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Effect of Organic Granules on the Productivity, Quality, and Nutrient Uptake Level of Tomato and the Fertility and Microbial Population of the Soil

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Abstract

Organic vegetable production is needed worldwide to minimize the use of inorganic fertilizers, protect the environment, and produce healthy food. Accordingly, in the present study, the effects of organic granules on the productivity, quality, and nutrient uptake level of tomatoes and the fertility and microbial population of the soil were determined. Briefly, organic NPK granules and organic N, P and K-rich sources were compared with synthetic NPK granules and synthetic fertilizers administered at 100 and 75% of the recommended fertilizer levels. Among the various treatments applied, treatment with 100% of the recommended NPK using the synthetic NPK granules (Urea, DAP and MOP) led to higher growth, yield attributes, and yield (fruit yield, - 24.21 t/ha and stover yield, -15.01 t/ha) of tomato. This treatment also enhanced the nutrient uptake by tomato. However, quality parameters, such as total soluble solids (6.64%), titrable acidity (0.62%), ascorbic acid content (14.31 mg/100 g), lycopene content (3.54 mg/100 g), reducing sugars (3.11%), non-reducing sugars (1.02%), total sugar (4.13%), and shelf life (15.76 days) of tomato were higher with 100% of the recommended NPK from organic NPK granules than from synthetic granules. This treatment also enhanced the available nutrients and microbial population in the soil. Notably, the same trend was observed for tomatoes fertilized with 75 % of the recommended NPK. The lowest values were obtained with the absolute control. Based on the results of this experiment, the application of 100% of the recommended NPK using organic NPK granules is the best approach to improve the quality of tomato fruits and to enhance the soil fertility.

Keywords: Organic Granules, Tomato, Yield, Quality, Nutrient Profile, Microbial Population

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INTRODUCTION

Tomatoes are important vegetable crops grown worldwide and consumed in salads. Tomatoes are also processed and used to prepare sauces, ketch-ups and pickles, which contain very high amounts of vitamins A, B complex, C, and sugars. Tomatoes are nutritionally superior and less expensive than other vegetables. Globally, tomato occupies 50,51,983 hectares of area and produce 187 million tons of fruits, with an average productivity of 37.10 t/ha.[1] In India, tomato is widely grown on plains in an area of 8.40 lakh hectares with an annual production level of 20.33 mt and average productivity of 24.20 t/ha.[2]

The demand for tomatoes is increasing daily owing to the growing population in India. To meet future demands, inorganic fertilizers are widely used to enhance tomato productivity. Although inorganic fertilizers significantly improves crop production, their continuous use depletes the organic matter in the soil, disrupt its physical, chemical, and biological properties,[3] and reduces its health. More than 50% of the nitrogen and 90% of the phosphorus delivered using chemical fertilizers are generally lost to the atmosphere or water sources,[4] causing the emission of greenhouse gases, water eutrophication, and other environmental pollution.[5] The excessive use of chemical fertilizers decreases the yield of crops and lowers the quality of vegetables.[6] As a result, people are getting increasingly concerned about environmental hazards, particularly health hazards, created by the indiscriminate use of agrochemicals.[7] In many countries, organic farming has become cropping system that minimizes the use of chemicals and protects the environment and foods.[8] India is a major producer and consumer of vegetables. Recently, organic farming garnered the attention of Indian farmers to enable high-quality vegetable production. Farmers use different types of organic manures, such as cow dung, goat manure, poultry manure, farmyard manure, compost, vermicompost, and oil cakes for vegetables production. Farmyard manure, vermicompost, and oil cakes are commonly used as sources of plant nutrients. These organic manures are eco-friendly, supplying essential plant nutrients to the crops including many vitamins and growth promoting substances. They also improve the soil fertility, soil microbial population, water holding capacity, and crop quality. However, the low availability of organic manure throughout the year and high transportation costs limit organic vegetable production. Further, handling and storage of these organic manures are expensive. These manures produce an undesirable odor that is inhaled by humans, and their storage is considered unhygienic as they are often stored in nearby households. Therefore, customized organic granules that are more similar to inorganic fertilizers and possess a relatively higher nutrient content than conventional organic manures are needed. These organic granules generally contain oil cakes, fish/bone meals, compost, well-rotted manure, or plant or animal residues, and provide numerous benefits to the soil ecosystem. One key advantage of organic granules is their ability to improve the soil structure. As these granules break down, they enhance soil aggregation, and promote better aeration and water drainage, inducing a healthy root environment for plants, and fostering robust growth and development. The slow-release of nutrients from the organic granules is another significant attribute. Unlike synthetic fertilizers, which induce nutrient runoff and environmental damage, organic granules gradually release nutrients. Such release ensures a sustained supply of essential elements to the plants over an extended period, thereby reducing the risk of nutrient imbalance. Furthermore, organic granules contribute to the development of rich, humus-filled soil. The organic matter in these granules serves as a food source for beneficial microorganisms, thereby promoting thriving soil microbial communities. Microbial activity enhances nutrient cycling and availability, creating a dynamic fertile soil ecosystem. In addition to enhancing soil fertility, the use of these granules aligns with environmentally friendly conscious agricultural practices. Organic materials in these granules are often recycled from waste products, thereby reducing the environmental impacts associated with conventional farming practices. By using organic granules, farmers and gardeners can contribute to biodiversity conservation and the overall health of the ecosystem.[9]

Organic granules slowly release nutrients into the crop; however, this release is faster than that exhibited by conventional organic manures.

The nutrient release rate of organic granules is dependent on the moisture status of the soil. Organic granules supply nutrients to crops and add organic carbon to the soil, thereby elevating yield, improving the quality of produce, and promoting a more sustainable and resilient agricultural system. Hence, in the present study, newly developed organic granules were tested to determine the productivity, quality, and nutrient uptake level of tomatoes, and the fertility and microbial populations of the soil.

MATERIALS AND METHODS

This study was conducted in a farmer's field in Seppakam village, Cuddalore, Tamil Nadu State, India, from December 2022 to April 2023. The texture of the soil was sandy loam and its pH and organic content were 7.5 and 2.31 g/kg, respectively. The initial soil had low available nitrogen (103.45 kg/ha), low available phosphorus (7.81 kg/ha), and medium available potassium (128.42 kg/ha). The bacterial, fungal, and actinomycete populations in the initial soil were 12.04×10^6 per g soil, 10.20×10^5 per g soil, and 5.39×10^4 per g soil, respectively. The following treatments were administered:T_1- Absolute control (No NPK), T_2 -100% RDF (Synthetic NPK granules – Urea: 46-0-0, DAP: 18-46-0, and MOP:0-0-60), T_3-100% RDF (Organic NPK granules: 5:5:5), T_4-100% RDF (Organic N-rich: 7-1-1, Organic P-rich: 0.5-15-1, and Organic K-rich: 0.5-0.5-15), T_5-100% RDF (Synthetic Fertilizers – Urea: 46-0-0, SSP: 0-16-0, and MOP: 0-0-60), T_6-75% RDF (Synthetic NPK granules – Urea: 46-0-0, DAP: 18-46-0, and MOP:0-0-60), T_7-75% RDF (Organic NPK granules: 5:5:5), T_8-75% RDF (Organic N-rich: 7-1-1, Organic P-rich: 0.5-15-1, and Organic K-rich: 0.5-0.5-15), and T_9-75% (Synthetic Fertilizers – Urea: 46-0-0, SSP: 0-16-0, and MOP: 0-0-60). Treatments were arranged in a Random Block Design (RBD) pattern and administered in triplicate. The tomato variety, Co 3 (Marutham), was used in this study. The Co 3 (Marutham) variety of tomato is 100-105 days duration. Thirty-day-old seedlings were transplanted in the main field. The tomato variety was fertilized with 150:100:50 kg NPK/ha. In particular, 75:100:50 kg NPK/ha was applied basally, and the remaining 75 kg NPK/ha was top-dressed at 30 using urea; this process was repeated for the organic N-rich sample. The Organic NPK granules (5:5:5% NPK), Organic N-rich (7-1-1% NPK), Organic P-rich (0.5-15-1% NPK), and Organic K-rich (0.5-0.5-15% NPK) samples were obtained from Privi Life Sciences Pvt. Ltd., Navi Mumbai, India to serve as test samples. Growth attributes (plant height, number of branches/plant and dry matter production) were recorded at the first harvest (80 DAT). Yield attributes (number of fruits/plant, single fruit weight, and fruit diameter) were recorded at the third picking (90 DAT). The fruit yield was recorded at every picking. The yield of seven picks of fruit is expressed in t/ha. At the end of the harvest period, the stover yield of the tomatoes was recorded. Fruit quality parameters were recorded at the third picking (90 DAT). Total soluble solids, titratable acidity, and ascorbic acid content of the tomato fruits were estimated using the method suggested by A.O.A.C.[10] The acetone extraction method described by Ranganna[11] was used to extract lycopene from the tomato samples. The reducing, non-reducing, and total sugar contents of the fruits were estimated by adopting the lane and Eyanam methods, as described by Ranganna.[11] The number of days taken for 10% spoilage of 60 to 70% of fruits was defined as the shelf-life period and is expressed in days. Nutrient uptake (N: Humphries,[12]; P: Jackson,[13]; and K: Toth and Prince,[14]), soil available nutrients (N: Subbiah and Asija,[15]; P: Watanabe and Olsen,[16]; and K: Stanford and English,[17]), and microbial population (Subba Rao,[18]) were recorded at different stages (flowering stage (FS), fruit development stage (FDS), and harvest stage (HS)) of tomatoes according to standard procedures. Significant treatment mean differences were determined using Duncan's multiple range test (DMRT) at a probability level of 0.05.[19]

RESULTS AND DISCUSSION

Growth and yield

As shown in Tables 1 and 2, the application of organic granules significantly influenced the growth and yield of tomatoes. The tallest plant (127.01 cm), highest branch number (18.15), and highest increase in dry matter production (16.44 t/ha) were obtained when 100% of the recommended NPK was applied using synthetic NPK granules (Urea, DAP, and MOP). This treatment also

Table 1. Effect of organic granules on growth and yield attributes of tomato

	Growth attributes			Yield attributes		
	Plant height (cm)	Number of Branches/ Plant	Dry matter production t/ha	Number of fruits/ Plant	Single fruit weight (g)	Fruit diameter (cm)
T1	91.27^{i}	9.05^{i}	5.83^{i}	22.13^{i}	48.90^{i}	3.01^{i}
T2	127.01^{a}	18.15^{a}	16.44^{a}	49.20^{a}	102.01^{a}	5.76^{a}
T3	117.69^{c}	17.24^{c}	15.21^{c}	45.11^{c}	92.69^{c}	5.29^{c}
T4	114.74^{cd}	17.19^{cd}	15.07^{cd}	44.04^{cd}	88.74^{cd}	5.17^{cd}
T5	123.79^{ab}	18.03^{ab}	16.05^{ab}	50.67^{ab}	98.86^{ab}	5.64^{ab}
T6	107.73^{e}	16.21^{e}	12.57^{e}	36.89^{e}	78.21^{e}	4.14^{e}
T7	99.40^{g}	14.50^{g}	10.87^{g}	31.43^{g}	65.36^{g}	3.76^{g}
T8	98.42^{gh}	13.79^{gh}	10.13^{gh}	31.96^{gh}	64.19^{gh}	3.57^{gh}
T9	105.59^{f}	15.48^{f}	11.86^{f}	35.38^{f}	73.25^{f}	4.02^{f}
S.Ed	2.75	0.35	0.41	1.14	2.48	0.11
CD (p-0.05)	5.98	0.78	0.82	2.48	5.21	0.24

Values not sharing a common superscript letters (a, b, c, d, e, f, g, h and i) differ significantly at $p < 0.05$
Duncan Multiple Range Test (DMRT)

Table 2. Effect of organic granules on fruit, stover yield and quality parameters of tomato

Treatments	Yield		Fruit quality parameters			
	Fruit yield (t/ha)	Stover Yield (t/ha)	Total soluble solids (%)	Titrable acidity (%)	Ascorbic acid (mg/100 g)	Lycopene content (mg/100 g)
T1	6.13^{i}	7.69^{i}	4.50^{i}	0.40^{i}	9.92i	2.63^{i}
T2	24.21^{a}	15.01^{a}	6.23^{c}	0.57^{c}	13.73^{c}	3.34^{c}
T3	22.33^{c}	13.02^{c}	6.64^{a}	0.62^{a}	14.31^{a}	3.54^{a}
T4	22.96^{cd}	13.93^{cd}	6.55^{ab}	0.59^{ab}	14.08^{ab}	3.51^{ab}
T5	23.91^{ab}	14.76^{ab}	6.11^{cd}	0.53^{cd}	13.61^{cd}	3.29^{cd}
T6	14.16^{e}	10.52^{e}	5.17^{g}	0.46^{g}	11.85^{g}	2.91^{g}
T7	12.94^{g}	8.24^{g}	5.42^{e}	0.51^{e}	12.63^{e}	3.11^{e}
T8	12.56^{gh}	8.12^{gh}	5.34^{f}	0.49^{f}	12.50^{f}	3.08^{f}
T9	13.92^{f}	9.98^{f}	5.10^{gh}	0.42^{gh}	11.60^{gh}	2.89^{gh}
S.Ed	0.46	0.31	0.29	NS	0.61	0.08
CD (p-0.05)	0.41	0.68	0.13	NS	0.29	0.17

Values not sharing a common superscript letters (a, b, c, d, e, f, g, h and i) differ significantly at $p < 0.05$
Duncan Multiple Range Test (DMRT)

led to the highest number of fruits/plant (49.20), highest single fruit weight (102.01 g), and highest increase in fruit diameter (5.76 cm) for tomato. These values may be ascribed to the supply of plant nutrients that are readily available at critical stages, ultimately enabling enhanced uptake of nutrients, increased plant metabolic activities, and improved photosynthesis. Such attributes may have led to the highest growth components and yield-attributing elements in tomatoes fertilized with this treatment. Similar results were reported by Adekiya *et al.*,[20] who reported that the increased growth and yield of tomatoes were attributed to increased nutrient content in the soil and absorption of available nutrients by plants. These attributes significantly boosted the growth and yield-attributing characteristics of tomatoes, ultimately resulting in a higher yield. The highest values for fruit yield (24.21 t/ha) and stover yield (15.01 t/ha) were also obtained with the application of 100% of the recommended NPK using the synthetic NPK granules (Urea, DAP, and MOP). In

Table 3. Correlation matrix between growth, yield parameters, yield, quality, nutrients availability, microbial population and uptake of nutrients by tomato

	PL	NBP	DMP	NFP	SFW	FD	FY	SY	TSS	TA	AA	LC	RS	NRS	TS	SL	N Fruit	N Stover	P Fruit	P Stover	K Fruit	K Stover	Avail. N	Avail. P	Avail. K	Bacteria	Fungi	Actinomyctes
PL	1.000																											
NBP	0.904**	1.000																										
DMP	0.962**	0.980**	1.000																									
NFP	0.985**	0.941**	0.984**	1.000																								
SFW	0.993**	0.941**	0.985**	0.994**	1.000																							
FD	0.989**	0.896**	0.965**	0.986**	0.988**	1.000																						
FY	0.962**	0.917**	0.975**	0.982**	0.975**	0.987**	1.000																					
SY	0.973**	0.844**	0.926**	0.960**	0.965**	0.982**	0.960**	1.000																				
TSS	0.828**	0.819**	0.886**	0.870**	0.862**	0.894**	0.940**	0.845**	1.000																			
TA	0.726**	0.722*	0.791*	0.764*	0.763*	0.802**	0.853**	0.731*	0.969**	1.000																		
AA	0.804**	0.861**	0.895**	0.865**	0.848**	0.862**	0.922**	0.783*	0.975**	0.956**	1.000																	
LC	0.762**	0.791*	0.846**	0.819**	0.804**	0.837**	0.900**	0.770*	0.990**	0.980**	0.986**	1.000																
RS	0.765**	0.884**	0.888**	0.838**	0.823**	0.815**	0.884**	0.732*	0.938**	0.926**	0.984**	0.957**	1.000															
NRS	0.800**	0.779*	0.853**	0.843**	0.831**	0.873**	0.921**	0.818**	0.996**	0.981**	0.973**	0.993**	0.930**	1.000														
TS	0.780**	0.794*	0.853**	0.835**	0.817**	0.852**	0.910**	0.784*	0.986**	0.978**	0.989**	0.996**	0.955**	0.993**	1.000													
SL	0.426^{NS}	0.622^{NS}	0.590^{NS}	0.469^{NS}	0.503^{NS}	0.474^{NS}	0.540^{NS}	0.396^{NS}	0.684*	0.765*	0.719**	0.718*	0.795*	0.675*	0.689**	1.000												
N Fruit	0.970**	0.973*	0.999**	0.989**	0.989**	0.973**	0.980**	0.933**	0.890**	0.799*	0.898**	0.849**	0.885**	0.860**	0.859**	0.575^{NS}	1.000											
N Stover	0.994**	0.910*	0.967**	0.985**	0.993**	0.991**	0.968**	0.984**	0.846**	0.741*	0.812**	0.778*	0.780*	0.816**	0.791*	0.466^{NS}	0.972**	1.000										
P Fruit	0.998**	0.916*	0.968**	0.984**	0.995**	0.987**	0.960**	0.973**	0.828**	0.721*	0.801**	0.759*	0.768*	0.796**	0.774*	0.447^{NS}	0.973**	0.997**	1.000									
P Stover	0.999**	0.901*	0.960**	0.982**	0.992**	0.990**	0.961**	0.978**	0.829**	0.726*	0.799**	0.760*	0.760*	0.800**	0.777*	0.434^{NS}	0.967**	0.996**	0.999**	1.000								
K Fruit	0.997**	0.928*	0.975**	0.987**	0.997**	0.987**	0.964**	0.966**	0.837**	0.737*	0.819**	0.774*	0.790*	0.806**	0.789**	0.475^{NS}	0.980**	0.995**	0.999**	0.997**	1.000							
K Stover	0.988**	0.955*	0.987**	0.988**	0.995**	0.977**	0.965**	0.941**	0.845**	0.748**	0.847**	0.793*	0.826**	0.814**	0.808**	0.507^{NS}	0.991**	0.982**	0.990**	0.985**	0.994**	1.000						
Avail. N	0.742*	0.729*	0.805**	0.783*	0.777*	0.824**	0.877**	0.764*	0.986**	0.991**	0.957**	0.990**	0.916**	0.993**	0.984**	0.715*	0.811**	0.761*	0.739*	0.744*	0.751*	0.760*	1.000					
Avail. P	0.758*	0.752*	0.823**	0.803**	0.795*	0.836**	0.889**	0.774*	0.989**	0.993**	0.968**	0.993**	0.932**	0.996**	0.989**	0.721*	0.829**	0.776*	0.755*	0.759*	0.768*	0.778*	0.998**	1.000				
Avail. K	0.746*	0.735*	0.809**	0.792*	0.779*	0.828**	0.883**	0.764*	0.984**	0.987**	0.966**	0.991**	0.921**	0.995**	0.991**	0.690*	0.816**	0.762*	0.741*	0.746*	0.754*	0.766*	0.996**	0.997**	1.000			
Bacteria	0.756*	0.784$^{*\backslash}$	0.839**	0.812**	0.800**	0.831**	0.890**	0.759*	0.988**	0.979**	0.979**	0.995**	0.949**	0.989**	0.987**	0.721*	0.842**	0.773*	0.757*	0.755*	0.770*	0.788*	0.989**	0.992**	0.987**	1.000		
Fungi	0.747*	0.693*	0.786*	0.786*	0.772*	0.833**	0.879**	0.784*	0.976**	0.976**	0.939**	0.975**	0.883**	0.990**	0.978**	0.635*	0.796*	0.765*	0.740*	0.749*	0.749*	0.749*	0.990**	0.989**	0.993**	0.969**	1.000	
Actino-mycetes	0.790*	0.767*	0.843**	0.834**	0.822**	0.866**	0.914**	0.811**	0.995**	0.981**	0.969**	0.992**	0.924**	0.995**	0.991**	0.671*	0.850**	0.807**	0.786*	0.791*	0.797*	0.804**	0.995**	0.997**	0.995**	0.989**	0.992**	1.000

PL - Plant height; NB - No. of Branches; DMP - Dry matter production; NF - Number of fruits; SFW - Single fruit weight; FD - Fruit diameter; FY - Fruit yield; SY - Stover Yield; TSS - Total soluble solids; TA - Titrable acidity; AA - Ascorbic acid; LC - Lycopene content; RS - Reducing sugars ; NRS - Non-reducing sugars; TS - Total sugar; SL - Shelf life; Bact. – Bacteria; Act. – Actinomycetes; N fruits – N uptake by fruits, N stover - N uptake by stover, P fruits - P uptake by fruits, P stover – P uptake by stover, K fruits - K uptake by fruits, K stover – K uptake by stover, Avail N – Available Nitrogen, Avail P – Available Phosphorus, Avail K – Available Potassium; ** Significance at 1 per cent level; * Significance at 5 per cent level; NS – Non – significant fact, the maximum number of fruits/plants and increased single fruit weight were recorded, which resulted in a higher fruit yield. The application of 100% of the recommended NPK using synthetic fertilizers led to the second highest values for the above attributes.

The application of 100% of the recommended NPK using organic NPK granules led to the third highest values, including a plant height of 117.69 cm, number of branches plant^{-1} of 17.24, and dry matter production of 15.21 t/ha. Owing to this treatment, the number of fruits/plant, single fruit weight, and fruit diameter of tomatoes were 45.11, 92.69 g, and 5.29 cm, respectively. The application of 100% of the recommended NPK using organic N-, P-, and K-rich sources led to the fourth highest values for the above attributes. This result may have been due to the slow and steady release of nutrients during their decomposition. Such pace ensures a continuous supply of essential elements, promotes robust vegetative growth, and supports the energy-demand of flowering and fruiting in tomato plants. Adequate nutrient availability and a well-structured soil contribute to healthier flowering and fruit setting in tomato plants. Such finding agrees with those of Melero *et al.*[21] and Thomas *et al.*[22] The same trends were observed in crops fertilized with 75% of the recommended NPK. The low values for the growth and yield (fruit yield - 6.13 t/ha and stover yield -7.69 t/ha) of tomatoes were obtained with the absolute control as the supply of essential nutrients was inadequate. Similar findings were reported by Melero *et al.*[21] and Muchanga *et al*.[23]

Soil available N (r=0.877* and 0.864**), P (r=0.889** and 0.874**), and K (r=0.883** and 0.864**) were significantly and positively correlated with the fruit and stover yield of tomatoes, there by supporting the findings of this study (Table 3).

Table 4. Effect of organic granules on quality parameters of tomato

Treatments	Fruit quality parameters			
	Reducing sugars (%)	Non-reducing sugars (%)	Total sugar	Shelf life (Days)
T1	2.30^{i}	0.82^{i}	3.31^{i}	7.68^{i}
T2	2.99^{a}	0.98^{a}	4.00^{a}	13.53^{a}
T3	3.11^{c}	1.02^{c}	4.13^{c}	15.76^{c}
T4	3.09^{cd}	1.01^{cd}	4.11^{cd}	15.24^{cd}
T5	2.97^{ab}	0.97^{ab}	3.97^{ab}	10.21^{ab}
T6	2.79^{e}	0.87^{e}	3.56^{e}	14.44^{e}
T7	2.85^{g}	0.91^{g}	3.77^{g}	14.17^{g}
T8	2.83^{gh}	0.90^{gh}	3.74^{gh}	11.49^{gh}
T9	2.65^{f}	0.86^{f}	3.52^{f}	9.76^{f}
S.Ed	0.04	0.01	0.05	0.32
CD (p-0.05)	0.08	0.02	0.10	0.69

Values not sharing a common superscript letters (a, b, c, d, e, f, g, h and i) differ significantly at $p < 0.05$
Duncan Multiple Range Test (DMRT).

Quality parameters

Organic granules were found to significantly influence tomato fruit quality (Tables 2 and 4). The highest total soluble solids (6.64%), titrable acidity (0.62%), ascorbic acid content (14.31 mg/100 g), lycopene content (3.54 mg/100 g), reducing sugars (3.11%), non-reducing sugars (1.02%), total sugar (4.13%), and shelf life (15.76 days) were obtained with the application of 100% of the recommended NPK using organic NPK granules; this was closely followed by the addition of 100% of the recommended NPK using organic N-, P-, and K-rich sources. The following results were obtained: total soluble solids, 6.55%; titrable acidity, 0.59%; ascorbic acid content, 14.08 mg/100 g; lycopene content, 3.51 mg/100 g; reducing sugars, 3.09%; non-reducing sugars, 1.01%; total sugar, 4.11%; and shelf life, 15.24 days. This result may be due to the ability of the organic granules to supply plant nutrients and the required organic matter in a sustained manner. This organic matter influenced the vegetative growth, yield components, and quality of tomato fruits by releasing nutrients, enhancing soil physical and chemical properties, and promoting the root activity of tomatoes.[24] Related studies have shown that organic manure increases the organic matter in soil, resulting in higher soil bacterial activity, which breaks down the organic matter and releases NPK and other nutrients that are positively influenced by soil enzymatic activity, ultimately improving the sugar/acid ratio. The slow release of nutrients from organic granules promotes the gradual development of tomatoes,

Table 5. Effect of organic granules on nutrient uptake (kg/ha) recorded at different stages of tomato

Treatments	Nitrogen Uptake				Phosphorus Uptake				Potassium Uptake			
	FS	FDS	F	S	FS	FDS	F	S	FS	FDS	F	S
T1	11.34^{i}	15.98^{i}	32.89^{i}	61.92^{i}	7.01^{i}	11.24^{i}	10.98^{i}	14.22^{i}	17.18^{i}	54.34^{i}	41.95^{i}	67.86^{i}
T2	18.40^{a}	23.46^{a}	50.46^{a}	87.56^{a}	9.98^{a}	15.68^{a}	21.02^{a}	26.56^{a}	27.48^{a}	78.86^{a}	76.14^{a}	120.40^{a}
T3	15.37^{c}	21.78^{c}	48.10^{c}	82.34^{c}	8.17^{c}	14.60^{c}	18.78^{c}	23.38^{c}	25.36^{c}	73.24^{c}	68.49^{c}	109.98^{c}
T4	15.08^{cd}	21.32^{cd}	47.56^{cd}	81.56^{cd}	8.92^{cd}	14.17^{cd}	17.92^{cd}	22.52^{cd}	24.87^{cd}	72.31^{cd}	65.65^{cd}	104.92^{cd}
T5	18.10^{ab}	22.98^{ab}	49.57^{ab}	86.58^{ab}	9.75^{ab}	15.24^{ab}	20.33^{ab}	25.42^{ab}	27.93^{ab}	76.93^{ab}	73.33^{ab}	116.19^{ab}
T6	15.42^{e}	19.58^{e}	43.38^{e}	75.41^{e}	8.43^{e}	12.88^{e}	16.08^{e}	19.96^{e}	23.15^{e}	67.06^{e}	59.81^{e}	96.71^{e}
T7	13.26^{g}	17.42^{g}	40.75^{g}	68.02^{g}	7.97^{g}	11.06^{g}	13.56^{g}	17.01^{g}	19.83^{g}	61.20^{g}	52.13^{g}	88.29^{g}
T8	13.89^{gh}	17.96^{gh}	39.95^{gh}	66.03^{gh}	7.71^{gh}	11.98^{gh}	12.73^{gh}	16.15^{gh}	19.78^{gh}	58.52^{gh}	49.29^{gh}	84.08^{gh}
T9	15.01^{f}	19.09^{f}	42.22^{f}	72.29^{f}	8.39^{f}	12.42^{f}	15.42^{f}	19.07^{f}	22.57^{f}	65.13^{f}	56.97^{f}	94.50^{f}
SE_D	0.85	1.08	2.45	1.89	0.23	0.28	0.72	0.88	0.60	1.35	1.76	2.40
CD(p=0.05)	0.43	0.51	1.17	4.12	0.36	0.61	1.43	1.86	1.26	2.93	3.84	5.21

Values not sharing a common superscript letters (a, b, c, d, e, f, g, h and i) differ significantly at $p < 0.05$; Duncan Multiple Range Test (DMRT).

leading to better quality fruits, as reflected by the improved taste, texture, and nutrient content. This finding agrees with that of Du *et al.*[25] The results of our study also aligned with that of Gao *et al.*,[26] who found that TSS, vitamin C, and lycopene were significantly improved by organic fertilizers relative to inorganic fertilizers due to the release of nutrients, addition of organic matter, and creation of favorable physical conditions in the soil.

The application of 100% of the recommended NPK using synthetic NPK granules (Urea, DAP, and MOP) led to the third highest values of 6.23%, 0.57%, 13.73 mg/100 g, 3.34 mg/100 g, 2.99%,0.98%, 4.00%, and 13.53 days for total soluble solids, titrable acidity, ascorbic acid content, lycopene content, reducing sugars, non-reducing sugars, total sugar, and shelf life, respectively. This treatment yielded similar results to the synthetic fertilizers that supplied 100% of the recommended NPK. The same trends were also observed in tomatoes treated with 75% of the recommended NPK. The lowest values for total soluble solids (4.50%), titrable acidity (0.40%), ascorbic acid content (9.92 mg/100 g), lycopene content (2.63 mg/100 g), reducing sugars (2.30%), non-reducing sugars (0.82%), total sugar (3.31%), and shelf life (7.68 days) were obtained with the absolute control. Similar findings were reported by Zhong *et al*.,[27] Yang *et al*.,[28] and Amadou *et al*.[29]

Soil available N (r=0.986**, 0.991, 0.957, 0.990, 0.916, 0.993, and 0.984), P (r=0.989, 0.993, 0.968, 0.993, 0.932, 0.996, and 0.989), and K (r=0.984, 0.987, 0.966, 0.991, 0.921, 0.995, and 0.991) were significantly and positively correlated with total soluble solids, titrable acidity, ascorbic acid, lycopene content, reducing sugars, non-reducing sugars, and total sugar content of tomato fruits, ultimately supporting the present findings (Table 3).

Nutrient (NPK) uptake

Organic granules and inorganic fertilizers significantly influenced nutrient uptake by tomato plants (Table 5). The application of 100% of the recommended NPK using synthetic NPK granules (Urea, DAP, and MOP) led to values that surpassed those obtained with the synthetic fertilizers and organic granules for nutrient uptake at the flowering (NPK - 18.40,9.98, and 27.48 kg/ha),

Table 6. Effect of organic granules on nutrient availability (kg/ha) recorded at different stages of tomato

Treatments	Available Nitrogen			Available Phosphorus			Available Potassium		
	FS	FDS	HS	FS	FDS	HS	FS	FDS	HS
T1	135.39[i]	118.69[i]	101.97[i]	13.84[i]	10.88[i]	7.33[i]	143.19[i]	138.99[i]	121.93[i]
T2	189.43[a]	155.90[a]	139.80[a]	21.96[a]	15.98[a]	10.37[a]	195.52[a]	187.98[a]	163.01[a]
T3	205.74[c]	169.14[c]	152.72[c]	24.36[c]	17.12[c]	11.38[c]	215.42[c]	203.42[c]	175.64[c]
T4	201.10[cd]	165.34[cd]	148.69[cd]	23.48[cd]	16.56[cd]	11.02[cd]	207.34[cd]	199.56[cd]	172.48[cd]
T5	182.37[ab]	149.42[ab]	133.45[ab]	21.23[ab]	14.86[ab]	10.01[ab]	191.78[ab]	179.73[ab]	159.86[ab]
T6	152.16[e]	128.25[e]	112.28[e]	16.42[e]	12.35[e]	8.35[e]	163.54[e]	152.34[e]	132.37[e]
T7	170.64[g]	141.45[g]	125.21[g]	19.75[g]	13.98[g]	9.22[g]	180.23[g]	169.33[g]	149.77[g]
T8	164.73[gh]	137.69[gh]	120.48[gh]	18.98[gh]	13.65[gh]	8.93[gh]	175.78[gh]	163.57[gh]	143.26[gh]
T9	149.23[f]	123.39[f]	109.86[f]	15.76[f]	11.78[f]	7.99[f]	159.68[f]	148.45[f]	130.48[f]
SE_D	4.34	3.43	3.32	0.48	0.34	0.22	4.20	4.10	3.37
CD(p=0.05)	9.43	7.45	7.22	1.06	0.74	0.48	9.12	8.91	7.32

Values not sharing a common superscript letters (a, b, c, d, e, f, g, h and i) differ significantly at $p < 0.05$
Duncan Multiple Range Test (DMRT).

Table 7. Effect of organic granules on microbial population recorded at different stages of tomato

Treatments	Bacteria (x 10^6 per g soil)			Fungi (x 10^5 per g soil)			Actinomycetes (x 10^4 per g soil)		
	FS	FDS	HS	FS	FDS	HS	FS	FDS	HS
T1	12.61[i]	16.13[i]	12.39[i]	10.59[i]	11.50[i]	11.23[i]	5.50[i]	7.69[i]	6.70[i]
T2	17.68[a]	20.99[a]	16.27[a]	13.87[a]	15.26[a]	13.82[a]	7.53[a]	10.25[a]	9.03[a]
T3	19.48[c]	22.95[c]	17.94[c]	14.91[c]	16.39[c]	14.61[c]	8.05[c]	10.98[c]	9.69[c]
T4	18.63[cd]	22.11[cd]	17.19[cd]	14.56[cd]	16.07[cd]	14.53[cd]	7.97[cd]	10.77[cd]	9.51[cd]
T5	17.53[ab]	20.84[ab]	16.12[ab]	13.52[ab]	14.94[ab]	13.69[ab]	7.41[ab]	10.12[ab]	8.89[ab]
T6	14.44[e]	17.93[e]	14.01[e]	11.74[e]	13.01[e]	11.57[e]	6.15[e]	8.69[e]	7.38[e]
T7	15.91[g]	19.16[g]	15.04[g]	12.51[g]	13.92[g]	12.67[g]	6.69[g]	9.29[g]	8.01[g]
T8	15.39[gh]	19.03[gh]	14.85[gh]	13.39[gh]	13.84[gh]	12.35[gh]	6.57[gh]	9.21[gh]	7.86[gh]
T9	13.55[f]	17.84[f]	13.92[f]	11.72[f]	12.76[f]	11.36[f]	6.03[f]	8.57[f]	7.26[f]
SE_D	0.41	0.50	0.38	0.30	0.35	0.31	0.17	0.23	0.20
CD(p=0.05)	0.89	1.09	0.83	0.66	0.78	0.69	0.38	0.51	0.45

Values not sharing a common superscript letters (a, b, c, d, e, f, g, h and i) differ significantly at $p < 0.05$
Duncan Multiple Range Test (DMRT)

fruit development (NPK - 23.46, 15.68, and 78.86 kg/ha), and harvesting stages (NPK: fruit and stover – 50.46 and 87.56, 21.02 and 26.56, and 76.14 and 120.40 kg/ha). The higher soil-available nutrients in the FS, FDS, and HS led to a higher uptake of NPK by the tomato crops. Similar results were previously obtained by Adekiya *et al.*[20], who revealed that rapid absorption of essential nutrients from inorganic fertilizers caused higher uptake of plant nutrients by tomato crops than that from organic sources. The application of 100% of the recommended NPK using synthetic fertilizers (Urea, SSP, and MOP) led to the second highest values for nutrient uptake, followed by 100% of the recommended NPK (100%) using organic NPK granules, with values of 15.37, 8.17, and 25.36 kg/ha at FS; 21.78, 14.60, and 73.24 kg/ha at FDS; and 48.10 and 82.34, 18.78 and 23.38 and 68.49 and 109.98 kg/ha at HS, respectively. The application of 100% of the recommended NPK using organic N-, P-, and K-rich sources led to the fourth highest values for nutrient uptake. The sustained release of nutrients from organic granules resulted in comparatively lower uptake than that from synthetic granules/fertilizers. This result aligns with that of Tonfack *et al.*[30] Similar results were obtained with 75% of the recommended NPK. At all stages, the lowest uptake was obtained with the absolute control owing to nutrient shortage in the experimental soil.

The increased growth and dry matter production in the present investigation were highlighted by the positive correlation between DMP and fruit N uptake (r=0.999**) and stover (r=0.967**), P uptake by fruit (r=0.968**) and stover (r=0.960**), and K uptake by fruit (r=0.975**) and stover (r=0.987**), supporting the present findings (Table 3).

Available nutrients

The application of organic granules improved nutrient availability in tomato soil (Table 6). The highest availability of nutrients (NPK) was obtained with 100% of the recommended NPK using organic NPK granules: 205.74, 24.36, and 215.42 kg/ha at FS, 169.14, 17.12, and 203.42 kg/ha at FDS, and 152.72, 11.38, and 175.64 kg/ha at HS, respectively. The increase in the available nutrients can be attributed to the gradual release of nutrients over time as they decompose. Organic granules contain significant amounts of organic matter, which improves soil structure, water retention capacity, and microbial activity.[31] As organic matter breaks down, nutrients, such as NPK, are released in forms that are readily available to plants. They also promote the multiplication and activity of beneficial microorganisms in the soil. These microorganisms break down complex organic materials into simpler forms that can be absorbed by plants. This microbial activity enhances the mineralization of nutrients, improving their accessibility to plants. These results are similar to those of Nabaei *et al.*[32] and Su *et al.*[33] The application of 100% of the recommended NPK using organic N-, P-, and K-rich sources led to the second highest availability of nutrients, followed by 100% of the recommended NPK using synthetic granules (Urea, DAP, and MOP), and 100% of the recommended NPK using synthetic fertilizers (Urea, SSP, and MOP). Generally, the leaching loss of nutrients is greater in inorganic fertilizers than in organic granules; therefore, the above synthetic chemical fertilizers recorded fewer available nutrients than the organics. The same trends were observed with the application of 75% of the recommended NPK. The lowest available nutrients were obtained with the absolute control as plant nutrients were not added to the soil.

Microbial population

The microbial population was higher in soil administered the organic granules (Table 7). Among the organic granules and inorganic fertilizer treatments, the highest numbers of bacteria, fungi, and actinomycetes were obtained in soil at FS (19.48×10^6 per g soil, 14.91×10^5 per g soil, and 8.05×10^4 per g soil), FDS (22.95×10^6 per g soil, 16.39×10^5 per g soil and 10.98×10^4 per g soil), and HS (17.94×10^6 per g soil, 14.61×10^5 per g soil and 9.69×10^4 per g soil), respectively, with 100% of the recommended NPK using organic NPK granules. The addition of organic granules enhanced the moisture retention capacity of the soil, improved the physical condition of the soil, and added a large amount of organic matter to the soil, which created favorable conditions for the growth of soil microorganisms. Similar results were reported by Meena *et al*.[34] and Umadevi *et al*.[35] The addition of organic NPK granules provided more area on the soil surface for colonization. Natarajan[36] found that organic manure contains essential nutrients, amino acids, and growth-promoting (IAA and GA) substances, which are delivered to the microorganisms in the soil, there by rapidly increasing the bacterial, fungal, and actinomycete populations. Similar results were obtained by Kanan *et al*.[37]

The application of 100% of the recommended NPK using organic N-, P-, and K-rich sources led to the second highest microbial population; this was followed by 100% of the recommended NPK using synthetic granules (Urea, DAP, and MOP) and 100% of the recommended NPK using synthetic fertilizers (Urea, SSP, and MOP). Similar results were obtained for tomato crops treated with 75% of the recommended NPK. Smaller microbial populations were observed in the control group.

CONCLUSION

Based on the results of this study, the application of 100% of the recommended NPK using synthetic NPK granules increased tomato yields. However, the yield was comparable to that obtained with the application of 100% of the recommended NPK using organic NPK granules. Regarding fruit quality, soil fertility, and soil microbial population, the application of 100% of the recommended NPK using organic NPK granules was superior to the other treatments. Hence, the use of organic NPK granules to deliver 100% of the recommended NPK is a viable and environmentally safe nutrient management practice to obtain better tomato yield and quality. Further studies are required to assess the combined effects of graded levels of NPK through inorganic fertilizers and organic NPK granules on the productivity and quality of tomatoes.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHORS' CONTRIBUTION

Both authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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DATA AVAILABILITY

All datasets generated or analyzed during this study are included in the manuscript.

ETHICS STATEMENT

Not applicable.

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