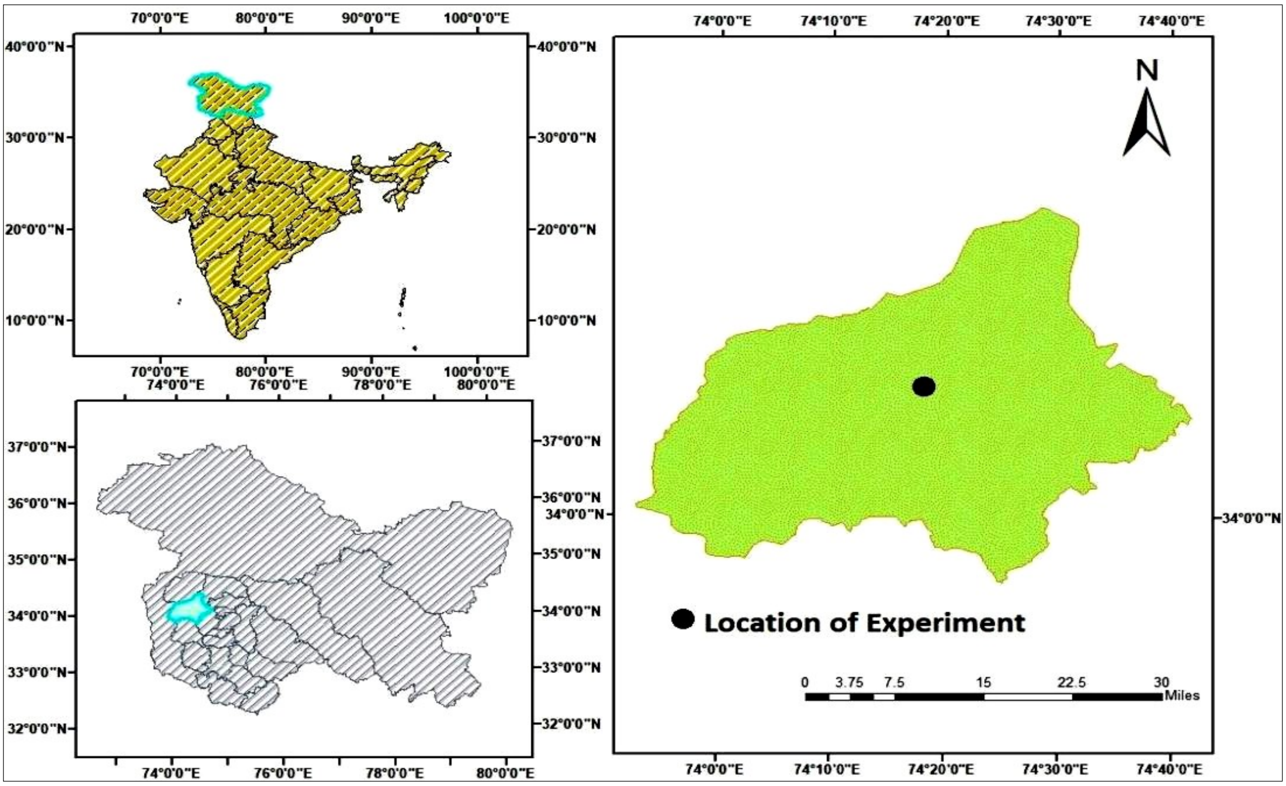


**Fig. 1.** Location of field experiment by map.

computed by multiplying the bulb yield per plot for each treatment by the conversion factor. The size of cloves (cm) was measured using a vernier caliper. The diameter of bulbs (cm) was measured using vernier caliper. Bulb weight (g) was measured using a digital balance and the results of experimental field initially are presented below in Table 2.

### Statistical analysis

To analyze the variance, RCBD was used to examine the data on various parameters that were gathered during the experiment. The analysis was done using OPSTAT and R software.

## Results

### Basic soil characteristics

The texture of the experimental soil was silty clay loam. The particle and bulk densities did not vary significantly by the application of various organic, inorganic and biofertilizers (Table 3). The highest values for particle (2.47 mg $m^{-3}$) and bulk (1.30 mg $m^{-3}$) densities were found in $T_1$ (Recommended NPK) and the lowest values (2.39 and 1.26 mg $m^{-3}$) for $T_5$ (Table 3). The pH of the soil did not show significant differences on application of various treatments. However, the pH decreased on increasing the concentration of organic manure. The pH was found highest in $T_{10}$ (6.95) and lowest in $T_7$ (6.71). However, a reverse trend was found in EC and OC, which increased with the application of organic, inorganic and biofertilizers. The highest value of EC and OC was recorded in $T_{11}$ (0.47) and $T_7$ (0.90) and was lowest in $T_8$ (0.37) and $T_9$ (0.81), respectively (Fig. 2).

**Table 2.** Initial physical and chemical properties of experimental field

| Particulars | Status | Rating | Method applied |
|---|---|---|---|
| **A. Physical analysis** | | | |
| Coarse sand (%) | 10.50 | | (10) |
| Silt (%) | 54.20 | | |
| Clay (%) | 35.30 | | |
| Texture | | Silty clay loam | |
| Particle density g/cm3 | 2.51 | Medium | (12, 13) |
| Bulk density g/cm3 | 1.34 | Medium | |
| **B. Chemical analysis** | | | |
| pH (1:2.5 soil water suspension) | 6.94 | Neutral | (14) |
| Electrical conductivity ($dSm^{-1}$) | 0.39 | Normal | (14) |
| Organic carbon (%) | 0.76 | Medium | (15) |
| Available nitrogen (kg $ha^{-1}$) | 316.40 | Medium | (16) |
| Available phosphorus (kg $ha^{-1}$) | 16.95 | Medium | (17) |
| Available potassium (kg $ha^{-1}$) | 201.22 | Medium | (14) |

**Table 3.** Effect of INM modules on soil basic properties

| Treatment | Bulk Density (Mg m$^{-3}$) | Particle Density (Mg m$^{-3}$) | pH | EC (dSm$^{-1}$) | OC (%) |
|---|---|---|---|---|---|
| T1 | 1.27 | 2.47 | 6.73 | 0.43 | 0.87 |
| T2 | 1.26 | 2.46 | 6.70 | 0.44 | 0.85 |
| T3 | 1.28 | 2.45 | 6.73 | 0.42 | 0.88 |
| T4 | 1.28 | 2.41 | 6.74 | 0.41 | 0.88 |
| T5 | 1.28 | 2.39 | 6.72 | 0.39 | 0.89 |
| T6 | 1.30 | 2.45 | 6.79 | 0.44 | 0.85 |
| T7 | 1.27 | 2.44 | 6.71 | 0.39 | 0.90 |
| T8 | 1.29 | 2.42 | 6.74 | 0.37 | 0.90 |
| T9 | 1.30 | 2.40 | 6.90 | 0.45 | 0.81 |
| T10 | 1.28 | 2.43 | 6.95 | 0.44 | 0.84 |
| T11 | 1.28 | 2.45 | 6.88 | 0.47 | 0.82 |
| T12 | 1.26 | 2.43 | 6.89 | 0.46 | 0.85 |
| SE(m) ± | 0.02 | 0.03 | 0.03 | 0.02 | 0.04 |
| C.D. p≤ 0.05) | NS | NS | NS | NS | NS |

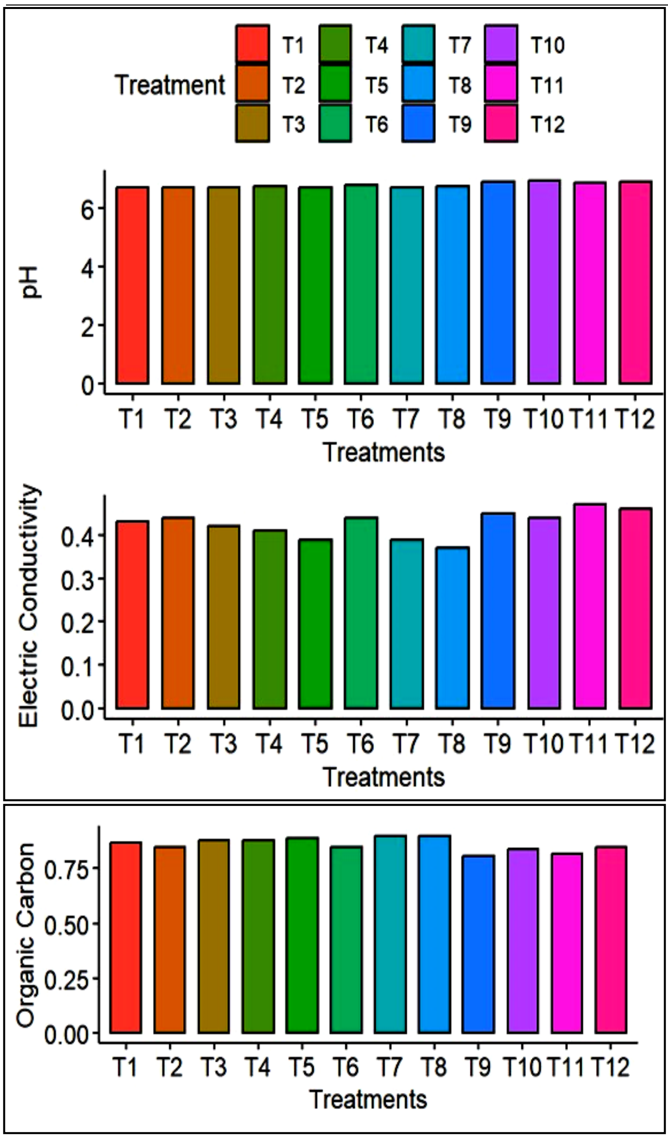


**Fig. 2.** Effect of INM on soil basic properties.

## Soil available nutrients

Available N, P and K status in soil varied significantly after the harvest of crop. The maximum content of the N, P and K was found in the $T_9$ (50 % RDF + FYM = 30 t ha$^{-1}$) while the minimum was recorded in $T_7$ (75 % RDF+ Vermicompost (10 t ha$^{-1}$) + {Biofertilizer (PSB (200 mL) + KSB (200 mL) + Azotobacter (200 mL)}). The maximum value of available nitrogen was recorded with $T_9$ (395.94 kg ha$^{-1}$), followed by $T_{11}$ (379.00 kg ha$^{-1}$) and $T_{10}$ (363.68 kg ha$^{-1}$) and the lowest was recorded for $T_7$ (271.96 kg ha$^{-1}$). The available phosphorus and potassium were also found maximum in $T_9$ (20.16 kg $P_2O_5$ ha$^{-1}$) and (274.18 kg $K_2O$ ha$^{-1}$), respectively, the minimum values for available phosphorus and potassium were recorded in $T_7$ with values of (11.45 kg ha$^{-1}$) and (141.07 kg ha$^{-1}$), respectively (Table 4 & Fig. 3).

**Table 4.** Effect of INM modules on soil available nutrients

| Treatments | N (kg ha$^{-1}$) | P (kg ha$^{-1}$) | K (kg ha$^{-1}$) |
|---|---|---|---|
| $T_1$ | 299.82 | 13.31 | 225.24 |
| $T_2$ | 341.92 | 14.21 | 240.71 |
| $T_3$ | 294.39 | 12.00 | 220.95 |
| $T_4$ | 292.02 | 11.62 | 201.42 |
| $T_5$ | 279.82 | 11.59 | 190.96 |
| $T_6$ | 320.96 | 13.39 | 232.03 |
| $T_7$ | 271.96 | 11.45 | 141.07 |
| $T_8$ | 275.29 | 11.51 | 174.84 |
| $T_9$ | 395.94 | 20.16 | 274.18 |
| $T_{10}$ | 363.68 | 18.40 | 259.40 |
| $T_{11}$ | 379.00 | 19.37 | 267.59 |
| $T_{12}$ | 348.41 | 16.47 | 250.64 |
| SE(m)± | 7.66 | 0.38 | 3.17 |
| C.D. p≤(0.05) | 14.43 | 1.13 | 9.60 |

## Soil available micronutrients

The available micronutrients Zn, Cu, Mn and Fe varied significantly among the different treatments. The value was highest for Treatment $T_{12}$ (0.96, 2.42, 15.25 and 47.42 mg kg$^{-1}$) for Zn, Cu, Mn and Fe, respectively. The results suggested that on increasing the concentration of organic manures accompanied by synthetic fertilizers, the concentration of Zn, Cu, Mn and Fe also increases. The Zn content among different treatments varied significantly, with highest in $T_{12}$, followed by $T_8$ (0.93) and $T_{11}$ (0.90) and was lowest recorded for $T_1$ (0.50). The Cu content in soil showed significant highest value with $T_{12}$, followed by $T_8$ (2.18) and $T_{11}$ (2.08) and the lowest recorded for $T_1$ (0.57). The lowest values of 5.75 and 18.19 were found in $T_1$ for Mn and Fe content in soil, respectively (Table 5 & Fig. 4).

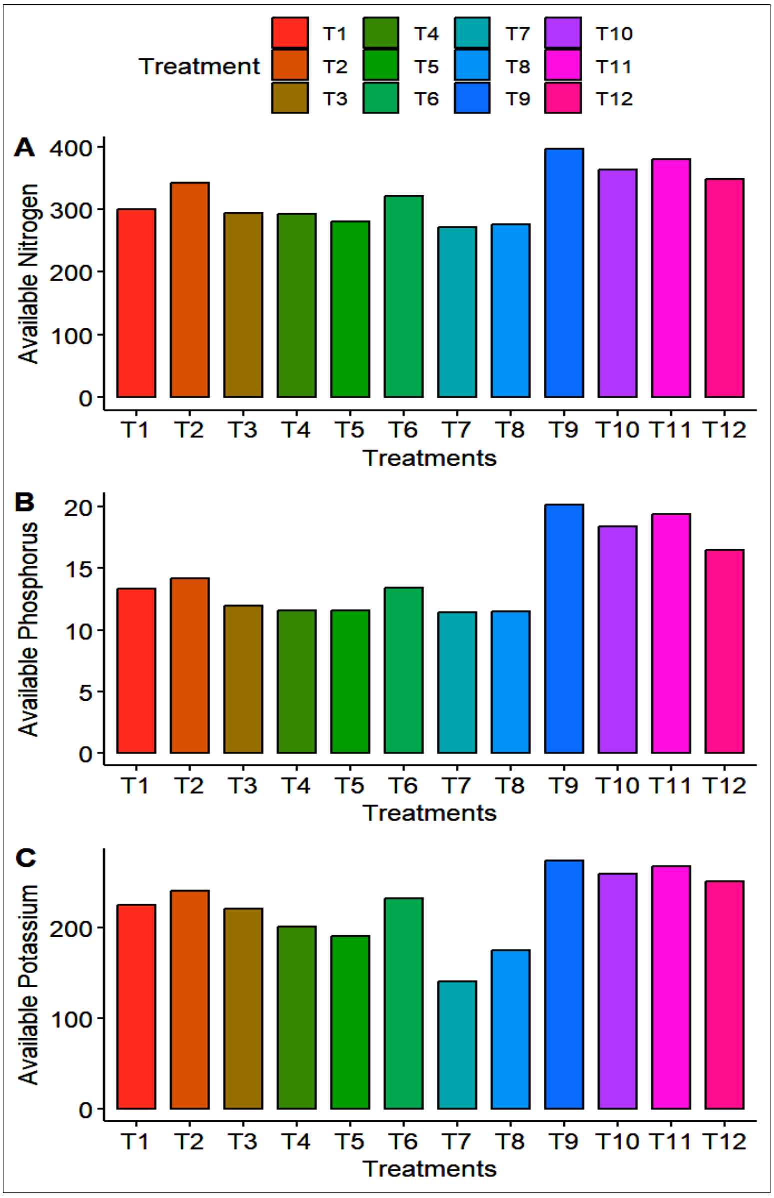


**Fig. 3.** Effect of INM modules on soil available nutrients.

**Table 5.** Effect of INM modules on soil available micronutrients

| **Treatments** | **Zn (mg kg$^{-1}$)** | **Cu (mg kg$^{-1}$)** | **Mn (mg kg$^{-1}$)** | **Fe (mg kg$^{-1}$)** |
|---|---|---|---|---|
| $T_1$ | 0.50 | 0.57 | 5.75 | 18.19 |
| $T_2$ | 0.80 | 1.47 | 10.28 | 33.07 |
| $T_3$ | 0.64 | 0.97 | 7.98 | 25.77 |
| $T_4$ | 0.70 | 1.12 | 8.89 | 28.65 |
| $T_5$ | 0.59 | 0.84 | 7.27 | 24.37 |
| $T_6$ | 0.54 | 0.71 | 6.42 | 20.38 |
| $T_7$ | 0.75 | 1.30 | 9.35 | 30.99 |
| $T_8$ | 0.93 | 2.18 | 13.45 | 40.11 |
| $T_9$ | 0.82 | 1.49 | 10.57 | 33.26 |
| $T_{10}$ | 0.87 | 1.81 | 12.11 | 35.06 |
| $T_{11}$ | 0.90 | 2.08 | 12.99 | 39.56 |
| $T_{12}$ | 0.96 | 2.42 | 15.25 | 47.42 |
| SE(m)± | 0.01 | 0.03 | 0.18 | 1.18 |
| C.D. p≤(0.05) | 0.03 | 0.12 | 0.54 | 3.50 |

## Nutrient uptake, biomass and bulb yield

The uptake of nitrogen, phosphorus and potassium (NPK) varied significantly among treatments involving different combinations of organic manures, inorganic fertilizers and biofertilizers. Treatment $T_7$ exhibited the highest nitrogen uptake at 28.17 kg ha$^{-1}$, which was statistically similar to $T_8$ (24.41 kg ha$^{-1}$). In contrast, $T_9$ recorded the lowest nitrogen uptake at 6.47 kg ha$^{-1}$. The uptake of P was also highest in $T_7$ (8.57 kg ha$^{-1}$), followed by $T_8$ (7.49 kg ha$^{-1}$) and $T_5$ (6.68 kg ha$^{-1}$) and lowest recorded for $T_9$ (2.66 kg ha$^{-1}$). Potassium uptake followed a similar trend to nitrogen uptake, with Treatment $T_7$ exhibiting the highest value at 24.70 kg ha$^{-1}$. Conversely, Treatment $T_9$ recorded the lowest potassium uptake at 7.20 kg ha$^{-1}$. The biomass of garlic with respect to different treatments was found to be varied significantly, with $T_7$ having the highest value of 10.30 t ha$^{-1}$ and was statistically par with $T_8$ (9.37 t ha$^{-1}$). The lowest biomass was recorded in $T_9$ (4.37 t ha$^{-1}$). The perusal of data for bulb yield revealed that the bulb yield was significant among the treatments. The highest value was found in $T_7$ (8.24 t ha$^{-1}$), followed by $T_8$ (7.50 t ha$^{-1}$) and $T_5$ (7.00 t ha$^{-1}$). The lowest value was recorded for $T_9$ (3.60 t ha$^{-1}$) (Table 6 & Fig. 5).

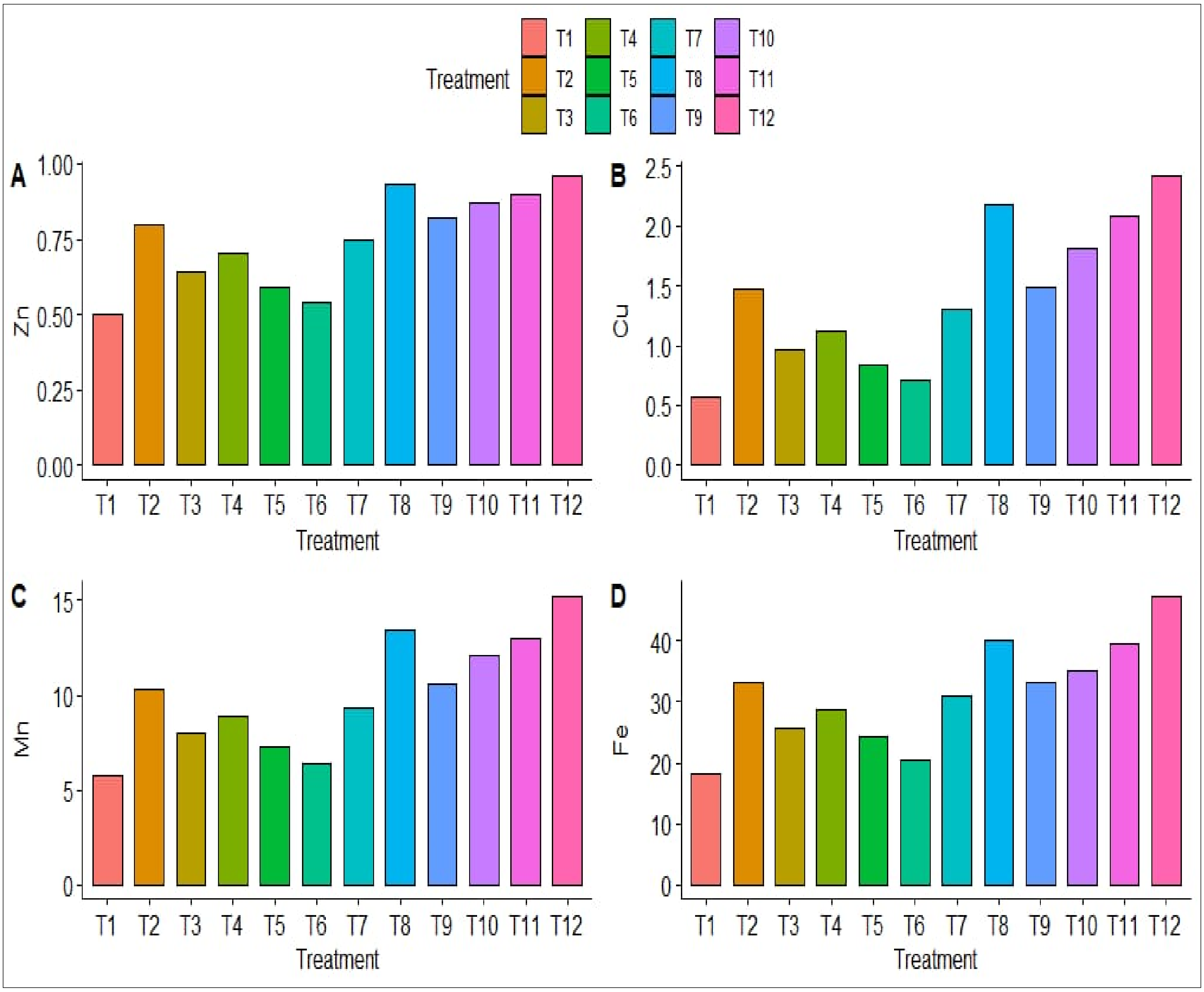


**Fig. 4.** Available soil micronutrient.

**Table 6.** Effect of INM modules on nutrient uptake, plant biomass and bulb yield of Garlic (*Allium sativum* L.)

| Treatments | Uptake N (kg ha $^{-1}$) | Uptake P (kg ha $^{-1}$) | Uptake K (kg ha $^{-1}$) | Biomass (t ha$^{-1}$) | Bulb Yield (t ha$^{-1}$) |
|---|---|---|---|---|---|
| T1 | 14.04 | 4.86 | 13.90 | 7.37 | 5.90 |
| T2 | 11.85 | 4.27 | 12.30 | 5.62 | 5.10 |
| T3 | 14.81 | 4.97 | 13.90 | 7.80 | 6.24 |
| T4 | 19.51 | 6.15 | 14.00 | 8.37 | 6.70 |
| T5 | 21.03 | 6.68 | 18.90 | 8.75 | 7.00 |
| T6 | 14.00 | 4.38 | 12.80 | 6.30 | 5.60 |
| T7 | 28.17 | 8.57 | 24.70 | 10.30 | 8.24 |
| T8 | 24.41 | 7.49 | 21.80 | 9.37 | 7.50 |
| T9 | 6.47 | 2.66 | 7.20 | 4.37 | 3.60 |
| T10 | 8.08 | 3.19 | 8.80 | 4.87 | 4.20 |
| T11 | 6.81 | 2.73 | 7.40 | 4.62 | 3.90 |
| T12 | 9.21 | 3.59 | 10.10 | 5.00 | 4.60 |
| **SE(m)±** | **1.53** | **0.32** | **1.26** | **0.39** | **0.10** |
| **C.D. p≤(0.05)** | **4.53** | **0.93** | **3.72** | **1.16** | **0.28** |

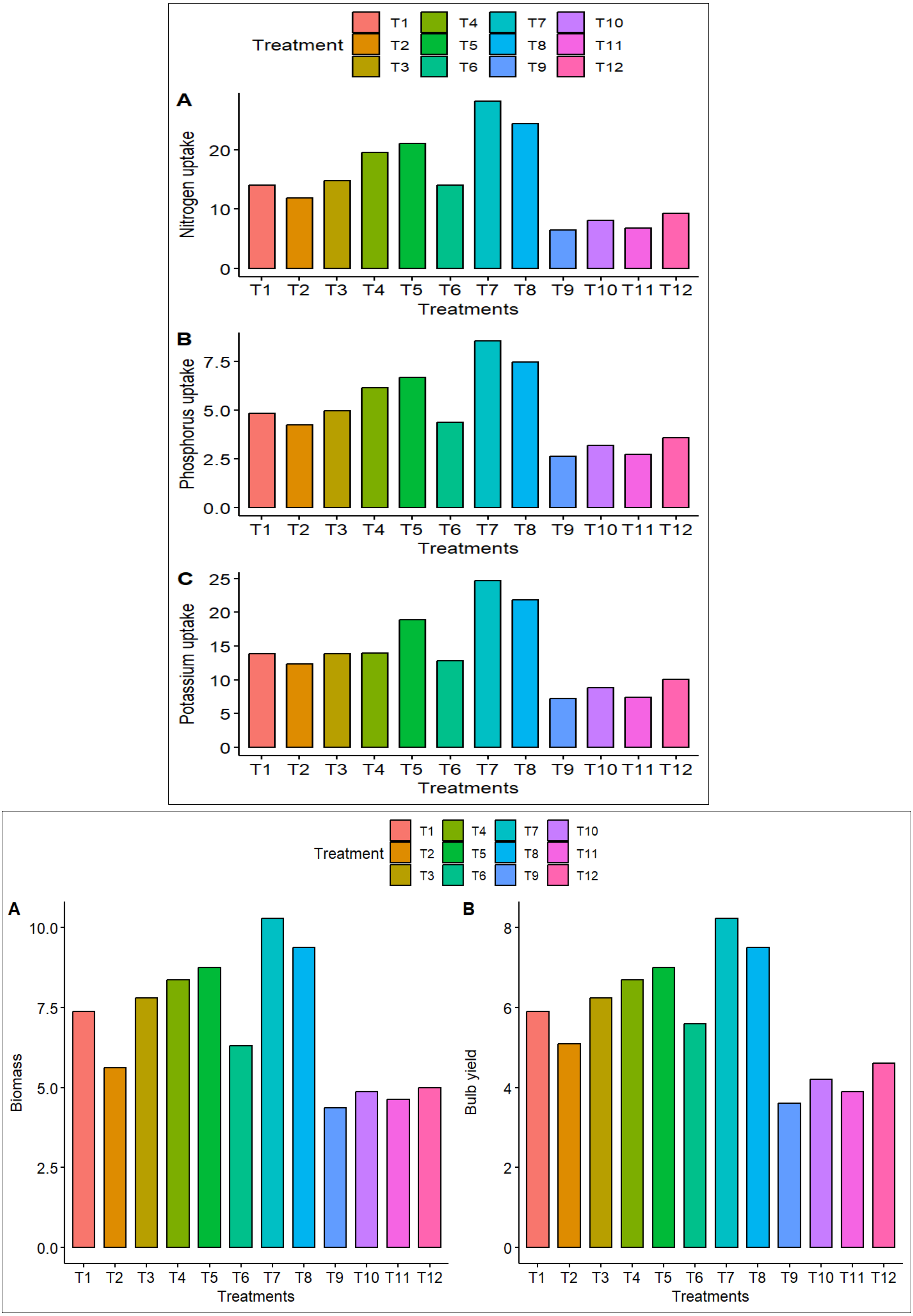


**Fig. 5.** Effect of INM modules on nutrient uptake, plant biomass and bulb yield of garlic.

## Quality parameters

The size of cloves, bulb diameter and bulb weight were recorded as maximum in $T_7$ (4.32 cm), followed by $T_8$ (4.16 cm), whereas minimum was recorded in $T_9$ (1.75 cm). Bulb weight was recorded as highest in $T_7$ (5.50 cm), followed by $T_8$ (5.37 cm) and minimum was recorded in $T_9$ (18.33 cm). However, the bulb weight was highest for $T_7$ (44.00 g), followed by $T_8$ (39.67 g) and $T_5$ (36.87 g) and was lowest in $T_9$ (18.33 g) (Table 7 & Fig. 6).

## Discussion

The texture of the experimental soil was silty clay loam. The particle and bulk densities did not vary significantly by the application of various organic, inorganic and biofertilizers. The highest values for particle and bulk densities were found in $T_1$ (Recommended NPK) and lowest values for $T_5$. This may be due to the fact that particle and bulk densities in soil may not vary within the shorter period of time. This stability in soil particle and bulk density suggests that the

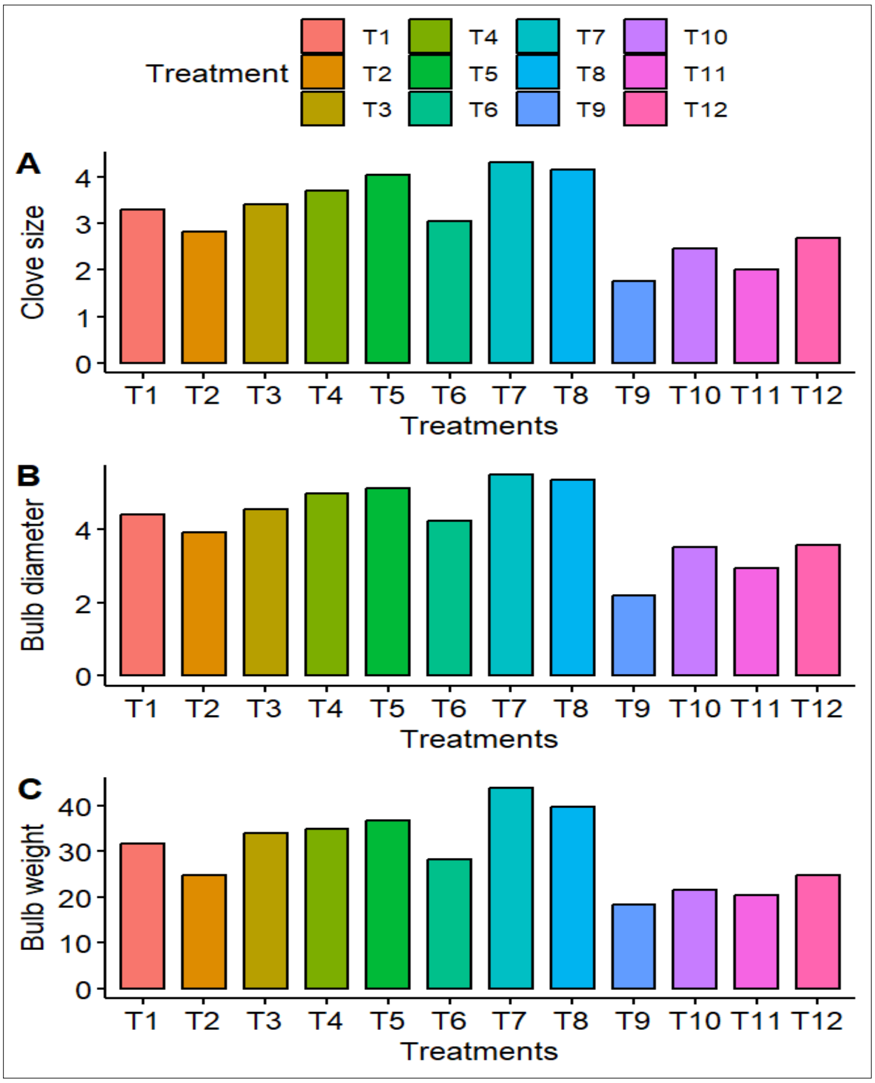


**Fig. 6.** Effect of INM modules on quality parameters of garlic (*Allium sativum* L.).

**Table 7.** Effect of INM modules on quality parameters of garlic (*Allium sativum* L.)

| Treatments | Size of Cloves (cm) | Bulb Diameter (cm) | Bulb Weight (g) |
|---|---|---|---|
| T1 | 3.30 | 4.42 | 31.80 |
| T2 | 2.83 | 3.93 | 24.88 |
| T3 | 3.41 | 4.54 | 33.90 |
| T4 | 3.70 | 4.97 | 34.87 |
| T5 | 4.03 | 5.13 | 36.87 |
| T6 | 3.04 | 4.25 | 28.27 |
| T7 | 4.32 | 5.50 | 44.00 |
| T8 | 4.16 | 5.37 | 39.67 |
| T9 | 1.75 | 2.18 | 18.33 |
| T10 | 2.46 | 3.52 | 21.58 |
| T11 | 2.01 | 2.94 | 20.37 |
| T12 | 2.68 | 3.57 | 24.76 |
| **SE(m)±** | **0.10** | **0.14** | **1.48** |
| **C.D. p≤(0.05)** | **0.32** | **0.29** | **4.37** |

structural integrity of the soil remains intact, providing a consistent medium for root growth and water infiltration regardless of the fertilizer type used (18). The pH of the soil did not show significant differences on application of various treatments. However, the pH decreased on increasing the concentration of organic manure. However, a reverse trend was found in EC and OC, which increased on applications of organic, inorganic and biofertilizers (19). Similar results were also earlier reported by (20). The status of N, P and K in soil varied significantly after the harvest of the crop. The post-fertility status of soil was increased by application of organic and inorganic fertilizers, which increased the pool of N, P and K after the harvest of the crop. The organic manure acts as a storehouse of energy for microorganisms and is responsible for nutrient transformation (21-23).

The available Zn, Cu, Mn and Fe varied significantly among the different treatments. The results suggested that on increasing the concentration of organic manures accompanied by synthetic fertilizers, the concentration of Zn, Cu, Mn and Fe also increases. The release of native soil micronutrients brought about by the dissolving action of organic manures and the release from applied organic manures are both contributing factors to the increasing concentration of micronutrients in the soil (24-27).

The uptake of NPK varied significantly on application of organic manures, inorganic fertilizers, along with biofertilizers. The highest nutrient uptake observed with the application of inorganic fertilizers and organic manures may result from the direct addition of plant nutrients through the organic manures. Furthermore, the organic manures probably help in the chelation of complex intermediate organic compounds created during the breakdown of the additional manures and the solubilization of native nutrients that would otherwise be inaccessible (28-30). The beneficial effects of combining biofertilizers with a 100 % recommended dose of chemical fertilizers significantly enhance the growth and yield of garlic. The increase in yield can be attributed to improved root proliferation, greater nutrient and water uptake, higher photosynthetic rates and enhanced food accumulation. This yield increase is primarily the result of the cumulative impact on plant growth and yield characteristics (31-33).

The size of cloves was significantly increased on the addition of organic, inorganic and biofertilizers. The increased size was linked to improved nutritional availability and production of stimulating chemicals as a result of balanced fertilization of nutrient sources, which could be responsible for elongation and multiplication of cells (34, 35). Bulb diameter increased on increasing the concentration of organic, inorganic and biofertilizers due to the fact that carbohydrates get accumulated on optimum application of nutrients produced by the leaves through proper photosynthesis (36, 37). The bulb weight was enhanced on application of organic, inorganic along with biofertilizers (38, 39). The enhancement in weight of bulbs was due to proper nutrient supply for bulb development by photosynthesis and balanced supply of carbohydrates, protein, etc. (37, 36, 40).

## Conclusion

Application of different integrated nutrient management modules improved soil physical and chemical properties and in general, the fertility status of the soil, significant influence occurred on uptake of nitrogen, phosphorus and potassium by garlic. The concentration of micronutrient cations, namely Zn, Cu, Mn and Fe, was enhanced by increasing the concentrations of different elements in various INM modules. Also, the content of NPK in soil was enhanced with increased application of fertilizers. The uptake of NPK varied significantly among the different treatment combinations of organic, inorganic and biofertilizers. Therefore, INM should be adopted to improve the productivity of garlic in the soils.

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## Authors' contributions

TM carried out the experiment, took observations, and analyzed the data. TA and ZAB guided the research by formulating the research concept. TAB and MAB approved the final manuscript. FJW and RK participated in the design of the study and performed the statistical analysis. SQW, SMA, AMA, ASA and NBN contributed by imposing the experiment and helped edit, summarize and revise the manuscript. RR and AG helped summarize and revise the manuscript. All authors read and approved the final manuscript.

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## Compliance with ethical standards

**Conflict of interest:** Authors do not have any conflict of interests to declare.

**Ethical issues:** None

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