ASIAN JOURNAL OF AGRICULTURE
Volume 8, Number 1, June 2024
Pages: 18-24

E-ISSN: 2580-4537
DOI: 10.13057/asianjagric/g080103

Growth and yield potential of sludge-based organic fertilizers on bell pepper *Capsicum annum*

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Manuscript received: 18 January 2024. Revision accepted: 1 March 2024.

Abstract. *Balkrishna A, Gautam AK, Sharma N, Arya V, Khelwade V. 2024. Growth and yield potential of sludge-based organic fertilizers on bell pepper* Capsicum annum*. Asian J Agric 8: 18-24.* This study investigated the effects of different organic fertilizers on bell pepper's growth and yield potential (*Capsicum annum* L.). A total of six fertilizer treatments and one control in three replications were analyzed using a Randomized Complete Block Design (RCBD). The effects of fertilizer application on plant parameters were evaluated on plant height, total number of leaves, leaf area, total number of branches, number of flowers, number of fruits, average fruit weight, average fruit diameter, total yield per plot, and total yield at every 30 days after sowing. All organic fertilizers positively impacted the growth and yield of the *Capsicum* crop. The experimental results revealed that treatment T1 (Jaivik Prom), T4 (Jaivik Poshak), and T6 (Jaivik Prom+ Jaivik Khad) displayed significant performance in all parameters, where T5 (Jaivik Khad) performed well in improving leaf area, fruit weight and total yield per plot. In addition, other treatments also exhibited a notable effect on different plant parameters. Based on these results, it was found that all organic fertilizers can potentially improve the growth and yield of *Capsicum*. From this, it was concluded that the sewage sludge processing into organic fertilizers highlighted the safer and environmentally friendly way of managing Ganga sludge. Further research should be conducted on different aspects of sludge-based organic fertilizers like processing, production and field application on more field crops.

Keywords: Agriculture, *Capsicum*, growth parameters, organic fertilizers, sludge management, yield

INTRODUCTION

The production of wastes from agriculture, food industries, and city compost is a big problem that represents an environmental and health challenge. These challenges are generated due to excess waste production; the non-availability of any eco-friendly permanent solution also contributed to raising this problem. The waste generated from food industries and city compost is generally called sewage. It produces Sewage Sludge (SS) as a by-product upon going through various treatment methods, including incineration, sanitary burial and composting. Besides treatment, sewage sludge management is still a big deal in economic and environment-friendly ways. However, one of its management solutions is hidden in its composition, which contains high Organic Carbon (OC), Nitrogen (N), and Phosphorous (P) content. The conversion of sewage sludge into organic fertilizers and their use in agriculture is the perfect way of management (Tchounwou et al. 2012; Camargo et al. 2016; Velasco-Munoz et al. 2021).

Organic fertilizers are now becoming much more popular due to the increased interest in organic farming all around the globe. Several synthetic fertilizers have come into existence that are being used in the agriculture system. These chemical fertilizers were mainly introduced during the implementation of various Green Revolution initiatives and are still in use. The long-term excess uses of these fertilizers have spoiled the soil structure and fertility (Jote 2023), and farmers are now moving towards organic farming using natural and organic fertilizers and pesticides. There is an increasing interest in organic farming as a trail to compensate for decreased soil fertility. Organic fertilizers not only help in improving soil fertility but also aid in achieving sustainable agriculture without compromising the soil health and its essential structure. Adding organic fertilizers also improves biological activity, soil exchange capacity, water retention capacity, and soil structure (Bastida et al. 2008; Hargreaves et al. 2008). Their application can gradually preserve the nutritional balance necessary for crop plants to thrive by releasing nutrients into the soil solution. In addition, they also serve as a productive source of energy for soil microorganisms, which enhance soil structure and crop development (Graham et al. 2017).

Organic fertilizers cannot only be considered free from harmful chemicals but their quality was also found superior to inorganic produce. Some studies depicted those vegetables grown in organic fertilization treatments performed better and yielded higher with significantly higher concentrations of sugars and vitamin C than chemical-fertilized vegetables. A significant enhancement in the yield of leafy vegetables was observed when the leaf-picking harvest was adopted to extend the growth and

harvest period (Xu et al. 2003; Mohamad et al. 2022). Organic farming has been described as the best practice with long-term potential to improve and sustain soil quality and productivity (Ahmad et al. 2013; Shaheen et al. 2014). Several organic products are now available in the market, contributing to achieving the mission of organic farming worldwide, including in India. Due to the increasing concern about sludge management, Patanjali Organic Research Institute (PORI) has initiated a pilot project for sludge management by producing organic fertilizers and their application in agriculture.

Capsicum is a genus of flowering plants in the nightshade family Solanaceae. It has many subspecies, varieties, and cultivars and is one of the oldest cultivated crops. This genus is important in agricultural production because it contains both pungent (hot pepper) and non-pungent (sweet pepper) species. Among sweet peppers, bell pepper (*Capsicum annum* L.) is the most commonly known cultivar produced mainly in greenhouse conditions and used mostly as a vegetable (Tripodi and Kumar 2019). Like other field and vegetable crops, nutrition is important in increasing the yield of bell peppers and the availability of nutrients in the soil plays an important role in fulfilling the plant's nutritional requirements (Hapsoh et al. 2019). The fruits of bell peppers are rich in vitamin C and a good source of vitamin A and fiber. Their antioxidant properties help to protect consumers from cardiovascular disease, some cancers inflammatory conditions, such as arthritis (Tripodi and Kumar 2019).

Organic fertilizers are reported to be a good source of nutrition for vegetable crops that help them improve crop health and yield. As sewage sludge is rich in all essential nutrients required for the growth and development of any crop/plant, the present study was carried out to evaluate the effects of Ganga-sludge-based organic fertilizers on the growth, yield parameters, and fruit quality of bell pepper plants.

MATERIALS AND METHODS

Study Site

The present study was conducted from September to December 2022 to May 2023 at experimental farms of Patanjali Research Institute (PRI), Haridwar, India. The experimental area is located at 29° 54′ 49″ N and 77°59′ 51″ E and 314 meters above sea level (m asl.) (1,030 ft). Total precipitation during the study was recorded as 16.5 mm with 27°C maximum and 7°C minimum temperature. Soil samples were collected (0-20 cm depth) before the implementation of the field trial to determine the properties of soil like pH, EC, organic carbon, available nitrogen, phosphorus, and potassium as per the standard procedures (Jackson 1973).

Collection and processing of Ganga sludge samples

The Ganga sludge samples were collected from the Sludge Treatment Plant (STP) at the Jagjeetpur, Haridwar district, Uttarakhand, India. These sludge samples were then processed further for the five different organic fertilizer products based on the patented technology of Patanjali (Patent application number: 202211069280) at Patanjali Organic Research Institute (PORI). Five major organic fertilizer products, Jaivik Prom, Pori Potash, Dharti ka Chaukidar, Jaivik Poshak, and Jaivik Khad, were prepared after a series of processing procedures. The final products were evaluated singly or in combination, and their effects were assessed on the growth and yield parameters of the bell pepper *Capsicum* crop.

Experimental section

The experimental design was framed with six fertilizer treatments replicated in a Randomized Block Design (RBD) three times. The seed varieties, namely Namdhari, were used for the field experiments. Five different organic fertilizer levels evaluated in this experiment under eight treatment combinations were as T0 (Control), T1 (Jaivik Prom @ 100 kg/ac), T2 (Pori Potash @ 100kg/ac), T3 (Dharti ka Chaukidar @10kg/ac), T4 (Jaivik Poshak @ 7 kg/ac), T5 (Jaivik Khad @ 80kg/ac), T6 (Jaivik Prom+ Jaivik Khad @ 50+ 40kg/ac), T7 (Pori Potash + Jaivik Poshak @ 50+ 3.5kg/ac) (Balkrishna et al. 2023, 2024). Treatment of *Capsicum* seedlings with bio-pesticide (*Trichoderma* and *Pseudomonas* @ 5ml/liter each) was carried out by dipping their roots for about 20-25 minutes to avoid the attack of any soil-borne pathogen. The test fertilizer treatments were used at each 30-day interval after sowing. The *Capsicum* seedlings were planted with 60 cm spacing between rows and 30 cm between plants in a plot size of (2×4 m) 8m^2. Therefore, 117 plants were used in this experiment for each fertilizer treatment. The irrigation of the crop was carried out crop once every 30-35 days (4-5 in total). Similarly, weeding the undesired weeds was carried out about three times, and 2 to 3 sprays of neem oil were utilized to eradicate the attack of many insects and pests.

Growth, yield, and fruit quality analysis

To study the effects of fertilizer application on plant parameters, five plants per plot were selected randomly and evaluated throughout the study for plant height (cm), leaf area (cm^2), total number of branches, number of flowers, number of fruits, average fruit weight (g), average fruit diameter (mm), total yield per plot (g) and total yield (g). The plant height was measured from the soil level to the tip of the shoot. *Capsicum* fruits were harvested at the full-sized lush green stage around once every two weeks, and the final yield in every 30 days till the last harvesting; the final yield was expressed as the total of all yields. The number of fruits per plant, average fruit diameter per plant, and fruit yield per plant and plot were evaluated under measured yield parameters. The percentage increase over control in plant height, leaf area, weight, and yield of fruits was also calculated.

Statistical analysis

The obtained experimental data for growth and yield parameters is presented as mean ± Standard Deviation (SD). Analysis of results with ANOVA (one-way) and Dunnett's multiple comparisons test was performed using GraphPad Prism version 8.02 for Windows.

RESULTS AND DISCUSSION

Effect of organic fertilizers on growth parameters

Organic fertilizers used in agriculture are now considered an eco-friendly and economical approach that can be considered the best and safest alternative to chemical fertilizers. Even at later stages of the bell pepper *Capsicum* crop, the positive effects on growth and yield revealed their long-term efficacy. Results of the present study were expressed in terms of the effects of organic fertilizers on growth (plant height, leaf area, and total number of flowers) parameters. After a comparison of results, it was observed that all fertilizer treatments could enhance the growth of *Capsicum* crop (Figure 1).

Plant height

The plant height in the present study was measured and expressed as shoot length only. The results indicate noteworthy trends in plant height increase over control for different treatments at various intervals. At 30 days, T1 (organic P fertilizer) demonstrates a significant early positive impact on growth, maintaining consistent positive effects throughout. At 60 days, T6 exhibits the highest increase, emphasizing its sustained positive effect. At 90 days, T4 surpasses others, suggesting the crucial role of mycorrhiza in promoting plant growth. This positive impact continues at 120 days, where T4 leads, closely followed by T1. Overall, the combined application of Mycorrhiza (T4) and the synergistic effects of K fertilizer and JaviK Khad (T6) consistently yield the best results across all time intervals, highlighting their significance in promoting sustained plant growth. The performance of other treatments was also found notable, and all posed potential effects on plant height (Table 1 and Figure 2).

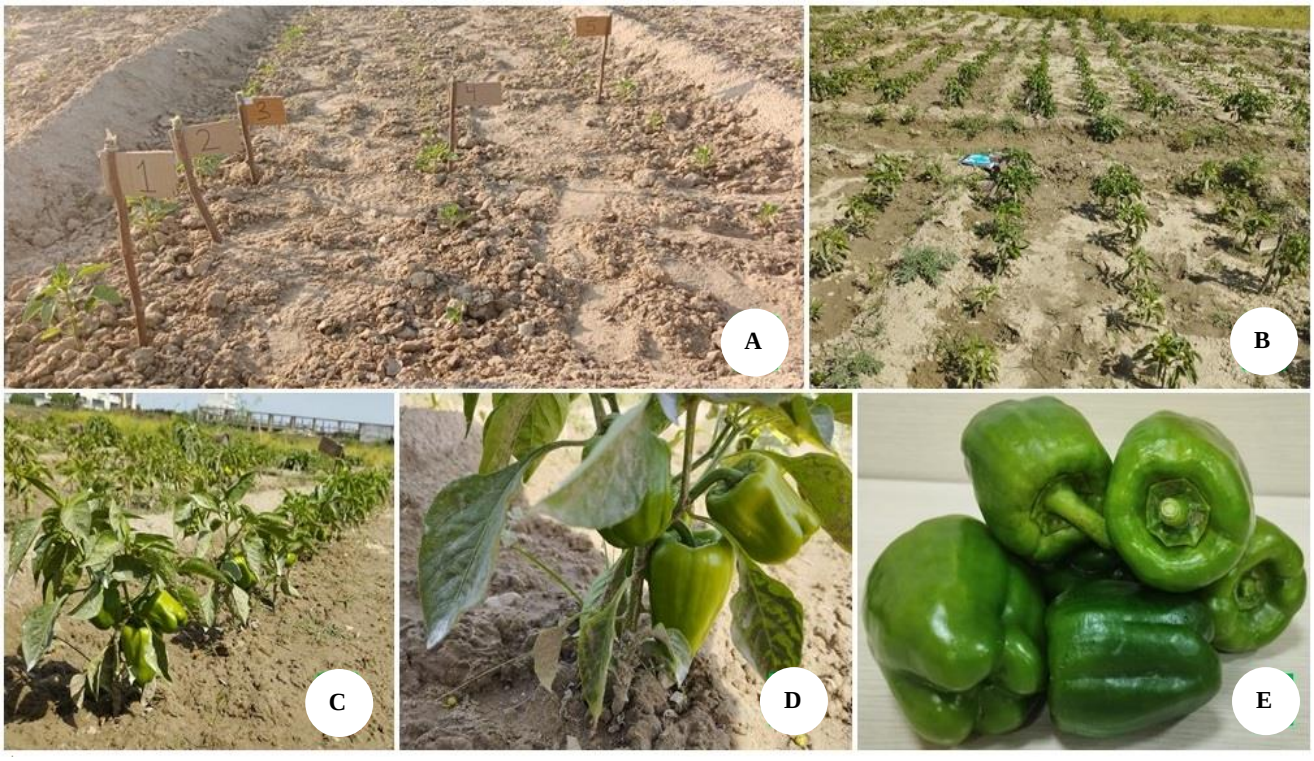

Figure 1. Comparative account on the effects of different treatments on plant parameters of bell pepper *Capsicum* at 30 and 60 days after sowing

Table 1. Effect of sludge-based organic fertilizers on plant height of bell pepper *Capsicum* at different time points

Treatments	Plant Height (cm)			
	30 Days	60 Days	90 Days	120 Days
T_0	10.600±1.778	21.133±3.139	29.267±4.793	36.000±4.400
T_1	14.800±1.562**	24.533±1.858*	37.200±8.697*	43.933±6.955**
T_2	12.000±1.744	23.200±2.623	31.800±2.778	38.800±1.249
T_3	11.400±1.058	23.667±3.449	32.800±4.303	37.533±4.206
T_4	13.733±0.503**	24.067±3.717	38.800±7.910**	45.733±3.765**
T_5	13.267±1.629**	25.200±1.458*	36.067±3.558*	42.533±1.605*
T_6	14.667±1.007**	26.133±1.514**	34.200±4.303	41.067±3.921*
T_7	12.400±0.872*	22.267±2.663	32.33±1.963	39.600±1.587

Note: Mean ± standard deviation of nine replicates. Means under each column with (*) and (**) show Significant ($p \leq 0.050$) and highly significant ($p \leq 0.001$) differences, respectively, in comparison to control

The efficacy of organic fertilizers on plant growth, even at later stages, reflects their slow release, which ensures nutrient availability up to the maximum duration of the crop (Diacono and Montemurro 2010; Jannoura et al. 2013; Lin et al. 2023). This property of organic fertilizers has been reported to have significant positive long-term effects on many crops. Based on this assumption, the basic composition of organic products used in the present study was prepared in such a way as to provide a complete nutritional balance of Nitrogen (N), Phosphorous (P), and Potassium (K) to the crops either through mycorrhiza or organic based materials (Balkrishna et al. 2023). The balanced nutritional approach enables the plants to regulate the opening and closing of the stomata, the exchange of water vapor, oxygen, and carbon dioxide, and overall growth and yield (Amanullah et al. 2016; Xu et al. 2020; Lin et al. 2023).

Leaf area and total number of flowers

Applying organic fertilizers could impact the formation of leaves, branching, and flowers. The percentage increase in leaf area compared to the control group in *Capsicum* plants exposed to different treatments at various time points reveals distinctive patterns. Throughout all stages, T5 consistently emerges as the most effective treatment, demonstrating the highest increments in leaf area. T6 also consistently showcases positive effects, particularly in the early stages, indicating a synergistic impact on leaf expansion. Notably, T1 significantly increases at 30 days, signifying an early positive influence on leaf area. T2 displays a noteworthy surge at 60 and 90 days, indicating a delayed yet positive effect on leaf expansion. Although T3 shows a substantial increase at 30 days, its impact diminishes later. T4, on the other hand, exhibits a substantial increase at 120 days, highlighting the role of mycorrhizal association in prolonged leaf development. The considerable performance of T5 establishing its effectiveness in promoting continuous leaf area growth. Furthermore, T7 manifests a notable increase at 30 days, indicating a positive effect on early leaf development. The results underscore the importance of specific treatments, such as Javik Khad and mycorrhizal association, in fostering consistent and prolonged leaf growth in *Capsicum* plants (Table 2). Therefore, the ample supply of N, P, and K by organic fertilizers can enhance nutrient uptake, including phosphorus, which is crucial for chlorophyll synthesis (Sharma and Agarawa 2009; Sardans and Peñuelas 2021; Aishwarya et al. 2022). The higher leaf area obtained in the case of treatments compared to control during the present study is perhaps associated with improved photosynthetic efficiency. Many earlier studies also demonstrated the influence of organic fertilizers on leaf area index as the result of improved chlorophyll content and influence on the growth of different crops, which also support our present findings (Hamblin et al. 2014; Nagaraj et al. 2019; Manjula et al. 2022; Ye et al. 2022).

Moreover, examining the number of branches in *Capsicum* plants under different treatments at 60 and 90 days highlights intriguing trends. However, it is crucial to note that no substancial increase in branches was observed at 60 and 90 days. Moreover, statistical analysis indicates no significant difference in branch numbers among treatments; these findings collectively suggest that the treatments did not significantly affect branching in *Capsicum* plants. At 60 days, T1 and T6 demonstrate a slight increase in branch number compared to the control (T0), indicating an early positive impact. However, by 90 days, T4 surpasses others, displaying the highest number of branches. T1 and T6 maintain respectable branch numbers, suggesting their continuous positive influence. Notably, T5 and T7 consistently demonstrate branch development, further highlighting the efficacy of Javik Khad and the combined application of phosphorus fertilizer and mycorrhiza (Table 2).

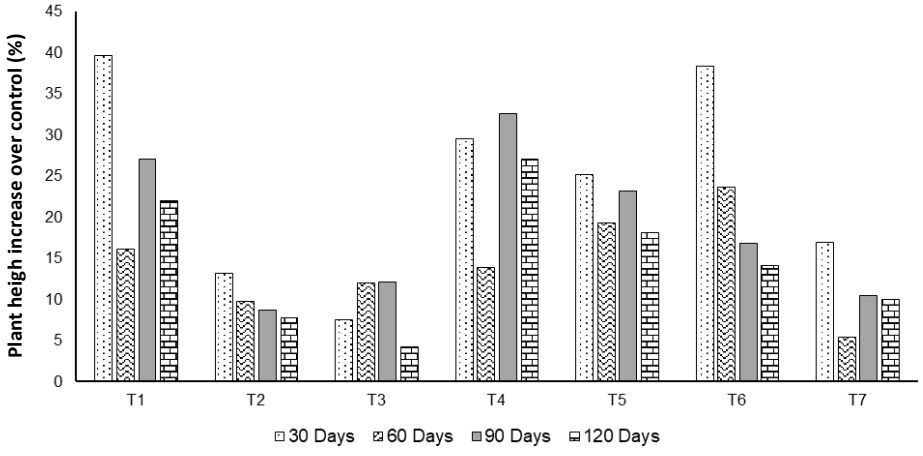

Figure 2. Percent increase over control in plant height at 30, 60, 90, and 120 DAS

A notable correlation between number of branches and number of flowers was found. At the sampled time (60 days), T4, T6, and T3 produced a considerable number of flowers (18.583±2.529, 16.267±7.814 and 15.333±8.353 respectively); other treatments also found potential in producing a respected number of flowers (Table 2, Figure 3). It also depicted the efficacy of organic fertilizer and underscored their overall significant effects on *Capsicum* growth characteristics like formation of leaves, branches, and leaves production. The credit for this improvement also goes to the balanced composition of nitrogen (N), phosphorous (P), and potassium (K) available in organic fertilizers used in the present study that can be helpful to enhance crop growth and development (Balkrishna et al. 2023). Although organic fertilizers can also lead to over-fertilization or nutrient deficiency in the soil when used improperly, their controlled release was useful to overcome such situations to neutralize these impacts and maintain sustainable agriculture yield. Their application can decline the repeated application of synthetic fertilizers. Their release of nutrients gradually into the soil can serve as a productive source of energy for soil microorganisms, which can enhance crop development and soil structure (Shaji et al. 2021).

Effect of organic fertilizers on yield parameters

Like in plant growth, increased fruit weight and total yield per plot of *Capsicum* plants were also observed continuously in all plants treated with different organic fertilizer treatments at 90 and 120 days after sowing. The yield parameters included were expressed in terms of the effects of organic fertilizers on the weight and diameter of fruits of selected plants, and total fruits yield per plot (Table 3). A positive effect of all treatments on yield parameters of *Capsicum* crops offers valuable insights into the effects of organic fertilizers on growth and overall crop yield. The yield regarding fruit weight and total yield per plot was also effectively increased in treatments compared to control. Notably, T5 consistently emerged as the most effective treatment, showcasing the highest average fruit weight (62.755±18.41 g) and total yield per plot (1839.72±355.88 g) at 90 days and maintaining its superiority at 120 days with a fruit weight of 69.24±8.17 g and a total yield of 1409.81±384.88 g. T6 also demonstrated promising results, displaying a fruit weight of 63.850±29.22 g and a total yield of 1792.22±349.70 g at 90 days and remaining competitive at 120 days with a fruit weight of 61.32±8.26 g and a total yield of 1385.11±196.99 g. Among the other treatments, T3 stands out, showcasing a significant increase at 90 days and a further at 120 days over the control. Notably, T4 also demonstrates positive effects, with a significant percentage increase at 90 days and 120 days over the control. The results emphasize the absolute yield and the substantial percentage improvements achieved by specific treatments, particularly T5 and T6, in enhancing *Capsicum* yield over the control conditions. A slight increase in average fruit was observed with the increase in days after sowing, possibly due to nutrition composition and the long-term effects of organic fertilizers. However, no significant variation in average fruit diameter was observed between treatment and control (Table 3, Figure 4). Based on the present study, organic fertilizers positively impacted crop yield; similar observations have been observed in several previous studies. Similar observations on crop yield were also observed on different crops like *Brassica*, lettuce, red chili, and other agricultural commodities (Verma and Verma 2012; Khandaker et al. 2017; Mohammed et al. 2019; Zandvakili et al. 2019; Zhang et al. 2023). Some earlier studies carried out by many researchers also concluded from their studies that the application of organic fertilizers not only enhances growth but also improves the yield in agriculture (Verma and Verma 2012; Zhou et al. 2022) and vegetable crops (Berova et al. 2010; Khandaker et al. 2017; Raturi et al. 2019). The nutrition composition of organic products produced by Patanjali Organic Research Institute (PORI) and their long-term effects contributed mainly to attaining and maintaining crop yield (Balkrishna et al. 2023). Many such findings, which revealed that suitable organic nutrient management practices could enhance the yield of field crops (Parewa et al. 2019; Jote et al. 2023), also validated the results of the present study. Such findings highlighted the utility of organic fertilizers in improving the growth and yields of crops in a safer and environmentally friendly way.

Table 2. Effect of sludge-based organic fertilizers on leaf area, number of branches, and number of flowers in bell pepper *Capsicum* at different time points

Treatments	Leaf area (cm^2)				Number of branches		Number of flowers
	30 Days	60 Days	90 Days	120 Days	60 Days	90 Days	60 Days
T_0	12.610±5.986	23.212±8.392	31.550±14.973	36.943±6.434**	5.000±0.872	6.067±1.361	13.867±7.614
T_1	19.241±4.211*	35.863±7.205*	39.317±4.276	52.940±11.244**	5.467±0.643	7.600±0.529	13.467±4.997
T_2	14.253±4.197	36.040±5.850*	40.833±8.410	53.303±11.743	5.000±2.030	7.533±1.858	12.267±0.902
T_3	17.990±5.990	29.447±4.343	40.973±15.673	44.097±4.195	5.400±1.929	7.267±2.641	15.333±8.353
T_4	17.125±2.365	32.580±9.591	38.633±7.910	38.579±0.364	5.200±1.311	8.133±1.528	18.583±2.529
T_5	19.567±2.043*	40.980±16.915**	48.930±10.266*	49.247±7.710*	5.067±1.206	7.400±1.587	12.533±2.996
T_6	20.207±3.443*	38.132±9.406*	39.133±3.855	48.030±2.920*	5.533±0.643	7.283±2.168	16.267±7.814
T_7	19.557±4.149*	34.880±2.156*	39.487±4.868	51.850±13.010*	5.267±0.503	7.200±0.872	12.533±4.692

Note: Mean ± standard deviation of nine replicates. Means under each column with (*) and (**) show Significant ($p \leq 0.050$) and highly significant ($p \leq 0.001$) differences, respectively, in comparison to control

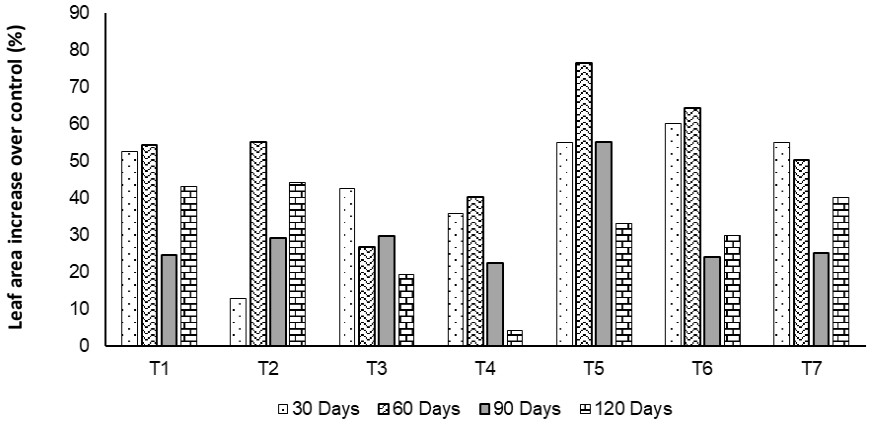

Figure 3. Percent increase over control in Leaf area at 30, 60, 90, and 120 DAS

Table 3. Effect of sludge-based organic fertilizers on weight, diameter of fruits, and total yield of bell pepper *Capsicum* at different time points

Treatments	Fruit weight (g)		Fruit diameter (mm)		Total yield per plot	
	90 days	120 days	90 days	120 days	90 days	120 days
T_0	36.514±7.042	46.607±8.559	2.0856±0.07	2.745±0.08	724.960±187.162	577.507±211.360
T_1	63.152±7.435*	60.985±12.855*	2.445±0.11	2.791±0.11	960.173±172.575	803.513±280.160
T_2	63.456±9.689*	60.024±8.859*	2.459±0.11	2.706±0.21	999.423±549.652	1047.640±135.202
T_3	55.540±18.737	66.386±10.997**	2.381±0.33	2.860±0.20	1359.490±106.062	1187.180±446.368
T_4	50.042±5.744	62.691±10.307*	2.058± 0.21	2.676±0.12	1723.027±429.965	1355.053±421.260*
T_5	62.755±18.407*	69.237±8.171**	2.460±0.49	2.791±0.04	1839.715±355.879*	1409.813±384.877*
T_6	63.850±29.224*	61.322±8.262*	2.525±0.38	2.869±0.19	1792.220±349.702*	1385.107±196.987*
T_7	61.864±19.162*	60.995±12.302*	2.653±0.29	2.829±0.18	1391.610±876.930	1164.253±223.932

Note: Yield/ plot is represented as Mean ± standard deviation of three replicates. Means under each column with (*) and (**) show Significant ($p \leq 0.050$) and highly significant ($p \leq 0.001$) differences, respectively, in comparison to control

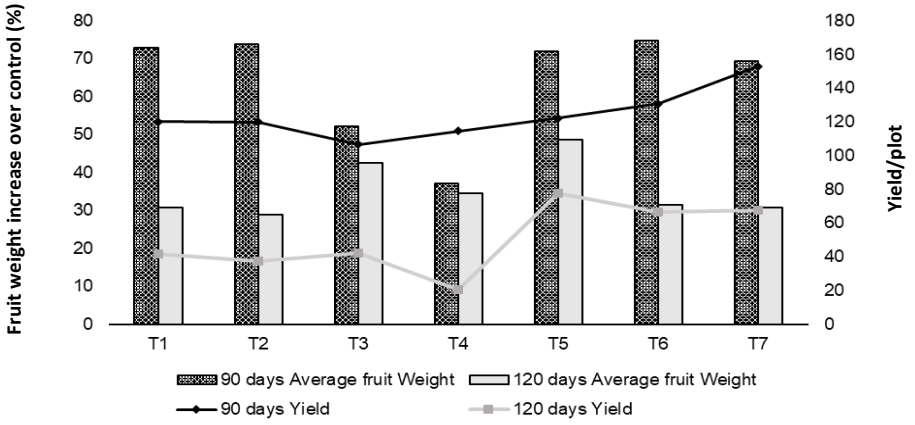

Figure 4. Percent increase over control in average fruit weight and yield/plot at 90 and 120 DAS

The overall conclusion drawn from the present study is that processing sewage sludge into organic fertilizers highlighted the safer and environmentally friendly way of managing Ganga sludge. Moreover, the importance of organic fertilizers concerning their long-term effects on growth and yield also advocated this approach of conversion of sludge into organic fertilizers. Therefore, more research should be conducted on different aspects of sludge-based organic fertilizers like processing, production and field application on more field crops.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to the revered Swami Ramdev for his inspiration. All organizations are gratefully acknowledged for providing all necessary facilities and every possible support throughout the study.

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