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Research Article

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Combination of composted poultry manure and inorganic fertilizers enhance growth and yield of tomato (*Lycopersicon esculentum* Mill.) in a rooftop growing system

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ABSTRACT

Rooftop vegetable productions are becoming an important part of the recent rejuvenation of urban agriculture particularly in densely populated urban areas. However, due to weight limits often associated with rooftop growing systems, rooftop plant growing media including soil, may not contain optimal fertility levels required to maximize plant growth and productivity. Therefore, the success of rooftop vegetable production often depends on proper fertility management schemes to create optimal plant growing conditions. Therefore, an experiment was conducted to investigate combine impacts of composted poultry manure (CPM) and inorganic fertilizers on growth and yield of tomato under rooftop growing conditions. The experiment was arranged in a completely randomized design (CRD) with eight treatments and three replications. The treatments included T_1: Control (no CPM and no NPK), T_2: 4 ton CPM ha^{-1}, T_3: $N_{55}P_{15}K_{50}$ kg ha^{-1}, T_4: $N_{110}P_{30}K_{100}$ kg ha^{-1}, T_5: $N_{165}P_{45}K_{150}$ kg ha^{-1}, T_6: 4 ton CPM ha^{-1}+ $N_{55}P_{15}K_{50}$ kg ha^{-1}, T_7: 4 ton CPM ha^{-1}+ $N_{110}P_{30}K_{100}$ kg ha^{-1}, and T_8: 4 ton CPM ha^{-1}+$N_{165}P_{45}K_{150}$ kg ha^{-1}. The results showed that NPK fertilizers alone and CPM combined with NPK fertilizers greatly improved tomato plant growth and fruit yield. However, maximum plant growth and tomato yields (68 t ha^{-1}) and economic benefits (benefit: cost ratio 6.9) were achieved with 4 t ha^{-1} CPM amendment and 100% recommended doses of NPK fertilizers. Control treatment (T_1: -CPM, -NPK) had the lowest tomato yield (6.2 t ha^{-1}). Composted poultry manure alone contributed for around 15.0 t ha^{-1} tomato yield and supplemented for around 30 kg ha^{-1} N fertilizer. Combine application of 4 t ha^{-1} CPM and 100% RDF of NPK fertilizers indicated as the agreeable combination in this study for optimal tomato plant growth and yield under rooftop growing conditions.

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INTRODUCTION

Cities are recognized as having environmental footprints, consuming resources, and producing wastes in ways that can globally impact nature and human well-being (Harada & Whitlow, 2020). However, over the last few years, rooftop gardens, especially in densely populated cities, have received particular attention as it creates opportunities for integrating agriculture into urban communities (Turner *et al.*, 2023). The utilization of alternative agricultural production systems, such as rooftop gardening or green roof technologies, will increase in importance as human populations become more urbanized and urban consumers become more interested in local foods. Rooftop gardens involve individuals growing vegetation on building rooftops using numerous possible methods such as containers, green roofs, or hydroponics (Aiholli & Bargavi, 2018) and can take the form of smaller, household or community gardens primarily for own consumption (Aiholli & Bargavi, 2018; Turner *et al.*, 2023) or large-scale commercial ventures (Akaeze & Nandwani, 2020). Rooftop agriculture allows urban areas to become more sustainable in their resource utilization, and to assist the development of food security for local residents.

Although there is great potential for using rooftops to grow vegetables in urban areas, vegetable production activities are currently minimal due to multiple challenges that must be overcome before widespread implementation will occur. Those include media composition and depth; cultural practices including nutrient management; roof weight limitations; potential water-quality issues of effluent runoff; influence of crop production on other well-known benefits attributed to green roofs and installation and maintenance cost (Walters & Midden, 2018).

Since most vegetables prefer deeper soil depths, intensive green roof systems (>15 cm medium depths) that provide greater rooting depths have been considered best to maximize their productivity. However, the greatest potential for sustained productivity is probably through extensive systems (<15 cm depths) due to weight load restrictions for most buildings. Thus, shallow-rooted vegetables that include important salad greens crops are thought to be the most suited for extensive systems as they can have high productivity with minimal inputs (Walters & Midden, 2018; Turner *et al.*, 2023). Some researchers, however, have indicated that deeper-root crops like tomato also can be effectively produced in extensive green roof systems when adequate fertility and moisture is provided (Rawal & Thapa, 2022).

Tomato (*Lycopersicon esculentum* Mill.) is one of the versatile, most popular, and most consumed vegetable crops globally, characterized by a chromosome number of 2n = 26. Belonging to the Solanaceae family and Lycopersicon genus, it constitutes a relatively small genus within the vast and diverse family, encompassing around 90 genera (Olaniyi & Ajibola, 2008; Usman, 2015). Native to Ecuador, Peru, and the Galapagos Islands, although evidence leans towards Mexico as the likely site of domestication (Usman, 2015), tomato is a significant commercial vegetable on a large scale due to its affordability as a source of Vitamin C. Whether consumed raw in salads or more commonly incorporated into savory stews, pure sauces, juices, and ketchup, tomatoes offer versatility. They bring refreshment to beverages and serve as excellent flavorings for soups, while also enhancing the appeal of green salads with their vibrant color (Ano & Agwu, 2005; Ilodibia & Chukwuma, 2015). Medicinally, tomatoes and their derivatives exhibit health-promoting and anti-cancer properties owing to their richness in folic acid, vitamin C, potassium, and oxalic acid (Bruulsema, 2002; Ilodibia & Chukwuma, 2015). Tomato is a high yielding vegetable that necessitate lots of essential nutrients, including N, P, K, Mg, Ca, Na, and S, to ensure optimal establishment, growth and yield. These nutrients serve specific functions and must be supplied to the plants at the appropriate time and in the correct quantities.

There is a renewed focus on the proper and effective utilization of organic manure to sustain soil fertility (Usman, 2015). Due to the widespread issue of soil degradation attributed to the loss of organic matter resulting from the indiscriminate use of inorganic fertilizers. This, in turn, leads to soil acidity, nutrient imbalances, and diminished crop yields. The application of organic manures emerges as a crucial method for maintaining soil fertility while also being environmentally friendly (Ilodibia & Chukwuma, 2015).

Numerous studies have reported the positive impacts of organic manures on overall soil health and crop productivity (Odlare & Swenson, 2008; Adebayo *et al.*, 2017). Notably, poultry manure is the most cherished of all animal manures since it contains all the essential plant nutrients such as N, P, K, Zn, Fe, Cl, Ca, Mg, B, Cu, Mo and S which makes it the most appropriate organic manure for tomato production (Agaba *et al.*, 2023; Noble *et al.*, 2024). It contributes to plant growth by improving the physical, chemical, and biological qualities of the soil. Also, ensure balanced nutrient delivery, and generate long-lasting residual effects on soil nutrient availability (Khaliq *et al.*, 2024). Despite their potential benefits, available research findings suggest that poultry manure alone may not provide enough nutrients to support proper plant growth and yield for the entire growing season due to their low nutrient contents and slow nutrient release characteristics (Abumere *et al.*, 2019). Excessive use of poultry manure can also lead to the eutrophication of ponds and water reservoirs, impacting their quality. On the contrary, mineral fertilizers alone though offer nutrients in easily accessible and concentrated forms; they lack in sustaining long-term crop production and contribute nothing to the build-up of soil organic matter and overall soil health (Richa *et al.*, 2020). Therefore, it is essential to determine the independent influence of poultry manure and inorganic nitrogen fertilizers, such as NPK, on the growth and yield of fast-growing vegetables like tomatoes.

In light of the aforementioned challenges and opportunities, this study was conducted to assess the individual impact of composted poultry manure (CPM) and NPK fertilizer, and the integrated use of CPM and NPK fertilizer on the growth and yield of tomatoes in a rooftop environment.

MATERIALS AND METHODS

Experimental Setup

In the winter season of 2021-2022, a pot experiment was conducted on the rooftop in Charfasson Upazila, located on the south coast of Bangladesh. The objective was to assess the growth and yield performance of tomatoes (*Lycopersicum esculentum* Mill.) when subjected to CPM and NPK fertilizers. Soil samples were collected from the Research Farm of Charfasson Govt. College, Bhola, Bangladesh, at a depth of 0-15 cm. The soil analysis revealed the following characteristics: pH of 8.10 (1:2.5 w/v H2O), organic carbon content 0.65%, available nitrogen 0.24% (determined using the Kjeldahl extraction method) (Marr & Cresser, 1983), available phosphorus 0.09% (Jackson, 1958), available potassium 1.40% (Pratt, 1965), available sulfur 0.18% (Bardsley & Lancaster, 1965), and a composition of 11.3% sand, 51.04% silt, and 37.66% clay. The soil was classified as silty clay loam, with a maximum water retention capacity of 41%.

Planting Materials, Experimental Design and Treatments

The seeds used for the experiment were sourced from the Fulbaria seed market in Siddique Bazaar, Dhaka, and the variety was BINAtomato-4. The experiment was laid out in a Completely Randomized Design (CRD) having eight treatments with three replications. The treatments were T_1: Control (no CPM, no NPK), T_2: 4 t PL ha^{-1}, T_3:$N_{55}P_{15}K_{50}$ kg ha^{-1}, T_4: $N_{110}P_{30}K_{100}$ kg ha^{-1}, T_5: $N_{165}P_{45}K_{150}$ kg ha^{-1}, T_6: 4 t CPM ha^{-1}+ $N_{55}P_{15}K_{50}$ kg ha^{-1}, T_7: 4 t CPM ha^{-1}+ $N_{110}P_{30}K_{100}$ kg ha^{-1} and T_8: 4 t CPM ha^{-1}+$N_{165}P_{45}K_{150}$ kg ha^{-1}, respectively.

Application of CPM and NPK Fertilizers

Each pot received a soil fill of 10.0 kg. Basal doses ($N_{25}P_{7.5}K_{25}$ kg ha^{-1}) were administered in accordance with the Fertilizer Recommendation Guide of Bangladesh Agricultural Research Council (BARC, 2018). During the initial preparation of pot soil, CPM was applied, and during the final pot soil preparation, urea, triple superphosphate, and muriate of potash were applied as sources of N, P, and K fertilizers respectively.

Seed Sowing and Agronomic Practices

Sowing of seeds took place on December 14, 2021, and the germination process was allowed to proceed. Subsequently, 25 day old seedlings with uniform growth and height were selected and a single seedling was planted in each pot. Throughout the experiment, the recorded environmental conditions included a mean temperature ranging from 14 to 31 °C, relative humidity fluctuating between 77 to 83%, and a day length spanning from 11 to 12 hours (BMD, 2022). Agronomic practices such as weeding, spading, staking, watering, and pesticide application were implemented as deemed necessary.

Data Collection and Analysis

Various agronomic parameters, including plant height, leaf number, leaf area, leaf area index, first flowering days, the number of fruits, length of fruits, and girth of plants, were recorded at intervals of 30, 60, and 90 days post-seed sowing. Leaf area and leaf area index were calculated using the formulas: Leaf area = length × width of leaf, and Leaf area index = leaf area/ground area. After harvest different parts of tomato plants, such as root, stem, leaf, and fruit, were gathered and weighed for both fresh and dry measurements. The drying process involved placing the samples in an oven at a temperature of 65 °C for 72 hours, after which the dry weight was determined. The Benefit Cost Ratio (BCR) was computed using the standard formula: (yield t ha^{-1} × selling rate Tk. ha^{-1}) divided by the cost of cultivation in Taka, which is equivalent to the net return in taka.

Statistical Analysis

The collected data underwent analysis through the one-way ANOVA test using SPSS version 17.0. To ascertain differences in means among treatments, the Least Significance Difference (LSD) test was applied at a 5% level of significance.

RESULTS AND DISCUSSION

Plant Height and Number of Leaves

The impact of CPM and NPK fertilizers on the height and leaf count of tomato plants is detailed in Table 1. At all intervals (30, 60, and 90 days), the height and leaf number of tomato plants were significantly higher ($p < 0.05$) in the groups treated with CPM and NPK compared to the control treatment. The results indicated a gradual increase in both height and leaf number of tomato plants throughout the growth period, regardless of the treatments. Notably, the combined application of NPK and CPM demonstrated superior performance compared to the sole application of CPM in both aspects. The maximum heights recorded were 37.00, 71.00, and 78.33 cm at the 30, 60, and 90 day intervals, respectively, in T_8 (4 t CPM ha^{-1}+$N_{165}P_{45}K_{150}$ kg ha^{-1}), T_3 ($N_{55}P_{15}K_{50}$ kg ha^{-1}), and T_3 ($N_{55}P_{15}K_{50}$ kg ha^{-1}), respectively.

The control treatment consistently displayed the minimum heights in all instances. The greatest leaf numbers (31.33, 451.67, 593.67 per plant) were observed at the 30, 60, and 90 day intervals, respectively, in treatments T_7 (4 t PL ha^{-1}+ $N_{110}P_{30}K_{150}$ kg ha^{-1}), T_5 ($N_{165}P_{45}K_{150}$ kg ha^{-1}) and T_5 ($N_{165}P_{45}K_{150}$ kg ha^{-1}). In line with these findings, Oyedeji *et al.* (2014) noted that the application of either NPK (15:15:15) or CPM at a rate of 30 kg ha^{-1}, incorporated into 12 kg topsoil, led to increased growth and yield of the Amaranthus species.

Leaf Area and Leaf Area Index: The impact of CPM and NPK fertilizers on the leaf area and leaf area index of tomato plants is presented in Table 2. At the observed intervals of 30, 60, and 90 days, the leaf area and leaf area index of tomato plants were significantly higher ($p < 0.05$) in treatments involving sole CPM, sole NPK, and integrated doses of CPM and NPK compared to the control treatment. The results indicated

Table 1: Effects of CPM and NPK fertilizers on the plant height (cm) and leaf number ($plant^{-1}$) of tomato plants

Treatments	Plant height (cm)			Leaf number ($plant^{-1}$)		
	Days after transplanting					
	30	60	90	30	60	90
T_1: Control (-CPM, -NPK)	18.83^e	42.33^e	48.00^f	11.00^f	93.00^h	135.67^h
T_2: 4 t CPM ha^{-1}	23.67^d	55.67^d	65.33^e	15.00^e	191.00^g	320.67^g
T_3:$N_{55}P_{15}K_{50}$ kg ha^{-1} (50% RDF)	29.00^c	71.00^a	78.33^a	11.67^f	240.33^f	469.00^d
T_4:$N_{110}P_{30}K_{100}$ kg ha^{-1} (100% RDF)	31.33^b	59.33^c	72.00^c	19.33^c	264.00^d	371.67^f
T_5: $N_{165}P_{45}K_{150}$ kg ha^{-1} (150% RDF)	35.00^a	60.00^c	70.67^d	23.67^b	451.67^a	593.67^a
T_6: 4 t CPM ha^{-1}+$N_{55}P_{15}K_{50}$ kg ha^{-1}	33.33^b	62.67^b	71.00^c	20.67^c	285.00^c	493.67^c
T_7: 4 t CPM ha^{-1}+$N_{110}P_{30}K_{100}$ kg ha^{-1}	31.00^b	54.33^d	65.00^e	31.33^a	293.33^b	591.00^b
T_8: 4 t CPM ha^{-1}+$N_{165}P_{45}K_{150}$ kg ha^{-1}	37.00^a	59.00^c	76.67^b	18.67^d	260.33^e	391.67^e
LSD at 5%	2.33	1.82	1.07	1.98	1.73	1.67

CPM=Composted Poultry Manure, RDF=Recommended doses of fertilizer. Means with a different lower-case letter(s) in the same column differ significantly at 5% level

Table 2: Effects of CPM and NPK fertilizers on the leaf area (cm^2) and leaf area index of tomato plants

Treatments	Leaf area (cm^2)			Leaf area index		
	Days after transplanting					
	30	60	90	30	60	90
T_1: Control (-CPM, -NPK)	17.67^g	18.50^f	23.42^e	0.12^h	1.34^d	2.48^e
T_2: 4 t CPM ha^{-1}	31.83^e	23.00^e	31.50^d	0.30^f	2.68^d	6.08^d
T_3:$N_{55}P_{15}K_{50}$ kg ha^{-1} (50% RDF)	33.17^e	27.50^d	40.50^c	0.25^g	4.63^c	11.53^b
T_4:$N_{110}P_{30}K_{100}$ kg ha^{-1} (100% RDF)	30.33^f	36.33^b	44.17^a	0.39^e	5.72^b	10.40^c
T_5: $N_{165}P_{45}K_{150}$ kg ha^{-1} (150% RDF)	50.00^b	44.92^a	44.91^b	0.76^b	13.12^a	17.34^a
T_6: 4 t CPM ha^{-1}+$N_{55}P_{15}K_{50}$ kg ha^{-1}	38.00^d	32.17^c	42.17^c	0.49^d	5.75^b	12.40^b
T_7: 4 t CPM ha^{-1}+$N_{110}P_{30}K_{100}$ kg ha^{-1}	42.17c	27.75^d	30.67^d	0.79^a	4.34^c	11.36^b
T_8: 4 t CPM ha^{-1}+$N_{165}P_{45}K_{150}$ kg ha^{-1}	54.17^a	41.17^a	49.33^a	0.70^c	6.43^b	9.73^c
LSD at 5%	2.43	4.55	2.24	1.56	1.4	1.33

CPM=Composted Poultry Manure, RDF=Recommended doses of fertilizer. Means with a different lower-case letter(s) in the same column differ significantly at 5% level

a gradual increase in both leaf area and leaf area index of tomato plants throughout the growth period, regardless of the treatments in most cases. Furthermore, the leaf area and leaf area index demonstrated an increase with the elevated levels of the combined treatment in many instances. The highest leaf area was recorded as 54.17, 44.92, and 49.33 cm at the 30, 60, and 90 day intervals in treatments T_8 (4 t CPM ha^{-1}+$N_{165}P_{45}K_{150}$ kg ha^{-1}), T_5 ($N_{165}P_{45}K_{150}$ kg ha^{-1}), and T_8 (4 t CPM ha^{-1}+$N_{165}P_{45}K_{150}$ kg ha^{-1}), respectively. Similarly, the highest leaf area index was found as 0.79, 13.12, and 17.34 per plant at the 30, 60, and 90 day intervals in treatments T_7 (4 t CPM ha^{-1}+ $N_{110}P_{30}K_{110}$ kg ha^{-1}), T_5 ($N_{165}P_{45}K_{150}$ kg ha^{-1}) and T_5 ($N_{165}P_{45}K_{150}$ kg ha^{-1}), respectively.

The control treatment consistently exhibited the smallest leaf area and leaf area index in all instances. In many cases, the combined doses demonstrated superior outcomes compared to the sole application of either CPM or NPK. The findings suggested a positive impact on the performance and yield of tomatoes, particularly with the use of organic manures, especially poultry manure. Similar results were noted in the study, where the growth of strawberry plants was enhanced under the I-ACT (chicken manure) treatment, although there were no notable differences in leaf area among the treatments (Roussos *et al.*, 2022).

Stem Diameter (cm), Number of Branches, and Root Length (cm)

The impact of CPM and NPK fertilizers on stem diameter (cm), the number of branches, and root length (cm) in tomato plants are presented in Table 3. Significantly higher stem diameters (cm) and numbers of branches in tomato plants were observed in various treatments compared to the control at the 30, 60, and 90 day intervals ($p < 0.05$). A similar trend was observed for root length, with significantly higher values in different treatments compared to the control. The results indicated a gradual increase in stem diameter (cm) and the number of branches in tomato plants with the escalating doses of NPK irrespective of CPM amendments, in most cases. The maximum stem diameter (cm) and number of branches were recorded as 3.17, 4.08, and 4.67 cm, and 5.00, 9.00, and 29.33 per plant, respectively, at the 30, 60, and 90 day intervals in the same treatment, i.e., T_7 (4 t CPM ha^{-1} +$N_{110}P_{30}K_{100}$ kg ha^{-1}).

Table 3: Effects of CPM and NPK fertilizers on the stem diameter (cm), no. of branch and root length of tomato plants

Treatments	Stem diameter (cm)			No. of branches			Root Length (cm)
	Days after transplanting						
	30	60	90	30	60	90	
T_1: Control (-CPM, -NPK)	0.50^g	2.33^e	2.75^e	0.66^b	0.10^c	4.33^f	11.67^e
T_2: 4 t CPM ha^{-1}	0.75^f	3.17^d	3.67^d	1.33^b	1.67^c	10.00^e	15.67^d
T_3:$N_{55}P_{15}K_{50}$ kg ha^{-1} (50% RDF)	1.20^e	3.17^d	4.17^b	1.10^b	4.67^b	16.67^d	18.67^c
T_4:$N_{110}P_{30}K_{100}$ kg ha^{-1} (100% RDF)	1.75^d	4.00^a	4.66^a	3.00^a	7.33^a	24.33^b	25.67^a
T_5: $N_{165}P_{45}K_{150}$ kg ha^{-1} (150%RDF)	2.17^c	4.00^a	4.66^a	3.33^a	8.33^a	25.67^b	22.33^b
T_6: 4 t CPM ha^{-1}+$N_{55}P_{15}K_{50}$ kg ha^{-1}	2.67^b	3.50^c	4.00^c	3.00^a	4.67^b	21.00^c	23.00^b
T_7: 4 t CPM ha^{-1}+$N_{110}P_{30}K_{100}$ kg ha^{-1}	3.17^a	4.08^a	4.67^a	5.00^a	9.00^a	29.33^a	22.00^b
T_8: 4 t CPM ha^{-1}+$N_{165}P_{45}K_{150}$ kg ha^{-1}	2.75^b	3.75^b	4.66^a	4.33^a	6.00^b	25.67^b	25.33^a
LSD at 5%	0.11	0.22	0.09	2.52	2.11	2.32	2.51

CPM=Composted Poultry Manure, RDF=Recommended doses of fertilizer. Means with a different lower-case letter(s) in the same column differ significantly at 5% level

Yet, the treatment T_5 ($N_{165}P_{45}K_{150}$ kg ha^{-1}) exhibited the greatest root length (25.67 cm). Conversely, the control treatment consistently yielded the lowest values in all instances. In most cases the combined doses demonstrated superior outcomes compared to the sole application of either CPM or NPK.

Fruits Parameters and Fruit Yield

The effects of CPM and NPK fertilizers on the different fruit traits of tomato fruit yield are shown in Table 4.

The number of trusses in tomato plants significantly varied ($p < 0.5$) between treatments, with the treatment T_7 (4 t CPM ha^{-1}+ $N_{110}P_{30}K_{100}$ kg ha^{-1}) demonstrating the highest value (39.67 per plant) and the control treatment showing the lowest (11.00 per plant). The number of flowers per plant also was significantly greater ($p < 0.5$) in treatment T_7 (4 t CPM ha^{-1}+ $N_{110}P_{30}K_{100}$ kg ha^{-1}) recording the highest value (207.00 per plant) and the control treatment displaying the lowest (55.00 per plant). Fruit length, however, did not vary among the treatment except T_1 and T_8. The treatment T_8 (4 t CPM ha^{-1}+$N_{165}P_{45}K_{150}$ kg ha^{-1}) had the highest fruit length (4.99 cm), and the control treatment, had the lowest (4.00 cm). Interestingly, fruit lengths were statistically similar in treatments T_2 to T_7. The fruit diameter (cm) also showed a significant increase ($p < 0.05$) over the control, with the treatment T_7 (4 t CPM ha^{-1}+ $N_{110}P_{30}K_{150}$ kg ha^{-1}) registering the

Table 4: Effects of CPM and NPK fertilizers on the fruits and fruits yield parameters of tomato plants

Treatments	No. of trusses	No. flower (p)	Fruits length (cm)	Fruits diameter (cm)	Number of fruits (plant^{-1})	Average wt. of fruits (g)	Fruit yield/pot (g)	Yield of fruits (t ha^{-1})
T_1: Control (-CPM, -NPK)	11.00^e	55.00^f	4.00^c	7.17^e	15.33^e	16.47^c	155.73^h	6.23^g
T_2: 4 t CPM ha^{-1}	27.00^d	123.33^e	4.25^b	11.25^d	29.00^d	18.39^c	527.96^g	21.12^f
T_3:$N_{55}P_{15}K_{50}$ kg ha^{-1} (50% RDF)	33.00^c	145.00^d	4.32^b	11.44^c	32.33^d	21.07^b	645.19^f	25.81^e
T_4:$N_{110}P_{30}K_{100}$ kg ha^{-1} (100% RDF)	35.33^b	176.67^b	4.43^b	12.91^c	46.67^b	29.38^a	1361.09^d	54.44^c
T_5: $N_{165}P_{45}K_{150}$ kg ha^{-1} (150%RDF)	33.00^c	165.00^c	4.46^b	11.12^d	61.00^a	31.84^a	1479.21^c	58.50^b
T_6: 4 t CPM ha^{-1}+$N_{55}P_{15}K_{50}$ kg ha^{-1}	27.33^d	142.67^d	4.42^b	12.92^c	39.00^c	26.24^b	1005.83^e	40.23^d
T_7: 4 t CPM ha^{-1}+$N_{110}P_{30}K_{100}$ kg ha^{-1}	39.67^a	207.00^a	4.13^b	13.90^a	57.67^a	29.06^a	1703.34^b	68.13^a
T_8: 4 t CPM ha^{-1}+$N_{165}P_{45}K_{150}$ kg ha^{-1}	33.33^b	166.67^c	4.99^a	13.03^b	51.00^b	34.59^a	1762.51^a	70.50^a
LSD at 5%	2.29	2.72	0.34	0.57	6.35	6.07	5.59	4.02

CPM=Composted Poultry Manure, RDF=Recommended doses of fertilizer. Means with a different lower-case letter(s) in the same column differ significantly at 5% level

highest fruit diameter (13.75 cm), while the control treatment exhibited the lowest value.

Number of fruits significantly varied among the treatments. Increasing rates of NPK fertilizers without CPM (T_3, T_4 and T_5), resulted in increasing number of fruits per plant. However, with 4 t ha^{-1} CPM amendment, the highest number of fruits per plants was recorded at 100% RDF (T_7: 4 t CPM ha^{-1}+ $N_{110}P_{30}K_{100}$ kg ha^{-1}). With further increase in NPK fertilizer (T_8: 4 t CPM ha^{-1}+ 150% RDF) resulted significant decrease in number of fruits per plant (Table 4).

Average fruit weights (g/fruit) significantly ($p < 0.5$) increased with 100 and 150% RDF with or without CPM amendments compared to control and 50% RDF. However, fruit weights at 100 and 150% RDF with or without CPM amendments were similar (Table 4).

Fruit yield per pot significantly ($p < 0.5$) varied between treatments. Increasing rates of NPK fertilizers irrespective of CPM amendments resulted in increased fruit yields per pot. However, CPM amendment at 4 t ha^{-1}, had significantly greater fruit yields per pot irrespective of NPK fertilizer doses being the highest in T_8 (4 t CPM ha^{-1}+ 150% RDF). Control treatment (T_1) had the lowest fruit yield per pot followed by T_2 (4 t ha^{-1} CPM alone) (Table 4).

Control treatment (T_1: no CPM, no NPK) had the lowest fruit yield of 6.2 t ha^{-1} (Table 4). Soil amendment with at 4 t ha^{-1} CPM alone (T_2) resulted 21.1 t ha^{-1} tomato yield which is around 3.5 times more compared to control. Increasing rates of NPK fertilizers without CPM amendment, increased fruit yields by around 4, 8.5 and 9.5 times respectively at 50%, 100% and 150% RDF compared to control. Increasing rates of NPK fertilizers, with 4 t ha^{-1} CPM amendments, increased tomato yield up to 100% RDF of NPK fertilizers (T_7). Then with 150% RDF (T_8), tomato yield was comparable with that of 100% RDF. At 100% and 150% RDF, 4 t ha^{-1} CPM amendments resulted around 68 t ha^{-1} tomato yield which is around 11 times greater tomato yield compared to control. In general, 50% RDF with 4 t ha^{-1} CPM amendments resulted in 40.2 t ha^{-1} tomato yield which is 56% greater yield compared to 50% RDF alone (25.8 t ha^{-1}). With 100% and 150% RDF and 4 t ha^{-1} CPM amendments resulted around 25% and 21% greater yields compared to 100% and 150% RDF alone respectively.

The results showed that while no CPM was used, tomato yield increased with increased rates of NPK fertilizers without any signs of isotherm up to 150% RDF. However, when 4 t CPM ha^{-1} was used, tomato yield showed isotherm at 100% RDF as tomato yields were at par at 100 and 150% RDF with 4 t ha^{-1} CPM indicating maximum tomato yield was achieved with 4 t ha^{-1} CPM plus 100% RDF of NPK fertilizers. Benefit: cost ratio also supported this. The results also showed that tomato yield was around 6.2 t ha^{-1} with no CPM and no NPK (T_1). However, 4 t ha^{-1} CPM alone (T_2) resulted 21.1 t ha^{-1} tomato yield. This indicated that 4 t ha^{-1} CPM alone contributed for around 15.0 t ha^{-1} tomato yield. At 50% RDF with 4 t ha^{-1} CPM amendments resulted in 40.2 t ha^{-1} tomato yield. While 50% RDF alone yielded 25.8 t ha^{-1} tomatoes. This again proved that 4 t ha^{-1} CPM alone contributed for around 15.0 t ha^{-1} tomato yield. On the other hand, 100% RDF alone contributed for around 55.0 t ha^{-1} tomato yield. While 100% RDF plus 4 t ha^{-1} CPM resulted around 70.0 t ha^{-1} tomatoes. This indicated that 100% RDF alone contributed for around 55.0 t ha^{-1} tomato yield (70-15 = 55). In other words, 4 t CPM ha^{-1} alone supplemented for around 30 kg ha^{-1} N fertilizer.

Nitrogen is one of the most important nutrients required by tomato for better yield and quality. Ayankojo and Morgan (2021) in a study with field grown tomato in Florida, USA reported application of 224, 12, and 224 kg ha^{-1} N, P_2O_5, and K_2O respectively for maximum tomato yield. In another study Cheng *et al.* (2021) suggested optimal nitrogen rate as between 236 and 354 kg ha^{-1} for maximum tomato yield. In Bangladesh context however, recommended NPK rates are 110, 30, and 100 kg ha^{-1} N, P, and K respectively for the particular tomato variety used for this study while grown in the field. Whereas our study showed that maximum tomato yields were achieved with 100% RDF plus 4 t ha^{-1} CPM where 4 t ha^{-1} CPM alone contributed for around 15.0 t ha^{-1} tomato yields. This may be due to the different growing conditions; pot vs field. Also, it is most likely that some the nutrients, particularly N, may have been lost from the pot through leaching with irrigation water (Cheng *et al.*, 2021). Nitrogen content in composted poultry manure greatly vary depending on its source and composting procedures. Available research findings suggest that CPM contains 3-5% N on dry weight basis and <1.0% on wet weight basis (Richa *et al.*, 2020). Composted poultry manure used in our study though was not analyzed for its fertilizer components, this evidence support our findings that 4 t ha^{-1} CPM alone supplemented for around 30 kg ha^{-1} N fertilizers.

The impact of CPM and NPK fertilizers on the fresh and dry weight of various organs of tomato plants is outlined in Table 5. In this instance, the results deviate somewhat from those observed in plant height, leaf number, leaf area, leaf area index, and other fruit and yield traits.

Fresh Weight of Root, Stem, and Leaf

The results indicated a significant increase ($p < 0.5$) in the fresh weight of the root, stem, and leaf of tomato plants compared to the control (Table 5). At harvest, the highest fresh weights for the root (11.87 g $plant^{-1}$), stem (40.14 g $plant^{-1}$), and leaf (29.54 g $plant^{-1}$) were recorded in the treatment T_6 (4 t CPM ha^{-1}+ $N_{55}P_{15}K_{50}$ kg ha^{-1}), T_4 ($N_{110}P_{30}K_{100}$ kg ha^{-1}), and T_4 ($N_{110}P_{30}K_{100}$ kg ha^{-1}), respectively. Conversely, the lowest values were consistently measured in the control treatment in all cases.

Total Biomass and Fruit Production

The total fresh biomass production and fruit yield demonstrated a significant increase ($p < 0.5$) compared to the control (Table 5). The highest total biomass production (78.53 g/plant) and fruit yield (1762.51 g $plant^{-1}$) were attained in the T_4 ($N_{110}P_{30}K_{100}$ kg ha^{-1}) and T_8 (4 t CPM ha^{-1}+$N_{165}P_{45}K_{150}$ kg ha^{-1}) treatments.

Dry Weight of Root, Stem, and Leaf

The dry weight of the root, stem, and leaf exhibited a significant increase ($p < 0.5$) in tomato plants compared to the control (Table 5). The treatment T_6 (4 t CPM ha^{-1} $N_{55}P_{15}K_{50}$ kg ha^{-1}), T_4 ($N_{110}P_{30}K_{100}$ kg ha^{-1}), and T_4 ($N_{110}P_{30}K_{100}$ kg ha^{-1}) yielded the highest dry weights for the root (4.02 g $plant^{-1}$), stem (13.64 g $plant^{-1}$), and leaf (8.08 g $plant^{-1}$), respectively. Conversely, the lowest values were consistently recorded in the control treatment in all cases. Abdulmaliq *et al.* (2019) found that the application of poultry manure, either alone or in combination with NPK fertilizer, significantly supported higher ($P < 0.05$) vine length, number of leaves, number of fruits, fruit development, and tomato yield in two cropping seasons.

Total Dry Biomass, Fruit Production, and Fresh Biomass: Fruit Ratio

The total dry biomass production, dry fruit production, and fresh biomass: fruit ratios were significantly ($p < 0.05$) higher than the control (Table 5). The treatment T_4 ($N_{110}P_{30}K_{100}$ kg ha^{-1}), T_8 (4 t CPM ha^{-1}+$N_{165}P_{45}K_{150}$ kg ha^{-1}), and T_8 (4 t CPM ha^{-1}+$N_{165}P_{45}K_{150}$ kg ha^{-1}) yielded the highest total dry biomass production (24.56 g $plant^{-1}$), fruit production (261.75 g/plant), and fresh biomass: fruit ratio (30.04 g $plant^{-1}$), respectively. Conversely, the lowest values were consistently recorded in the control treatment in all cases. In a study, Jandaghi *et al.* (2020) demonstrated that increasing the amount of chicken manure (up to 50%) significantly increased shoot length, stem diameter, true leaf length and width, shoot fresh and dry weights, and total fruit weight of cucumber. Another study found that the application of 30 tons ha^{-1} resulted in the highest growth values, including plant height (65.91 cm), stem girth (1.51 cm), number of leaves (14.20), and higher stem weight (2249.9 g) and leaf biomass (3610.5 g) (Alessandra *et al.*, 2017). Ferreira *et al.* (2022) observed a 20% increase in grain production on average with the application of organic manures on maize and oat compared to mineral fertilization. Alessandra *et al.* (2021) reported that the highest yield of 'Compack' tomatoes was observed with mineral fertilization, CPM and SWW with mineral supplementation and CPM + SWW, whereas for the Gaucho tomato cultivar, the highest yield was obtained with CPM + SWW fertilization.

Benefit-Cost Ratio of Tomato Cultivation

Variable benefit-cost ratios were evident among the treatments (Table 6). Economic analysis of tomato fruit yield revealed the highest benefit-cost ratio (6.92) in the T_8 (4 t CPM ha^{-1}+$N_{165}P_{45}K_{150}$ kg ha^{-1}) treatment, with the second-highest ratio (6.87) observed in the T_7 (4 t CPM ha^{-1}+$N_{110}P_{45}K_{150}$ kg ha^{-1}) treatment. Benefit-cost ratios demonstrated an increase with the escalating rates of NPK fertilizers.

Selling rates were determined based on the freshness and size of the fruits. All inputs and selling rates were assessed according to local market prices. The price of fruits may vary from year to

Table 5: Effect of CPM and NPK fertilizers on the fresh and dry weight of tomato plants

Treatments	Fresh wt. (g $plant^{-1}$)					Dry wt. (g $plant^{-1}$)					Fresh biomass: Fruit ratio
	Root	stem	Leaf	Total	Fruit	Root	stem	Leaf	Total	Fruit	
T_1: Control (-CPM,-NPK)	3.31^b	11.06^e	8.01^d	22.37^e	155.73^h	1.08^d	3.44^g	2.21^e	6.73^g	23.30^h	6.60^g
T_2: 4 t CPM ha^{-1}	4.54^b	17.02^d	11.88^d	33.44^d	527.96^g	1.45^d	5.31^f	3.23^d	10.09^f	78.25^g	15.95^e
T_3:$N_{55}P_{15}K_{50}$ kg ha^{-1} (50%RDF)	6.53^b	23.42^c	17.31^c	57.57^c	45.19^f	2.15^c	7.84^e	4.77^c	18.94^e	97.50^f	11.46^f
T_4:$N_{110}P_{30}K_{100}$ kg ha^{-1} (100% RDF)	9.05^a	40.14^a	29.54^a	78.53^a	1361.09^d	2.84^b	13.64^a	8.08^a	24.56^a	195.26^d	17.13^d
T_5: $N_{165}P_{45}K_{150}$ kg ha^{-1} (150%RDF)	10.22^a	37.12^a	24.51^b	71.84^b	1479.21^c	2.90^b	11.99^b	7.00^b	22.13^c	210.24^c	21.57^c
T_6: 4 t CPM ha^{-1}+$N_{55}P_{15}K_{50}$ kg ha^{-1}	11.87^a	37.33^a	23.68^b	72.87^a	1005.83^e	4.02^a	11.93^b	6.91^b	22.92^b	148.28^e	15.46^e
T_7: 4 t CPM ha^{-1}+$N_{110}P_{30}K_{100}$ kg ha^{-1}	9.22^a	35.05^b	22.85^b	67.12^b	1703.34^b	2.94^b	11.20^c	6.72^b	20.86^d	251.40^b	26.33^b
T_8: 4 t CPM ha^{-1}+$N_{165}P_{45}K_{150}$ kg ha^{-1}	9.27^a	32.67^b	20.39^b	62.23^c	1762.51^a	2.87^b	10.44^d	5.54^c	18.85^e	261.75^a	30.04^a
LSD at 5%	4.91	4.70	4.40	5.79	5.56	0.38	0.23	0.87	0.23	4.47	3.56

CPM=Composted Poultry Manure, RDF=Recommended doses of fertilizer. Means with a different lower-case letter(s) in the same column differ significantly at 5% level

Table 6: Benefit: cost ratio of tomato cultivation on the effects of CPM and NPK fertilizers

Treatments	Yield (t ha^{-1})	Selling rate (ha^{-1})	Gross return (Tk.)	Cost of cultivation (Tk.)	Net return (Tk.)	Benefit: cost
T_1: Control (-CPW, -NPK)	6.23	6000	37380	77550	-40170	-0.51
T_2: 4 t CPW ha^{-1}	21.12	7000	147840	81550	66290	0.81
T_3:$N_{55}P_{15}K_{50}$ kg ha^{-1} (50% RDF)	25.81	8000	206480	80035	126445	1.60
T_4:$N_{110}P_{30}K_{100}$ kg ha^{-1} (100% RDF)	54.44	10000	544400	82520	461880	5.60
T_5: $N_{165}P_{45}K_{150}$ kg ha^{-1} (150% RDF)	58.50	10000	585000	85005	499995	5.88
T_6: 4 t CPW ha^{-1}+$N_{55}P_{15}K_{50}$ kg ha^{-1}	40.23	10000	402300	84035	318265	3.79
T_7: 4 t CPW ha^{-1}+$N_{110}P_{30}K_{100}$ kg ha^{-1}	68.13	10000	681300	86520	594780	6.87
T_8: 4 t CPW ha^{-1}+$N_{165}P_{45}K_{150}$ kg ha^{-1}	70.50	10000	705000	89005	615995	6.92

CPW=Composted Poultry Maure, RDF=Recommended doses of fertilizer

year, depending on the market conditions during the harvesting period.

To conclude, NPK fertilizers alone and soil amendment with 4 t ha^{-1} CPM greatly improved tomato plant agronomic parameters and yields compared to the control treatment. However, maximum tomato yields were achieved with 4 t ha^{-1} CPM and 100% recommended doses of NPK fertilizers. Therefore, the application of 4 t ha^{-1} CPM with 100% RDF of NPK fertilizers connoted a recommended combination for satisfactory tomato plant growth and yield under rooftop growing conditions. Further research should focus on achieving satisfactory plant growth and maximum tomato yields using optimum doses of CPM to supplement NPK fertilizers as much a possible considering environmental impact and roof weight mitigation. Also, exploring the possibility of using dehydrated poultry manure under rooftop growing conditions as it is light in weight and contains greater amounts of N compared to CPM.

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AUTHORS CONTRIBUTIONS

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