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Impact of Nano-phosphorus, Organic, and Bio-Fertilizer on Soil and plant nutrient content in Protected Agriculture

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Abstract

A field experiment was conducted for the agricultural season 2023-2024 in a greenhouse at the Second Agricultural Research Station of the College of Agriculture, Al-Muthanna University, to evaluate the effect of Nano-phosphorus and Bio-Organic fertilizer on the growth and yield of tomatoes in protected agriculture. Newton hybrid Tomato (*Solanum Lycopersicum*) were used. This study focused on the effect of two factors, The first factor: adding Nano-phosphorus fertilizer, which was designated by the symbol P, Applied to the soil with irrigation water at three levels; P_1: without adding Nano-phosphorus fertilizer (comparison treatment), P_2: half the recommended percentage of Nano-phosphorus fertilizer (5 kg ha^{-1}) and P_3: the full recommendation for Nano-phosphorus fertilizers (10 kg ha^{-1}). The second factor: adding organic bio-fertilizers to the soil at seven levels as follows; T_1: comparison treatment (without addition), T_2: full traditional fertilizer recommendation (120:160:120), T_3: 10 gm mycorrhizae, T_4: 3% sheep waste with 10 gm mycorrhizae, T_5: 5% sheep waste with 10 gm mycorrhizae, T_6: 3% sheep waste with 0 gm mycorrhizae, T_7: 5% sheep waste with 0 gm mycorrhizae, All treatments was according to the fertilizer recommendation (120:80:120) for each of nitrogen, phosphorus and potassium, for each T_3, T_4, T_5, T_6, T_7, respectively. A factorial experiment was conducted using a Randomized Complete Block Design (RCBD) with three replicates. The means were compared using the least significant difference test (LSD) at a probability level of 0.05. The results showed a significant superiority of the full Nano-phosphorus fertilizer recommendation (P3) in the soil and plant content of nitrogen, phosphorus, and potassium, Treatment T_4 significantly increased soil and leaf content of nitrogen, phosphorus, and potassium, while T_5 showed superior performance in soil phosphorus, and potassium content. Regarding interaction treatments, the combination P_3T_4 was most effective in increasing soil phosphorus content and leaf nitrogen, phosphorus, and potassium levels. Additionally, the combination P_3T_5 excelled in improving soil potassium content.

Keyword: Nano-phosphorus, Bio-Organic Fertilizer, Tomato, Nutrient Content of Soil and Plants,

Introduction

The rapid increase in global population has led to the excessive use of chemical fertilizers to boost crop yields. While this practice has improved productivity, it has often been at the expense of fruit quality, which has declined, and has contributed significantly to environmental pollution. Consequently, there has been a growing interest in alternative fertilizers that promote soil, plant, and human health, including Nano fertilizers. Nano-fertilizers are highly efficient, reducing the quantity of chemical fertilizers required in agriculture, thereby mitigating pollution caused by conventional fertilizers. Traditional fertilizers, while effective, can be expensive and harmful to both humans and the environment. Conversely, Nano-materials not only enhance plant growth but also improve resistance to various biotic and abiotic stresses [31; 20].

Phosphorus is an essential nutrient for plant growth, playing a critical role in photosynthesis and aiding in absorption of other nutrients [26; 22]. It is vital for cellular metabolism as a structural component of biomolecules. However, soil processes such as adsorption and precipitation can reduce phosphorus availability, limiting plant growth. On the other hand, excessive use of phosphorus fertilizers causes environmental harm and depletes phosphorus reserves. Plant adapt to phosphorus deficiency by undergoing physiological and metabolic modifications to enhance nutrient absorption and utilization. Nevertheless, phosphorus availability can be reduced by interaction with elements like iron and aluminum, forming insoluble compounds that hinder its uptake [25]. The combination of conventional fertilizers with Nano NPK fertilizers, as well as foliar application of nitrogen and soil application of phosphorus and potassium, has demonstrated positive results. For instance, these combination have increased plant height (120.21 cm), the number of leaves per plant (83.99), the number of branches per plant (3.62), plant yield (370.39 gm.), and total soluble solids (TSS) to 2.930 [16]. Organic fertilizers have also proven effective in enhancing tomato productivity and fruit quality, improving yield by 42.18% compared to untreated plants. Organic fertilizers of animal origin increased plant growth and fruit production by 50.53% [14].

Inoculation of cultivated plants with arbuscular mycorrhizal fungi (AMF) has shown significant benefits. AMF added to the root zone during seedling production enhanced the yield and quality of sweet pepper, resulting in fruits with thicker skins and larger masses. AMF also contributed to increased phosphorus accumulation in sweet pepper fruits [13]. Similarly, the use of organic bio-fertilizers containing biocontrol agents has proven effective in controlling Fusarium wilt disease in tomatoes. These fertilizers increased the soil's organic matter content, enhanced nutrient availability, and promoted optimal plant growth [10]. Mycorrhizae, as a bio-fertilizer, have been shown to improve vegetative growth and yield by increasing nutrient availability and enhancing the physical and chemical properties of the soil [27].

Tomato (*Solanum Lycopersicum*) is one of the most important vegetable crops, belonging to the Solanaceae family. it is nutritionally valuable, containing essential nutrients like nitrogen, phosphorus, potassium, magnesium, calcium, iron, vitamins (A, B), carbohydrates, proteins, fats and organic acids such as ascorrbic, malic, and citric acids. and some phenolic compounds, Tomatoes are also rich in phytochemicals like carotene and lycopene [8]. Due to the high global consumption, tomatoes are cultivated extensively worldwide. In 2020, the global tomato cultivation area reached 5.05 million hectares, producing 186.82 million tons. In Iraq, tomatoes are highly valued for their economic and nutritional importance, with cultivation areas spanning approximately 31.98 thousand hectares and yielding about 754.76 thousand tons in 2020 [11].

The research aims to study the effect of Nano-phosphorus fertilizer, organic fertilizer, and bio-fertilizers on the availability and concentration of NPK in tomato crops grown under protected agriculture.

Material and methods

A field experiment was conducted during the winter agricultural season (2023-2024) in Al-Muthanna Governorate at the Second Agricultural Research Station, affiliated with the College of Agriculture, Al-Muthanna University. The study evaluated the effects of different proportions of Nano-phosphorus fertilizer, Organic fertilizer levels, and Bio-fertilizer on Soil and plant (tomato) (*Solanum lycopersicum*) nutrient content in protected agriculture.

The field experiment was conducted in a greenhouse with dimensions of 9 x 50 meters. The greenhouse area was divided into raised beds, and the experimental units were arranged for planting seedlings. A total of six raised beds were prepared within the greenhouse, divided into three blocks, with each block consisting of two raised beds. Each block contained 21 experimental units.The dimensions of each experimental unit 1.5 m². Each experimental unit included six plants, with a spacing of .030 m between plants. The distance between raised beds was .075 m, and the gap between experimental units was .064 m. Chemical and physical soil analyses were performed (Table 1).

Table 1: Some Chemical and Physical Properties of the Study Soil.

VARIABLES	VALUES	UNITS	
$pH_{1:1}$	7.3	Du]g	
EC_E	4.2	ds m^{-1}	
AVAILABLE NITROGEN	27.4	mg N kg^{-1} Soil	
AVAILABLE PHOSPHOROUS	17.6		
AVAILABLE POTASSIUM	182		
ORGANIC MATTER	0.6	%	
BULK DENSITY	1.4	Mg m^{-3}	
PARTICLE DENSITY	2.5		
POROSITY	44	%	
CLAY	52.17		
SAND	17.40		
SILT	30.43		
SOIL TEXTURE	_____	Clay	

Newton tomato seedlings Hybrid (F1) Indian origin were used. The drip irrigation system was used to irrigate the entire field. The vines were covered with black nylon (Mulching), to maintain soil moisture, reduce of irrigation water, water evaporation, salt accumulation and prevent weed growth.

Nano phosphorus fertilizer were add, symbolized by P, to the soil with irrigation water at three levels as indicated on the package as follows:

P_1: Without adding Nano-fertilizer (0 kg P ha^{-1}).

P_2: Half of the fertilizer recommendation: Nano fertilizer (5 kg P ha^{-1}).

P_3: Complete fertilizer recommendation: Nano fertilizer (10 kg P ha^{-1}).

Nano fertilizer were add according to the levels for each liter in each experimental unit, where add 166 ml of the fertilizer dissolved in water for each plant, evenly distributed among all the plants in the experimental unit.

The Bio-Organic Fertilizer was added to the soil at seven levels, symbol (T) as follows:

T_1: Comparative treatment (without addition)

T_2: A complete traditional fertilizer recommendation (120:160:120) for nitrogen, phosphorus, and potassium respectively [2].

T_3: 0 sheep waste+10 gm of mycorrhiza, with the same fertilization recommendation at half phosphorus (120: 80: 120) for nitrogen (N), phosphorus (P), and potassium (K), respectively .

T_4: 3% sheep waste+10 gm of mycorrhiza, with the same fertilization recommendation at half phosphorus (120: 80: 120) for N, P and K respectively.

T_5: 5% sheep waste + 10 gm of mycorrhiza, with the same fertilization recommendation at half phosphorus (120: 80: 120) for N, P and K respectively.

T_6: 3% sheep waste + 0 gm of mycorrhiza, with the same fertilization recommendation at half phosphorus (120: 80: 120) for N, P and K respectively.

T_7: 5% sheep waste + 0 gm of mycorrhiza, with the same fertilization recommendation at half phosphorus (120: 80: 120) for N, P and K respectively.

Studied characteristics

Concentration of available nitrogen, phosphorus and potassium in soil (mg kg^{-1} soil), and concentration of total nitrogen, phosphorus and potassium in tomato leaves (%).

Results and Discussion

Concentration of available nitrogen in the soil (mg kg^{-1} soil)

Table 2 shows significant differences among treatments of Nano-phosphorus fertilizer on the concentration of available nitrogen in the soil in the middle of the season. The **P_3** of Nano-fertilizer (6 gm L^{-1}) was superior, as it gave the highest rate of available nitrogen concentration in the soil (36.95 mg kg^{-1} soil). Significantly superior compared to the rest of **P_1** and **P_2** (33.97 and 32.40 mg kg^{-1} soil) with an increase rate of 8.7 and 14%, respectively. This may be attributed to the competition between the Nano fertilizer and the soil's nitrogen content, creating ionic antagonism between them, which in turn increases its concentration in the soil.

The same table shows significant differences among organic and bio-fertilizer treatments in the concentration of available nitrogen in the soil in the middle of the season. **T_4** (40.47 mg kg^{-1} soil) was significantly superior compared to the rest of the treatments **T_1, T_2, T_3, T_6** and **T_7** (25.03, 33.56, 34.74, 33.46 and 33.99 mg kg^{-1} soil) respectively, with an increase rate of 61.6, 20.5, 16.4, 20.9 and 19%, respectively. It was not significantly superior to **T_5** (39.82 mg kg^{-1} soil). The increase in the percentage of nitrogen in the soil, may be attributed to the decomposition of organic fertilizer, the release of the nutrient from the fertilizer, its release into the soil solution, thus increasing its concentration in the soil. The reason may be attributed to the fact that organic fertilizer increases the nitrogen content in the soil, by increasing the decomposition of organic fertilizer, increasing the mineralization process, releasing the element and releasing it to the soil solution. Nitrogen is in the organic form by 90-95%, this form is not used, by the plant because it cannot absorb, it except after it is mineralized, by the mineralization process and the element is released from organic fertilizer. The plant can absorb its mineral form, which represents 1-5%, perhaps the reason for the increase in the percentage of available nitrogen in the soil is that organic fertilizer, improves the various properties of the soil, which increases the availability of nutrients [29; 1; 17].

There was no significant effect in the interactions among Nano-phosphorus fertilizer treatments and bio-organic fertilizer treatments.

Table 2: Effect of Nano-phosphate fertilizer and bio-organic fertilizer on soil nitrogen content (mg kg^{-1} soil)

Bio-organic	**Nano-** phosphorus

	P1	P2	P3	Mean of Bio-organic
T1	20.33	21.70	33.07	25.03
T2	36.03	29.63	35.00	33.56
T3	35.00	31.97	37.27	34.74
T4	39.73	38.50	43.17	40.47
T5	39.20	40.83	39.43	39.82
T6	34.80	32.20	33.37	33.46
T7	32.67	31.97	37.33	33.99
Mean of Nano- phosphorus	33.97	32.40	36.95	
L.S.D$_{(0.05)}$	P= 2.558	T= 3.907	P*T= N.S	

Concentration of available phosphorus in the soil (mg kg^{-1} soil)

Table 3 shows significant differences among treatments in the soils available phosphorus content, The P_3 treatment with Nano fertilizer (6 gm L^{-1}) was superior, resulting in the highest available phosphorus concentration in the soil (33.32 mg kg^{-1} soil), compared to P_1 (20.12 mg kg^{-1} soil) and P_2 (24.56 mg kg^{-1} soil). This represented an increase of 65.6% and 35.6%, respectively. The increase in available phosphorus may be due to the properties of Nano fertilizers, which enhance phosphorus availability by preventing its loss and immobilization in the soil, thereby keeping it accessible to plant roots for longer periods [4; 7; 15].

The same table indicates significant differences among organic bio-fertilizer treatments regarding the soils available phosphorus content. T_5 (31.42 mg kg^{-1} soil) was significantly superior to the other treatments T_1, T_2, T_3, T_6 and T_7 which had phosphorus concentrations of (19.54, 21.42, 24.26, 26.44, and 28.06 mg kg^{-1} soil), respectively. The percentage increases were 60.7%, 46.6%, 29.5%, 18.8%, and 11.9%, respectively. T_5 was not significantly different from T_4 (30.86 mg kg^{-1} soil). The increase in available phosphorus can be attributed to the decomposition of organic fertilizers, which release phosphorus into the soil. Organic fertilizers also lower soil pH, improve soil properties, and form chelating compounds that bind phosphorus, reducing its loss through precipitation or fixation and enhancing its availability. Additionally, organic fertilizers contain humic acids, which absorb elements, while mycorrhizae secrete substances that increase the solubility and availability of phosphorus [2;1].

The interaction between Nano-phosphorus fertilizers and organic bio-fertilizer treatments significantly impacted the soil's available phosphorus content. The highest phosphorus concentration was observed in the P_3T_4 treatment (41.23 mg kg^{-1} soil), while the lowest concentration (13.60 mg kg^{-1} soil) was recorded in the P_1T_1 treatment. The increase in available phosphorus in the P_3T_4 combination may be attributed to the synergistic effect of Nano-fertilizers and organic fertilizers. Nano-fertilizers reduce phosphorus loss and keep it in an available form for longer periods, preventing immobilization. Similarly, organic fertilizers lower soil pH, increase the availability of precipitated phosphorus, and release phosphorus into the soil solution, enhancing its over all availability [32; 33].

Table 3: Effect of Nano-Phosphorus fertilizer and Bio-Oganic fertilizer on Soil Phosphorus conten(mgkg^{-1}Soil).

Bio-organic	**Nano-** phosphorus			**Mean of Bio-organic**
	P1	**P2**	**P3**	
T1	13.60	20.67	24.37	19.54
T2	17.00	22.27	25.00	21.56
T3	18.50	25.23	29.03	24.26
T4	21.40	29.93	41.23	30.86
T5	25.63	28.80	39.83	31.42
T6	23.57	20.63	35.13	26.44
T7	21.17	24.37	38.63	28.06
Mean of Nano- phosphorus	20.12	24.56	33.32	
L.S.D$_{(0.05)}$	P= 1.392	T= 2.126	P*T= 3.683	

Available potassium concentration in soil (mg kg^{-1} soil)

Table 4 shows significant differences among treatments in soil potassium content in the middle of the season, The $\mathbf{P_3}$ treatment with Nano fertilizer (6 gm L^{-1}) outperformed the others, yielding the highest potassium concentration in the soil (232.42 mg kg^{-1} soil). This was significantly higher compared to $\mathbf{P_1}$ **(**201.13 mg kg^{-1} soil)

and P_2 (207.63 mg kg^{-1} soil), with increase of 15.5% and 11.9%, respectively. This increase may be attributed to improved soil fertility and nutrient availability, which can enhance
the activity of beneficial organisms in the soil [15].

The same table highlights significant differences among organic bio-fertilizer treatments regarding soil potassium content in the middle of the season (after three harvests). T_5 (232.67 mg kg^{-1} soil) was significantly superior to the other treatments T_1, T_2, T_3, T_6 and T_7 with soil potassium contents of (182.42, 213.52, 210.56, 210.73 and 216.88 mg kg^{-1} soil), respectively. The corresponding increases were 27.5%, 8.9%, 10.5%, 10.4%, and 7.2%. T_5 was not significantly superior to T_4 (229.32 mg kg^{-1} soil), with a marginal increase of 1.4%. The increase in potassium concentration can be attributed to the decomposition of organic fertilizers, which release potassium into the soil, making it available for plant absorption throughout growth stages. Organic fertilizers also help reduce soil pH, enhancing the solubility of minerals and nutrients. Additionally, mycorrhizae play a role in increasing potassium availability [5; 1].

There was a significant interaction effect between Nano-phosphorus fertilizer and bio-organic fertilizer treatments. The highest potassium concentration in the soil was recorded in the P_3T_5 treatment (250.50 mg kg^{-1} soil), while the lowest concentration (176.33 mg kg^{-1} soil) was observed in the P_1T_1 treatment. The increase in soil potassium concentration may be due to the decomposition of organic fertilizers, which releases potassium and enhances its availability. Organic fertilizers also lower soil pH, increasing potassium solubility. Similarly, bio-fertilizers contribute to potassium availability by releasing acids that improve its solubility [6; 14;3].

Table 4: Effect of Nano-phosphate fertilizer and bio-organic fertilizer on soil potassium content (mg kg^{-1} soil)

Bio-organic	**Nano-** phosphorus			**Mean of Bio-organic**
	P1	**P2**	**P3**	
T1	176.33	185.30	185.63	182.42
T2	195.67	206.23	238.67	213.52
T3	198.00	199.67	234	210.56

T4	220.50	216.97	250.50	229.32
T5	215.43	225.90	256.67	232.67
T6	197.50	207.00	227.70	210.73
T7	204.50	212.33	233.80	216.88
Mean of Nano- phosphorus	201.13	207.63	232.42	
L.S.D$_{(0.05)}$	P= 3.663	T= 5.596	P*T= 9.692	

Nitrogen concentration in tomato leaves (%)

Table 5 indicates significant differences among treatments in nitrogen concentration in tomato leaves. The **P_3** treatment with Nano fertilizer (6 g L^{-1}) showed superiority, achieving the highest nitrogen content in tomato leaves (4.41%), significantly surpassing **P_1** (2.73%) and **P_2** (3.61%) by 61.1% and 22%, respectively. This increase may be attributed to the role of phosphorus in enhancing root growth, which improves the absorption of water and nutrients, promotes vegetative growth, and alters the plant's biological structure and biomass, thereby increasing nitrogen uptake from the soil [21; 12].

Significant differences were also observed among organic fertilizer treatments in nitrogen concentration in tomato leaves in the middle of the season. The **T_4** treatment (4.43%) was significantly superior to **T_1**, **T_2**, **T_6**, and **T_7**, which had nitrogen concentrations of 2.04%, 3.15%, 3.33%, and 3.85%, respectively, with increases of 116.5%, 40.4%, 33.1%, and 15.1%. However, **T_4** was not significantly superior to **T_3** (4.04%) or **T_5** (4.25%), with increases of 9.8% and 4.3%, respectively. The enhanced nitrogen concentration in the leaves may be due to the synergy between organic and bio-fertilizers, which improve the availability of nitrogen to the plant. Organic fertilizers contain nitrogen in forms ranging from 90% to 95%. The decomposition of organic fertilizers releases nitrogen into the soil, making it readily available for absorption by plant roots. Mycorrhizae also play a vital role in this process by extending fungal hyphae in the soil, increasing the plant's access to nutrients beyond the reach of its roots. In some cases, these fungal extensions can be 100 times the length of the roots, significantly enhancing nitrogen absorption. Furthermore, organic fertilizers provide a consistent supply of nitrogen throughout the growing season as they decompose gradually, supporting plant growth at various stages [29; 34].

There was a significant interaction effect on nitrogen concentration in tomato leaves among Nano-phosphorus fertilizer and bio-organic fertilizer treatments. The highest nitrogen concentration in leaves was observed in the **P_3T_4** treatment (6.18%), while the lowest was recorded in the **P_1T_1** treatment (1.32%).

Table 5: Effect of Nano-Phosphate Fertilizer and Bio-Organic Fertilizer on Nitrogen Content in Leaves (%).

Bio-organic	**Nano-** phosphorus			**Mean of Bio-organic**
	P1	**P2**	**P3**	
T1	1.32	2.27	2.55	2.04
T2	1.78	3.53	4.16	3.15
T3	3.71	4.37	4.04	4.04
T4	3.60	3.53	6.18	4.43
T5	2.83	4.82	5.09	4.25
T6	2.72	2.83	4.44	3.33
T7	3.18	3.95	4.42	3.85
Mean of Nano- phosphorus	2.73	3.61	4.41	
L.S.D$_{(0.05)}$	P= 1.228	T= 0.709	P*T= 0.464	

Total phosphorus concentration in tomato leaves (%)

Table 6 shows significant differences among treatments in the total phosphorus concentration in tomato leaves. The **P_3** treatment with Nano fertilizer (6 g L^{-1}) was superior, achieving the highest phosphorus concentration in tomato leaves (0.42%). This was significantly higher than **P_1** (0.22%) and **P_2** (0.28%), with increase rates of 90.9% and 50%, respectively. The increase in phosphorus concentration may be attributed to the addition of Nano-fertilizers, which supply phosphorus in a highly efficient, absorbable form. Nano-fertilizers keep the element readily available for uptake by plant roots for extended periods, reducing its loss and deposition in the soil, thereby enhancing its concentration in various parts of the plant, including the leaves [24].

Significant differences were also observed among organic fertilizer treatments in the total phosphorus content of tomato leaves.

The **T_4** treatment (0.45%) was significantly superior to **T_1**, **T_2**, **T_3**, **T_6**, and **T_7**, which had phosphorus concentrations of 0.18%, 0.21%, 0.31%, 0.28%, and 0.31%, respectively, with increase rates of 150%, 114%, 45.1%, 60.7%, and 45.1%. However, **T_4** was not significantly superior to **T_5**, which achieved 0.41%, representing an increase rate of 9.7%. The increase in phosphorus concentration is likely due to the decomposition of organic fertilizers, which release phosphorus into a form that plants can readily absorb. Organic fertilizers also reduce soil pH, increasing the availability of deposited phosphorus. Additionally, organic fertilizers enhance root growth, leading to improved nutrient absorption. Mycorrhizae play a crucial role in increasing phosphorus solubility in the soil by secreting acids that enhance its availability. Mycorrhizae also increase the amount of phosphorus absorbed by plants due to their unique relationship with this nutrient [9; 30].

The interaction between Nano-phosphorus fertilizer and bio-organic fertilizer treatments had a significant effect on the total phosphorus content of tomato leaves. The highest phosphorus concentration (0.70%) was recorded in the **P_3T_4** treatment, while the lowest (0.10%) was observed in the **P_1T_1** treatment. This increase in phosphorus concentration may be attributed to the role of Nano-fertilizers in reducing nutrient loss and maintaining phosphorus in a ready-to-absorb form for extended periods. Bio-organic fertilizers further enhance this effect by reducing soil pH and increasing the solubility of phosphorus in the soil. Together, these fertilizers improve the percentage of phosphorus absorption from the soil solution [18; 23].

Table 6: Effect of Nano-Phosphate Fertilizer and Bio-Organic Fertilizer on Leaf Phosphorus Content (%).

Bio-organic	**Nano-** phosphorus			**Mean of Bio-organic**
	P1	**P2**	**P3**	
T1	0.10	0.16	0.30	0.18
T2	0.13	0.23	0.26	0.21

T3	0.16	0.26	0.50	0.31
T4	0.33	0.33	0.70	0.45
T5	0.36	0.36	0.50	0.41
T6	0.23	0.33	0.30	0.28
T7	0.26	0.26	0.40	0.31
Mean of Nano- phosphorus	0.22	0.28	0.42	
L.S.D$_{(0.05)}$	P= 0.053	T= 0.081	P*T= 0.141	

Potassium concentration in tomato leaves (%)

Table 7 indicates significant differences among treatments in the potassium content of tomato leaves in the middle of the season. The **P_3** treatment with Nano fertilizer (6 g L^{-1}) was superior, achieving the highest potassium concentration in plant leaves (3.04%). This was significantly higher than **P_1** (2.56%) but not significantly higher than **P_2** (2.94%), with increase rates of 18.7% and 3.4%, respectively. The increase in potassium content during the middle of the season may be attributed to enhanced absorption from the soil solution, including areas typically out of reach for roots. This is facilitated by phosphorus, which promotes root growth and extension in the soil [21].

Significant differences were also observed among organic fertilizer treatments in potassium content after three harvests. The **T_4** treatment (3.36%) was significantly superior to **T_1**, **T_3**, **T_5**, **T_6**, and **T_7**, which had potassium concentrations of 2.21%, 2.87%, 3.04%, 2.56%, and 2.70%, respectively, with increase rates of 52%, 17%, 10.5%, 31.25%, and 24.4%. However, **T_4** was not significantly superior to **T_2** (3.17%), which showed an increase rate of 5.9%. The increase in potassium content may be due to the decomposition of organic fertilizer, which releases nutrients into the soil solution, making them available for plant uptake. Additionally, mycorrhizae play a role in enhancing nutrient absorption, increasing the amount of potassium available in the soil, which aligns with findings by [1].

The interaction between Nano-phosphorus fertilizer treatments and bio-organic fertilizer treatments significantly affected potassium content in plant leaves. The highest potassium concentration (3.66%) was observed in the **P_3T_4** treatment, while the lowest (2.00%) was recorded in the **P_1T_1** treatment. The increase in potassium content during the middle of the season may be attributed to the absorption of the element from the soil solution, where it is readily available for uptake by plant roots. Phosphorus addition promotes root growth, extension, and length, enabling greater potassium absorption from the soil. Organic fertilizers also enhance potassium solubility, both exchangeable and fixed forms, and encourage the activity of potassium-dissolving organisms. These organisms break down insoluble or poorly soluble potassium, making it accessible to plants. Mycorrhizae further facilitate this process by significantly increasing root growth and extension, enabling the plant to access potassium from hexagonal plates where it is fixed. Mycorrhizal hyphae penetrate these plates and directly absorb potassium [18; 28; 10].

Table 7: Effect of Nano-Phosphate Fertilizer and Bio-Organic Fertilizer on the Potassium Content of Leaves (%).

Bio-organic	**Nano-** phosphorus			**Mean of Bio-organic**
	P1	**P2**	**P3**	
T1	2.00	2.23	2.40	2.21
T2	2.96	3.20	3.36	3.17
T3	2.50	3.46	2.66	2.87
T4	2.93	3.50	3.66	3.36
T5	2.80	2.93	3.40	3.04
T6	2.10	2.66	2.93	2.56
T7	2.63	2.60	2.86	2.70
Mean of Nano- phosphorus	2.56	2.94	3.04	
L.S.D$_{(0.05)}$	P= 0.151	T= 0.231	P*T= 0.400	

Bio-Organic Fertilizers and Nutrient Availability

Bio-organic fertilizers enhance the soil's organic matter content and nutrient levels, enabling optimal plant growth. They increase the soil's nitrogen, phosphorus, and potassium content, making these nutrients more readily available for tomato plants [10]. The rise in nutrient levels in the soil can be attributed to the decomposition of organic fertilizers, which release nutrients such as nitrogen and phosphorus. This process provides plants with readily available nutrients that meet their growth needs, resulting in higher absorption of these elements. Consequently, this availability supports robust plant growth, improves yield quantity, and enhances the nutrient composition of the resulting fruits. Nano-fertilizers, on the other hand, supply nutrients in a form that is ready for by releasing nutrients gradually, aligning with plant growth. The addition of nano-fertilizers, combined with organic and bio-fertilizers, creates a synergistic effect. Nano-fertilizers, particularly those containing phosphorus, enhance root absorption and remains available for extended periods. These fertilizers minimize nutrient loss and sedimentation length and extension in the soil, thereby increasing nutrient uptake. Organic fertilizers contribute to nutrient availability through decomposition, while mycorrhizal fungi, as bio-fertilizers, extend root systems to areas otherwise inaccessible to roots. These fungi help absorb nutrients like phosphorus, which shares a unique symbiotic relationship with mycorrhizae.

Moreover, the bio-fertilizers enhance potassium absorption, particularly from hexagonal openings in the soil structure. The improved availability of nutrients supports ideal plant growth, leading to enhanced vegetative and fruit development. This results in higher productivity and nutrient-rich fruits [4; 7; 15; 2; 5; 1; 19].

Conclusion

This experiment concludes that it is possible to enhance the efficiency of Nano-phosphorus fertilizers, organic fertilizer and bio-fertilizer (10 gm of mycorrhizal fungi), with 3% sheep manure, This combination achieved the best results in increasing soil nutrient content, making nutrients available for plant uptake. The improved nutrient absorption by roots positively impacted vegetative growth, tomato productivity, and fruit quality.

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