Report on Bio efficacy study on "FIB-SOL NutriGel^{+} in Tomato and Onion"

1. First season field experiment on Aggregatum Onion

The field experiment was conducted from December 2023 to March 2024 in Kuppepalayam village, Coimbatore district, Tamil Nadu, India (10°95"N, 76°87" E). The aggregatum onion variety Co (On) 5 was used to evaluate various combinations of the recommended fertilizer dose (RDF), NPK combo, Nutrigel (Nano micronutrient in gel formulation) and commercial micronutrient formulation.

The FIB SOL NutriGel^{+} was evaluated with the following objectives

1. To study the efficacy of NutriGel+ on growth, yield and quality of tomato and onion
2. To study effect of NutriGel+ on soil nutrient availability and nutrient uptake of tomato and onion
3. To study effect of NutriGel+ on phyllosphere and Rhizosphere

Treatment details

The field experiment was conducted using a Randomized Block Design (RBD) with ten treatments and three replications. The NPK combo included nitrogen fixing, phosphorus solubilizing and potassium mobilizing bio fertilizers in single formulation. The nutrigel included nano micronutrient along with essential amino acids in gel formulation. The recommended dose of fertilizers adopted for aggregatum onion is 30:60:30 kg of N , P_2O_5 and K_2O per ha. The details of the treatments, spraying schedule are given below.

Table. 1. The spraying schedule for the field experiment on aggregatum onion

Spray	Time / dose
First spray	25 DAS
Second spray	45 DAS
Third spray	60 DAS
Foliar spray of Nutrigel	250 ml in 500 litres of water for 1 hectare
Soil application of NPK combo	250 ml in 500 litres of water for 1 hectare
Foliar spray of Commercial micronutrient	125 g in 500 litres of water for 1 hectare

Table. 2. The details of the treatments for the field experiment on aggregatum onion

Treatment	Treatment details
T_1	Absolute Control
T_2	50 % Recommended dose of fertilizer (RDF) + NPK combo
T_3	50% Recommended dose of fertilizer + NPK combo + Nutrigel
T_4	50% Recommended dose of fertilizer + NPK combo + commercial micronutrient
T_5	75% Recommended dose of fertilizer + NPK combo
T_6	75% Recommended dose of fertilizer + NPK combo + Nutrigel
T_7	75% Recommended dose of fertilizer + NPK combo + commercial micronutrient
T_8	100% Recommended dose of fertilizer
T_9	100% Recommended dose of fertilizer + Nutrigel
T_{10}	100% Recommended dose of fertilizer + commercial micronutrient

Effects of imposed treatments on plant growth attributes, yield and yield attibutes, nutrient uptake, availability of nutrient and microbial growth in soil were discussed below.

1.1. Plant growth attributes (Table 3)

Plant Height: The tallest plants were observed in treatment T_9 (100% RDF + Nutrigel) reaching 52.31 cm at 45 DAS, 54.13 cm at 60 DAS and 57.42 cm at 90 DAS. Treatment T_{10} (100% RDF + Commercial micronutrient) recorded plant heights of 51.1cm, 53.37 cm and 56.66 cm at the respective stages and was statistically on par with T_9 (100% RDF + Nutrigel). However, T_{10} was on par with T_8 (100% RDF), which recorded plant heights of 50.1cm, 51.47 cm and 55.12 cm respectively at 45, 60, and 90 DAS. The absolute control (T_1) treatment, with 38.09, 39.56 and 45.13 cm of plant mean height at 45, 60, and 90 DAS respectively in which shortest plant height was observed. The plant mean height was increased from bulb formation to harvest stage.

Number of Leaves: Treatment T_9 (100% RDF + Nutrigel) produced the higher leaf count across all stages, recording 40.34 leaves at 45 DAS, 41.95 leaves during 60 DAS and 36.30 leaves at 90 DAS. This treatment was statistically on par with T_{10} (100% RDF + Commercial micronutrient), which recorded 39.45, 41.12, and 35.48 leaves at 45, 60, and 90 DAS respectively. Treatment T_8 (100% RDF) achieved 38.83, 40.45 and 35.40 leaves at 45, 60, and 90 DAS respectively and remained on par with T_{10}. The absolute control (T_1) treatment pronounced, 32.34, 32.90 and 31.20 number of leaves per plant at 45, 60, and 90 DAS respectively which stands lowest among the all treatments.

Leaf length: The highest mean leaf length of multiplier onion, was observed 36.30, 43.43 and 40.13 cm at 45, 60, and 90 DAS respectively in the treatment 100% RDF + Nutrigel (T_9). These results were on par with the treatment 100% RDF + commercial micronutrients (T_{10}), which recorded 35.65, 42.71 and 39.10 cm of mean leaf length at 45, 60, and 90 DAS respectively.

Then the treatment 100% RDF (T_8) had recorded 34.50, 41.56 and 38.85 cm of leaf length at 45, 60, and 90 DAS respectively, were seen to be in non-significant with the treatment T_{10}. The absolute control (T_1) treatment produced the lowest leaf length of 28.30, 33.56 and 32.80cm at 45, 60, and 90 DAS respectively.

Leaf diameter: The treatment with 100% RDF + Nutrigel (T_9) produced the highest mean leaf diameter in multiplier onion, with 1.93, 2.27 and 1.78 cm at 45, 60, and 90 DAS respectively. This outcome was non-significant to the treatment 100% RDF + commercial micronutrients (T_{10}), which recorded 1.89, 2.20 and 1.72 cm of leaf diameter at 45, 60, and 90 DAS respectively were on par with the treatment 100% RDF (T_8) which recorded 1.86, 2.07 and 1.63 cm at 45, 60, and 90 DAS respectively. Conversely, the absolute control (T_1) recorded the lowest leaf diameter, with 0.83, 1.56 and 1.09 cm at 45, 60, and 90 DAS respectively.

Relative Chlorophyll Content: 100% RDF + Nutrigel (T_9) recorded the highest Relative Chlorophyll Content (SPAD Meter values) with values of 52.16 at 45 DAS, 57.36 at 60 DAS and 47.24 at 90 DAS. Treatment T_{10} (100% RDF + Commercial micronutrient) followed with 51.32, 56.92 and 46.83which was statistically on par with T_9. However, T_{10} remained on par with T_8 (100% RDF) which recorded 50.57, 55.50 and 45.30 at 45, 60, and 90 DAS of onion respectively. The lowest SCMR values were observed in the treatment absolute control (T_1), with 43.86, 46.85 and 37.20 at 45, 60, and 90 days respectively.

The treatment 100% RDF + Nutrigel (T_9) recorded significantly higher plant growth parameters *viz.,* plant height, number of leaves, leaf length, leaf diameter and relative chlorophyll content (SPAD values) compared to 100%RDF (T_8). Even though, the treatment 100% RDF + commercial micronutrient (T_{10}) was statistically on par with 100% RDF + Nutrigel (T_9), it did not differ significantly over 100% RDF (T_8).

1.2. The yield and yield attributes of aggregatum onion (Table 4)

Bulb Polar diameter: The use of 100% RDF + Nutrigel (T_9) resulted in greater bulb polar diameter of 4.63 cm, which was on par with the treatment 100% RDF + Commercial micronutrients (T_{10}) which recorded 4.37 cm of polar bulb diameter. On the other hand, the treatment, 100% RDF (T_8) 4.30 cm of polar bulb diameter, showed statistical similarity with the treatment T_{10}**.** The absolute control (T_1) showed a lesser bulb polar diameter of 1.36 cm.

Bulb equatorial diameter: The 100% RDF + Nutrigel significantly influenced bulb equatorial diameter and the results were well pronounced. The highest equatorial diameter was recorded in the treatment 100% RDF+ Nutrigel (T_9) with 5.92 cm, Which has no significant difference with the treatment,100% RDF + commercial micronutrients (T_{10}) which recorded 5.46 cm of equatorial diameter, was on par with the treatment, 100%RDF (T_8) which measured 5.32 cm

of equatorial diameter. At last, the absolute control (T_1) showed a lower bulb equatorial diameter of 2.50 cm.

Bulb neck diameter : The treatment 100% RDF + Nutrigel (T_9) had the maximum bulb neck diameter content of 1.67 cm, which was statistically comparable to the treatment 100% RDF + commercial micronutrients (T_{10}) with 1.60 cm of bulb neck diameter this was on par with the treatment, 100% RDF (T_8) which had 1.58 cm of bulb neck diameter. At last, the absolute control (T_1) showed a lower bulb neck diameter of 0.90 cm.

Fresh bulb weight: Higher bulb fresh weight (g plant^{-1}) was recorded in 100%RDF+ Nutrigel (T_9) which recorded 67.13 g plant^{-1} was on par with the treatment 100% RDF + commercial micronutrients (T_{10}) which recorded 64.92 g plant^{-1} and which was on par with the treatment, 100% RDF (T_8) which recorded 62.80 g plant^{-1}. Lower bulb fresh weight of 41.87 g plant^{-1} was recorded in absolute control (T_1).

Bolting percentage: The lowest Bolting percentage was observed in the treatment 100% RDF + Nutrigel (T_9) which measured 4.66 %. This was statistically equivalent, to the treatment with 100% RDF + commercial micronutrients (T_{10}), which measured 4.90 %. T_{10} was on par with the treatment 100% RDF (T_8) which measured 5.01%. The highest bolting percentage was observed in the absolute control (T_1), which was recorded to be 6.20 %.

Days to maturity: The lowest days to maturity was recorded in 100% RDF + Nutrigel (T_9) which was 88.13 days, followed by the treatment, 100% RDF + Nutrigel (T_{10}) which recorded 88.93 days this was followed by the treatment 100% RDF (T_8) which recorded 88.97 days. The highest was 90.32 days to maturity was observed in the absolute control (T_1).

Shoot dry matter yield: The maximum shoot dry matter yield was recorded in 100% RDF + Nutrigel (T_9) with the value of 655 Kg ha^{-1}, this was on par with the treatment, 100% RDF + commercial micronutrients (T_{10}) which recorded 653 Kg ha^{-1}. T_{10} was found to be on par the treatment 100% RDF (T_8) which recorded 647 Kg ha^{-1}. The minimum shoot dry matter yield was obtained in the absolute control (T_1) which was 586 Kg ha^{-1}.

Bulb dry matter yield: The maximum bulb dry matter yield was recorded in 100% RDF + Nutrigel (T_9-2760 Kg ha$^{-1)}$ this was on par with the treatment 100% RDF + commercial micronutrients (T_{10}) which recorded 2740 Kg ha^{-1}. Next to this, the treatment 100% RDF (T_8) recorded 2709 Kg ha^{-1}. The minimum shoot dry matter yield was obtained in the absolute control (T_1) 1770 Kg/ha.

Total biomass yield: The maximum total biomass yield was recorded in 100% RDF + Nutrigel (T_9) which was found to be 3415 Kg ha^{-1}, this was on par with the treatment, 100% RDF + commercial micronutrients (T_{10}) which recorded 3393 Kg ha^{-1}. Next to this, the treatment

100% RDF (T_8) recorded 3356 Kg ha^{-1} was on par with (T_8). The minimum shoot dry matter yield was obtained in the absolute control (T1) 2356 Kg/ha.

Harvest Index: The treatments 100 % RDF + Nutrigel (T_9) , 100% RDF + Commercial micronutrients (T_{10}), 100% RDF (T_8) which were recorded 81% of Harvest Index. And then absolute control (T_1) recorded 75 % of Harvest Index.

Bulb yield:

Different quantities of RDF in combination with Nutrigel comprising Nano micronutrients showed greater impact on the total yield of aggregatum onion. The yield was improved with the Nutrigel application and the results reached the target yield of 18t ha^{-1}. The values oscillated from 7.5 to 18.28 t ha^{-1}. The treatment 100% RDF + Nutrigel (T_9) had the highest total yield of 18.28 t ha^{-1}, which is comparable to the treatment 100% RDF + commercial micronutrients (T_{10}) which recorded 17.50 t ha^{-1}. T_{10} was on par with the treatment 100% RDF (T_8) which recorded 17.06 t ha^{-1}.

Marketable bulb yield:

There was a significant variation in terms of marketable yield among the treatments. The marketable yield among the treatments showed a notable effect with the range 5.56 to17.19 t ha^{-1}. In the treatment 100%RDF+ Nutrigel (T_9) had the higher total marketable yield of 17.19 t ha^{-1}, which was comparable to the treatment 100% RDF + commercial micronutrients (T_{10}) which recorded 15.93 t ha^{-1}, this was on par with the treatment, 100% RDF (T_8) which recorded 15.76 t ha^{-1}.

In short application of 100% RDF + Nutrigel (T_9) recorded significantly higher yield attributes and bulb yield compared to 100% RDF (T_8), while yield attributes and bulb yield of 100% RDF + commercial micronutrient (T_{10}) was statistically comparable with 100% RDF (T_8).

1.3. Quality parameters of aggregatum onion bulbs (Table 5)

Ascorbic acid: The highest ascorbic acid content was observed in the treatment with 100% RDF + Nutrigel (T_9) measuring 16.23 mg $100g^{-1}$ of ascorbic acid. This was comparable to the treatment 100% RDF + commercial micronutrients (T_{10}) which recorded 15.92 mg $100g^{-1}$. T_{10} was on par with the treatment 100% RDF (T_8) with the value of 15.56 mg $100g^{-1}$. The lowest ascorbic acid content was found in the absolute control (T_1) which recorded, 11.93 mg $100g^{-1}$.

Total Antioxidant Activity (TAA) by DPPH (2,2 -diphenyl -1-1-picrylhyrazyl): The TAA content was maximum, that is 6.3 %, was observed in the treatment 100% RDF + Nutrigel (T_9), which was comparable with the value of 6.18 % recorded with the treatment 100% RDF + commercial micronutrients (T_{10}). T_{10} was on par with the treatment 100% RDF (T_8) which

measured 6.06%. In contrast, the absolute control (T_1) had the lowest TSS content of 4.93%.

Pyruvic acid: The highest pyruvic acid content was recorded in the treatment 100% RDF + Nutrigel (T_9), measured 2.69 µmol g^{-1}. This was statistically equivalent, to the treatment 100% RDF + commercial micronutrients (T_{10}), which measured 2.56 µmol g^{-1}. T_{10} was on par with the treatment 100% RDF (T_8), which measured 2.53 µmol g^{-1}. The lowest pyruvic acid content was observed in the absolute control (T_1), with 1.83 µmol g^{-1} of pyruvic acid.

Total phenols: The total phenols was recorded higher in the treatment with 100% RDF + Nutrigel (T_9), measuring 0.85 mg g^{-1}. This was comparable to the treatment with 100% RDF + commercial micronutrients (T_{10}), which recorded 0.82 mg g^{-1}. T_{10} was on par with treatment 100% RDF (T_8) which recorded 0.80 mg g^{-1}. The minimum content was noted in the absolute control (T_1), with the value of 0.54 mg g^{-1}.

Titratable Acidity (TA): The TA content was maximum that is 0.46% , was observed in the treatment 100% RDF + Nutrigel (T_9), which was comparable to the treatment 100% RDF + commercial micronutrients (T_{10}) which recorded 0.43% of TA The treatment 100% RDF (T_8) which recorded 0.40 % of TA. In contrast, the absolute control (T_1) had the lowest titratable acidity of 0.16%.

Total Sugars: The Total sugar content was maximum that is 55.98 mg $100g^{-1}$, which was observed in the treatment with 100% RDF + Nutrigel (T_9). It was comparable to the treatment 100% RDF + commercial micronutrients (T_{10}) which recorded 54.92 mg $100g^{-1}$ of total sugars. T_{10} is statistically similar with the treatment 100% RDF (T_8) which recorded 54.75 mg $100g^{-1}$ of total sugars. In contrast, the absolute control (T_1) had the lowest content at 40.32 mg $100g^{-1}$ of total sugars.

pH: The spraying of Nutrigel, NPK Combo and RDF didn't showed the significant impact on pH of onion.

Total Soluble Solids (°Brix): Total soluble solids were highest in T_9 (100% RDF + Nutrigel) with 18.63 degree Brix which was on par with T_{10} (100% RDF + Commercial micronutrient) having 17.45 degree Brix. T_{10} was on par with T_8 (100% RDF) having the TSS of 17.26 degree Brix. In contrast, the absolute control (T_1) had the lowest TSS content of 11.30 degree Brix.

1.4. The soil available nutrients (kg ha^{-1}) at various growth stages of aggregatum onion (Table 6)

The soil available nitrogen, phosphorus and potassium among the treatments that received 100% RDF (T_8, T_9 and T_{10}) were followed by treatments that received 75% RDF (T_5,T_6 and T_7) followed by treatments that received 50% RDF (T_2,T_3 and T_4) and lowest in

absolute control (T_1) at 45, 60 and 90 DAS. The soil available nitrogen, phosphorus and potassium decreased with progressive crop growth in all the treatments.

1.5. The nutrient uptake (kg ha^{-1}) at various growth stages of aggregate onion (Table 7)

Nitrogen, Phosphorous and Potassium uptake:

The N uptake was higher in 100% RDF + Nutrigel (T_9) with values of 25.26 and 35.20 kg ha^{-1} at 45 and 60 DAS respectively and 5.2 kg ha^{-1} in leaves and 65.3 kg ha^{-1} in bulbs at the harvest stage. It was on par with 100% RDF + commercial micronutrient (T_{10}), having values 24.32 and 32.94 at 45 and 60 DAS respectively and 4.90 kg ha^{-1} in leaves and 63.26 kg ha^{-1} in bulbs at harvest. However, T_{10} was on par with 100% RDF (T_8) having the values of 23.05 and 31.76 kg ha^{-1} at 45 and 60 DAS respectively and 4.60 kg ha^{-1} in leaves and 61.68 kg ha^{-1} in bulbs at harvest.

The P uptake was higher in 100% RDF + Nutrigel (T_9) with values of 8.35 and 10.59 kg ha^{-1} at 45 and 60 DAS respectively and 1.5 kg ha^{-1} in leaves and 20.34 kg ha^{-1} in bulbs at the harvest stage. It was statistically similar to 100% RDF + commercial micronutrient (T_{10}), which recorded values of 7.59, and 10.36 at 45 and 60 DAS respectively and 1.46 kg ha^{-1} in leaves and 19.13 kg ha^{-1} in bulbs at harvest. However T_{10} was on par with 100% RDF (T_8) having values of 7.40 and 10.27 kg ha at 45 and 60 DAS respectively and 1.44 kg ha^{-1} in leaves and 19.02 Kg ha^{-1} in bulbs at harvest.

The K uptake was higher in 100% RDF + Nutrigel (T_9) with 26.23 and 35.37 kg ha^{-1} at 45 and 60 DAS respectively and 6.20 kg ha^{-1} in leaves and 69.26 kg ha^{-1} in bulbs at the harvest, which was on par with 100% RDF + commercial micronutrient (T_{10}), having K uptake of 25.36 and 34.12 kg ha^{-1} at 45 and 60 DAS respectively and 6.06 kg ha^{-1} in leaves and 67.43 kg ha^{-1} in bulbs at harvest. However, T_{10} was in turn on par with 100% RDF (T_8) with values of 24.80 and 33.05 kg ha^{-1} at 45 and 60 DAS respectively and 5.95 kg ha^{-1} in leaves and 66.60 kg ha^{-1} in bulbs at harvest.

1.6. The micronutrient uptake in aggregatum onion and plant at harvest stage (Table 8).

Iron uptake

The uptake values fluctuated from 887.10 to 1502.04 g ha^{-1} in bulb and 90.28 to 197.12 Kg ha^{-1} in leaves. The uptake was notably higher in the treatment 100% RDF + Nutrigel (T_9), showed values of 1502.04 g ha^{-1} in bulbs and 197.12 g ha^{-1} in leaves. This was statistically similar to the treatment with 100% RDF + commercial micronutrients (T_{10}), which recorded values of 1485.12 g ha^{-1} in bulbs and 188.96 g ha^{-1} in leaves. Followed by the treatment, 100% RDF (T_8) with the values 1440.34 g ha^{-1} in bulb and 185.43 g ha^{-1} in leaves which was on par with the treatment 75% RDF + NPK combo + Nutrigel (T_6) with the values 1428.1 2 g ha^{-1} in bulb and 180.56 g ha^{-1} in leaves. This trend was followed by the treatment, 75% RDF + NPK combo + Commercial micronutrient (T_7) with the values 1386.04 g ha^{-1} in bulb and 174.07 g ha^{-1} in leaves which was statistically on par with the treatment, 75% RDF + NPK combo (T_5) with the values 1370.00 g ha^{-1} in bulb and 170.20 g ha^{-1} in leaves.

These were followed by the treatment, 50% RDF +NPK combo + Nutrigel (T_3) which had the uptake values of 1173.12 g ha^{-1} in bulb and 128.32 g ha^{-1} in leaves, and then the treatment 50% RDF + NPK combo + Commercial micronutrient (T_4) recorded 1136.45 g ha^{-1} in bulbs and 125.49 g ha^{-1} in leaves were on par with each other . Next to these, the treatment 50 % RDF + NPK combo (T_2) acquired 1170.10 g ha^{-1} in bulbs and 119.90 g ha^{-1} in leaves. Whereas absolute control (T_1) treatment exhibited the lowest iron uptake, with values of 887.10 g ha^{-1} in bulbs and 90.28 g ha^{-1} in leaves respectively.

Manganese uptake

The range of uptake values ranged from 274.13 to 550.21 g ha^{-1} in bulb and 47.43 to 100.12 g ha^{-1} in leaves. The uptake of Manganese was significantly elevated in the treatment incorporating 100% RDF combined with Nutrigel (T_9), demonstrating values of 550.21 g ha^{-1} in bulbs and 100.12 g ha^{-1} in leaves. This outcome was analogous to the treatment involving 100% RDF + commercial micronutrients (T_{10}), which recorded values of 545.16 g ha^{-1} in bulbs and 93.45 g ha^{-1} in leaves. This was on par with the treatment100% RDF (T_8) which recorded values of 532.46 g ha^{-1} in bulbs and 92.90 g ha^{-1} in leaves, this was comparable to the treatment 75% RDF combined with NPK and Nutrigel (T_6), with values of 525.37 g ha^{-1} in bulbs and 86.20 g ha^{-1} in leaves. This pattern was on par with the treatment of 75% RDF combined + NPK+ commercial micronutrients (T_7), which exhibited values of 513.38 g ha^{-1} in bulbs and 85.70 g ha^{-1} in foliage, which was similarly aligned with the treatment, 75% RDF combined with NPK (T_5), showing values of 505.58 g ha^{-1} in bulbs and 79.02 g ha^{-1} in foliage.

Consequently the treatment, 50% RDF +NPK combo + Nutrigel (T_3) which had the uptake values of 448.13g ha^{-1} in bulb and 69.09 g ha^{-1} in leaves. And then the treatment, 50% RDF + NPK combo + Commercial micronutrient (T_4) 442.16 g ha^{-1} in bulbs and 63.25 g ha^{-1} in leaves were on par with the treatment. Next to these, the treatment, 50 % RDF + NPK combo (T_2) recorded 430.34g ha^{-1} in bulbs and 61.90 g ha^{-1} in leaves showed on par with T_4. Lastly, the absolute control treatment (T_1) manifested the lowest zinc uptake, presented values of 274.13 g ha^{-1} in bulbs and 47.43 g ha^{-1} in foliage, respectively.

Zinc uptake

The values of zinc uptake ranged from 168.08 to 320.13 g ha^{-1} in bulbs and 12.83 to 40.02g ha^{-1} in leaves. There was a well noted difference in the uptake values of zinc and recorded during the harvest stage. The uptake of zinc was higher in the treatment 100% RDF combined with Nutrigel (T_9), which demonstrated values of 320.13 g ha^{-1} in bulbs and 40.02 g ha^{-1} in leaves. This outcome was statistically homogenous to the treatment incorporating 100% RDF + commercial micronutrients (T_{10}), which documented values of

317.16 g ha^{-1} in bulbs and 39.32 g ha^{-1} in leaves this was on par with the treatment 100% RDF (T_8) with the values of 308.31 g ha^{-1} in bulbs and 38.49 g ha^{-1} in leaves, a performance comparable to that of the treatment, 75% RDF + NPK combo+ Nutrigel (T_6), which recorded values of 305.52 g ha^{-1} in bulbs and 37.70 g ha^{-1} in leaves. This pattern was mirrored by the treatment 75% RDF + NPK combo + commercial micronutrients (T_7), which presented values of 295.65 g ha^{-1} in bulbs and 36.15 g ha^{-1} in leaves, this results comparable to that achieved by the 75% RDF +NPK combo (T_5), which yielded values of 293.83 g ha^{-1} in bulbs and 36.70 g ha^{-1} in leaves.

And then the treatment, 50% RDF +NPK combo + Nutrigel (T_3) which had the uptake values of 205.17 g ha^{-1} in bulb and 25.40 g ha^{-1} in leaves this was on par with the treatment, 50% RDF + NPK combo + Commercial micronutrient (T_4) which recorded 197.36 g ha^{-1} in bulbs and 24.13 g ha^{-1} in leaves. Next to these, the treatment 50 % RDF + NPK combo (T_2) recorded 193.51 g ha^{-1} in bulbs and 24.49 g ha^{-1} in leaves was on par with T_4. The treatment designated as absolute control (T_1) exhibited the least zinc uptake, with values of 168.08 g ha^{-1} in bulbs and 12.83 g ha^{-1} in leaves, respectively.

Copper uptake

Range of copper uptake varied from 92.07 to 150.56 g ha^{-1} in bulb and 9.5 to 30.12 g ha^{-1} in leaves. The treatment with 100% RDF + Nutrigel (T_9) demonstrated notably higher copper uptake, showing values of 150.56 g ha^{-1} in bulbs and 30.12 g ha^{-1} in leaves. This was comparable to the treatment, 100% RDF + commercial micronutrients treatment (T_{10}), which recorded values of 146.32 g ha^{-1} in bulbs and 29.14 g ha^{-1} in leaves. T_{10} was on par with the treatment 100% RDF (T_8) with values of 141.98 g ha^{-1} in bulbs and 28.66 g ha^{-1} in leaves, which was on par with the treatment 75% RDF + NPK combo + Nutrigel treatment (T_6), showing values of 136.28 g ha^{-1} in bulbs and 27.70 g ha^{-1} in leaves. T_6 was on par with the treatment, 75% RDF + NPK combo + commercial micronutrient treatment (T_7), which recorded values of 132.58 g ha^{-1} in bulbs and 26.92 g ha^{-1} in leaves and on par with the treatment, 75% RDF + NPK combo treatment (T_5), with values of 127.36 g ha^{-1} in bulbs and 26.30 g ha^{-1} in leaves. Next to these, the treatment 50% RDF +NPK combo + Nutrigel (T_3) which had the uptake values of 112.34 g ha^{-1} in bulb and 15.98 g ha^{-1} in leaves this was on par with the treatment, 50% RDF + NPK combo + Commercial micronutrient (T_4) 105.35 g/ha in bulbs and 14.93 g/ha in leaves. Next to these, the treatment, 50 % RDF + NPK combo (T_2) with values of 103.92 g ha^{-1} in bulbs and 14.60 g ha^{-1} in leaves was on par with the treatment T_4. The absolute control treatment (T_1) exhibited the lowest copper uptake of 92.05 g ha^{-1} in bulbs and 9.5 g ha^{-1} in leaves, respectively.

1.7. Scanning Electron Microscopy (SEM) Analysis (Fig 1)

The findings indicate that nutrient absorption through stomata is significantly more efficient in plants treated with Nutrigel compared to those receiving conventional micronutrient formulations. Scanning Electron Microscopy (SEM) observations at 3000X magnification revealed a greater accumulation of nano micronutrients near the stomata in the Nutrigel-treated plants, emphasizing enhanced uptake relative to the commercial formulations. Under similar field conditions, it was noted that the stomata on Nutrigel-treated leaves were open, with a larger stomatal diameter of 2.52 µm and a length of 21.25 µm. In contrast, the leaves treated with commercial micronutrients exhibited smaller stomatal dimensions, with a diameter of 1.84 µm and a length of 16.69 µm.

1.8. Economics (Table 9)

The financial analysis of the various treatments revealed notable differences in their economic outcomes. The 100% RDF + Nutrigel treatment (T9) performs better compare to other treatments, with a cultivation cost of Rs.2,48,686 a gross income of Rs. 8,42,310 and a net income of Rs. 5,93,625 yielding the highest BCR of 3.39. Overall, the inclusion of Nutrigel significantly enhanced economic returns. 100% RDF treatment (T8) has a cultivation cost of Rs. 2,39,686 resulting in a gross income of Rs. ,72,240 and a net income of Rs.75,32,555 which leads to a benefit-cost ratio (BCR) of 3.22. The 100% RDF + Commercial Micronutrients treatment (T10) has a cultivation cost of Rs.2,41,936 with a gross income of Rs. 7,80,570 and a net income of Rs. 5,38,635 achieving a BCR of 3.23. This indicates that treatments with Nutrigel offer improved BCR compared to those using only the NPK combo.

Table. 3. Effect of levels of RDF, NPK combo, Nutrigel and commercial micronutrient on the growth parameters at various growth stages of aggregatum onion.

Treatment	Plant height (cm)			Number of leaves			leaf length (cm)			leaf diameter (cm)			Relative Chlorophyll Content (SPAD)		
	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
T_1	38.09	39.56	45.13	32.34	32.90	31.20	28.30	33.56	32.80	0.83	1.56	1.09	43.86	46.85	37.20
T_2	41.31	43.11	47.45	33.90	34.98	32.13	30.35	35.43	34.10	1.42	1.70	1.23	45.50	48.69	39.16
T_3	42.31	48.47	49.72	35.29	36.58	33.07	31.55	37.25	35.40	1.65	1.82	1.36	47.10	50.50	41.10
T_4	43.59	45.17	49.60	34.62	35.86	32.72	30.63	36.95	34.93	1.59	1.76	1.26	45.93	49.13	40.36
T_5	45.71	47.58	52.06	36.67	38.12	34.06	32.75	39.04	36.70	1.75	1.93	1.54	48.72	52.35	43.03
T_6	48.90	50.97	54.36	38.05	39.59	34.98	33.95	40.83	37.98	1.82	2.03	1.60	50.33	54.19	44.96
T_7	47.45	49.32	53.21	37.43	38.94	34.50	33.30	39.78	37.56	1.79	1.97	1.57	48.95	53.62	43.35
T_8	50.1	51.47	55.12	38.83	40.45	35.40	34.50	41.56	38.85	1.86	2.07	1.63	50.57	55.50	45.30
T_9	52.31	54.13	57.42	40.34	41.95	36.30	36.30	43.43	40.13	1.93	2.27	1.78	52.16	57.36	47.24
T_{10}	51.1	53.37	56.66	39.45	41.12	35.48	35.65	42.71	39.10	1.89	2.20	1.72	51.32	56.92	46.83
SEd	0.95	0.977	0.64	0.64	0.75	0.43	0.58	0.87	0.62	0.031	0.044	0.039	0.866	0.786	0.905
CD (P=0.05)	2.03	2.05	1.86	1.30	1.50	0.87	1.17	1.75	1.10	0.06	0.09	0.08	1.58	1.82	1.91

***I – Bulb formation stage (45 DAS), II –Bulb development stage (60 DAS), III – Harvest stage (90 DAS)**

Table. 4. Effect of levels of RDF, NPK combo, Nutrigel and commercial micronutrient on the yield attributes and yield of aggregatum onion.

Treatment	Polar diameter (cm)	Equatorial diameter (cm)	Bulb neck diameter (cm)	Fresh bulb weight (g plant^{-1})	Bolting %	Stand count %	Days to Maturity	Shoot dry matter yield (Kg/ha)	Bulb dry matter yield (Kg/ha)	Total biomass yield (Kg/ha)	Harvest Index (%)	Total Bulb yield	Market able yield
T_1	1.36	2.50	0.90	41.87	6.20	95.65	90.32	586	1770	2356	75	7.50	5.56
T_2	2.65	3.10	1.18	46.30	5.98	95.97	90.30	595	2402	2997	80	12.70	11.03
T_3	3.40	3.70	1.28	50.68	5.70	96.70	90.16	605	2460	3065	80	14.03	12.27
T_4	3.16	3.26	1.23	47.19	5.84	96.62	90.28	600	2435	3035	80	12.96	11.13
T_5	3.72	4.32	1.40	55.00	5.43	97.36	90.13	627	2636	3263	81	15.30	13.50
T_6	4.08	4.92	1.50	59.32	5.15	98.06	89.32	635	2679	3314	81	16.56	14.96
T_7	3.97	4.73	1.48	58.50	5.30	97.43	90.05	633	2663	3296	81	15.80	14.32
T_8	4.30	5.32	1.58	62.80	5.01	98.17	88.97	647	2709	3356	81	17.06	15.76
T_9	4.63	5.92	1.67	67.13	4.66	99.91	88.13	655	2760	3415	81	18.28	17.19
T_{10}	4.37	5.46	1.60	64.92	4.90	99.83	88.93	653	2740	3393	81	17.50	15.93
SEd	0.149	0.28	0.044	2.139	0.13	2.054	6.691	4.1	20.5	26	1.942	0.483	0.776
CD (P=0.05)	0.30	0.56	0.09	4.30	0.28	NS	NS	8	41.3	52.3	NS	0.97	1.56

Table. 5. Effect of levels of RDF, NPK combo, Nutrigel and commercial micronutrient on the quality parameters of aggregatum onion bulb and plant.

Treatment	Ascorbic acid (mg $100g^{-1}$)	TAA (%)	Pyruvic acid (µmol g^{-1})	Total phenols (mg g^{-1})	TA (%)	Total sugars (mg$100g^{-1}$)	pH	TSS (^{0} Brix)
T_1	11.93	4.93	1.83	0.54	0.16	40.32	5.93	11.30
T_2	13.30	5.20	2.16	0.62	0.22	50.28	5.91	12.75
T_3	13.96	5.47	2.28	0.67	0.27	51.50	5.81	14.13
T_4	13.42	5.25	2.25	0.64	0.25	50.76	5.83	13.29
T_5	14.63	5.72	2.39	0.72	0.32	52.74	5.74	15.50
T_6	15.32	5.96	2.50	0.77	0.37	53.96	5.66	16.93
T_7	14.90	5.82	2.43	0.75	0.35	53.56	5.72	15.89
T_8	15.56	6.06	2.53	0.80	0.40	54.75	5.63	17.26
T_9	16.23	6.3	2.69	0.85	0.46	55.98	5.43	18.63
T_{10}	15.92	6.18	2.56	0.82	0.43	54.92	5.55	17.45
SEd	0.32	0.11	0.044	0.019	0.019	0.59	0.37	0.671
CD (P=0.05)	0.65	0.23	0.09	0.04	0.04	1.20	NS	1.35

Table. 6. Effect of levels of RDF, NPK combo, Nutrigel and commercial micronutrient on the soil available nutrients (kg ha^{-1}) at various growth stages of aggregate onion

Treatment	Soil available nitrogen (kg ha^{-1})				Soil available phosphorus (kg ha^{-1})				Soil available potassium (kg ha^{-1})			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
T_1	195.0	186.0	182.0	174.0	32.8	30.5	28.0	27.6	302	296	291	283
T_2	209.0	196.0	191.0	183.0	35.69	33.09	31.1	30.1	311	309	298	290
T_3	207.0	194.0	189.0	181.0	34.82	32.54	29.84	29.67	309	306	296	288
T_4	208.0	195.0	190.0	182.0	35.18	32.96	31.02	29.96	310	307	297	289
T_5	220.0	208.0	201.0	192.0	38.29	35.36	33.63	32.63	320	316	304	299
T_6	218.0	206.0	199.0	190.0	37.97	34.92	32.97	32.12	318	314	302	297
T_7	219.0	207.0	200.0	191.0	38.05	35.14	33.45	32.3	319	315	303	298
T_8	232.0	220.0	211.0	201.0	42.63	38.56	36.92	35.52	332	323	312	308
T_9	230.0	218.0	209.0	199.0	41.93	37.36	35.46	35.19	330	321	309	305
T_{10}	231.0	219.0	210.0	200.0	42.17	37.91	36.78	35.36	331	322	310	306
SEd	4.000	3.894	3.527	3.243	0.895	0.794	0.683	0.859	2.8	2.1	3.4	2.7
CD (P=0.05)	8.403	8.181	7.410	6.812	1.881	1.668	1.436	1.805	6	4	5	5

*** I – Vegetative (25 DAS), II – Bulb formation (45 DAS), III – Bulb development (60 DAS), IV- Harvest (90 DAS)**

Table. 7. Effect of levels of RDF, NPK combo, Nutrigel and commercial micronutrient on the nutrient uptake (kg ha^{-1}) at various growth stages of aggregatum onion

Treatment	Nitrogen uptake (kg ha^{-1})					Phosphorus uptake (kg ha^{-1})					Potassium uptake (kg ha^{-1})				
	I	II	III	IV		I	II	III	IV		I	II	III	IV	
				Bulb	Leaf				Bulb	Leaf				Bulb	Leave
T_1	8.50	11.43	15.70	35.42	1.96	1.63	2.57	4.45	9.32	0.70	8.63	11.32	16.73	39.68	1.92
T_2	10.35	14.69	19.17	42.20	2.20	2.12	3.53	7.30	11.80	1.15	11.50	16.40	21.10	50.80	3.55
T_3	10.15	16.10	22.60	45.80	2.90	2.05	4.51	7.63	13.18	1.20	11.36	17.86	23.43	53.46	3.82
T_4	10.27	15.42	19.37	43.36	2.50	2.10	3.46	7.45	12.32	1.17	11.43	17.50	22.95	52.93	3.63
T_5	12.13	19.13	26.08	55.43	3.50	2.70	5.49	9.74	16.50	1.34	12.40	21.47	29.48	61.30	5.48
T_6	11.96	21.35	29.50	59.60	4.20	2.58	6.50	10.04	17.83	1.40	12.18	22.90	31.80	64.80	5.80
T_7	12.06	20.84	29.34	58.05	3.80	2.62	6.40	9.93	17.70	1.38	12.32	22.37	30.36	63.97	5.70
T_8	13.52	23.05	31.76	61.68	4.60	3.47	7.40	10.27	19.02	1.44	13.37	24.80	33.05	66.60	5.95
T_9	13.14	25.26	35.20	65.30	5.20	3.19	8.35	10.59	20.34	1.5	13.10	26.23	35.37	69.26	6.20
T_{10}	13.46	24.32	32.94	63.26	4.90	3.36	7.59	10.36	19.13	1.46	13.25	25.36	34.12	67.43	6.06
SEd	0.796	1.095	2.139	1.791	0.299	0.224	0.478	0.149	0.647	0.025	0.299	0.697	1.144	1.294	0.114
CD (P=0.05)	1.6	2.2	4.3	3.60	0.60	0.45	0.96	0.30	1.30	0.05	0.60	1.40	2.3	2.6	0.23

***I – Vegetative stage (25 DAS), II – Bulb formation stage (45 DAS), III – Bulb development stage (60 DAS), IV – Harvest stage (90 DAS)**

Table. 8. Effect of levels of RDF, NPK combo, Nutrigel and commercial micronutrient on the micronutrient uptake in aggregatum onion at harvest stage.

Treatments	Bulb				Leaves			
	Fe g ha^{-1}	Mn g ha^{-1}	Zn g ha^{-1}	Cu g ha^{-1}	Fe g ha^{-1}	Mn g ha^{-1}	Zn g ha^{-1}	Cu g ha^{-1}
T_1	887.10	274.13	168.08	92.07	90.28	47.43	12.83	9.50
T_2	1170.10	430.34	193.51	103.92	119.90	61.90	24.49	14.60
T_3	1173.12	448.13	205.17	112.34	128.32	69.09	25.40	15.98
T_4	1136.45	442.16	197.36	105.35	125.49	63.25	24.13	14.93
T_5	1370.00	505.58	293.83	127.36	170.20	79.02	36.70	26.30
T_6	1428.12	525.37	305.52	136.28	180.56	86.20	37.70	27.70
T_7	1386.04	513.38	295.65	132.58	174.07	85.70	36.15	26.92
T_8	1440.34	532.46	308.31	141.98	185.43	92.90	38.49	28.66
T_9	1502.04	550.21	320.13	150.56	197.12	100.12	40.02	30.12
T_{10}	1485.12	545.16	317.16	146.32	188.96	93.45	39.32	29.14
SEd	27.697	8.353	5.303	4.179	4.159	3.532	0.458	0.677
CD (P=0.05)	55.67	16.79	10.66	8.4	8.36	7.10	0.92	1.36

Table. 9. Effect of levels of RDF, Nutrigel, NPK combo and Commercial micronutrients on Economics of Marketable yield by aggregatum onion

Treatments		Cost of cultivation (Rs.)	Gross income (Rs.)	Net income (Rs.)	BCR
T_1	Absolute Control	237869	272440	34571	1.15
T_2	50 % RDF + NPK combo	254977	540470	285493	2.12
T_3	50% RDF +NPK combo + Nutrigel	263977	601230	337253	2.28
T_4	50% RDF + NPK combo + Commercial micronutrient	257227	545370	288143	2.12
T_5	75% RDF + NPK combo	255431	661500	406069	2.59
T_6	75% RDF + NPK combo + Nutrigel	264431	733040	468609	2.77
T_7	75% RDF + NPK combo + Commercial micronutrient	257681	701680	443999	2.72
T_8	100% RDF	239686	772240	532555	3.22
T_9	100% RDF + Nutrigel	248686	842310	593625	3.39
T_{10}	100% RDF + Commercial micronutrients	241936	780570	538635	3.23

2. Second Season Field Experiment on Aggregatum Onion

The second field experiment was conducted from December 2024 to March 2025 in Kuppepalayam village, Coimbatore district, Tamil Nadu, India (11°00'71.2"N, 76°81'43.4" E). The aggregatum onion variety Co (On) 5 was used to evaluate various combinations of the recommended fertilizer dose (RDF), NPK combo, Nutrigel (Nano micronutrient in gel formulation) and commercial micronutrient formulation. The spraying schedule and the treatment details are same as that of first season onion experiment (Table 1 and 2).

Effects of imposed treatments on plant growth attributes, yield and yield attributes, nutrient uptake, availability of nutrient and microbial growth in soil were discussed below.

2.1. Plant growth attributes (Table 10)

Plant Height: The tallest plants were observed in treatment T_9 (100% RDF + Nutrigel) reaching 51.41 cm at 45 DAS, 53.33 cm at 60 DAS and 57.12 cm at 90 DAS. Treatment T_{10} (100% RDF + Commercial micronutrient) recorded plant heights of 50.00 cm, 52.37 cm and 56.16 cm at the respective stages and was statistically on par with T_9 (100% RDF + Nutrigel). However, T_{10} was on par with T_8 (100% RDF), which recorded plant heights of 48.90 cm, 50.37 cm and 54.52 cm respectively at 45, 60, and 90 DAS. The absolute control (T_1) treatment, with 36.69, 38.26 and 43.33 cm of mean plant height at 45, 60, and 90 DAS respectively in which shortest plant height was observed. The plant mean height was increased from bulb formation to harvest stage.

Number of Leaves: Treatment T_9 (100% RDF + Nutrigel) produced the higher leaf count across all stages, recording 39.34 leaves at 45 DAS, 40.75 leaves during 60 DAS and 36.90 leaves at 90 DAS. This treatment was statistically on par with T_{10} (100% RDF + Commercial micronutrient), which recorded 38.35, 39.42 and 36.08 leaves at 45, 60, and 90 DAS respectively. Treatment T_8 (100% RDF) achieved 37.53, 39.35 and 36.30 leaves at 45, 60, and 90 DAS respectively and remained on par with T_{10}. The absolute control (T_1) treatment pronounced, 31.24, 32.10 and 30.00 number of leaves per plant at 45, 60, and 90 DAS respectively which stands lowest among the all treatments.

Leaf length: The highest mean leaf length of aggregatum onion, was observed 36.50, 43.80 and 40.60 cm at 45, 60, and 90 DAS respectively in the treatment 100% RDF + Nutrigel (T_9). These results were on par with the treatment 100% RDF + commercial micronutrients (T_{10}), which recorded 35.65, 42.61 and 39.62 cm of mean leaf length at 45, 60, and 90 DAS respectively. Then the treatment 100% RDF (T_8) had recorded 34.80, 41.73 and 37.98 cm of leaf length at 45, 60, and 90 DAS respectively, were seen to be in non-significant with the

treatment $T_{10.}$ The absolute control (T_1) treatment produced the lowest leaf length of 28.20, 33.54 and 31.98 cm at 45, 60, and 90 DAS respectively.

Leaf diameter: The treatment with 100% RDF + Nutrigel (T_9) produced the highest mean leaf diameter in multiplier onion, with 1.87, 2.24 and 1.71 cm at 45, 60, and 90 DAS respectively. This outcome was non-significant to the treatment 100% RDF + commercial micronutrients (T_{10}), which recorded 1.83, 2.16 and 1.66 cm of leaf diameter at 45, 60, and 90 DAS respectively were on par with the treatment 100% RDF (T_8) which recorded 1.78, 2.01 and 1.56 cm at 45, 60, and 90 DAS respectively. Conversely, the absolute control (T_1) recorded the lowest leaf diameter, with 1.05, 1.47 and 1.01 cm at 45, 60, and 90 DAS respectively.

Relative Chlorophyll Content (SPAD): 100% RDF + Nutrigel (T_9) recorded the highest relative chlorophyll content, with values of 53.50 at 45 DAS, 59.39 at 60 DAS and 50.28 at 90 DAS. Treatment T_{10} (100% RDF + Commercial micronutrient) followed with 51.81, 57.89 and 47.35 which was statistically on par with T_9. However, T_{10} remained on par with T_8 (100% RDF) which recorded 52.86, 57.93 and 49.08 at 45, 60, and 90 DAS of onion respectively. The lowest SCMR values were observed in the treatment absolute control (T_1), with 45.40, 49.06 and 39.12 at 45, 60, and 90 days respectively.

The treatment 100% RDF + Nutrigel (T_9) recorded significantly higher plant growth parameters *viz.,* plant height, number of leaves, leaf length, leaf diameter and relative chlorophyll content (SPAD values) compared to 100%RDF (T_8). Even though, the treatment 100% RDF + commercial micronutrient (T_{10}) was statistically on par with 100% RDF + Nutrigel (T_9), it did not differ significantly over 100% RDF (T_8).

2.2. The yield and yield attributes of aggregatum onion (Table 11)

Bulb Polar diameter: The use of 100% RDF + Nutrigel (T_9) resulted in greater bulb polar diameter of 4.67 cm, which was on par with the treatment 100% RDF + Commercial micronutrients (T_{10}) which recorded 4.56 cm of polar bulb diameter. On the other hand, the treatment, 100% RDF (T_8) 4.43 cm of polar bulb diameter, showed statistical similarity with the treatment T_{10}**.** The absolute control (T_1) showed a lesser bulb polar diameter of 1.58 cm.

Bulb equatorial diameter: The 100% RDF + Nutrigel significantly influenced bulb equatorial diameter and the results were well pronounced. The highest equatorial diameter was recorded in the treatment 100% RDF+ Nutrigel (T_9) with 5.83 cm, Which has no significant difference with the treatment,100% RDF + commercial micronutrients (T_{10}) which recorded 5.41 cm of equatorial diameter, was on par with the treatment, 100%RDF (T_8) which measured 5.23 cm of equatorial diameter. At last, the absolute control (T_1) showed a lower bulb equatorial diameter of 2.55 cm.

Bulb neck diameter : The treatment 100% RDF + Nutrigel (T_9) had the maximum bulb neck diameter content of 1.69 cm, which was statistically comparable to the treatment 100% RDF + commercial micronutrients (T_{10}) with 1.61 cm of bulb neck diameter this was on par with the treatment, 100% RDF (T_8) which had 1.59 cm of bulb neck diameter. At last, the absolute control (T_1) showed a lower bulb neck diameter of 0.93 cm.

Fresh bulb weight: Higher bulb fresh weight (g plant^{-1}) was recorded in 100%RDF+ Nutrigel (T_9) which recorded 68.22 g plant^{-1} was on par with the treatment 100% RDF + commercial micronutrients (T_{10}) which recorded 66.54 g plant^{-1} and which was on par with the treatment, 100% RDF (T_8) which recorded 64.69 g plant^{-1}. Lower bulb fresh weight of 43.57 g plant^{-1} was recorded in absolute control (T_1).

Bolting percentage: The lowest Bolting percentage was observed in the treatment 100% RDF + Nutrigel (T_9) which measured 4.37 %. This was statistically equivalent, to the treatment with 100% RDF + commercial micronutrients (T_{10}), which measured 4.54 %. T_{10} was on par with the treatment 100% RDF (T_8) which measured 4.64%. The highest bolting percentage was observed in the absolute control (T_1), which was recorded to be 5.84 %.

Stand count percentage: The variation among treatments does not attained the statistical significance.

Days to maturity: The days to maturity ranged from 87.11 to 90.48 and the variation among the treatments does not attained the statistical significance.

Shoot dry matter yield: The maximum shoot dry matter yield was recorded in 100% RDF + Nutrigel (T_9) with the value of 657 kg ha^{-1}, this was on par with the treatment, 100% RDF + commercial micronutrients (T_{10}) which recorded 655 kg ha^{-1}. The treatment T_{10} was found to be on par the treatment 100% RDF (T_8) which recorded 654 kg ha^{-1}. The minimum shoot dry matter yield was obtained in the absolute control (T_1) which was 587 kg ha^{-1}.

Bulb dry matter yield: The maximum bulb dry matter yield was recorded in 100% RDF + Nutrigel (T_9-2760 kg ha$^{-1)}$ this was on par with the treatment 100% RDF + commercial micronutrients (T_{10}) which recorded 2745 kg ha^{-1}. Next to this, the treatment 100% RDF (T_8) recorded 2720 kg ha^{-1}. The minimum shoot dry matter yield was obtained in the absolute control (T_1) 1906 kg ha^{-1}.

Total biomass yield: The maximum total biomass yield was recorded in 100% RDF + Nutrigel (T_9) which was found to be 3417 kg ha^{-1}, this was on par with the treatment, 100% RDF + commercial micronutrients (T_{10}) which recorded 3400 kg ha^{-1}. Next to this, the treatment 100% RDF (T_8) recorded 3374 kg ha^{-1} was on par with (T_8). The minimum shoot dry matter yield was obtained in the absolute control (T1) 2493 kg ha^{-1}.

Harvest Index:

The harvest index among the treatments ranged from 76 to 81 percent and the variation among the treatments did not attain significance.

Bulb yield:

Different quantities of RDF in combination with Nutrigel comprising Nano micronutrients showed greater impact on the total yield of aggregatum onion. The yield was improved with the Nutrigel application and the results reached the yield of 18.49 t ha^{-1}. The values oscillated from 7.94 to 18.49 t ha^{-1}. The treatment 100% RDF + Nutrigel (T_9) had the highest total yield of 18.49 t ha^{-1}, which is comparable to the treatment 100% RDF + commercial micronutrients (T_{10}) which recorded 17.77 t ha^{-1}. T_{10} was on par with the treatment 100% RDF (T_8) which recorded 17.17 t ha^{-1}.

Marketable bulb yield:

There was a significant variation in terms of marketable yield among the treatments. The marketable yield among the treatments showed a notable effect with the range 5.89 to 17.38 t ha^{-1}. In the treatment 100%RDF+ Nutrigel (T_9) had the higher total marketable yield of 17.38 t ha^{-1}, which was comparable to the treatment 100% RDF + commercial micronutrients (T_{10}) which recorded 16.17 t ha^{-1}, this was on par with the treatment, 100% RDF (T_8) which recorded 15.84 t ha^{-1}.

Application of 100% RDF + Nutrigel (T_9) recorded significantly higher yield attributes and bulb yield compared to 100% RDF (T_8), while yield attributes and bulb yield of 100% RDF + commercial micronutrient (T_{10}) was statistically comparable with 100% RDF (T_8).

2.3. Quality parameters of aggregatum onion bulbs (Table 12)

Ascorbic acid: The highest ascorbic acid content was observed in the treatment with 100% RDF + Nutrigel (T_9) measuring 16.92 mg $100g^{-1}$ of ascorbic acid. This was comparable to the treatment 100% RDF + commercial micronutrients (T_{10}) which recorded 16.43 mg $100g^{-1}$. T_{10} was on par with the treatment 100% RDF (T_8) with the value of 16.08 mg $100g^{-1}$. The lowest ascorbic acid content was found in the absolute control (T_1) which recorded, 12.12 mg $100g^{-1}$.

Total Antioxidant Activity (TAA) by DPPH (2,2 -diphenyl -1-1-picrylhyrazyl): The TAA content was maximum, that is 6.97 %, was observed in the treatment 100% RDF + Nutrigel (T_9), which was comparable with the value of 6.85 % recorded with the treatment 100% RDF + commercial micronutrients (T_{10}). T_{10} was on par with the treatment 100% RDF (T_8) which measured 6.72%. In contrast, the absolute control (T_1) had the lowest TSS content of 5.22%, which were found to be statistically equivalent.

Pyruvic acid: The highest pyruvic acid content was recorded in the treatment 100% RDF + Nutrigel (T_9), measured 2.78 µmol g^{-1}. This was statistically equivalent, to the treatment 100% RDF + commercial micronutrients (T_{10}), which measured 2.63 µmol g^{-1}. T_{10} was on par with the treatment 100% RDF (T_8), which measured 2.61 µmol g^{-1}. The lowest pyruvic acid content was observed in the absolute control (T_1), with 1.95 µmol g^{-1} of pyruvic acid.

Total phenols: The total phenols was recorded higher in the treatment with 100% RDF + Nutrigel (T_9), measuring 0.92 mg g^{-1}. This was comparable to the treatment with 100% RDF + commercial micronutrients (T_{10}), which recorded 0.89 mg g^{-1}. T_{10} was on par with treatment 100% RDF (T_8) which recorded 0.86 mg g^{-1}. The minimum content was noted in the absolute control (T_1), with the value of 0.56 mg g^{-1}.

Titratable Acidity (TA): The TA content was maximum that is 0.43% , was observed in the treatment 100% RDF + Nutrigel (T_9), which was comparable to the treatment 100% RDF + commercial micronutrients (T_{10}) which recorded 0.40% of TA The treatment 100% RDF (T_8) which recorded 0.36 % of TA. In contrast, the absolute control (T_1) had the lowest TSS content of 0.09% of TA.

Total Sugars: The Total sugar content was maximum that is 56.43 mg $100g^{-1}$, which was observed in the treatment with 100% RDF + Nutrigel (T_9). It was comparable to the treatment 100% RDF + commercial micronutrients (T_{10}) which recorded 55.81 mg $100g^{-1}$ of total sugars. T_{10} is statistically similar with the treatment 100% RDF (T_8) which recorded 55.62 mg $100g^{-1}$ of total sugars. In contrast, the absolute control (T_1) had the lowest content at 43.83 mg $100g^{-1}$ of total sugars.

pH: The spraying of Nutrigel, NPK Combo and RDF didn't showed the significant impact on pH of onion. The pH values oscillated from 5.31 to 5.85. The treatment with 100% RDF + Nutrigel (T_9) showed lowest pH 5.31 followed by the treatment, 100% RDF + Commercial micronutrient (T_{10}) which recorded 5.42 this was followed by the treatment 100% RDF (T_8) which recorded 5.49. The highest was 5.85 at maturity was observed in the absolute control (T_1).

Total Soluble Solids (°Brix): Total soluble solids were highest in T_9 (100% RDF + Nutrigel) with 18.75 degree Brix which was on par with T_{10} (100% RDF + Commercial micronutrient) having 17.77 degree Brix. T_{10} was on par with T_8 (100% RDF) having the TSS of 17.38 degree Brix. In contrast, the absolute control (T_1) had the lowest TSS content of 11.60 degree Brix.

2.4. The soil available nutrients (kg ha^{-1}) at various growth stages of aggregatum onion (Table 13)

The soil available nitrogen, phosphorus and potassium among the treatments that received 100% RDF (T_8, T_9 and T_{10}) were followed by treatments that received 75% RDF (T_5,T_6 and T_7) followed by treatments that received 50% RDF (T_2,T_3 and T_4) and lowest in absolute control (T_1) at 45, 60 and 90 DAS**.**

2.5. The nutrient uptake (kg ha^{-1}) at various growth stages of aggregate onion (Table 14)

Nitrogen uptake:

The uptake at vegetative stage was higher in the treatment (T_8) 100% RDF which recorded 14.75 kg ha^{-1} and followed by 100% RDF + Commercial micronutrients (T_{10}) which recorded 14.60 kg ha^{-1} this is followed by 100% RDF + Nutrigel (T_9) 14.31 kg ha^{-1} which are on par with each other. The absolute control showed lowest Nitrogen uptake of all that is 9.43 kg ha^{-1}.

Phosphorous uptake:

The uptake at vegetative stage was higher in the treatment(T_8) 100% RDF which recorded 3.89 kg ha^{-1} followed by 100% RDF + Commercial micronutrients (T_{10}) which recorded 3.73 kg ha^{-1} this is followed by 100% RDF + Nutrigel (T_9) which recorded 3.53 kg ha^{-1} which are on par with each other. The absolute control showed lowest Phosphorous uptake of all that is 1.78 kg ha^{-1}.

Potassium uptake:

The uptake at vegetative stage was higher in the treatment 100% RDF (T_8) which recorded 13.59 kg ha^{-1} followed by 100% RDF + Commercial micronutrients (T_{10}) which recorded 13.46 kg ha^{-1} this was followed by 100% RDF + Nutrigel (T_9) which showed 13.25 kg ha^{-1} which were on par with each other. The absolute control showed lowest potassium uptake of all that is 8.93 kg ha^{-1}.

2.6. The micronutrient uptake in aggregatum onion and plant at harvest stage (Table 15).

Iron uptake

The uptake values fluctuated from 892 to 1507 g ha^{-1} in bulb and 92 to 201 kg ha^{-1} in leaves. The uptake was notably higher in the treatment 100% RDF + Nutrigel (T_9), showed values of 1507 g ha^{-1} in bulbs and 201 g ha^{-1} in leaves. This was statistically similar to the treatment with 100% RDF + commercial micronutrients (T_{10}), which recorded values of 1490 g ha^{-1} in bulbs and 193 g ha^{-1} in leaves. Followed by the treatment, 100% RDF (T_8) with the values 1444 g ha^{-1} in bulb and 189 g ha^{-1} in leaves which was on par with the treatment 75%

RDF + NPK combo + Nutrigel (T_6) with the values 1433 g ha^{-1} in bulb and 183 g ha^{-1} in leaves. This trend was followed by the treatment, 75% RDF + NPK combo + Commercial micronutrient (T_7) with the values 1391 g ha^{-1} in bulb and 177 g ha^{-1} in leaves which was statistically analogous with the treatment, 75% RDF + NPK combo (T_5) with the values 1374 g ha^{-1} in bulb and 175 g ha^{-1} in leaves.

These were followed by the treatment, 50% RDF +NPK combo + Nutrigel (T_3) which had the uptake values of 1177 g ha^{-1} in bulb and 131 g ha^{-1} in leaves, and then the treatment 50% RDF + NPK combo + Commercial micronutrient (T_4) recorded 1141 g ha^{-1} in bulbs and 129 g ha^{-1} in leaves were on par with each other . Next to these, the treatment 50 % RDF + NPK combo (T_2) acquired 1174 g ha^{-1} in bulbs and 122 g ha^{-1} in leaves. Whereas absolute control (T_1) treatment exhibited the lowest iron uptake, with values of 892 g ha^{-1} in bulbs and 92 g ha^{-1} in leaves respectively.

Manganese uptake

The Range of uptake values oscillated from 277 to 555 g ha^{-1} in bulb and 50 to 105 g ha^{-1} in leaves. The uptake of Manganese was significantly elevated in the treatment incorporating 100% RDF combined with Nutrigel (T_9), demonstrating values of 555 g ha^{-1} in bulbs and 105 g ha^{-1} in leaves. This outcome was analogous to the treatment involving 100% RDF + commercial micronutrients (T_{10}), which recorded values of 549 g ha^{-1} in bulbs and 98 g ha^{-1} in leaves. This was on par with the treatment100% RDF (T_8) which recorded values of 537 g ha^{-1} in bulbs and 95 g ha^{-1} in leaves, this was comparable to the treatment 75% RDF combined with NPK and Nutrigel (T_6), with values of 530 g ha^{-1} in bulbs and 88 g ha^{-1} in leaves. This pattern was on par with the treatment of 75% RDF combined + NPK+ commercial micronutrients (T_7), which exhibited values of 517 g ha^{-1} in bulbs and 87 g ha^{-1} in foliage, which was similarly aligned with the treatment, 75% RDF combined with NPK (T_5), showing values of 509 g ha^{-1} in bulbs and 83 g ha^{-1} in foliage.

Consequently the treatment, 50% RDF +NPK combo + Nutrigel (T_3) which had the uptake values of 452 g ha^{-1} in bulb and 71 g ha^{-1} in leaves. And then the treatment, 50% RDF + NPK combo + Commercial micronutrient (T_4) 446 g ha^{-1} in bulbs and 66 g ha^{-1} in leaves were on par with the treatment. Next to these, the treatment, 50 % RDF + NPK combo (T_2) recorded 434g ha^{-1} in bulbs and 64 g ha^{-1} in leaves showed on par with T_4. Lastly, the absolute control treatment (T_1) manifested the lowest zinc uptake, presented values of 277 g ha^{-1} in bulbs and 50 g ha^{-1} in foliage, respectively.

Zinc uptake

The values of zinc uptake oscillated from 172 to 325 g ha^{-1} in bulbs and 14 to 44 g ha^{-1} in leaves. There was a well noted difference in the uptake values of zinc and recorded during the harvest stage. The uptake of zinc was higher in the treatment 100% RDF combined with Nutrigel (T_9), which demonstrated values of 325 g ha^{-1} in bulbs and 44 g ha^{-1} in leaves. This outcome was statistically homogenous to the treatment incorporating 100% RDF + commercial micronutrients (T_{10}), which documented values of 320 g ha^{-1} in bulbs and 42 g ha^{-1} in leaves this was on par with the treatment 100% RDF (T_8) with the values of 312 g ha^{-1} in bulbs and 42 g ha^{-1} in leaves, a performance comparable to that of the treatment, 75% RDF + NPK combo+ Nutrigel (T_6), which recorded values of 309 g ha^{-1} in bulbs and 40 g ha^{-1} in leaves. This pattern was mirrored by the treatment 75% RDF + NPK combo + commercial micronutrients (T_7), which presented values of 299 g ha^{-1} in bulbs and 40 g ha^{-1} in leaves, this results comparable to that achieved by the 75% RDF +NPK combo (T_5), which yielded values of 298 g ha^{-1} in bulbs and 39 g ha^{-1} in leaves.

And then the treatment, 50% RDF +NPK combo + Nutrigel (T_3) which had the uptake values of 207 g ha^{-1} in bulb and 28 g ha^{-1} in leaves this was on par with the treatment, 50% RDF + NPK combo + Commercial micronutrient (T_4) which recorded 201 g ha^{-1} in bulbs and 26 g ha^{-1} in leaves. Next to these, the treatment 50 % RDF + NPK combo (T_2) recorded 196 g ha^{-1} in bulbs and 25 g ha^{-1} in leaves was on par with T_4. The treatment designated as absolute control (T_1) exhibited the least zinc uptake, with values of 172 g ha^{-1} in bulbs and 14 g ha^{-1} in leaves, respectively.

Copper uptake

Range of copper uptake varied from 95 to 155 g ha^{-1} in bulb and 12 to 34 g ha^{-1} in leaves. The treatment with 100% RDF + Nutrigel (T_9) demonstrated notably higher copper uptake, showing values of 155 g ha^{-1} in bulbs and 34 g ha^{-1} in leaves. This was comparable to the treatment, 100% RDF + commercial micronutrients treatment (T_{10}), which recorded values of 151 g ha^{-1} in bulbs and 33 g ha^{-1} in leaves. T_{10} was on par with the treatment 100% RDF (T_8) with values of 145 g ha^{-1} in bulbs and 33 g ha^{-1} in leaves, which was on par with the treatment 75% RDF + NPK combo + Nutrigel treatment (T_6), showing values of 140 g ha^{-1} in bulbs and 32 g ha^{-1} in leaves. T_6 was on par with the treatment, 75% RDF + NPK combo + commercial micronutrient treatment (T_7), which recorded values of 136 g ha^{-1} in bulbs and 31 g ha^{-1} in leaves and on par with the treatment, 75% RDF + NPK combo treatment (T_5), with values of 131 g ha^{-1} in bulbs and 30 g ha^{-1} in leaves. Next to these, the treatment 50% RDF +NPK combo + Nutrigel (T_3) which had the uptake values of 116 g ha^{-1} in bulb and 20 g ha^{-1}

in leaves this was on par with the treatment, 50% RDF + NPK combo + Commercial micronutrient (T_4) 108 g/ha in bulbs and 19 g/ha in leaves. Next to these, the treatment, 50 % RDF + NPK combo (T_2) with values of 107 g ha^{-1} in bulbs and 18 g ha^{-1} in leaves was on par with the treatment T_4. The absolute control treatment (T_1) exhibited the lowest copper uptake of 95 g ha^{-1} in bulbs and 12 g ha^{-1} in leaves, respectively.

2.7. Economics (Table 16)

The financial analysis of the various treatments revealed notable differences in their economic outcomes. The 100% RDF + Nutrigel treatment (T9) performs better compare to other treatments, with a cultivation cost of Rs.2,50,486 a gross income of Rs.7,82,100 and a net income of Rs.5,31,615 yielding the highest BCR of 3.12. Overall, the inclusion of Nutrigel significantly enhanced economic returns. 100% RDF treatment (T8) has a cultivation cost of Rs. 2,39,686 resulting in a gross income of Rs.7,12,800 and a net income of Rs.4,73,115 which leads to a benefit-cost ratio (BCR) of 2.97. The 100% RDF + Commercial Micronutrients treatment (T10) has a cultivation cost of Rs.2,50,486 with a gross income of Rs.7,27,650 and a net income of Rs.4,77,165, achieving a BCR of 2.90. This indicates that treatments with Nutrigel offer improved BCR compared to those using only the NPK combo.

Table. 10. Effect of levels of RDF, NPK combo, Nutrigel and commercial micronutrient on the growth parameters at various growth stages of aggregatum onion.

Treatment	Plant height (cm)			Number of leaves			Leaf length (cm)			Leaf diameter (cm)			Relative chlorophyll content (SPAD)		
	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
T_1	36.69	38.26	43.33	31.24	32.10	30.00	28.20	33.54	31.98	1.05	1.47	1.01	45.40	49.06	39.12
T_2	39.61	41.51	46.35	33.00	34.48	32.20	30.45	35.89	39.20	1.37	1.64	1.17	47.74	51.94	41.58
T_3	40.71	47.57	48.52	33.70	35.30	32.63	31.45	36.94	34.76	1.58	1.76	1.28	48.44	53.56	42.21
T_4	41.79	43.67	48.60	33.62	35.16	32.50	30.83	36.75	35.29	1.53	1.69	1.19	47.87	52.70	42.02
T_5	44.71	45.88	51.66	35.37	37.72	34.76	33.35	39.14	34.93	1.70	1.89	1.48	51.21	56.32	44.66
T_6	47.90	50.07	53.96	36.85	38.89	35.68	34.35	40.87	37.00	1.75	1.99	1.54	51.47	56.88	46.76
T_7	46.55	48.52	52.91	36.33	38.64	34.90	33.60	40.00	38.22	1.74	1.94	1.51	51.32	56.55	44.86
T_8	48.90	50.37	54.52	37.53	39.35	36.30	34.80	41.73	37.98	1.78	2.01	1.56	52.86	57.93	49.08
T_9	51.41	53.33	57.12	39.34	40.75	36.90	36.50	43.80	40.60	1.87	2.24	1.71	53.50	59.39	50.28
T_{10}	50.00	52.37	56.16	38.35	39.42	36.08	35.65	42.61	39.62	1.83	2.16	1.66	51.81	57.89	47.35
SEd	1.108	1.089	1.239	0.584	1.068	0.694	0.744	0.716	0.678	0.035	0.036	0.034	0.923	1.246	0.920
CD (P=0.05)	2.33	2.29	2.60	1.23	2.24	1.46	1.56	1.50	1.42	0.07	0.08	0.07	1.94	2.62	1.93

***I – Bulb formation stage (45 DAS), II –Bulb development stage (60 DAS), III – Harvest stage (90 DAS)**

Table. 11. Effect of levels of RDF, NPK combo, Nutrigel and commercial micronutrient on the yield attributes and yield of aggregatum onion.

Treatment	Polar diameter (cm)	Equatorial diameter (cm)	Bulb neck diameter (cm)	Fresh bulb weight (g plant^{-1})	Bolting %	Stand count %	Days to Maturity	Shoot dry matter yield (kg/ha)	Bulb dry matter yield (kg/ha)	Total biomass yield (kg/ha)	Harvest Index (%)	Total Bulb yield	Market able yield
T_1	1.58	2.55	0.93	43.57	5.84	96.14	90.48	587	1906	2493	76	7.94	5.89
T_2	2.68	3.26	1.20	50.88	5.66	96.20	90.34	599	2440	3039	80	12.88	11.18
T_3	3.51	3.54	1.27	54.29	5.38	96.79	90.29	608	2491	3099	80	14.18	12.40
T_4	3.36	3.37	1.24	52.96	5.51	96.72	90.26	605	2463	3068	80	13.40	11.50
T_5	3.98	4.52	1.44	59.92	5.17	97.46	90.08	629	2669	3298	81	15.46	13.64
T_6	4.27	4.89	1.52	63.08	4.80	98.18	89.10	638	2708	3346	81	16.61	15.01
T_7	4.10	4.64	1.49	61.44	4.99	97.60	88.30	634	2678	3312	81	15.98	14.48
T_8	4.43	5.23	1.59	64.69	4.64	98.25	87.50	654	2720	3374	81	17.17	15.84
T_9	4.67	5.83	1.69	68.22	4.37	98.94	87.27	657	2760	3417	81	18.49	17.38
T_{10}	4.56	5.41	1.61	66.54	4.54	98.89	87.11	655	2745	3400	81	17.77	16.17
SEd	0.087	0.309	0.047	1.087	0.105	2.168	5.055	3.17	17.74	27.0	1.979	0.363	0.612
CD (P=0.05)	0.18	0.65	0.10	2.28	0.22	NS	NS	7	37	57	NS	0.76	1.29

Table. 12. Effect of levels of RDF, NPK combo, Nutrigel and commercial micronutrient on the quality parameters of aggregatum onion bulb and plant.

Treatment	Ascorbic acid (mg $100g^{-1}$)	TAA (%)	Pyruvic acid (µmol g^{-1})	Total phenols (mg g^{-1})	TA (%)	Total sugars (mg$100g^{-1}$)	pH	TSS (^{0} Brix)
T_1	12.12	5.22	1.95	0.56	0.09	43.83	5.85	11.60
T_2	13.78	5.61	2.19	0.66	0.15	50.67	5.82	13.78
T_3	14.07	5.93	2.32	0.71	0.18	52.08	5.71	14.51
T_4	13.91	5.75	2.27	0.69	0.16	51.19	5.75	14.17
T_5	15.14	6.29	2.47	0.79	0.29	53.60	5.64	16.09
T_6	15.70	6.65	2.56	0.84	0.34	54.86	5.53	16.89
T_7	15.21	6.47	2.53	0.81	0.32	54.51	5.62	16.42
T_8	16.08	6.72	2.61	0.86	0.36	55.62	5.49	17.38
T_9	16.92	6.97	2.78	0.92	0.43	56.43	5.31	18.75
T_{10}	16.43	6.85	2.63	0.89	0.40	55.81	5.42	17.77
SEd	0.296	0.122	0.065	0.016	0.026	0.644	0.126	0.616
CD (P=0.05)	0.62	0.26	0.14	0.03	0.05	1.35	NS	1.29

Table. 13. Effect of levels of RDF, NPK combo, Nutrigel and commercial micronutrient on the soil available nutrients (kg ha^{-1}) at various growth stages of aggregate onion

Treatment	Soil available nitrogen (kg ha^{-1})				Soil available phosphorus (kg ha^{-1})				Soil available potassium (kg ha^{-1})			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
T_1	212	196	191	186	35.5	32.5	30.8	29.1	324	316	307	303
T_2	225	209	205	196	38.7	35.5	33.8	32.9	335	325	317	315
T_3	222	207	203	195	37.8	34.8	33.3	32.2	333	323	315	313
T_4	223	208	204	195	38.1	35.0	33.7	32.5	334	324	316	314
T_5	236	221	215	206	41.6	38.6	37.4	36.2	347	336	328	324
T_6	234	219	213	204	41.1	38.0	36.6	35.0	345	334	325	322
T_7	235	220	214	205	41.4	38.2	36.9	35.6	346	335	326	323
T_8	247	234	225	217	45.9	43.5	42.2	40.8	358	347	339	335
T_9	245	232	222	215	45.2	42.1	40.8	39.9	356	345	337	333
T_{10}	246	233	224	216	45.6	42.7	41.1	40.2	357	346	338	334
SEd	3.647	4.717	3.386	3.391	0.706	0.924	0.841	0.683	2.114	1.598	2.420	2.069
CD (P=0.05)	7.66	9.91	7.11	7.12	1.48	1.94	1.77	1.43	4.44	3.36	5.09	4.35

*** I – Vegetative (25 DAS), II – Bulb formation (45 DAS), III – Bulb development (60 DAS), IV- Harvest (90 DAS)**

Table. 14. Effect of levels of RDF, NPK combo, Nutrigel and commercial micronutrient on the nutrient uptake (kg ha^{-1}) at various growth stages of aggregatum onion

Treatment	Nitrogen uptake (kg ha^{-1})					Phosphorus uptake (kg ha^{-1})					Potassium uptake (kg ha^{-1})				
	I	II	III	IV		I	II	III	IV		I	II	III	IV	
				Bulb	Leaf				Bulb	Leaf				Bulb	Leave
T_1	9.43	13.21	17.27	37.97	2.20	1.78	3.67	5.31	10.33	1.24	8.93	12.36	17.03	39.07	2.04
T_2	11.40	17.45	20.91	44.61	2.87	2.40	5.78	8.75	13.86	1.48	11.66	18.08	22.35	51.39	3.71
T_3	10.91	19.05	24.67	48.44	3.48	2.26	6.68	9.06	15.45	1.54	11.48	19.40	24.72	54.01	3.96
T_4	11.06	18.36	21.59	46.19	3.10	2.33	6.23	8.89	14.50	1.51	11.50	18.65	23.91	53.69	3.82
T_5	13.36	21.98	28.38	58.25	4.08	3.06	7.69	10.40	17.96	1.80	12.53	22.56	30.55	61.44	5.57
T_6	12.88	24.08	32.04	62.44	4.62	2.89	8.41	10.77	19.72	1.86	12.32	23.99	32.59	64.98	5.96
T_7	13.18	23.58	31.24	60.35	4.28	2.97	8.18	10.57	18.92	1.83	12.45	23.72	31.06	64.35	5.89
T_8	14.75	25.55	34.13	64.03	4.87	3.89	8.71	10.96	20.08	1.88	13.59	25.39	33.79	67.00	6.05
T_9	14.31	27.31	37.07	68.00	5.74	3.53	9.53	11.42	21.58	1.96	13.25	27.04	36.80	70.28	6.41
T_{10}	14.60	26.45	35.81	65.51	5.27	3.73	8.83	11.13	20.84	1.91	13.46	26.15	35.44	68.22	6.17
SEd	0.699	0.835	1.894	1.337	0.354	0.153	0.442	0.220	1.123	0.028	0.253	1.442	1.406	1.474	0.252
CD (P=0.05)	1.47	1.75	3.98	2.81	0.74	0.32	0.93	0.46	2.36	0.06	0.53	3.03	2.96	3.10	0.53

***I – Vegetative stage (25 DAS), II – Bulb formation stage (45 DAS), III – Bulb development stage (60 DAS), IV – Harvest stage (90 DAS)**

Table. 15. Effect of levels of RDF, NPK combo, Nutrigel and commercial micronutrient on the micronutrient uptake in aggregatum onion at harvest stage.

Treatments	Bulb				Leaves			
	Fe g ha^{-1}	Mn g ha^{-1}	Zn g ha^{-1}	Cu g ha^{-1}	Fe g ha^{-1}	Mn g ha^{-1}	Zn g ha^{-1}	Cu g ha^{-1}
T_1	892	277	172	95	92	50	14	12
T_2	1174	434	196	107	122	64	25	18
T_3	1177	452	207	116	131	71	28	20
T_4	1141	446	201	108	129	66	26	19
T_5	1374	509	298	131	175	83	39	30
T_6	1433	530	309	140	183	88	40	32
T_7	1391	517	299	136	177	87	40	31
T_8	1444	537	312	145	189	95	42	33
T_9	1507	555	325	155	201	105	44	34
T_{10}	1490	549	320	151	193	98	42	33
SEd	23.339	9.692	6.062	4.081	4.026	4.401	0.915	0.632
CD (P=0.05)	49.03	20.36	12.74	8.57	8.46	9.25	1.92	1.33

Table. 16. Effect of levels of RDF, NPK combo, Nutrigel and commercial micronutrient on the economics of the marketable yield by aggregatum onion.

Treatments		Cost of cultivation (Rs.)	Gross income (Rs.)	Net income (Rs.)	BCR
T_1	Absolute Control	237869	265050	27181	1.11
T_2	50 % RDF + NPK combo	254977	503100	248123	1.97
T_3	50% RDF +NPK combo + Nutrigel	265777	558000	292223	2.10
T_4	50% RDF + NPK combo + Commercial micronutrient	265777	517500	251723	1.95
T_5	75% RDF + NPK combo	255431	613800	358369	2.40
T_6	75% RDF + NPK combo + Nutrigel	266231	675450	409219	2.54
T_7	75% RDF + NPK combo + Commercial micronutrient	266231	651600	385369	2.45
T_8	100% RDF	239686	712800	473115	2.97
T_9	100% RDF + Nutrigel	250486	782100	531615	3.12
T_{10}	100% RDF + Commercial micronutrients	250486	727650	477165	2.90

3. First Season Field Experiment on hybrid Tomato

The field experiment was conducted from December 2023 to March 2024 in Kuppepalayam village, Coimbatore district, Tamil Nadu, India (11°00'39.4"N, 76°48'51.5" E). The hybrid tomato 'Madhan' was used to evaluate various combinations of the recommended fertilizer dose (RDF), NPK combo, Nutrigel (Nano micronutrient in gel formulation) and commercial micronutrient formulation. The spraying schedule and the treatment details are same as that of first season onion experiment (Table 17 and 18).

Treatment details

The field experiment was conducted using a Randomized Block Design (RBD) with ten treatments and three replications. The NPK combo included nitrogen fixing, phosphorus solubilizing and potassium mobilizing bio fertilizers in single formulation. The Nutrigel included nano micronutrient along with essential amino acids in gel formulation. The recommended dose of fertilizers adopted for hybrid tomato is 250:200:200 kg of N, P_2O_5 and K_2O per ha. The details of the treatments, spraying schedule are given below

Table. 17. The spraying schedule for the field experiment on tomato

Spray	Time / dose
First spray	20 DAT
Second spray	40 DAT
Third spray	At the time of fruit development stage
Foliar spray of Nutrigel	250 ml in 500 litres of water for 1 hectare
Soil application of NPK combo	250 ml in 500 litres of water for 1 hectare
Foliar spray of Commercial micronutrient	125 g in 500 litres of water for 1 hectare

Table. 18. The details of the treatments for the field experiment on tomato

Treatment	Treatment details
T_1	Absolute Control
T_2	50 % Recommended dose of fertilizer (RDF) + NPK combo
T_3	50% Recommended dose of fertilizer +NPK combo + Nutrigel
T_4	50% Recommended dose of fertilizer +NPK combo + commercial micronutrient
T_5	75% Recommended dose of fertilizer + NPK combo
T_6	75% Recommended dose of fertilizer + NPK combo + Nutrigel
T_7	75% Recommended dose of fertilizer +NPK combo + commercial micronutrient
T_8	100% Recommended dose of fertilizer
T_9	100% Recommended dose of fertilizer + Nutrigel
T_{10}	100% Recommended dose of fertilizer + commercial micronutrient

3.1. Plant growth attributes (Table 19)

Plant Height: The tallest plants were observed in treatment T_9 (100% RDF + Nutrigel) reaching 55.0 cm at flowering, 80.0 cm during fruiting and 110.0 cm at harvest. Treatment T_{10} (100% RDF + Commercial micronutrient) recorded plant heights of 53.5 cm, 77.0 cm and 106.6 cm at the respective stages and was statistically on par with T_9 (100% RDF + Nutrigel). However, T_{10} was on par withT_8 (100% RDF), which recorded plant heights of 52.1 cm, 73.9 cm and 102.7 cm respectively at flowering, fruiting and harvest stages.

Root Length: The study on root length of hybrid tomato at various growth stages flowering, fruiting and harvest indicated significant variations among the treatments. Treatment T_9 (100% RDF + Nutrigel) exhibited the longest roots across all stages recording 15.0 cm at flowering, 19.0 cm during fruiting and 23.0 cm at harvest. This treatment was statistically on par with T_{10} (100% RDF + Commercial micronutrient) which recorded 14.7 cm, 18.7 cm and 22.3 cm at the respective stages. However, T_8 (100% RDF)achieved root lengths of 14.3 cm, 18.2 cm and 21.5 cm at flowering, fruiting and harvest stages respectively and remained on par with T_{10}indicating comparable growth promotion through the recommended dose of fertilizer.

Number of Leaves: Treatment T_9 (100% RDF + Nutrigel) produced the higher leaf count across all stages, recording 230.0 leaves at flowering, 255.8 leaves during fruiting and 295.0 leaves at harvest. This treatment was statistically on par with T_{10} (100% RDF + Commercial micronutrient), which recorded 223.2, 249.1 and 288.3 leaves at flowering, fruiting and harvest stages respectively. Treatment T_8 (100% RDF) achieved 215.1, 241.6 and 282.9 leaves at flowering, fruiting and harvest stages respectively and remained on par with T_{10}.

Stem Girth: The larger stem girth was recorded in T_9 (100% RDF + Nutrigel) with values of 7.1 cm at flowering, 7.4 cm at fruiting and 8.0 cm at harvest and was on par with T_{10} (100% RDF + Commercial micronutrient) exhibiting a stem girth of 7.0 cm at flowering, 7.2 cm at fruiting and 7.7 cm at harvest. However, the treatment T_{10}remained on par with T_8 (100% RDF) which recorded 6.7 cm, 7.0 cm and 7.5 cm at flowering, fruiting and harvest stages of tomato respectively.

Relative Chlorophyll Content: Application of 100% RDF + Nutrigel (T_9) recorded the highest relative chlorophyll content (SPAD meter readings), with values of 45.3 at flowering, 61.4 at fruiting and 58.3 at harvest. Treatment T_{10} (100% RDF + Commercial micronutrient) followed with 44.4, 60.2 and 56.9 which was statistically on par with T_9. However, T_{10} remained on par with T_8 (100% RDF) which recorded 43.5, 58.9 and 55.4 at flowering, fruiting and harvest stages of tomato respectively.

Leaf Area Index: The highest leaf area index was observed in T_9 (100% RDF + Nutrigel), with values of 0.84 at flowering, 2.66 at fruiting and 3.80 at harvest. 100% RDF + Commercial micronutrient (T_{10}) followed closely, with values of 0.81, 2.56 and 3.66 and remained on par with T_9. T_8 (100% RDF) showed values of 0.79, 2.45 and 3.52, significantly lower than T_{10}.

Primary, Secondary and Tertiary Branches: Application of 100% RDF+ Nutrigel (T_9) achieved counts of 8.4, 9.1 and 9.3 primary branches, while 100% RDF + commercial micronutrient (T_{10}) recorded the branch counts of 8.1, 8.9 and 9.1 and remained on par with each other. However, 100% RDF + commercial micronutrient (T_{10}) remained on par with T_8 (100% RDF), which recorded 7.9, 8.6 and 8.8 numbers of primary branches at flowering, fruiting and harvest stages of tomato respectively. Similar pattern was observed with respect to secondary and tertiary branches of tomato at flowering, fruiting and harvest stages.

The treatment 100 RDF + Nutrigel (T_9) recorded significantly higher plant growth parameters *viz.*, plant height, root length, number of leaves, stem girth, relative chlorophyll content (SPAD values), leaf area index, and number of branches compared to100% RDF (T_8). Even though the treatment 100% RDF + commercial micronutrient (T_{10}) was statistically on par with 100% RDF + Nutrigel (T_9), it did not differ significantly over 100% RDF (T_8).

3.2. The yield attributes and yield of hybrid tomato (Table 20)

Single Fruit Weight (g): The highest single fruit weight (109.1 g) was recorded in T_9 (100% RDF + Nutrigel) at whereas the lowest (79.6 g) was observed in the absolute control (T_1). The single fruit weight in T_9 (100% RDF + Nutrigel) was 109.1 g and it remained on par with T_{10} (100% RDF + commercial micronutrient) having 105.6 g and it was in turn on par with T_8 (100% RDF) having single fruit weight of 102.2 g.

Number of Flowers per Plant: Treatment T_9 (100% RDF + Nutrigel) recorded the highest number of flowers per plant (60.0) while T_1 (absolute control) had the lowest (44.6). The number of flowers in T_9 was on par with T_{10} (100% RDF + commercial micronutrient) having 58.2 number of flowers and T_{10} was in turn on par with T_8 (100% RDF) having 57.1.

Number of Fruits per Plant: The highest number of fruits per plant was observed in T_9 (100% RDF + Nutrigel) at 58.0 while the lowest was in T_1 (absolute control) at 36.0. The number of fruits in T_9 was 58.0 and remained on par with T_{10} (100% RDF + Commercial micronutrient) having 56.2 and T_{10} was in turn on par with T_8 (100% RDF) having 55.1.

Fruit Length (cm): The fruit length of hybrid tomato varied significantly among the treatments. The highest fruit length was observed in T_9 (100% RDF + Nutrigel) having 5.0 cm, while the lowest was recorded in the (absolute control) T_1having fruit length of 3.4 cm. The

fruit length in T_9 was on par with T_{10} (100% RDF + Commercial micronutrient) having 4.9 cm and T_{10} was in turn on par with T_8 (100% RDF) having fruit length of 4.8 cm.

Fruit Width (cm): The maximum fruit width was recorded in T_9 (100% RDF + Nutrigel) that recoded fruit width of 5.6 cm whereas the minimum was observed in T_1 (absolute control) having 4.2 cm. The fruit width in T_9 was on par with T_{10} (100% RDF + Commercial micronutrient) having 5.5 cm and T_{10} was in turn on par with T_8 (100% RDF) having fruit width of 5.3 cm.

Fruit Girth (cm): The fruit girth of hybrid tomato showed significant differences among the treatments. T_9 (100% RDF + Nutrigel) exhibited the highest fruit girth of 23.0 cm and on par with T_{10} (100% RDF + Commercial micronutrient) having fruit girth of 22.2 cm. However T_{10} was in turn on par with T_8 (100% RDF) which recorded the fruit girth of 21.4 cm.

Fruit Volume (cm^3): Fruit volume varied significantly across the treatments, with the highest value recorded in T_9 (100% RDF + Nutrigel) with 83.2 cm^3, and the lowest in T_1 (absolute control) having 58.9 cm^3. The fruit volume in T_9 was on par with T_{10} (100% RDF + commercial micronutrient) having the value of 80.8 cm^3 and T_{10} was in turn on par with T_8 (100% RDF) having fruit volume of 78.7 cm^3.

The yield attributes viz., single fruit weight (g)**,** number of flowers per plant, number of fruits per plant**,** fruit length (cm)**,** fruit width (cm)**,** fruit girth (cm)**,** fruit volume (cm^3)

Fruit Yield (t ha^{-1}): The higher fruit yield (74.95 t ha^{-1}) was observed in T_9 (100% RDF + Nutrigel) and it remained on par with T_{10} (100% RDF + commercial micronutrient) yielding 72.35 t ha^{-1} which in turn remained on par with T_8 (100% RDF) that recorded the fruit yield of 71.05 t ha^{-1}. Treatment T_9 (100% RDF + Nutrigel) produced 5.5% increased fruit yield compared to 100% RDF (T_8) and a 3.6% increase over 100% RDF + commercial micronutrient (T_{10}).

The treatment T_8 (100% RDF) recorded the fruit yield of 71.05 t ha^{-1}, which was on par with T_6 (75% RDF + NPK combo + Nutrigel) producing 68.73 t ha^{-1}. Treatment, T_6 was on par with T_7 (75% RDF + NPK combo + commercial micronutrient) yielding 66.41 t ha^{-1} and T_7 was on par with T_5 (75% RDF + NPK combo) which yielded 65.56 t ha^{-1}. Among the treatments receiving 50% RDF, T_3 (50% RDF + NPK combo + Nutrigel) recorded the fruit yield of 60.38 t ha^{-1} which was on par with T_4 (50% RDF + NPK combo + commercial micronutrient) yielding 57.86 t ha^{-1}. Treatment T_4 was on par with T_2 (50% RDF + NPK combo) which recorded the fruit yield of 57.00 t ha^{-1}. The absolute control (T_1) registered the lowest yield (54.30 t ha^{-1}).

Application of 100% RDF + Nutrigel (T_9) recorded significantly higher yield attributes and fruit yield compared to 100% RDF (T_8), while yield attributes and fruit yield of 100% RDF + commercial micronutrient (T_{10}) was statistically comparable with 100% RDF (T_8).

3.3. The enzyme activities of hybrid tomato plant (Table 21)

Peroxidase Activity (gFW^{-1}): Treatment T_9 (100% RDF + Nutrigel) recorded the higher value (80.2 µg FW^{-1}) of peroxidase enzyme activities in hybrid tomato plants and was on par with T_{10} (100% RDF + commercial micronutrient) recording 77.9 µg FW^{-1}. Treatment T_{10} was on par with T_8 (100% RDF) having 75.6 µg FW^{-1}. The lowest peroxidase activity (54.3 µg FW^{-1}) was observed in absolute control (T_1).

Polyphenol Oxidase Activity (gFW^{-1}): Polyphenol oxidase activity in T_9 (100% RDF + Nutrigel) was higher (114.8 µg FW^{-1}) and statistically on par with T_{10} (100% RDF + commercial micronutrient) having 111.5 µg FW^{-1}. However, treatment T_{10} wason par with T_8 (100% RDF) having polyphenol oxidase activity of 108.2 µg FW^{-1}. The lowest polyphenol oxidase activity (79.5 µg FW^{-1}) was recorded in T_1 (absolute Control).

3.4. Quality parameters of hybrid tomato fruits (Table 21)

Lycopene Content (mg 100g^{-1}): The lycopene content in hybrid tomato fruits varied significantly across treatments. T_9 (100% RDF + Nutrigel) recorded the highest lycopene level of 3.6 mg 100g^{-1} which was on par with T_{10} (100% RDF + Commercial micronutrient) having 3.5 mg 100g^{-1}. The treatment T_{10} was in turn on par with T_8 (100% RDF) having lycopene content of 3.4 mg 100g^{-1}.

Beta Carotene (mg 100g^{-1}): Beta carotene content was significantly influenced by different treatments. T_9 achieved the highest level of beta carotene of 3.5 mg 100g^{-1} and it was on par with T_{10} (100% RDF + commercial micronutrient) having beta carotene content of 3.4 mg 100g^{-1}. Treatment $T_{10}$was in turn on par with T_8 (100% RDF) having beta carotene content of 3.3 mg 100g^{-1}

Polygalacturonase Activity (kJ m^{-2}): Polygalacturonase activity decreased with increasing nutrient levels showing significant variation among treatments. T_1 (Absolute Control) recorded the highest activity of 3.8 kJ m^{-2} while T_9 (100% RDF + Nutrigel) had the lowest of 2.7 kJ m^{-2} and was on par with T_{10} (100% RDF + Commercial micronutrient) having polygalacturonase activity of 2.8 kJ m^{-2} which was in turn on par with T_8 (100% RDF) having the value of 2.9 kJ m^{-2}.

Firmness (N m^{-1}): Fruit firmness showed significant differences among the treatments. T_9 (100% RDF + Nutrigel) exhibited the highest firmness value of 5.2 N m^{-1} and on par with T_{10}

(100% RDF + Commercial micronutrient) having the firmness of 5.0 N m^{-1}. Treatment $T_{10}$was on par with T_8 (100% RDF) having fruit firmness of 4.9 N m^{-1}.

Ascorbic Acid (mg $100g^{-1}$): Ascorbic acid content was highest in T_9 (100% RDF + Nutrigel) having the value of 43.0 mg $100g^{-1}$ and was on par with T_{10} (100% RDF + Commercial micronutrient) which recorded ascorbic acid content of 41.6 mg $100g^{-1}$ which was in turn on par with T_8 (100% RDF) having 40.7 mg $100g^{-1}$.

Titratable Acidity (%): Titratable acidity was significantly affected by different nutrient combinations. T_9 (100% RDF + Nutrigel) recorded the highest acidity of 0.60% which was on par with T_{10} (100% RDF + commercial micronutrient) having the acidity of 0.58%. T_{10} was on par with T_8 (100% RDF) having titratable acidity of 0.56% which was on par with T_6 (75% RDF + NPK Combo + Nutrigel) having 0.54%.

Total Soluble Solids (°Brix): Total soluble solids were highest in T_9 (100% RDF + Nutrigel) with 4.74 degree Brix which was on par with T_{10} (100% RDF + commercial micronutrient) having 4.64 degree Brix. T_{10} was on par with T_8 (100% RDF) having the TSS of 4.52 degree Brix.

pH: The lower pH was recorded in T_9 (100% RDF + Nutrigel) at 3.63, but the differences were marginal and did not attain statistical significance.

3.5. The micronutrient uptake in hybrid tomato and plant at harvest stage. (Table 22)

Zinc Uptake (g ha^{-1}) in Fruit: Zinc uptake in tomato fruits varied significantly across treatments. Among the treatments T_9 (100% RDF+ Nutrigel) recorded the highest zinc uptake of 144.8 g ha^{-1} which was on par with T_{10} (100% RDF+ commercial micronutrient) having 139.2 g ha^{-1}. Zinc uptake in fruits of T_{10} was on par with T_8 (100% RDF) having Zn uptake of 134.5 g ha^{-1}. Zinc uptake in fruits of T_8 was on par with T_6 (75% RDF + NPK combo + Nutrigel) having 129.8 g ha^{-1} and it was in turn on par with T_7 (75% RDF + NPK combo + commercial micronutrient) which reported the zinc uptake of 125.0 g ha^{-1}. Zinc uptake of T_7 was on par with T_5 (75% RDF + NPK combo) having the value of 120.3 g ha^{-1}. Further, T_3 (50% RDF+ NPK combo + Nutrigel) recorded zinc uptake of 113.5 g ha^{-1} and was on par with T_4 (50% RDF+ NPK combo + commercial micronutrient) having 108.8 g ha^{-1} which was on par with T_2 (50% RDF + NPK combo) having 104.0 g ha^{-1}. The lowest zinc uptake was observed in T_1 (absolute control) with 81.8 g ha^{-1}.

Zinc Uptake (g ha^{-1}) in Plant: Zinc uptake in tomato plants exhibited significant variations across treatments. Treatment T_9 (100% RDF + Nutrigel) had the highest zinc uptake of 140.0 g ha^{-1} which was on par with T_{10} (100% RDF + commercial micronutrient) having 135.4 g ha^{-1}. Treatment T_{10} was on par with T_8 (100% RDF) which recorded the zinc uptake of 130.8 g ha^{-1}. The zinc uptake in T_8 was on par with T_6 (75% RDF + NPK combo + Nutrigel)

having 126.2 g ha^{-1} and again T_6 was on par with T_7 (75% RDF + NPK combo + commercial micronutrient) having the zinc uptake of 121.6 g ha^{-1}. Zinc uptake in plants of T_7 was on par with T_5 (75% RDF + NPK combo) having 117.0 g ha^{-1} of zinc uptake. Application of 50% RDF+ NPK combo + Nutrigel (T_3) recorded 110.4 g ha^{-1} of zinc uptake in plants and was on par with T_4 (50% RDF + NPK combo + commercial micronutrient) having 105.8 g ha^{-1} which was in turn on par with T_2 (50% RDF + NPK combo) having 101.2 g ha^{-1}. The lowest zinc uptake in plants was recorded in T_1 (absolute control) with 81.3 g ha^{-1}.

Iron Uptake (g ha^{-1}) in Fruit: Among the treatments iron uptake in fruits of T_9 (100% RDF + Nutrigel) achieved the highest value of 260.0 g ha^{-1} which was on par with T_{10} (100% RDF + commercial micronutrient) having 251.0 g ha^{-1}. Iron uptake in fruits of T_{10} was on par with T_8 (100% RDF) having 241.9 g ha^{-1}. Iron uptake in fruits of T_8 was on par with T_6 (75% RDF + NPK combo + Nutrigel) having 232.9 g ha^{-1} and T_6 was again on par with T_7 (75% RDF + NPK combo + commercial micronutrient) having 223.8 g ha^{-1}. Iron uptake in T_7 was on par with T_5 (75% RDF + NPK combo) having 214.8 g ha^{-1}. These treatments were followed by T_3 (50% RDF + NPK combo + Nutrigel) which recorded 203.1 g ha^{-1} and was on par with T_4 (50% RDF + NPK combo + commercial micronutrient) having 194.0 g ha^{-1} which was again on par with T_2 (50% RDF + NPK combo) having 185.0 g ha^{-1}. The lowest iron uptake in fruits (140.9 g ha^{-1}) was observed in T_1 (absolute control).

Iron Uptake (g ha^{-1}) in Plant: The tomato plants at harvest stage in T_9 (100% RDF + Nutrigel) recorded the highest iron uptake of 498.1 g ha^{-1} which was on par with T_{10} (100% RDF + commercial micronutrient) having 489.9 g ha^{-1}. Iron uptake in plants of T_{10} was on par with T_8 (100% RDF) which had an uptake of 469.8 g ha^{-1}. Iron uptake in plants of T_8 was on par with T_6 (75% RDF + NPK combo + Nutrigel) had 449.7 g ha^{-1} and T_6 was on par with T_7 (75% RDF + NPK combo + commercial micronutrient) having 429.6 g ha^{-1}. Iron uptake in plants of T_7 was on par with T_5 (75% RDF + NPK combo) having iron uptake in plants of 409.5 g ha^{-1}. Iron uptake in plants of T_3 (50% RDF + NPK combo + Nutrigel) recorded was 387.4 g ha^{-1} and it remained on par with T_4 (50% RDF + NPK combo + commercial micronutrient) having 367.3 g ha^{-1} which was in turn on par with T_2 (50% RDF + NPK combo) having 347.2 g ha^{-1}. The lowest iron uptake in plants was observed in T_1 (absolute control) having 321.4 g ha^{-1}.

Manganese Uptake (g ha^{-1}) in Fruit: In terms of manganese uptake in fruits at harvest T_9 (100% RDF + Nutrigel) recorded the highest value of 110.0 g ha^{-1} and remained on par with T_{10} (100% RDF + commercial micronutrient) having 106.3 g ha^{-1}. Manganese uptake on T_{10} was also on par with T_8 (100% RDF) had 102.6 g ha^{-1}. Treatment T_8 was on par with T_6 (75% RDF + NPK combo + Nutrigel) had 98.9 g ha^{-1} and T_6 was on par with T_7 (75% RDF+ NPK

combo + commercial micronutrient) had 95.2 g ha^{-1}. Treatment T_7 was on par with T_5 (75% RDF + NPK combo) had 91.5 g ha^{-1}. These treatments were followed by T_3 (50% RDF + NPK combo + Nutrigel) which recorded 85.8 g ha^{-1} and was on par with T_4 (50% RDF + NPK combo + commercial micronutrient) having 82.1 g ha^{-1} which was again on par with T_2 (50% RDF + NPK combo) having 81.5 g ha^{-1}. The lowest manganese uptake was in T_1 (absolute control) with 62.5 g ha^{-1}.

Manganese Uptake (g ha^{-1}) in Plant: Manganese uptake in plants at harvest stage showed significant differences. Among the treatments T_9 (100% RDF + Nutrigel) had the highest value of 205.0 g ha^{-1} which was on par with T_{10} (100% RDF + commercial micronutrient) having 197.9 g ha^{-1}. Manganese uptake in plants of T_{10} was on par with T_8 (100% RDF) which had an uptake of 190.9 g ha^{-1}. Treatment T_8 was on par with T_6 (75% RDF + NPK combo + Nutrigel) that had an uptake of 183.8 g ha^{-1} and treatment T_6 was on par with T_7 (75% RDF + NPK combo + commercial micronutrient) which had an uptake of 176.8 g ha^{-1}. Treatment T_7 was on par with T_5 (75% RDF + NPK combo) having 169.7 g ha^{-1}. These treatments were followed by T_3 (50% RDF + NPK combo + Nutrigel) which recorded iron uptake 160.6 g ha^{-1} which was on par with T_4 (50% RDF + NPK combo + commercial micronutrient) had 153.6 g ha^{-1} which in turn was on par with T_2 (50% RDF + NPK combo) having 146.5 g ha^{-1}. The lowest manganese uptake of 108.5 g ha^{-1} was recorded in T_1 (absolute control).

Copper Uptake (g ha^{-1}) in Fruit: Copper uptake in fruit at harvest stage showed significant differences. Treatment T_9 (100% RDF + Nutrigel) recorded the highest uptake of 40.0 g ha^{-1} and was on par with T_{10} (100% RDF + commercial micronutrient) having 38.9 g ha^{-1}. Treatment T_{10} was on par with T_8 (100% RDF) having copper uptake in fruits to the tune of 37.7 g ha^{-1}. Additionally, T_8 was on par with T_6 (75% RDF + NPK combo + Nutrigel) having copper uptake of 36.5 g ha^{-1} and T_6 was in turn on par with T_7 (75% RDF + NPK combo + commercial micronutrient) having 35.4 g ha^{-1}. Copper uptake in fruits of T_7 was on par with T_5 (75% RDF + NPK combo) having 34.3 g ha^{-1}. These treatment were followed by T_3 (50% RDF + NPK combo + Nutrigel) which recorded 31.1 g ha^{-1} and was on par with T_4 (50% RDF + NPK combo + commercial micronutrient) having30.0 g ha^{-1} which was in turn on par with T_2 (50% RDF + NPK combo) having 28.8 g ha^{-1}. The lowest copper uptake 22.2 g ha^{-1} was observed in T_1 (absolute control).

Copper Uptake (g ha^{-1}) in Plant: Copper uptake in tomato plants at harvest stage showed a marked variation. Treatment T_9 (100% RDF + Nutrigel) recorded the highest copper uptake of 65.2 g ha^{-1} which was on par with T_{10} (100% RDF + commercial micronutrient) having 62.9 g ha^{-1}. Treatment T_{10} was on par with T_8 (100% RDF) having copper uptake of 60.7 g ha^{-1}.

Treatment T_8 was on par with T_6 (75% RDF + NPK combo + Nutrigel) which recorded copper uptake of 58.4 g ha^{-1} and T_6 was on par with T_7 (75% RDF + NPK combo + commercial micronutrient) had 56.1 g ha^{-1}. Copper uptake in plants of T_7 was on par with T_5 (75% RDF + NPK combo) had 53.9 g ha^{-1}. These treatments were followed by T_3 (50% RDF + NPK combo + Nutrigel) which recorded an uptake of 49.6 g ha^{-1}in in plants and was on par with T_4 (50% RDF + NPK combo + commercial micronutrient) having 47.3 g ha^{-1} which was in turn on par with T_2 (50% RDF + NPK combo) having 45.0 g ha^{-1}. The lowest copper uptake (33.9 g ha^{-1}) was observed in T_1 (absolute control).

3.6. The soil available nutrients (kg ha^{-1}) at various growth stages of hybrid tomato (Table 23)

The soil available nitrogen, phosphorus and potassium among the treatments that received 100% RDF (T_8, T_9 and T_{10}) were followed by treatments that received 75% RDF (T_5, T_6 and T_7) followed by treatments that received 50% RDF (T_2, T_3 and T_4) and lowest in absolute control (T_1) at flowering, fruiting and harvest stages. The soil available nitrogen, phosphorus and potassium decreased with progressive crop growth in all the treatments.

3.7. The total nutrient uptake (kg ha^{-1}) at various growth stages of hybrid tomato (Table 24)

Total Nitrogen Uptake

In the flowering, fruiting and harvest stages, T_9 (100% RDF + Nutrigel) recorded total N uptake of 72.10 kg ha^{-1}, 81.20 kg ha^{-1} and 143.00 kg ha^{-1} respectively which was on par with T_{10} (100% RDF + commercial micronutrient) having total N uptake of 70.80 kg ha^{-1}, 80.12 kg ha^{-1} and 140.10 kg ha^{-1}. The Treatment T_{10} was on par with T_8 (100% RDF) having total N uptake of 68.90 kg ha^{-1}, 77.36 kg ha^{-1} and 138.90 kg ha^{-1} across these stages. The lowest total nitrogen uptake was recorded in T_1 (Absolute control) with 48.60 kg ha^{-1} during flowering, 45.25 kg ha^{-1} during fruiting and 96.40 kg ha^{-1} at harvest.

Total Phosphorus Uptake

Total P uptake inT_9 (100% RDF + Nutrigel)was 29.84 kg ha^{-1} during flowering, 32.10 kg ha^{-1} during fruiting and 37.80 kg ha^{-1} at harvest stage and was on par with T_{10} (100% RDF + commercial micronutrient) having 29.20 kg ha^{-1}, 31.50 kg ha^{-1} and 36.60 kg ha^{-1} during these stages respectively. Treatment T_{10} was on par with T_8 (100% RDF) having total P uptake of 28.60 kg ha^{-1}, 30.60 kg ha^{-1} and 35.90 kg ha^{-1} during these stages respectively. The lowest total phosphorus uptake was recorded in T_1 (absolute control) with 16.10 kg ha^{-1} during flowering, 18.40 kg ha^{-1} during fruiting and 23.60 kg ha^{-1} at harvest.

Total Potassium Uptake

The total plant potassium uptake in T_9 (100% RDF + Nutrigel) was 57.10 kg ha^{-1} during flowering, 62.80 kg ha^{-1} during fruiting and 154.30 kg ha^{-1} at harvest and on par with T_{10} (100% RDF + commercial micronutrient) having 56.30 kg ha^{-1}, 61.20 kg ha^{-1} and 151.70 kg ha^{-1}. The total potassium uptake of T_{10} was on par with T_8 (100% RDF) having 54.90 kg ha^{-1}, 60.10 kg ha^{-1} and 147.60 kg ha^{-1}. The lowest total potassium uptake was recorded in T_1 (absolute control) with 39.10 kg ha^{-1} during flowering, 44.10 kg ha^{-1} during fruiting and 98.20 kg ha^{-1} at harvest.

3.8. SEM (Scanning Electron Microscope) analysis (Fig. 2)

Scanning electron microscopy (SEM) analysis revealed distinctive ultra-structural modifications in tomato leaf surfaces across treatments. The control specimens exhibited uniform, smooth surface topography with minimal stomatal definition, representing baseline leaf architecture. Treatment with Nutrigel (nano micronutrient gel formulation) induced pronounced morphological enhancements, characterized by well defined stomata and systematic foliar deposits. In contrast, commercial micronutrient application resulted in complex surface modifications, displaying smaller foliar deposits. The Nutrigel formulation demonstrated superior structural organization with a broader particle size distribution compared to the commercial treatment's confined range, suggesting enhanced control over nutrient delivery. These morphological variations and distinct particle size distributions indicate that delivery methods significantly influence leaf surface architecture and nutrient particle distribution, potentially affecting absorption efficiency and plant physiological responses to Nutrigel applications.

3.8. Economics (Table 25)

The economic analysis of hybrid tomato cultivation highlights that Treatment T_9 (100% RDF + Nutrigel) was the most profitable, with a net income of Rs. 327,861 and the highest benefit-cost ratio (BCR) of 2.21. The additional income due to Nutrigel application along with 100% RDF (T_9) compared to standard 100% RDF alone (T_8) is Rs. 22,200. This indicates that T_9 provided the best economic return among all treatments. Following T_9, treatment T_{10} (100% RDF+ commercial micronutrient) was the next most profitable, generating a net income of Rs. 313,811 and a BCR of 2.18. The additional income due to commercial micronutrient application along with 100% RDF (T_{10}) compared to standard 100% RDF alone (T_8) was Rs.8150. The economic analysis emphasize the importance of combining fertilizer with micronutrients, especially Nutrigel, for maximizing profitability in hybrid tomato cultivation.

Table. 19. Effect of levels of RDF, NPK combo, Nutrigel and commercial micronutrient on the growth parameters at various growth stages of hybrid tomato.

Treatment	Plant height (cm)			Root length (cm)			Number of leaves			Stem girth (cm)			Relative chlorophyll content (SPAD)			Leaf area index			Primary branches			Secondary branches			Tertiary branches		
	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
T_1	30.9	53.1	79.0	10.2	14.3	16.3	157.5	169.4	226.8	5.0	5.4	4.7	37.0	50.3	45.6	0.56	1.77	2.82	5.8	5.9	6.5	10.8	12.7	14.5	4.6	6.2	6.4
T_2	38.2	57.7	83.3	11.7	15.4	17.3	171.3	186.8	242.1	5.4	5.8	6.0	38.8	52.7	48.2	0.62	1.96	2.98	6.3	6.6	6.9	11.5	13.7	15.2	5.1	6.6	7.2
T_3	40.4	60.9	87.7	12.3	16.0	18.2	180.3	197.0	251.8	5.7	6.2	6.3	39.0	52.8	48.3	0.64	2.00	3.03	6.6	7.0	7.3	12.2	14.4	15.9	5.4	6.9	7.7
T_4	38.6	60.5	85.3	12.2	15.7	17.8	175.6	192.4	245.2	5.6	6.0	6.2	38.9	52.8	48.3	0.63	1.98	3.00	6.5	6.9	7.2	11.8	14.3	15.8	5.4	6.8	7.6
T_5	48.4	64.9	92.6	13.0	16.8	19.5	196.6	213.7	263.9	6.0	6.5	6.7	40.7	55.2	51.1	0.70	2.15	3.22	7.1	7.5	7.7	13.1	15.3	16.6	5.6	7.3	8.1
T_6	50.6	70.9	99.4	13.9	17.6	20.8	210.8	232.7	276.5	6.5	6.9	7.3	42.6	57.6	54.0	0.76	2.35	3.38	7.6	8.2	8.5	14.1	16.3	17.7	6.0	7.9	8.8
T_7	49.1	67.9	95.5	13.4	17.4	20.0	204.1	223.5	270.3	6.3	6.7	7.0	41.6	56.4	52.5	0.73	2.25	3.24	7.3	7.9	8.1	13.6	15.8	17.2	5.8	7.6	8.4
T_8	52.1	73.9	102.7	14.3	18.2	21.5	218.1	241.6	282.9	6.7	7.0	7.5	43.5	58.9	55.4	0.79	2.45	3.52	7.9	8.6	8.8	14.7	16.7	18.2	6.2	8.2	9.2
T_9	55.0	80.0	110.0	15.0	19.0	23.0	230.0	255.8	295.0	7.1	7.4	8.0	45.3	61.4	58.3	0.84	2.66	3.80	8.4	9.1	9.3	15.3	17.7	19.0	6.5	8.8	9.9
T_{10}	53.5	77.0	106.6	14.7	18.7	22.3	223.2	249.1	288.3	7.0	7.2	7.7	44.4	60.2	56.9	0.81	2.56	3.66	8.1	8.9	9.1	15.0	17.2	18.5	6.3	8.5	9.5
SEd	**1.00**	**1.51**	**1.89**	**0.27**	**0.31**	**0.40**	**3.72**	**4.85**	**4.18**	**0.14**	**0.14**	**0.13**	**0.73**	**0.96**	**0.90**	**0.02**	**0.06**	**0.08**	**0.15**	**0.18**	**0.18**	**0.28**	**0.33**	**0.31**	**0.12**	**0.14**	**0.19**
CD(P= 0.05)	**2.1**	**3.2**	**4.0**	**0.6**	**0.7**	**0.8**	**7.8**	**10.2**	**8.8**	**0.3**	**0.3**	**0.3**	**1.5**	**2.0**	**1.9**	**0.03**	**0.13**	**0.16**	**0.3**	**0.4**	**0.4**	**0.6**	**0.7**	**0.6**	**0.3**	**0.3**	**0.4**

***I – Vegetative stage, II – Flowering stage, III – Fruiting stage**

Table. 20. Effect of levels of RDF, NPK combo, Nutrigel and commercial micronutrient on the yield attributes and yield of hybrid tomato.

Treatment	Single fruit weight (g)	Number of flowers per plant	Number of fruits per plant	Fruit length (cm)	Fruit width (cm)	Fruit girth (cm)	Fruit Volume (cm^3)	Fruit yield (t ha^{-1})
T_1	79.6	44.6	36.0	3.4	4.2	16.2	58.9	54.30
T_2	83.5	47.2	43.3	3.8	4.4	17.2	62.3	57.00
T_3	87.5	49.6	45.4	4.0	4.6	18.1	65.6	60.38
T_4	86.6	48.9	44.9	4.0	4.6	17.8	64.8	57.86
T_5	91.9	52.7	50.6	4.3	4.9	19.0	71.8	65.56
T_6	98.7	55.7	53.7	4.7	5.2	20.6	77.0	68.73
T_7	95.2	54.2	52.3	4.5	5.0	19.8	74.4	66.41
T_8	102.2	57.1	55.1	4.8	5.3	21.4	78.7	71.05
T_9	109.1	60.0	58.0	5.0	5.6	23.0	83.2	74.95
T_{10}	105.6	58.2	56.2	4.9	5.5	22.2	80.8	72.35
SEd	**1.70**	**1.05**	**0.94**	**0.10**	**0.10**	**0.40**	**1.43**	**1.37**
CD (P=0.05)	**3.6**	**2.2**	**2.0**	**0.2**	**0.2**	**0.8**	**3.0**	**2.89**

Table. 21. Effect of levels of RDF, NPK combo, Nutrigel and commercial micronutrient on the enzyme activities of hybrid tomato fruit and plant.

Treatment	Peroxidase (gFW^{-1})	Poly Phenol Oxidase (gFW^{-1})	Lycopene (mg $100g^{-1}$)	Beta carotene (mg $100g^{-1}$)	Poly galacturonase (kj m^{-2})	Firmness (N m^{-1})	Ascorbic acid (mg $100g^{-1}$)	Titratable acidity (%)	Total Soluble Solids (◦Brix)	pH
T_1	54.3	79.5	2.6	2.4	3.8	3.2	29.2	0.35	3.26	4.13
T_2	59.7	86.4	2.8	2.6	3.6	3.4	30.9	0.40	3.48	4.11
T_3	64.3	93.0	3.0	2.8	3.4	3.7	32.6	0.44	3.70	4.01
T_4	62.0	89.7	2.9	2.8	3.5	3.6	31.9	0.43	3.65	4.03
T_5	68.7	98.3	3.1	3.0	3.2	4.5	37.5	0.50	4.20	3.94
T_6	73.3	104.9	3.3	3.2	3.0	4.8	39.3	0.54	4.40	3.86
T_7	71.0	101.6	3.2	3.1	3.1	4.6	38.2	0.52	4.30	3.92
T_8	75.6	108.2	3.4	3.3	2.9	4.9	40.7	0.56	4.52	3.83
T_9	80.2	114.8	3.6	3.5	2.7	5.2	43.0	0.60	4.74	3.63
T_{10}	77.9	111.5	3.5	3.4	2.8	5.0	41.6	0.58	4.64	3.75
SEd	**1.11**	**1.80**	**0.07**	**0.07**	**0.08**	**0.09**	**0.75**	**0.01**	**0.10**	**0.12**
CD (P=0.05)	**2.3**	**3.8**	**0.1**	**0.2**	**0.2**	**0.2**	**1.6**	**0.03**	**0.20**	**NS**

Table. 22. Effect of levels of RDF, NPK combo, Nutrigel and commercial micronutrient on the micronutrient uptake in hybrid tomato and plant at harvest stage.

Treatments	Nutrient uptake in fruit				Nutrient uptake in plant at harvest stage			
	Zinc (g ha^{-1})	Iron (g ha^{-1})	Manganese (g ha^{-1})	Copper (g ha^{-1})	Zinc (g ha^{-1})	Iron (g ha^{-1})	Manganese (g ha^{-1})	Copper (g ha^{-1})
T_1	81.8	140.9	62.5	22.2	81.3	321.4	108.5	33.9
T_2	104.0	185.0	81.5	28.8	101.2	347.2	146.5	45.0
T_3	113.5	203.1	85.8	31.1	110.4	387.4	160.6	49.6
T_4	108.8	194.0	82.1	30.0	105.8	367.3	153.6	47.3
T_5	120.3	214.8	91.5	34.3	117.0	409.5	169.7	53.9
T_6	129.8	232.9	98.9	36.5	126.2	449.7	183.8	58.4
T_7	125.0	223.8	95.2	35.4	121.6	429.6	176.8	56.1
T_8	134.5	241.9	102.6	37.7	130.8	469.8	190.9	60.7
T_9	144.8	260.0	110.0	40.0	140.0	498.1	205.0	65.2
T_{10}	139.2	251.0	106.3	38.9	135.4	489.9	197.9	62.9
SEd	**3.08**	**5.49**	**1.85**	**0.80**	**2.27**	**10.22**	**3.95**	**1.26**
CD (P=0.05)	**6.5**	**11.5**	**3.9**	**1.7**	**4.8**	**21.5**	**8.3**	**2.6**

Table. 23. Effect of levels of RDF, NPK combo, Nutrigel and commercial micronutrient on the soil available nutrients (kg ha^{-1}) at various growth stages of hybrid tomato

Treatment	Soil available nitrogen (kg ha^{-1})				Soil available phosphorus (kg ha^{-1})				Soil available potassium (kg ha^{-1})			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
T_1	214	203	194	186	35.2	30.3	29.6	28.2	328	334	327	321
T_2	227	216	207	199	40.5	35.5	33.7	32.7	343	342	335	329
T_3	223	212	203	195	38.0	33.8	32.9	31.6	342	341	333	328
T_4	225	214	205	197	39.3	34.3	33.5	32.1	343	342	334	328
T_5	240	229	220	212	45.8	40.8	36.7	35.5	357	353	343	336
T_6	236	225	216	208	43.3	38.9	35.5	34.4	355	362	341	335
T_7	238	227	218	210	44.5	39.5	35.9	34.9	356	352	342	336
T_8	253	242	233	225	51.0	46.0	40.8	38.1	375	365	352	345
T_9	249	238	229	221	48.5	44.5	39.6	37.2	373	365	349	344
T_{10}	251	240	231	223	49.8	44.8	40.2	37.6	373	364	352	344
SEd	**4.3**	**3.9**	**3.2**	**3.8**	**1.3**	**0.98**	**0.71**	**0.72**	**4.1**	**3.4**	**2.7**	**3.9**
CD (P=0.05)	**9.0**	**8.0**	**7.0**	**8**	**2.7**	**2.1**	**1.5**	**1.5**	**12.0**	**7.0**	**6.0**	**6.0**

***I – Vegetative stage, II – Flowering stage, III – Fruiting stage, IV – Harvest stage**

Table. 24. Effect of levels of RDF, NPK combo, Nutrigel and commercial micronutrient on the total nutrient uptake (kg ha^{-1}) at various growth stages of hybrid tomato

Treatment	Total nitrogen uptake (kg ha^{-1})				Total phosphorus uptake (kg ha^{-1})				Total potassium uptake (kg ha^{-1})			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
T_1	17.9	48.6	45.3	96.4	2.48	16.1	18.4	23.6	5.80	39.1	44.1	98.2
T_2	10.2	54.3	55.7	110.5	2.96	18.2	21.5	27.9	7.10	43.9	48.5	112.1
T_3	9.57	60.1	59.1	116.5	2.81	19.1	23.2	29.4	6.69	46.9	50.7	121.8
T_4	9.70	57.2	57.3	113.4	2.82	18.7	22.6	28.8	6.80	45.1	49.6	116.5
T_5	12.4	63.7	72.1	130.2	3.59	26.7	28.2	33.7	8.40	51.4	56.9	134.4
T_6	12.0	66.9	76.0	135.7	3.44	27.9	29.7	35.1	7.97	52.5	59.1	142.8
T_7	12.1	65.1	73.7	132.6	3.47	27.3	29.1	34.3	8.20	53.4	58.0	139.2
T_8	13.6	68.9	77.4	138.9	4.02	28.6	30.6	35.9	10.7	54.9	60.1	147.6
T_9	13.1	72.1	81.2	143.0	3.89	29.8	32.1	37.8	10.3	57.1	62.8	154.3
T_{10}	13.4	70.8	80.1	140.1	3.92	29.2	31.5	36.6	10.5	56.3	61.2	151.7
SEd	**0.21**	**1.43**	**1.55**	**1.39**	**0.08**	**0.41**	**0.62**	**0.61**	**0.24**	**0.94**	**0.81**	**2.82**
CD (P=0.05)	**0.63**	**3.01**	**3.26**	**4.1**	**0.17**	**0.87**	**1.30**	**1.28**	**0.5**	**2.0**	**1.7**	**5.9**

***I – Vegetative stage, II – Flowering stage, III – Fruiting stage, IV – Harvest stage**

Table 25. Effect of levels of RDF, NPK combo, Nutrigel and commercial micronutrient on economics of hybrid tomato cultivation.

Treatments		Economics			
		Total cost of cultivation (Rs.)	Total Income (Rs.)	Net Income (Rs.)	Benefit cost ratio (BCR)
T_1	Absolute control	250869	434400	183531	1.73
T_2	50% Recommended dose of fertilizer + NPK combo	274084	456000	181916	1.66
T_3	50% Recommended dose of fertilizer + NPK combo + Nutrigel	283084	483040	199956	1.71
T_4	50% Recommended dose of fertilizer + combo + Commercial micronutrient	276334	462880	186546	1.68
T_5	75% Recommended dose of fertilizer + NPK combo	276511.5	524480	247969	1.90
T_6	75% Recommended dose of fertilizer + NPK combo + Nutrigel	285511.5	549840	264329	1.93
T_7	75% Recommended dose of fertilizer + NPK combo + Commercial micronutrient	278761.5	531280	252519	1.91
T_8	100% Recommended dose of fertilizer	262739	568400	305661	2.16
T_9	100% Recommended dose of fertilizer + Nutrigel	271739	599600	327861	2.21
T_{10}	100% Recommended dose of fertilizer + Commercial micronutrient	264989	578800	313811	2.18

4. Second Season Field Experiment on hybrid Tomato

The second filed experiment was conducted from December 2024 to April 2025 in Kuppepalayam village, Coimbatore district, Tamil Nadu, India (11°00'71.2"N, 76°81'43.4" E). The hybrid tomato 'Madhan' was used to evaluate various combinations of the recommended fertilizer dose (RDF), NPK combo, Nutrigel (Nano micronutrient in gel formulation) and commercial micronutrient formulation. The spraying schedule and the treatment details are same as that of first season onion experiment (Table 17 and 18).

Effects of imposed treatments on plant growth attributes, yield and yield attributes, nutrient uptake, availability of nutrient and microbial growth in soil were discussed below.

4.1. Plant growth attributes (Table 26)

Plant Height: The tallest plants were observed in treatment T_9 (100% RDF + Nutrigel) reaching 56.5 cm at flowering, 81.3 cm during fruiting and 112.8 cm at harvest. Treatment T_{10} (100% RDF + Commercial micronutrient) recorded plant heights of 54.8 cm, 79.0 cm and 109.9 cm at the respective stages and was statistically on par with T_9 (100% RDF + Nutrigel). However, T_{10} was on par withT_8 (100% RDF), which recorded plant heights of 53.0 cm, 76.5 cm and 106.7 cm respectively at flowering, fruiting and harvest stages.

Root Length: The study on root length of hybrid tomato at various growth stages of flowering, fruiting and harvest indicated significant variations among the treatments. Treatment T_9 (100% RDF + Nutrigel) exhibited the longest roots across all stages recording 16.0 cm at flowering, 19.3 cm during fruiting and 23.9 cm at harvest. This treatment was statistically on par with T_{10} (100% RDF + Commercial micronutrient) which recorded 15.6 cm, 18.7 cm and 23.2 cm at the respective stages. However, T_8 (100% RDF) achieved root lengths of 15.2 cm, 17.8 cm and 22.6 cm at flowering, fruiting and harvest stages respectively and remained on par with T_{10} indicating comparable growth promotion through the recommended dose of fertilizer.

Number of Leaves: Treatment T_9 (100% RDF + Nutrigel) produced the higher leaf count across all stages, recording 232.5 leaves at flowering, 259.4 leaves during fruiting and 302.3 leaves at harvest. This treatment was statistically on par with T_{10} (100% RDF + Commercial micronutrient), which recorded 228.2, 252.4 and 294.1 leaves at flowering, fruiting and harvest stages respectively. Treatment T_8 (100% RDF) achieved 223.9, 241.1 and 289.9 leaves at flowering, fruiting and harvest stages respectively and remained on par with T_{10}.

Stem Girth: The larger stem girth was recorded in T_9 (100% RDF + Nutrigel) with values of 7.3 cm at flowering, 7.7 cm at fruiting and 8.1 cm at harvest and was on par with T_{10} (100% RDF + Commercial micronutrient) exhibiting a stem girth of 7.0 cm at flowering, 7.4 cm at fruiting and 7.9 cm at harvest. However, the treatment T_{10} remained on par with T_8 (100%

RDF) which recorded 6.7 cm, 7.0 cm and 7.6 cm at flowering, fruiting and harvest stages of tomato respectively.

Relative Chlorophyll Content (SPAD): Application of 100% RDF + Nutrigel (T_9) recorded the highest relative chlorophyll content, with values of 46.6 at flowering, 63.9 at fruiting and 61.7 at harvest. Treatment T_{10} (100% RDF + Commercial micronutrient) followed with 45.1, 62.4 and 60.4 which was statistically on par with T_9. However, T_{10} remained on par with T_8 (100% RDF) which recorded 43.8, 61.5 and 58.9 at flowering, fruiting and harvest stages of tomato respectively.

Leaf Area Index: The highest leaf area index was observed in T_9 (100% RDF + Nutrigel), with values of 0.95 at flowering, 2.80 at fruiting and 3.91 at harvest. 100% RDF + Commercial micronutrient (T_{10}) followed closely, with values of 0.92, 2.77 and 3.79 and remained on par with T_9. T_8 (100% RDF) showed values of 0.91, 2.73 and 3.69, significantly lower than T_{10}.

Primary, Secondary and Tertiary Branches: Application of 100% RDF+ Nutrigel (T_9) achieved counts of 8.9, 9.6 and 9.9 primary branches, while 100% RDF + commercial micronutrient (T_{10}) recorded the branch counts of 8.7, 9.4 and 9.7 and remained on par with each other. However, 100% RDF + commercial micronutrient (T_{10}) remained on par with T_8 (100% RDF), which recorded 8.5, 9.2 and 9.4 numbers of primary branches at flowering, fruiting and harvest stages of tomato respectively. Similar pattern was observed with respect to secondary and tertiary branches of tomato at flowering, fruiting and harvest stages.

The treatment 100 RDF + Nutrigel (T_9) recorded significantly higher plant growth parameters *viz.*, plant height, root length, number of leaves, stem girth, relative chlorophyll content, leaf area index, and number of branches compared to100% RDF (T_8). Even though the treatment 100% RDF + commercial micronutrient (T_{10}) was statistically on par with 100% RDF + Nutrigel (T_9), it did not differ significantly over 100% RDF (T_8).

4.2. The yield attributes and yield of hybrid tomato (Table 27)

Single Fruit Weight (g): The highest single fruit weight (112.6 g) was recorded in T_9 (100% RDF + Nutrigel) at whereas the lowest (80.2 g) was observed in the absolute control (T_1). The single fruit weight in T_9 (100% RDF + Nutrigel) was 112.6 g and it remained on par with T_{10} (100% RDF + commercial micronutrient) having 109.8 g and it was in turn on par with T_8 (100% RDF) having single fruit weight of 106.7 g.

Number of Flowers per Plant: Treatment T_9 (100% RDF + Nutrigel) recorded the highest number of flowers per plant (68.6) while T_1 (absolute control) had the lowest (44.8). The number of flowers in T_9 was on par with T_{10} (100% RDF + commercial micronutrient) having 67.1 number of flowers and T_{10} was in turn on par with T_8 (100% RDF) having 65.1.

Number of Fruits per Plant: The highest number of fruits per plant was observed in T_9 (100% RDF + Nutrigel) having 60.6 while the lowest was in T_1 (absolute control) at 36.7. The number of fruits in T_9 was 60.6 and remained on par with T_{10} (100% RDF + Commercial micronutrient) having 58.5 and T_{10} was in turn on par with T_8 (100% RDF) having 56.6.

Fruit Length (cm): The fruit length of hybrid tomato varied significantly among the treatments. The highest fruit length was observed in T_9 (100% RDF + Nutrigel) having 5.5 cm, while the lowest was recorded in the (absolute control) T_1 having fruit length of 3.5 cm. The fruit length in T_9 was on par with T_{10} (100% RDF + Commercial micronutrient) having 5.3 cm and T_{10} was in turn on par with T_8 (100% RDF) having fruit length of 5.2 cm.

Fruit Width (cm): The maximum fruit width was recorded in T_9 (100% RDF + Nutrigel) that recoded fruit width of 5.9 cm whereas the minimum was observed in T_1 (absolute control) having 4.4 cm. The fruit width in T_9 was on par with T_{10} (100% RDF + Commercial micronutrient) having 5.8 cm and T_{10} was in turn on par with T_8 (100% RDF) having fruit width of 5.6 cm.

Fruit Girth (cm): The fruit girth of hybrid tomato showed significant differences among the treatments. T_9 (100% RDF + Nutrigel) exhibited the highest fruit girth of 23.7 cm and on par with T_{10} (100% RDF + Commercial micronutrient) having fruit girth of 23.2 cm. However T_{10} was in turn on par with T_8 (100% RDF) which recorded the fruit girth of 22.5 cm.

Fruit Volume (cm^3): Fruit volume varied significantly across the treatments, with the highest value recorded in T_9 (100% RDF + Nutrigel) with 85.8 cm^3, and the lowest in T_1 (absolute control) having 60.0 cm^3. The fruit volume in T_9 was on par with T_{10} (100% RDF + commercial micronutrient) having the value of 84.0 cm^3 and T_{10} was in turn on par with T_8 (100% RDF) having fruit volume of 81.6 cm^3.

The yield attributes viz., single fruit weight (g)**,** number of flowers per plant, number of fruits per plant**,** fruit length (cm)**,** fruit width (cm)**,** fruit girth (cm)**,** fruit volume (cm^3)

Fruit Yield (t ha^{-1}): The higher fruit yield (80.7 t ha^{-1}) was observed in T_9 (100% RDF + Nutrigel) and it remained on par with T_{10} (100% RDF + commercial micronutrient) yielding 79.0 t ha^{-1} which in turn remained on par with T_8 (100% RDF) that recorded the fruit yield of 76.8 t ha^{-1}. Treatment T_9 (100% RDF + Nutrigel) produced 5.1% increased fruit yield compared to 100% RDF (T_8) and a 2.2% increase over 100% RDF + commercial micronutrient (T_{10}).

The treatment T_8 (100% RDF) recorded the fruit yield of 76.8 t ha^{-1}, which was on par with T_6 (75% RDF + NPK combo + Nutrigel) producing 75.6 t ha^{-1}. Treatment, T_6 was on par with T_7 (75% RDF + NPK combo + commercial micronutrient) yielding 72.7 t ha^{-1} and T_7 was on par with T_5 (75% RDF + NPK combo) which yielded 72.2 t ha^{-1}. Among the treatments

receiving 50% RDF, T_3 (50% RDF + NPK combo + Nutrigel) recorded the fruit yield of 65.8 t ha^{-1} which was on par with T_4 (50% RDF + NPK combo + commercial micronutrient) yielding 62.9 t ha^{-1}. Treatment T_4 was on par with T_2 (50% RDF + NPK combo) which recorded the fruit yield of 62.8 t ha^{-1}. The absolute control (T_1) registered the lowest yield (58.8 t ha^{-1}).

Application of 100% RDF + Nutrigel (T_9) recorded significantly higher yield attributes and fruit yield compared to 100% RDF (T_8), while yield attributes and fruit yield of 100% RDF + commercial micronutrient (T_{10}) was statistically comparable with 100% RDF (T_8).

4.3. The enzyme activities of hybrid tomato plant (Table 28)

Peroxidase Activity (gFW^{-1}): Treatment T_9 (100% RDF + Nutrigel) recorded the higher value (80.7 µg FW^{-1}) of peroxidase enzyme activities in hybrid tomato plants and was on par with T_{10} (100% RDF + commercial micronutrient) recording 78.3 µg FW^{-1}. Treatment T_{10} was on par with T_8 (100% RDF) having 76.1 µg FW^{-1}. The lowest peroxidase activity (54.9 µg FW^{-1}) was observed in absolute control (T_1).

Polyphenol Oxidase Activity (gFW^{-1}): Polyphenol oxidase activity in T_9 (100% RDF + Nutrigel) was higher (116.1 µg FW^{-1}) and statistically on par with T_{10} (100% RDF + commercial micronutrient) having 112.6 µg FW^{-1}. However, treatment T_{10} was on par with T_8 (100% RDF) having polyphenol oxidase activity of 109.2 µg FW. The lowest polyphenol oxidase activity (80.3 µg FW^{-1}) was recorded in T_1 (absolute Control).

4.4. Quality parameters of hybrid tomato fruits (Table 28)

Lycopene Content (mg 100g^{-1}): The lycopene content in hybrid tomato fruits varied significantly across treatments. T_9 (100% RDF + Nutrigel) recorded the highest lycopene level of 4.0 mg $100g^{-1}$ which was on par with T_{10} (100% RDF + Commercial micronutrient) having 3.9 mg $100g^{-1}$. The treatment T_{10} was in turn on par with T_8 (100% RDF) having lycopene content of 3.8 mg $100g^{-1}$.

Beta Carotene (mg 100g^{-1}): Beta carotene content was significantly influenced by different treatments. T_9 achieved the highest level of beta carotene of 3.7 mg $100g^{-1}$ and it was on par with T_{10} (100% RDF + commercial micronutrient) having beta carotene content of 3.6 mg $100g^{-1}$. Treatment T_{10} was in turn on par with T_8 (100% RDF) having beta carotene content of 3.5 mg $100g^{-1}$

Polygalacturonase Activity (kJ m^{-2}): Polygalacturonase activity decreased with increasing nutrient levels showing significant variation among treatments. T_1 (Absolute Control) recorded the highest activity of 3.6 kJ m^{-2} while T_9 (100% RDF + Nutrigel) had the lowest of 2.5 kJ m^{-2} and was on par with T_{10} (100% RDF + Commercial micronutrient) having polygalacturonase

activity of 2.6 kJ m^{-2} which was in turn on par with T_8 (100% RDF) having the value of 2.7 kJ m^{-2}.

Firmness (N m^{-1}): Fruit firmness showed significant differences among the treatments. T_9 (100% RDF + Nutrigel) exhibited the highest firmness value of 5.4 N m^{-1} and on par with T_{10} (100% RDF + Commercial micronutrient) having the firmness of 5.2 N m^{-1}. Treatment T_{10} was on par with T_8 (100% RDF) having fruit firmness of 5.1 N m^{-1}.

Ascorbic Acid (mg $100g^{-1}$): Ascorbic acid content was highest in T_9 (100% RDF + Nutrigel) having the value of 43.7 mg $100g^{-1}$ and was on par with T_{10} (100% RDF + Commercial micronutrient) which recorded ascorbic acid content of 42.7 mg $100g^{-1}$ which was in turn on par with T_8 (100% RDF) having 40.6 mg $100g^{-1}$.

Titratable Acidity (%): Titratable acidity was significantly affected by different nutrient combinations. T_9 (100% RDF + Nutrigel) recorded the highest acidity of 0.57% which was on par with T_{10} (100% RDF + commercial micronutrient) having the acidity of 0.56%. T_{10} was on par with T_8 (100% RDF) having titratable acidity of 0.55% which was on par with T_6 (75% RDF + NPK Combo + Nutrigel) having 0.53%.

Total Soluble Solids (°Brix): Total soluble solids were highest in T_9 (100% RDF + Nutrigel) with 4.57 degree Brix which was on par with T_{10} (100% RDF + commercial micronutrient) having 4.46 degree Brix. T_{10} was on par with T_8 (100% RDF) having the TSS of 4.33 degree Brix.

pH: The lower pH was recorded in T_9 (100% RDF + Nutrigel) at 3.66, but the differences were marginal and did not attain statistical significance.

4.5. The micronutrient uptake in hybrid tomato and plant at harvest stage. (Table 29)

Zinc Uptake (g ha^{-1}) in Fruit: Zinc uptake in tomato fruits varied significantly across treatments. Among the treatments T_9 (100% RDF+ Nutrigel) recorded the highest zinc uptake of 150.1 g ha^{-1} which was on par with T_{10} (100% RDF+ commercial micronutrient) having 146.7 g ha^{-1}. Zinc uptake in fruits of T_{10} was on par with T_8 (100% RDF) having Zn uptake of 140.9 g ha^{-1}. Zinc uptake in fruits of T_8 was on par with T_6 (75% RDF + NPK combo + Nutrigel) having 136.1 g ha^{-1} and it was in turn on par with T_7 (75% RDF + NPK combo + commercial micronutrient) which reported the zinc uptake of 130.9 g ha^{-1}. Zinc uptake of T_7 was on par with T_5 (75% RDF + NPK combo) having the value of 125.8 g ha^{-1}. Further, T_3 (50% RDF+ NPK combo + Nutrigel) recorded zinc uptake of 115.5 g ha^{-1} and was on par with T_4 (50% RDF+ NPK combo + commercial micronutrient) having 112.6 g ha^{-1} which was on par with T_2

(50% RDF + NPK combo) having 107.3 g ha^{-1}. The lowest zinc uptake was observed in T_1 (absolute control) with 84.4 g ha^{-1}.

Zinc Uptake (g ha^{-1}) in Plant: Zinc uptake in tomato plants exhibited significant variations across treatments. Treatment T_9 (100% RDF + Nutrigel) had the highest zinc uptake of 144.7 g ha^{-1} which was on par with T_{10} (100% RDF + commercial micronutrient) having 140.0 g ha^{-1}. Treatment T_{10} was on par with T_8 (100% RDF) which recorded the zinc uptake of 136.5 g ha^{-1}. The zinc uptake in T_8 was on par with T_6 (75% RDF + NPK combo + Nutrigel) having 132.8 g ha^{-1} and again T_6 was on par with T_7 (75% RDF + NPK combo + commercial micronutrient) having the zinc uptake of 128.5 g ha^{-1}. Zinc uptake in plants of T_7 was on par with T_5 (75% RDF + NPK combo) having 123.6 g ha^{-1} of zinc uptake. Application of 50% RDF+ NPK combo + Nutrigel (T_3) recorded 113.6 g ha^{-1} of zinc uptake in plants and was on par with T_4 (50% RDF + NPK combo + commercial micronutrient) having 109.0 g ha^{-1} which was in turn on par with T_2 (50% RDF + NPK combo) having 104.0 g ha^{-1}. The lowest zinc uptake in plants was recorded in T_1 (absolute control) with 83.1 g ha^{-1}.

Iron Uptake (g ha^{-1}) in Fruit: Among the treatments iron uptake in fruits of T_9 (100% RDF + Nutrigel) achieved the highest value of 266.3 g ha^{-1} which was on par with T_{10} (100% RDF + commercial micronutrient) having 259.9 g ha^{-1}. Iron uptake in fruits of T_{10} was on par with T_8 (100% RDF) having 253.7 g ha^{-1}. Iron uptake in fruits of T_8 was on par with T_6 (75% RDF + NPK combo + Nutrigel) having 248.0 g ha^{-1} and T_6 was again on par with T_7 (75% RDF + NPK combo + commercial micronutrient) having 241.8 g ha^{-1}. Iron uptake in T_7 was on par with T_5 (75% RDF + NPK combo) having 237.5 g ha^{-1}. These treatments were followed by T_3 (50% RDF + NPK combo + Nutrigel) which recorded 224.5 g ha^{-1} and was on par with T_4 (50% RDF + NPK combo + commercial micronutrient) having 217.1 g ha^{-1} which was again on par with T_2 (50% RDF + NPK combo) having 211.4 g ha^{-1}. The lowest iron uptake in fruits (185.3 g ha^{-1}) was observed in T_1 (absolute control).

Iron Uptake (g ha^{-1}) in Plant: The tomato plants at harvest stage in T_9 (100% RDF + Nutrigel) recorded the highest iron uptake of 506.9 g ha^{-1} which was on par with T_{10} (100% RDF + commercial micronutrient) having 493.5 g ha^{-1}. Iron uptake in plants of T_{10} was on par with T_8 (100% RDF) which had an uptake of 478.3 g ha^{-1}. Iron uptake in plants of T_8 was on par with T_6 (75% RDF + NPK combo + Nutrigel) had 463.4 g ha^{-1} and T_6 was on par with T_7 (75% RDF + NPK combo + commercial micronutrient) having 448.4 g ha^{-1}. Iron uptake in plants of T_7 was on par with T_5 (75% RDF + NPK combo) having iron uptake in plants of 433.2 g ha^{-1}. Iron uptake in plants of T_3 (50% RDF + NPK combo + Nutrigel) recorded was 397.5 g ha^{-1} and it remained on par with T_4 (50% RDF + NPK combo + commercial micronutrient) having 384.2

g ha^{-1} which was in turn on par with T_2 (50% RDF + NPK combo) having 372.2 g ha^{-1}. The lowest iron uptake in plants was observed in T_1 (absolute control) having 327.7 g ha^{-1}.

Manganese Uptake (g ha^{-1}) in Fruit: In terms of manganese uptake in fruits at harvest T_9 (100% RDF + Nutrigel) recorded the highest value of 114.4 g ha^{-1} and remained on par with T_{10} (100% RDF + commercial micronutrient) having 111.1 g ha^{-1}. Manganese uptake on T_{10} was also on par with T_8 (100% RDF) had 108.0 g ha^{-1}. Treatment T_8 was on par with T_6 (75% RDF + NPK combo + Nutrigel) had 104.8 g ha^{-1} and T_6 was on par with T_7 (75% RDF+ NPK combo + commercial micronutrient) had 101.4 g ha^{-1}. Treatment T_7 was on par with T_5 (75% RDF + NPK combo) had 98.2 g ha^{-1}. These treatments were followed by T_3 (50% RDF + NPK combo + Nutrigel) which recorded 86.6 g ha^{-1} and was on par with T_4 (50% RDF + NPK combo + commercial micronutrient) having 83.6 g ha^{-1} which was again on par with T_2 (50% RDF + NPK combo) having 80.4 g ha^{-1}. The lowest manganese uptake was in T_1 (absolute control) with 66.3 g ha^{-1}.

Manganese Uptake (g ha^{-1}) in Plant: Manganese uptake in plants at harvest stage showed significant differences. Among the treatments T_9 (100% RDF + Nutrigel) had the highest value of 208.5 g ha^{-1} which was on par with T_{10} (100% RDF + commercial micronutrient) having 202.5 g ha^{-1}. Manganese uptake in plants of T_{10} was on par with T_8 (100% RDF) which had an uptake of 196.4 g ha^{-1}. Treatment T_8 was on par with T_6 (75% RDF + NPK combo + Nutrigel) that had an uptake of 187.2 g ha^{-1} and treatment T_6 was on par with T_7 (75% RDF + NPK combo + commercial micronutrient) which had an uptake of 179.1 g ha^{-1}. Treatment T_7 was on par with T_5 (75% RDF + NPK combo) having 175.9 g ha^{-1}. These treatments were followed by T_3 (50% RDF + NPK combo + Nutrigel) which recorded iron uptake 164.6 g ha^{-1} which was on par with T_4 (50% RDF + NPK combo + commercial micronutrient) had 155.6 g ha^{-1} which in turn was on par with T_2 (50% RDF + NPK combo) having 151.5 g ha^{-1}. The lowest manganese uptake of 116.3 g ha^{-1} was recorded in T_1 (absolute control).

Copper Uptake (g ha^{-1}) in Fruit: Copper uptake in fruit at harvest stage showed significant differences. Treatment T_9 (100% RDF + Nutrigel) recorded the highest uptake of 43.2 g ha^{-1} and was on par with T_{10} (100% RDF + commercial micronutrient) having 41.8 g ha^{-1}. Treatment T_{10} was on par with T_8 (100% RDF) having copper uptake in fruits to the tune of 40.4 g ha^{-1}. Additionally, T_8 was on par with T_6 (75% RDF + NPK combo + Nutrigel) having copper uptake of 39.2 g ha^{-1} and T_6 was in turn on par with T_7 (75% RDF + NPK combo + commercial micronutrient) having 37.8 g ha^{-1}. Copper uptake in fruits of T_7 was on par with T_5 (75% RDF + NPK combo) having 36.6 g ha^{-1}. These treatment were followed by T_3 (50% RDF + NPK combo + Nutrigel) which recorded 32.3 g ha^{-1} and was on par with T_4 (50% RDF

+ NPK combo + commercial micronutrient) having 30.9 g ha^{-1} which was in turn on par with T_2 (50% RDF + NPK combo) having 29.5 g ha^{-1}. The lowest copper uptake 24.7 g ha^{-1} was observed in T_1 (absolute control).

Copper Uptake (g ha^{-1}) in Plant: Copper uptake in tomato plants at harvest stage showed a marked variation. Treatment T_9 (100% RDF + Nutrigel) recorded the highest copper uptake of 68.0 g ha^{-1} which was on par with T_{10} (100% RDF + commercial micronutrient) having 65.9 g ha^{-1}. Treatment T_{10} was on par with T_8 (100% RDF) having copper uptake of 63.7 g ha^{-1}. Treatment T_8 was on par with T_6 (75% RDF + NPK combo + Nutrigel) which recorded copper uptake of 61.5 g ha^{-1} and T_6 was on par with T_7 (75% RDF + NPK combo + commercial micronutrient) had 59.5 g ha^{-1}. Copper uptake in plants of T_7 was on par with T_5 (75% RDF + NPK combo) had 57.6 g ha^{-1}. These treatments were followed by T_3 (50% RDF + NPK combo + Nutrigel) which recorded an uptake of 53.5 g ha^{-1}in in plants and was on par with T_4 (50% RDF + NPK combo + commercial micronutrient) having 51.3 g ha^{-1} which was in turn on par with T_2 (50% RDF + NPK combo) having 49.2 g ha^{-1}. The lowest copper uptake (37.4 g ha^{-1}) was observed in T_1 (absolute control).

4.6. The soil available nutrients (kg ha^{-1}) at various growth stages of hybrid tomato (Table 30)

The soil available nitrogen, phosphorus and potassium among the treatments that received 100% RDF (T_8, T_9 and T_{10}) were followed by treatments that received 75% RDF (T_5, T_6 and T_7) followed by treatments that received 50% RDF (T_2, T_3 and T_4) and lowest in absolute control (T_1) at flowering, fruiting and harvest stages. The soil available nitrogen, phosphorus and potassium decreased with progressive crop growth in all the treatments.

4.7. The total nutrient uptake (kg ha^{-1}) at various growth stages of hybrid tomato (Table 31)

Total Nitrogen Uptake

In the flowering, fruiting and harvest stages, T_9 (100% RDF + Nutrigel) recorded total N uptake of 78.5 kg ha^{-1}, 88.5 kg ha^{-1} and 155.9 kg ha^{-1} respectively which was on par with T_{10} (100% RDF + commercial micronutrient) having total N uptake of 76.7 kg ha^{-1}, 86.8 kg ha^{-1} and 153.7 kg ha^{-1}. The Treatment T_{10} was on par with T_8 (100% RDF) having total N uptake of 74.8 kg ha^{-1}, 83.9 kg ha^{-1} and 149.9 kg ha^{-1} across these stages. The lowest total nitrogen uptake was recorded in T_1 (Absolute control) with 54.8 kg ha^{-1} during flowering, 49.0 kg ha^{-1} during fruiting and 104.4 kg ha^{-1} at harvest.

Total Phosphorus Uptake

Total P uptake in T_9 (100% RDF + Nutrigel) was 32.5 kg ha^{-1} during flowering, 35.0 kg ha^{-1} during fruiting and 41.2 kg ha^{-1} at harvest stage and was on par with T_{10} (100% RDF + commercial micronutrient) having 31.8 kg ha^{-1}, 34.3 kg ha^{-1} and 39.9 kg ha^{-1} during these stages respectively. Treatment T_{10} was on par with T_8 (100% RDF) having total P uptake of 31.2 kg ha^{-1}, 33.4 kg ha^{-1} and 39.1 kg ha^{-1} during these stages respectively. The lowest total phosphorus uptake was recorded in T_1 (absolute control) with 17.6 kg ha^{-1} during flowering, 20.1 kg ha^{-1} during fruiting and 25.7 kg ha^{-1} at harvest.

Total Potassium Uptake

The total plant potassium uptake in T_9 (100% RDF + Nutrigel) was 62.9 kg ha^{-1} during flowering, 69.2 kg ha^{-1} during fruiting and 157.4 kg ha^{-1} at harvest and on par with T_{10} (100% RDF + commercial micronutrient) having 62.4 kg ha^{-1}, 67.9 kg ha^{-1} and 154.7 kg ha^{-1}. The total potassium uptake of T_{10} was on par with T_8 (100% RDF) having 61.6 kg ha^{-1}, 66.6 kg ha^{-1} and 150.6 kg ha^{-1}. The lowest total potassium uptake was recorded in T_1 (absolute control) with 43.6 kg ha^{-1} during flowering, 49.8 kg ha^{-1} during fruiting and 100.2 kg ha^{-1} at harvest.

4.8. Economics (Table 32)

The economic analysis of hybrid tomato cultivation ascertain that Treatment T_9 (100% RDF + Nutrigel) was the most profitable, with a net income of Rs. 3,78,861 and the highest benefit-cost ratio (BCR) of 2.38. The additional income due to Nutrigel application along with 100% RDF (T_9) compared to standard 100% RDF alone (T_8) is Rs. 22,000. This indicates that T_9 provided the best economic return among all treatments. Following T_9, treatment T_{10} (100% RDF+ commercial micronutrient) was the next most profitable, generating a net income of Rs. 3,67,011 and a BCR of 2.33. The additional income due to commercial micronutrient application along with 100% RDF (T_{10}) compared to standard 100% RDF alone (T_8) was Rs.8,600. The economic analysis emphasize the importance of combining fertilizer with micronutrients, especially Nutrigel, for maximizing profitability in hybrid tomato cultivation.

Table. 26. Effect of levels of RDF, NPK combo, Nutrigel and commercial micronutrient on the growth parameters at various growth stages of hybrid tomato.

Treatment	Plant height (cm)			Root length (cm)			Number of leaves			Stem girth (cm)			Relative Chlorophyll content (SPAD)			Leaf area index			Primary branches			Secondary branches			Tertiary branches		
	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
T_1	32.3	55.2	79.1	9.4	10.1	14.6	156.9	173.8	223.0	4.7	5.3	5.5	33.5	48.5	47.3	0.70	1.89	2.80	6.1	6.2	6.8	10.0	14.0	14.1	4.6	6.3	6.6
T_2	39.8	61.2	89.0	11.9	11.2	16.0	169.4	189.0	238.9	5.1	5.7	6.2	36.1	52.6	50.1	0.73	2.41	2.99	6.9	7.0	7.5	11.7	15.1	15.2	5.1	7.1	8.3
T_3	44.0	65.2	94.0	12.7	12.6	17.3	181.2	199.9	253.1	5.7	6.1	6.5	38.6	54.0	52.4	0.76	2.48	3.17	7.3	7.5	7.9	12.1	15.6	15.7	5.6	7.8	8.8
T_4	41.9	63.1	91.2	12.2	12.0	16.7	174.8	196.2	245.3	5.5	6.0	6.4	37.3	53.4	51.3	0.74	2.43	3.08	7.1	7.2	7.6	11.8	15.4	15.5	5.3	7.4	8.6
T_5	47.7	70.3	99.2	14.1	15.7	20.7	207.7	213.7	268.2	6.0	6.4	7.0	41.4	57.4	55.1	0.83	2.61	3.37	7.9	8.4	8.3	14.9	16.6	16.7	5.7	8.1	9.1
T_6	51.0	73.3	104.1	14.9	17.6	21.9	220.0	232.8	282.4	6.4	6.9	7.3	42.9	59.8	58.3	0.88	2.68	3.58	8.3	8.9	9.1	15.5	17.3	18.0	6.1	8.6	9.6
T_7	49.8	71.3	102.7	14.4	16.7	21.2	213.6	223.7	275.0	6.2	6.6	7.1	41.7	58.8	56.5	0.86	2.65	3.48	8.1	8.6	8.7	15.2	16.8	17.3	5.9	8.3	9.4
T_8	53.0	76.5	106.7	15.2	17.8	22.6	223.9	241.1	289.9	6.7	7.0	7.6	43.8	61.5	58.9	0.91	2.73	3.69	8.5	9.2	9.4	15.8	18.0	18.7	6.4	8.8	9.8
T_9	56.5	81.3	112.8	16.0	19.3	23.9	232.5	259.4	302.3	7.3	7.7	8.1	46.6	63.9	61.7	0.95	2.80	3.91	8.9	9.6	9.9	16.2	19.1	20.1	6.8	9.4	10.3
T_{10}	54.8	79.0	109.9	15.6	18.7	23.2	228.2	252.4	294.1	7.0	7.4	7.9	45.1	62.4	60.4	0.92	2.77	3.79	8.7	9.4	9.7	16.0	18.5	19.3	6.6	9.1	10.0
SEd	**1.0**	**1.9**	**2.2**	**0.4**	**0.5**	**0.5**	**4.4**	**5.6**	**6.2**	**0.2**	**0.2**	**0.2**	**1.1**	**3.4**	**0.9**	**0.02**	**0.06**	**0.08**	**0.2**	**0.2**	**0.2**	**0.3**	**0.4**	**0.5**	**0.1**	**0.2**	**0.2**
CD(P= 0.05)	**2.2**	**3.9**	**4.7**	**0.8**	**1.0**	**1.0**	**9.2**	**11.7**	**12.9**	**0.3**	**0.3**	**0.4**	**2.3**	**3.2**	**1.9**	**0.03**	**0.12**	**0.18**	**0.4**	**0.4**	**0.4**	**0.7**	**0.9**	**1.0**	**0.3**	**0.3**	**0.4**

***I – Vegetative stage, II – Flowering stage, III – Fruiting stage**

Table. 27. Effect of levels of RDF, NPK combo, Nutrigel and commercial micronutrient on the yield attributes and yield of hybrid tomato.

Treatment	Single fruit weight (g)	Number of flowers per plant	Number of fruits per plant	Fruit length (cm)	Fruit width (cm)	Fruit girth (cm)	Fruit Volume (cm^3)	Fruit yield (t ha^{-1})
T_1	80.2	44.8	36.7	3.5	4.4	17.2	60.0	58.8
T_2	85.6	49.8	42.5	3.7	4.6	18.3	64.5	62.8
T_3	92.3	54.2	45.8	4.0	4.8	19.3	66.5	65.8
T_4	88.9	51.9	44.5	3.8	4.7	18.7	66.1	62.9
T_5	97.7	58.7	51.0	4.9	5.1	20.4	73.6	72.2
T_6	103.1	62.7	54.6	5.1	5.4	21.7	78.7	75.6
T_7	100.0	60.3	52.5	5.1	5.3	21.1	76.8	72.7
T_8	106.7	65.1	56.6	5.2	5.6	22.5	81.6	76.8
T_9	112.6	68.6	60.6	5.5	5.9	23.7	85.8	80.7
T_{10}	109.8	67.1	58.5	5.3	5.8	23.2	84.0	79.0
SEd	**2.48**	**1.68**	**1.25**	**0.10**	**0.12**	**0.42**	**1.65**	**1.60**
CD (P=0.05)	**5.2**	**3.5**	**2.6**	**0.2**	**0.2**	**0.9**	**3.5**	**3.4**

Table. 28. Effect of levels of RDF, NPK combo, Nutrigel and commercial micronutrient on the enzyme activities of hybrid tomato fruit and plant.

Treatment	Peroxidase (gFW^{-1})	Poly Phenol Oxidase (gFW^{-1})	Lycopene (mg $100g^{-1}$)	Beta carotene (mg $100g^{-1}$)	Poly galacturonase (kj m^{-2})	Firmness (N m^{-1})	Ascorbic acid (mg $100g^{-1}$)	Titratable acidity (%)	Total Soluble Solids (◦Brix)	pH
T_1	54.9	80.3	2.4	2.8	3.6	4.2	27.1	0.32	2.10	4.07
T_2	59.6	86.9	3.2	3.0	3.3	4.3	30.5	0.39	3.06	4.04
T_3	64.7	93.6	3.4	3.1	3.2	4.4	32.0	0.41	3.32	3.96
T_4	61.6	90.1	3.3	3.1	3.3	4.3	31.4	0.40	3.18	4.00
T_5	68.9	99.5	3.5	3.2	2.8	4.9	37.0	0.51	4.01	3.87
T_6	73.8	106.1	3.7	3.4	2.7	5.0	38.6	0.53	4.20	3.74
T_7	71.8	102.9	3.6	3.4	2.8	4.9	37.8	0.52	4.10	3.83
T_8	76.1	109.2	3.8	3.5	2.7	5.1	40.6	0.55	4.33	3.70
T_9	80.7	116.1	4.0	3.7	2.5	5.4	43.7	0.57	4.57	3.66
T_{10}	78.3	112.6	3.9	3.6	2.6	5.2	42.7	0.56	4.46	3.69
SEd	1.4	1.9	0.06	0.10	0.04	0.15	0.97	0.01	0.10	0.12
CD (P=0.05)	2.9	3.9	0.1	0.2	0.1	0.3	2.0	0.02	0.20	NS

Table. 29. Effect of levels of RDF, NPK combo, Nutrigel and commercial micronutrient on the micronutrient uptake in hybrid tomato and plant at harvest stage.

Treatments	Nutrient uptake in fruit				Nutrient uptake in plant at harvest stage			
	Zinc (g ha^{-1})	Iron (g ha^{-1})	Manganese (g ha^{-1})	Copper (g ha^{-1})	Zinc (g ha^{-1})	Iron (g ha^{-1})	Manganese (g ha^{-1})	Copper (g ha^{-1})
T_1	84.4	185.3	66.3	24.7	83.1	327.7	116.3	37.4
T_2	107.3	211.4	80.4	29.5	104.0	372.2	151.5	49.2
T_3	115.5	224.6	86.6	32.3	113.6	397.5	164.6	53.5
T_4	112.6	217.1	83.6	30.9	109.0	384.2	155.6	51.3
T_5	125.8	237.5	98.2	36.6	123.6	433.2	175.9	57.6
T_6	136.1	248.0	104.8	39.2	132.8	463.4	187.2	61.5
T_7	130.9	241.8	101.4	37.8	128.5	448.4	179.1	59.5
T_8	140.9	253.7	108.0	40.4	136.5	478.3	196.4	63.7
T_9	150.1	266.3	114.4	43.2	144.7	506.9	208.5	68.0
T_{10}	146.7	259.9	111.1	41.8	140.0	493.5	202.5	65.9
SEd	3.20	5.16	1.96	0.83	2.44	10.43	4.64	1.52
CD (P=0.05)	6.7	10.9	4.1	1.8	5.1	21.9	9.8	3.2

Table. 30. Effect of levels of RDF, NPK combo, Nutrigel and commercial micronutrient on the soil available nutrients (kg ha^{-1}) at various growth stages of hybrid tomato

Treatment	Soil available nitrogen (kg ha^{-1})				Soil available phosphorus (kg ha^{-1})				Soil available potassium (kg ha^{-1})			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
T_1	227	205	201	189	41.4	37.3	37.0	35.1	336	343	328	317
T_2	240	222	216	204	46.7	42.5	40.9	39.0	357	359	344	334
T_3	236	218	212	200	44.2	40.8	40.1	37.9	356	358	344	333
T_4	238	220	214	202	45.5	41.3	40.7	38.4	357	359	344	334
T_5	253	239	231	219	52.0	47.8	44.1	42.1	379	376	364	353
T_6	249	235	227	215	49.5	45.9	42.9	41.0	377	391	360	349
T_7	251	237	229	217	50.7	46.5	43.3	41.5	378	374	360	351
T_8	266	256	246	234	56.9	53.0	48.2	45.0	400	395	380	370
T_9	262	252	242	230	54.4	51.5	47.0	44.1	399	395	379	369
T_{10}	264	254	244	232	55.7	51.8	47.6	44.5	398	394	380	370
SEd	4.7	4.6	3.6	2.9	0.97	0.93	0.86	0.67	7.2	6.4	6.7	7.2
CD (P=0.05)	10	10	8	6	2.0	1.9	1.8	1.4	15	14	14	15

***I – Vegetative stage, II – Flowering stage, III – Fruiting stage, IV – Harvest stage**

Table. 31. Effect of levels of RDF, NPK combo, Nutrigel and commercial micronutrient on the total nutrient uptake (kg ha^{-1}) at various growth stages of hybrid tomato

Treatment	Total nitrogen uptake (kg ha^{-1})				Total phosphorus uptake (kg ha^{-1})				Total potassium uptake (kg ha^{-1})			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
T_1	18.9	54.8	49.0	104.4	2.7	17.6	20.1	25.7	5.9	43.6	49.8	100.2
T_2	10.9	60.8	61.4	121.8	3.1	19.8	23.4	30.4	7.2	48.6	54.3	114.3
T_3	10.0	63.0	64.3	127.1	3.2	20.8	25.3	32.1	6.9	51.7	56.6	123.2
T_4	10.2	65.4	62.4	123.2	3.1	20.4	24.6	31.4	7.0	49.8	55.5	118.8
T_5	13.2	69.3	79.3	143.4	3.8	29.1	30.7	36.7	8.6	56.4	63.8	137.1
T_6	12.8	72.7	83.3	148.8	4.1	30.4	32.4	38.3	8.3	57.5	65.4	145.7
T_7	12.9	70.9	80.3	145.8	3.9	29.8	31.7	37.4	8.4	59.5	64.2	142.0
T_8	14.2	74.8	83.9	149.9	4.2	31.2	33.4	39.1	10.9	61.6	66.6	150.6
T_9	13.9	78.5	88.5	155.9	4.4	32.5	35.0	41.2	10.5	62.9	69.2	157.4
T_{10}	14.1	76.7	86.8	153.7	4.3	31.8	34.3	39.9	10.8	62.4	67.9	154.7
SEd	**0.28**	**1.65**	**1.51**	**2.98**	**0.08**	**0.58**	**0.85**	**0.73**	**0.17**	**1.07**	**1.29**	**2.45**
CD (P=0.05)	**0.6**	**3.5**	**3.2**	**6.3**	**0.2**	**1.2**	**1.8**	**1.5**	**0.3**	**2.3**	**2.7**	**5.1**

***I – Vegetative stage, II – Flowering stage, III – Fruiting stage, IV – Harvest stage**

Table. 32. Effect of levels of RDF, NPK combo, Nutrigel and commercial micronutrient on the economics of hybrid tomato

Treatments		Economics			
		Total cost of cultivation (Rs.)	Total Income (Rs.)	Net Income (Rs.)	Benefit cost ratio (BCR)
T_1	Absolute control	250869	470400	219531	1.88
T_2	50% Recommended dose of fertilizer + NPK combo	274084	502400	228316	1.83
T_3	50% Recommended dose of fertilizer + NPK combo + Nutrigel	283084	526400	243316	1.86
T_4	50% Recommended dose of fertilizer + combo + Commercial micronutrient	283084	503200	220116	1.78
T_5	75% Recommended dose of fertilizer + NPK combo	276512	577600	301089	2.09
T_6	75% Recommended dose of fertilizer + NPK combo + Nutrigel	285512	604800	319289	2.12
T_7	75% Recommended dose of fertilizer + NPK combo + Commercial micronutrient	285512	581600	296089	2.04
T_8	100% Recommended dose of fertilizer	262739	614400	351661	2.34
T_9	100% Recommended dose of fertilizer + Nutrigel	271739	645600	373861	2.38
T_{10}	100% Recommended dose of fertilizer + Commercial micronutrient	271739	632000	360261	2.33

5. Biosafety and toxicology studies of Nutrigel on Onion and Tomato crop

5.1. First season experiment on Onion

5.1.1 Microbial population assessment in rhizosphere (Table 33).

The total bacterial, fungal, and actinomycetes population in the soil samples were enumerated using serial dilution and pour plate method. Each soil sample was serially diluted until the required dilution. For serial dilution 10 g of representative soil sample was suspended in 9 ml of sterile distilled water and then serially diluted up to 10^{-6} dilutions for bacteria, 10^{-4} dilution for fungi and 10^{-2} dilution for actinomycetes. 1 ml of the appropriate dilutions were plated on nutrient agar medium for bacteria, Rose Bengal Agar medium for fungi, and Kenknight's Agar medium for actinomycetes. The plates were incubated for 2 days for bacterial colonies, 3 days for fungal colonies, and 7 days for actinomycetes colonies. After the incubation period, the colonies on each plate were counted and the Colony Forming Units (CFU) per gram of soil were calculated and expressed as CFUs per g of dry weight of the soil (Table 33).

Bacteria

The microbial populations in the rhizosphere showed significant variations in bulb development and harvest stages of onion crop. During the vegetative stage, the variation in bacterial, fungal and actinomycetes populations among the treatments were found to be non-significant.

In the bulb development stage, 100% RDF + Nutrigel (T_9) had higher bacterial population of 1.72 $\times 10^6$ log cfu g^{-1} which were on par with each other with 100% RDF + commercial micronutrients (T_{10}) which showed 1.71 $\times 10^6$ log cfu g^{-1}. However, T_{10} is statistically similar with the treatment 100% RDF (T_8) which recorded 1.66 $\times$ log10^6 cfu g^{-1}. In contrast, the Absolute control (T_1) had the lowest bacterial population at 1.34 $\times 10^6$ log cfu g^{-1}.

In the harvest stage, 100% RDF + Nutrigel (T_9) had the highest bacterial population of 1.67 $\times 10^6$ log cfu g^{-1} followed by 100% RDF + commercial micronutrients (T_{10}) which showed 1.65 $\times 10^6$ log cfu g^{-1} which were on par with each other. T_{10} was statistically similar with the treatment 100% RDF (T_8) which recorded 1.54 $\times 10^6$ log cfu g^{-1}. In contrast, the Absolute control (T_1) had the lowest bacterial population at 0.75 log 10^6 cfu g^{-1}.

Fungi

In the bulb development stage,100% RDF + Nutrigel (T_9) had highest fungal population of 1.23$\times 10^3$ log cfu g^{-1} followed by 100% RDF + commercial micronutrients (T_{10}) which showed 1.21 $\times 10^3$ log cfu g^{-1} which were on par with each other. T_{10} is statistically similar with

the treatment 100% RDF (T_8) which recorded 1.16 $\times 10^3$ log cfu g^{-1}. In contrast, the Absolute control (T_1) had the fungal population at 0.52 $\times 10^3$log cfu g^{-1}

In the harvest stage, T_9 had highest fungal population of 1.17 $\times 10^3$ log cfu g^{-1} followed by 100% RDF + commercial micronutrients (T_{10}) which showed 1.13 $\times 10^3$ log cfu g^{-1} which were on par with each other. T_{10} is statistically similar with the treatment 100% RDF (T_8) which recorded 1.09 $\times 10^3$ log cfu g^{-1}. In contrast, the Absolute control (T_1) had the 0.77 $\times 10^3$ log cfu g^{-1}.

Actinomycetes

In the Bulb development stage, T_9 had highest actinomycetes population of 1.1 $\times 10^4$ log cfu g^{-1} followed by 100% RDF + commercial micronutrients (T_{10}) which showed 1.08 $\times 10^4$ log cfu g^{-1} which were on par with each other. T_{10} is statistically similar with the treatment 100% RDF (T_8) which recorded 1.04 $\times 10^4$ log cfu g^{-1}. In contrast, the Absolute control (T_1) had the fungal population at 0.79 $\times 10^4$ log cfu g^{-1}.

In the harvest stage, T_9 had highest actinomycetes population of 1.05 log $\times 10^4$ log cfu g^{-1} followed by 100% RDF + commercial micronutrients (T_{10}) which showed 1.01 $\times 10^4$ log cfu g^{-1} which were on par with each other. T_{10} is statistically similar with the treatment 100% RDF (T_8) which recorded 0.97 $\times 10^4$ log cfu g^{-1}. In contrast, the Absolute control (T_1) had the lowest fungal population at 0.60 $\times 10^4$ log cfu g^{-1}.

5.1.2. Bacterial population assessment in phyllosphere (Table 34)

To assess the microbial population in the phyllosphere, the leaf imprint method was used. This technique involves pressing the onion leaf surface onto an agar plate, which allows microorganisms present on the leaf to transfer onto the agar medium. The plates are then incubated to promote microbial growth, enabling the enumeration and identification of the microbial communities inhabiting the phyllosphere (Table 34).

Microbial population on leaf is significantly impacted by the application of Nano micronutrients in combination with RDF. The treatment, 100% RDF + Nutrigel (T_9) had highest leaf bacterial population of 1.2, 1.25 and 1.00 $\times 10^6$ log cfu g^{-1} at 25, 60 and 90 DAS respectively followed by the treatment 100% RDF + commercial micronutrients (T_{10}) which showed 1.18, 1.23 and 0.98 log $\times 10^6$ log cfu g^{-1} at 25, 60 and 90 DAS respectively which were on par with each other. T_{10} is statistically similar with the treatment 100% RDF (T_8) which recorded 1.10, 1.20 and 0.96$\times 10^6$ log cfu g^{-1} at 25, 60 and 90 DAS respectively. In contrast, Absolute control (T_1) had the lowest bacterial population at 0.58, 0.85, 0.5 $\times 10^6$ log cfu $g^{-}1$. The treatment with Nutrigel (Nano micronutrients) and 100% RDF significantly increased the microbial population in the phyllosphere.

5.1.3. Toxicology studies of Nutrigel on Zinc Solubilising Bacteria

Toxicity of Nutrigel against zinc solubilising bacteria was analysed at different concentrations (1, 2.5, 5, 7.5, and 10 ml) i.e. 0.4 to 4 % of Nutrigel in 250 ml of nutrient agar media using pour plate method. The toxicology studies were performed on organisms, Phosphorous Solubilising Bacteria (PSB), Potassium Releasing Bacteria (KRB) Zinc Solubilizing Bacteria (ZnSB) at field concentration (0.2 ml) of Nutrigel in 250 ml of nutrient agar. (Fig.1)

Firstly, at 0.2 ml of Nutrigel, the toxicity was studied on Phosphorous Solubilising Bacteria (PSB), Potassium Releasing Bacteria (KRB) Zinc Solubilizing Bacteria (ZnSB) it was found that the Nutrigel didn't cause any toxic effects, then the same experiment was carried out by choosing ZnSB at different concentrations (1, 2.5, 5, 7.5, and 10 ml) i.e. 0.4 to 4 % of Nutrigel indicated that growth was highest at the 1 ml concentration and decreased progressively as the concentration increased. Despite the decline, at all tested levels visible growth was observed. Therefore, it was concluded that the product did not exhibit toxicity even the concentration is increased up to 4%.

Toxicology was first studied in 0.2 ml of Nutrigel on Phosphorous Solubilising Bacteria (PSB), Potassium Releasing Bacteria (KRB) Zinc Solubilizing Bacteria (ZnSB) which thrived well later studied on ZnSB at various concentrations (1.0 to 10.0 ml). Despite this decline, visible growth was observed at all tested levels, indicating that Nutrigel does not exhibit toxicity up to 4% concentration. This finding is significant as it confirms the safety of Nutrigel for agricultural applications. The results suggest that Nutrigel can be safely used in varying concentrations without causing toxicity to beneficial bacteria.

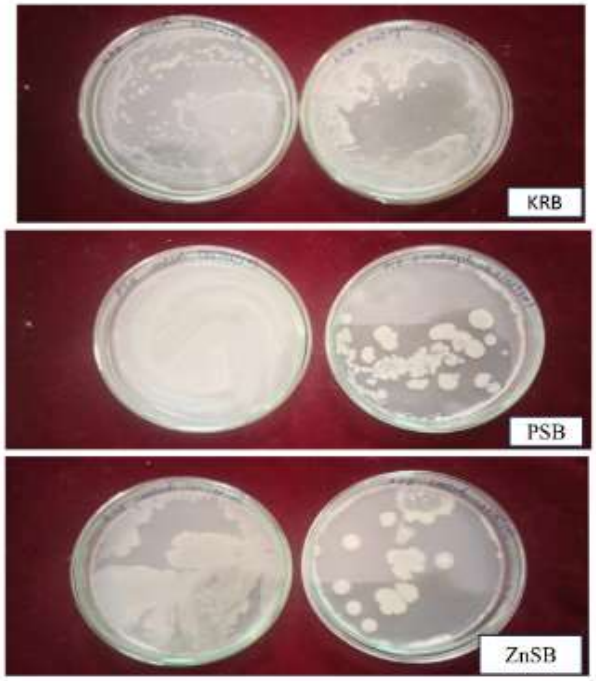
Table. 33. Effect of levels of RDF, Nutrigel, NPK combo, and Commercial micronutrients on microbial population in rhizosphere at various growth stages of onion

Treatments		Vegetative			Bulb Development			Harvest		
		Bacteria	Fungi	Actinomycetes	Bacteria	Fungi	Actinomycetes	Bacteria	Fungi	Actinomycetes
T_1	Absolute Control	0.96	0.41	0.74	1.34	0.63	0.85	0.75	0.87	0.71
T_2	50 % RDF + NPK combo	0.96	0.41	0.74	1.39	0.65	0.87	0.79	0.89	0.73
T_3	50% RDF +NPK combo + Nutrigel	0.96	0.42	0.74	1.51	0.83	0.93	1.03	0.95	0.80
T_4	50% RDF + NPK combo + Commercial micronutrient	0.96	0.42	0.74	1.45	0.80	0.92	0.99	0.93	0.78
T_5	75% RDF + NPK combo	0.96	0.42	0.74	1.56	0.89	0.98	1.28	1.00	0.87
T_6	75% RDF + NPK combo + Nutrigel	0.96	0.42	0.74	1.62	1.03	1.03	1.50	1.06	0.95
T_7	75% RDF + NPK combo + Commercial micronutrient	0.96	0.42	0.74	1.58	0.91	0.96	1.30	1.02	0.89
T_8	100% RDF	0.96	0.42	0.74	1.66	1.06	1.04	1.54	1.08	0.97
T_9	100% RDF + Nutrigel	0.96	0.42	0.74	1.72	1.22	1.10	1.67	1.15	1.07
T_{10}	100% RDF + Commercial micronutrients	0.96	0.42	0.74	1.71	1.21	1.09	1.65	1.13	1.05
	SEd	0.024	0.01	0.013	0.03	0.02	0.025	0.027	0.017	0.017
	CD (P=0.05)	NS	NS	NS	0.07	0.04	0.05	0.06	0.04	0.04

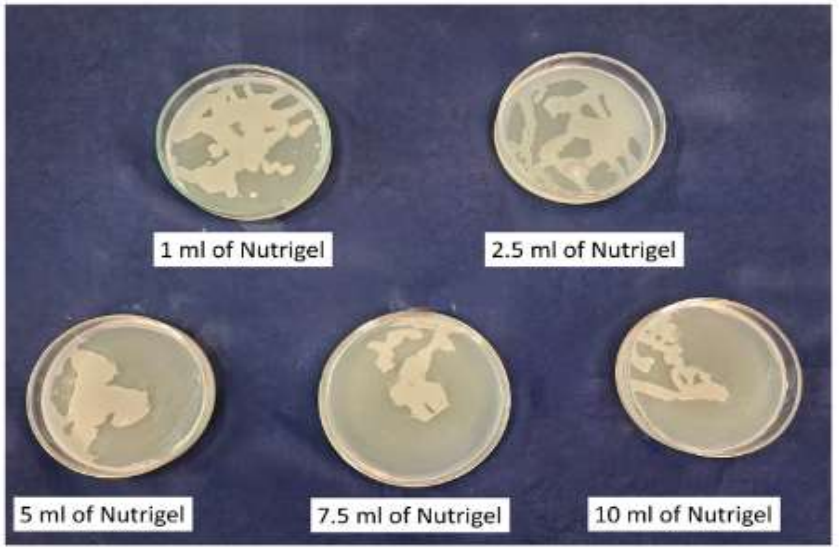
***B - Bacteria log (x 10^6cfu g^{-1}), F- Fungi log (x 10^3cfu g^{-1}), A - Actinomycetes log (x 10^4 cfu g^{-1})**

Table.34. Effect of levels of RDF, Nutrigel, NPK combo, and Commercial micronutrients on microbial (Bacteria) population in Phyllosphere region of aggregatum onion at various stages

Treatments		Vegetative	Bulb Development	Harvest
T_1	Absolute Control	0.67	0.85	0.50
T_2	50 % RDF + NPK combo	0.70	0.87	0.55
T_3	50% RDF +NPK combo + Nutrigel	0.77	0.96	0.68
T_4	50% RDF + NPK combo + Commercial micronutrient	0.75	0.95	0.66
T_5	75% RDF + NPK combo	0.83	1.10	0.76
T_6	75% RDF + NPK combo + Nutrigel	1.05	1.18	0.97
T_7	75% RDF + NPK combo + Commercial micronutrient	0.87	1.13	0.79
T_8	100% RDF	1.07	1.20	1.01
T_9	100% RDF + Nutrigel	1.19	1.25	1.15
T_{10}	100% RDF + Commercial micronutrients	1.18	1.23	1.14
	SEd	0.018	0.021	0.017
	CD (P=0.05)	0.039	0.044	0.036



a) Growth of KRB,PSB and ZnSB of Nutigel (0.2 ml)



b) Toxicity of Nutrigel on ZnSB

Toxicology studies on Microorganisms

Fig. 3. Toxicity of Nutrigel on Soil Micro organisms

5.2. Second season experiment on Onion

5.2.1 Microbial population assessment in rhizosphere (Table 35).

The total bacterial, fungal, and actinomycetes population in the soil samples were enumerated using serial dilution and pour plate method. Each soil sample was serially diluted until the required dilution. For serial dilution 10 g of representative soil sample was suspended in 9 ml of sterile distilled water and then serially diluted up to 10^{-6} dilutions for bacteria, 10^{-4} dilution for fungi and 10^{-2} dilution for actinomycetes. 1 ml of the appropriate dilutions were plated on nutrient agar medium for bacteria, Rose Bengal Agar medium for fungi, and Kenknight's Agar medium for actinomycetes. The plates were incubated for 2 days for bacterial colonies, 3 days for fungal colonies, and 7 days for actinomycetes colonies. After the incubation period, the colonies on each plate were counted and the Colony Forming Units (CFU) per gram of soil were calculated and expressed as CFUs per g of dry weight of the soil (Table 35).

Bacteria

The microbial populations in the rhizosphere showed significant variations in bulb development and harvest stages of onion crop. During the vegetative stage, the variation in bacterial, fungal and actinomycetes populations among the treatments were found to be non-significant.

In the bulb development stage, 100% RDF + Nutrigel (T_9) had higher bacterial population of 1.75 $\times 10^6$ log cfu g^{-1} which were on par with each other with 100% RDF + commercial micronutrients (T_{10}) which showed 1.74 $\times 10^6$ log cfu g^{-1}. However, T_{10} is statistically similar with the treatment 100% RDF (T_8) which recorded 1.68 $\times$ log10^6 cfu g^{-1}. In contrast, the Absolute control (T_1) had the lowest bacterial population at 1.37 $\times 10^6$ log cfu g^{-1}.

In the harvest stage, 100% RDF + Nutrigel (T_9) had the highest bacterial population of 1.69$\times 10^6$ log cfu g^{-1} followed by 100% RDF + commercial micronutrients (T_{10}) which showed 1.66 $\times 10^6$ log cfu g^{-1} which were on par with each other. T_{10} was statistically similar with the treatment 100% RDF (T_8) which recorded 1.56 $\times 10^6$ log cfu g^{-1}. In contrast, the Absolute control (T_1) had the lowest bacterial population at 0.77 log 10^6 cfu g^{-1}.

Fungi

In the bulb development stage,100% RDF + Nutrigel (T_9) had highest fungal population of 1.25$\times 10^3$ log cfu g^{-1} followed by 100% RDF + commercial micronutrients (T_{10}) which showed 1.23 $\times 10^3$ log cfu g^{-1} which were on par with each other. T_{10} is statistically similar with the treatment 100% RDF (T_8) which recorded 1.09 $\times 10^3$ log cfu g^{-1}. In contrast, the Absolute control (T_1) had the fungal population at 0.66 $\times 10^3$log cfu g^{-1}.

In the harvest stage, T_9 had highest fungal population of 1.17 $\times 10^3$ log cfu g^{-1} followed by 100% RDF + commercial micronutrients (T_{10}) which showed 1.16 $\times 10^3$ log cfu g^{-1} which were on par with each other. T_{10} is statistically similar with the treatment 100% RDF (T_8) which recorded 1.10 $\times 10^3$ log cfu g^{-1}. In contrast, the Absolute control (T_1) had the 0.89 $\times 10^3$ log cfu g^{-1}.

Actinomycetes

In the Bulb development stage, T_9 had highest actinomycetes population of 1.13 $\times 10^4$ log cfu g^{-1} followed by 100% RDF + commercial micronutrients (T_{10}) which showed 1.12 $\times 10^4$ log cfu g^{-1} which were on par with each other. T_{10} is statistically similar with the treatment 100% RDF (T_8) which recorded 1.07 $\times 10^4$ log cfu g^{-1}. In contrast, the Absolute control (T_1) had the fungal population at 0.88 $\times 10^4$ log cfu g^{-1}.

In the harvest stage, T_9 had highest actinomycetes population of 1.09 log $\times 10^4$ log cfu g^{-1} followed by 100% RDF + commercial micronutrients (T_{10}) which showed 1.06 $\times 10^4$ log cfu g^{-1} which were on par with each other. T_{10} is statistically similar with the treatment 100% RDF (T_8) which recorded 0.99 $\times 10^4$ log cfu g^{-1}. In contrast, the Absolute control (T_1) had the lowest fungal population at 0.73 $\times 10^4$ log cfu g^{-1}.

5.2.2. Bacterial population assessment in phyllosphere (Table 36)

To assess the microbial population in the phyllosphere, the leaf imprint method was used. This technique involves pressing the onion leaf surface onto an agar plate, which allows microorganisms present on the leaf to transfer onto the agar medium. The plates are then incubated to promote microbial growth, enabling the enumeration and identification of the microbial communities inhabiting the phyllosphere (Table 36).

Microbial population on leaf is significantly impacted by the application of Nano micronutrients in combination with RDF. The treatment, 100% RDF + Nutrigel (T_9) had highest leaf bacterial population of 1.22, 1.27 and 1.17 $\times 10^6$ log cfu g^{-1} at 25, 60 and 90 DAS respectively followed by the treatment 100% RDF + commercial micronutrients (T_{10}) which showed 1.2, 1.24 and 1.15 log $\times 10^6$ log cfu g^{-1} at 25, 60 and 90 DAS respectively which were on par with each other. T_{10} is statistically similar with the treatment 100% RDF (T_8) which recorded 1.1, 1.22 and 1.06$\times 10^6$ log cfu g^{-1} at 25, 60 and 90 DAS respectively. In contrast, the Absolute control (T_1) had the lowest bacterial population at 0.7, 0.86, 0.65 $\times 10^6$ log cfu $g^{-}1$. The treatment with Nutrigel (Nano micronutrients) and 100% RDF significantly increased the microbial population in the phyllosphere.

Table. 35. Effect of levels of RDF, Nutrigel, NPK combo, and Commercial micronutrients on microbial population in rhizosphere at various growth stages of onion

Treatments		Vegetative			Bulb Development			Harvest		
		Bacteria	Fungi	Actinomycetes	Bacteria	Fungi	Actinomycetes	Bacteria	Fungi	Actinomycetes
T_1	Absolute Control	0.98	0.42	0.75	1.37	0.66	0.88	0.77	0.89	0.73
T_2	50 % RDF + NPK combo	0.98	0.42	0.75	1.41	0.68	0.89	0.82	0.91	0.75
T_3	50% RDF +NPK combo + Nutrigel	0.98	0.44	0.75	1.54	0.85	0.95	1.05	0.97	0.81
T_4	50% RDF + NPK combo + Commercial micronutrient	0.98	0.44	0.75	1.48	0.82	0.94	1.01	0.96	0.80
T_5	75% RDF + NPK combo	0.98	0.44	0.75	1.6	0.92	1.01	1.29	1.03	0.89
T_6	75% RDF + NPK combo + Nutrigel	0.98	0.44	0.75	1.65	1.05	1.06	1.52	1.09	0.97
T_7	75% RDF + NPK combo + Commercial micronutrient	0.98	0.44	0.75	1.61	0.94	0.98	1.32	1.04	0.90
T_8	100% RDF	0.98	0.44	0.75	1.68	1.09	1.07	1.56	1.10	0.99
T_9	100% RDF + Nutrigel	0.98	0.44	0.75	1.75	1.25	1.13	1.69	1.17	1.09
T_{10}	100% RDF + Commercial micronutrients	0.98	0.44	0.75	1.74	1.23	1.12	1.66	1.16	1.06
	SEd	0.024	0.011	0.017	0.036	0.022	0.023	0.031	0.02	0.017
	CD (P=0.05)	NS	NS	NS	0.075	0.046	0.048	0.065	0.043	0.036

***B - Bacteria log (x 10^6cfu g^{-1}), F- Fungi log (x 10^3cfu g^{-1}), A - Actinomycetes log (x 10^4 cfu g^{-1})**

Table.36. Effect of levels of RDF, Nutrigel, NPK combo, and Commercial micronutrients on microbial (Bacteria) population in Phyllosphere region of aggregatum onion at various stages

Treatments		Vegetative	Bulb Development	Harvest
T_1	Absolute Control	0.70	0.86	0.65
T_2	50 % RDF + NPK combo	0.73	0.89	0.7
T_3	50% RDF +NPK combo + Nutrigel	0.80	0.97	0.78
T_4	50% RDF + NPK combo + Commercial micronutrient	0.77	0.96	0.77
T_5	75% RDF + NPK combo	0.86	1.12	0.97
T_6	75% RDF + NPK combo + Nutrigel	1.08	1.21	1.02
T_7	75% RDF + NPK combo + Commercial micronutrient	0.91	1.14	0.98
T_8	100% RDF	1.10	1.22	1.06
T_9	100% RDF + Nutrigel	1.22	1.27	1.17
T_{10}	100% RDF + Commercial micronutrients	1.20	1.24	1.15
	SEd	0.019	0.027	0.016
	CD (P=0.05)	0.04	0.06	0.03

5.3. First season Tomato crop

5.3.1 Population of microbes in the rhizosphere of tomato (Table 37)

Bacteria

The bacterial population in the rhizosphere of tomato increased with increased levels of fertilizer application and advancement of the crop growth from flowering to fruiting. At the Flowering stage, the bacterial count in the rhizosphere of 100% RDF (T_8) treated was 6.78 log cfu g^{-1} soil, which was significantly increased to 7.40 log cfu g^{-1} soil in 100% RDF + Nutrigel (T_9), indicating an increase of 9.15%. In the Fruiting stage, 100% RDF (T_8) showed a count of 7.13 log cfu g^{-1} soil, while 100% RDF + Nutrigel (T_9) reached 7.75 log cfu g^{-1} soil, reflecting an improvement of 8.68%. At the Harvest stage, 100% RDF (T_8) recorded 7.38 log cfu g^{-1} soil, and in 100% RDF + Nutrigel (T_9), bacterial count rose to 8.00 log cfu g^{-1} soil, demonstrating an increase of 8.45%. The application of 100% RDF + Nutrigel (T_9) recorded significantly higher rhizosphere bacterial population over 100% RDF (T_8), while the increase in 100% RDF + commercial micronutrient (T_{10}) over 100% RDF (T_8) was only slight and did not attain statistical significance during flowering, fruiting and at harvest stages of tomato.

Fungi

The fungal population in the rhizosphere of tomato increased with increased levels of fertilizer application and advancement of the crop growth from flowering to fruiting. In terms of fungal population, 100% RDF (T_8) exhibited a count of 4.39 log cfu g^{-1} soil during the flowering**,** which increased to 4.77 log cfu g^{-1} soil in 100% RDF + Nutrigel (T_9), marking an increase of 8.66%. At the fruiting stage**,** fungal population in 100% RDF (T_8) was 4.49 log cfu g^{-1} soil, while fungal population in 100% RDF + Nutrigel (T_9) rose to 4.87 log cfu g^{-1} soil, reflecting a growth of 8.46%. By the time of harvest stage**,** fungal population in 100% RDF (T_8) was 4.57 log cfu g^{-1} soil, while 100% RDF + Nutrigel (T_9) achieving 4.95 log cfu g^{-1} soil, indicating an increase of 8.32%. The application of 100% RDF + Nutrigel (T_9) recorded significantly higher rhizosphere fungal population over 100% RDF (T_8), while the increase in 100% RDF + commercial micronutrient (T_{10}) over 100% RDF (T_8) was slight and did not attain statistical significance at flowering, fruiting and at harvest stages of tomato.

Actinomycetes

The actinomycetes population in the rhizosphere of tomato crop increased with increased levels of fertilizer application and advancement of the crop growth stages from flowering to fruiting. The 100% RDF (T_8) recorded the actinomycetes population of 3.79 log cfu g^{-1} soil in the rhizosphere during the flowering stage of tomato**,** which increased to 4.04 log cfu g^{-1} soil in 100% RDF + Nutrigel (T_9), resulting in an increase of 6.58%. At the fruiting

stage**,** 100% RDF (T_8) had registered the actinomycetes population of 3.87 log cfu g^{-1} soil in rhizosphere and 100% RDF + Nutrigel (T_9) rose to 4.12 log cfu g^{-1} soil, marking a 6.46% increase. At the time of harvest**,** 100% RDF (T_8) showed the rhizosphere actinomycetes population of 3.92 log cfu g^{-1} soil, while 100% RDF + Nutrigel (T_9) reached 4.17 log cfu g^{-1} soil, indicating a growth of 6.36%. The application of 100% RDF + Nutrigel (T_9) recorded significantly higher rhizosphere actinomycetes population over 100% RDF (T_8), while the increase in 100% RDF + commercial micronutrient (T_{10}) over 100% RDF (T_8) was slight and did not attain statistical significance at flowering, fruiting and at harvest stages of tomato crop growth.

5.3.2. Bacterial Population in the Phyllosphere (Table 37)

In the phyllosphere, 100% RDF (T_8) recorded a bacterial count of 6.68 log cfu g^{-1} at the flowering stage**,** which increased to 7.30 log cfu g^{-1} in 100% RDF + Nutrigel (T_9), registering an increase of 9.32%. During the fruiting stage**,** 100% RDF (T_8) had registered a phyllosphere bacterial population of 6.93 log cfu g^{-1}, while phyllosphere bacterial population in 100% RDF + Nutrigel (T_9) rose to 7.55 log cfu g^{-1}, reflecting an increment of 8.94%. At the harvest stage**,** 100% RDF (T_8) recorded a phyllosphere bacterial population of 7.18 log cfu g^{-1} soil, while 100% RDF + Nutrigel (T_9), achieved 7.80 log cfu g^{-1}, demonstrating an increase of 8.65%. The application of 100% RDF + Nutrigel (T_9) recorded significantly higher phyllosphere bacterial population over 100% RDF (T_8), while the increase in 100% RDF + commercial micronutrient (T_{10}) over 100% RDF (T_8) was slight, and did not attain statistical significance at flowering, fruiting and at harvest stages of tomato crop growth.

5.3.3 Toxicological evaluation of nano micronutrient on phosphorus solubilizing bacteria (Fig 2.)

This study was conducted to assess the impact of nano micronutrient formulation (Nutrigel) on phosphorus solubilizing bacteria at various concentrations: 1 ml (0.4%), 2.5 ml (1%), 5 ml (2%), 7.5 ml (3%) and 10 ml (4%) of nano micronutrient formulation. The objective was to evaluate the safety and potential inhibitory effects of nano micronutrient formulation on the beneficial soil microorganisms, which play a crucial role in nutrient cycling and overall soil health. The results indicated that bacterial growth was most robust at the lowest concentration of 1 ml (0.4%) and progressively decreased as the concentration increased. Despite this decline, bacterial growth remained visible across all tested concentrations, including the maximum concentration of 10 ml (4%). Notably, even at the highest concentration, nano micronutrient formulation did not completely inhibit bacterial growth, suggesting that the product does not exhibit toxic effects on phosphorus solubilizing bacteria, even at elevated levels.

These findings confirm that while nano micronutrient formulation may slightly reduce bacterial growth at higher concentrations, it remains safe for use at recommended levels. The absence of toxicity at concentrations up to 10 ml (4%) supports the conclusion that nano micronutrient formulation can be effectively employed in agricultural practices without compromising the soil microbial ecosystem. This makes nano micronutrient formulation a viable option for enhancing crop growth while preserving the beneficial bacterial populations essential for maintaining soil health.

Fig. 4. Toxicological evaluation of various concentrations of nano micronutrient in on phosphorus solubilizing bacteria.

Table 37. Population of microbes in the rhizosphere and phyllosphere during different growth stages of hybrid tomato

Treatment	Rhizosphere Bacteria @ 10^6 (log Cfu g^{-1} soil)			Rhizosphere Fungi @ 10^3 (log Cfu g^{-1} soil)			Rhizosphere Actinomycetes @ 10^4 (log Cfu g^{-1} soil)			Phyllosphere Bacteria @ 10^6 (log Cfu g^{-1})		
	I	II	III	I	II	III	I	II	III	I	II	III
T_1	4.44	4.76	5.10	3.02	3.12	3.20	2.85	2.87	2.96	4.42	4.61	4.71
T_2	4.90	5.25	5.50	3.23	3.33	3.41	3.04	3.06	3.15	4.80	5.05	5.30
T_3	5.50	5.85	6.10	3.61	3.71	3.79	3.29	3.31	3.40	5.40	5.65	5.90
T_4	5.21	5.56	5.81	3.42	3.52	3.60	3.17	3.19	3.28	5.11	5.36	5.61
T_5	5.85	6.20	6.45	3.82	3.92	4.00	3.43	3.51	3.56	5.75	6.00	6.25
T_6	6.47	6.82	7.07	4.20	4.30	4.38	3.67	3.75	3.80	6.37	6.62	6.87
T_7	6.16	6.51	6.76	4.01	4.11	4.19	3.55	3.63	3.68	6.06	6.31	6.56
T_8	6.78b	7.13	7.38	4.39	4.49	4.57	3.79	3.87	3.92	6.68	6.93	7.18
T_9	7.40 a	7.75	8.00	4.77	4.87	4.95	4.04	4.12	4.17	7.30	7.55	7.80
T_{10}	7.09ab	7.44	7.69	4.58	4.68	4.76	3.91	3.99	4.04	6.99	7.24	7.49
SEd	**0.15**	**0.12**	**0.16**	**0.10**	**0.09**	**0.10**	**0.06**	**0.07**	**0.07**	**0.16**	**0.15**	**0.16**
CD (P=0.05)	**0.32**	**0.35**	**0.34**	**0.21**	**0.20**	**0.20**	**0.13**	**0.15**	**0.15**	**0.33**	**0.32**	**0.33**

***I – Flowering stage, II – Fruiting stage, III – Harvest stage**

5.4. Second season on Tomato crop

5.4.1 Population of microbes in the rhizosphere of tomato (Table 38)

Bacterial

The bacterial population in the rhizosphere of tomato increased with increased levels of fertilizer application and advancement of the crop growth from flowering to fruiting. At the Flowering stage, the bacterial count in the rhizosphere of 100% RDF (T_8) treated was 7.44 log cfu g^{-1} soil, which was significantly increased to 8.10 log cfu g^{-1} soil in 100% RDF + Nutrigel (T_9), indicating an increase of 8.87%. In the Fruiting stage, 100% RDF (T_8) showed a count of 7.91 log cfu g^{-1} soil, while 100% RDF + Nutrigel (T_9) reached 8.57 log cfu g^{-1} soil, reflecting an improvement of 8.38%. At the Harvest stage, 100% RDF (T_8) recorded 8.18 log cfu g^{-1} soil, and in 100% RDF + Nutrigel (T_9), bacterial count rose to 8.84 log cfu g^{-1} soil, demonstrating an increase of 8.07%. The application of 100% RDF + Nutrigel (T_9) recorded significantly higher rhizosphere bacterial population over 100% RDF (T_8), while the increase in 100% RDF + commercial micronutrient (T_{10}) over 100% RDF (T_8) was only slight and did not attain statistical significance during flowering, fruiting and at harvest stages of tomato.

Fungi

The fungal population in the rhizosphere of tomato increased with increased levels of fertilizer application and advancement of the crop growth from flowering to fruiting. In terms of fungal population, 100% RDF (T_8) exhibited a count of 4.60 log cfu g^{-1} soil during the flowering**,** which increased to 4.98 log cfu g^{-1} soil in 100% RDF + Nutrigel (T_9), marking an increase of 8.26%. At the fruiting stage**,** fungal population in 100% RDF (T_8) was 4.69 log cfu g^{-1} soil, while fungal population in 100% RDF + Nutrigel (T_9) rose to 5.07 log cfu g^{-1} soil, reflecting a growth of 8.10%. By the time of harvest stage**,** fungal population in 100% RDF (T_8) was 4.79 log cfu g^{-1} soil, while 100% RDF + Nutrigel (T_9) achieving 5.17 log cfu g^{-1} soil, indicating an increase of 7.93%. The application of 100% RDF + Nutrigel (T_9) recorded significantly higher rhizosphere fungal population over 100% RDF (T_8), while the increase in 100% RDF + commercial micronutrient (T_{10}) over 100% RDF (T_8) was slight and did not attain statistical significance at flowering, fruiting and at harvest stages of tomato.

Actinomycetes

The actinomycetes population in the rhizosphere of tomato crop increased with increased levels of fertilizer application and advancement of the crop growth stages from flowering to

fruiting. The 100% RDF (T_8) recorded the actinomycetes population of 3.82 log cfu g^{-1} soil in the rhizosphere during the flowering stage of tomato**,** which increased to 4.09 log cfu g^{-1} soil in 100% RDF + Nutrigel (T_9), resulting in an increase of 7.07%. At the fruiting stage**,** 100% RDF (T_8) had registered the actinomycetes population of 3.91 log cfu g^{-1} soil in rhizosphere and 100% RDF + Nutrigel (T_9) rose to 4.17 log cfu g^{-1} soil, marking a 6.65% increase. At the time of harvest**,** 100% RDF (T_8) showed the rhizosphere actinomycetes population of 3.96 log cfu g^{-1} soil, while 100% RDF + Nutrigel (T_9) reached 4.21 log cfu g^{-1} soil, indicating a growth of 6.31%. The application of 100% RDF + Nutrigel (T_9) recorded significantly higher rhizosphere actinomycetes population over 100% RDF (T_8), while the increase in 100% RDF + commercial micronutrient (T_{10}) over 100% RDF (T_8) was slight and did not attain statistical significance at flowering, fruiting and at harvest stages of tomato crop growth.

5.4.2. Bacterial Population in the Phyllosphere

In the phyllosphere, 100% RDF (T_8) recorded a bacterial count of 6.76 log cfu g^{-1} at the flowering stage**,** which increased to 7.38 log cfu g^{-1} in 100% RDF + Nutrigel (T_9), registering an increase of 9.17%. During the fruiting stage**,** 100% RDF (T_8) had registered a phyllosphere bacterial population of 7.02 log cfu g^{-1}, while phyllosphere bacterial population in 100% RDF + Nutrigel (T_9) rose to 7.64 log cfu g^{-1}, reflecting an increment of 8.83%. At the harvest stage**,** 100% RDF (T_8) recorded a phyllosphere bacterial population of 7.29 log cfu g^{-1} soil, while 100% RDF + Nutrigel (T_9), achieved 7.91 log cfu g^{-1}, demonstrating an increase of 8.50%. The application of 100% RDF + Nutrigel (T_9) recorded significantly higher phyllosphere bacterial population over 100% RDF (T_8), while the increase in 100% RDF + commercial micronutrient (T_{10}) over 100% RDF (T_8) was slight, and did not attain statistical significance at flowering, fruiting and at harvest stages of tomato crop growth.

Table 38. Population of microbes in the rhizosphere and phyllosphere during different growth stages of hybrid tomato

Treatment	Rhizosphere Bacteria @ 10^6 (log Cfu g^{-1} soil)			Rhizosphere Fungi @ 10^3 (log Cfu g^{-1} soil)			Rhizosphere Actinomycetes @ 10^4 (log Cfu g^{-1} soil)			Phyllosphere Bacteria @ 10^6 (log Cfu g^{-1})		
	I	II	III	I	II	III	I	II	III	I	II	III
T_1	4.93	5.36	5.67	3.23	3.32	3.42	2.88	2.90	3.02	4.47	4.71	4.90
T_2	5.46	5.89	6.17	3.44	3.53	3.63	3.08	3.11	3.21	4.87	5.13	5.41
T_3	6.08	6.55	6.82	3.82	3.91	4.01	3.32	3.38	3.44	5.47	5.73	6.01
T_4	5.77	6.24	6.51	3.63	3.72	3.82	3.21	3.25	3.33	5.18	5.44	5.72
T_5	6.45	6.92	7.19	4.03	4.12	4.22	3.48	3.57	3.61	5.86	6.09	6.36
T_6	7.11	7.58	7.85	4.41	4.50	4.60	3.71	3.80	3.85	6.45	6.71	6.98
T_7	6.78	7.25	7.52	4.22	4.31	4.41	3.59	3.68	3.72	6.14	6.40	6.67
T_8	7.44	7.91	8.18	4.60	4.69	4.79	3.82	3.91	3.96	6.76	7.02	7.29
T_9	8.10	8.57	8.84	4.98	5.07	5.17	4.09	4.17	4.21	7.38	7.64	7.91
T_{10}	7.77	8.24	8.51	4.79	4.88	4.98	3.95	4.03	4.09	7.07	7.33	7.60
SEd	0.160	0.168	0.172	0.092	0.094	0.091	0.074	0.084	0.079	0.166	0.166	0.148
CD (P=0.05)	0.34	0.35	0.36	0.19	0.20	0.19	0.16	0.18	0.17	0.35	0.35	0.31

***I – Flowering stage, II – Fruiting stage, III – Harvest stage**