Special Issue (2024), S13 (1-7)

International Journal of Recycling Organic Waste in Agriculture (IJROWA), Special Issue

https://doi.org/10.57647/ijrowa-86ve-7x21

Enhancing bottle gourd yield through organic waste recycling

Shan Arain[1], Muhammad Saleem Sarki[1], Saleem Maseeh Bhatti[1], Zohaib ur Rehman Bughio[2,*], Shahnawaz Mari[3]

[1]*Department of Soil Science, Sindh Agriculture University Tandojam, Pakistan.*
[2]*Agriculture Extension Wing, Agriculture Supply and Prices Department Sindh, Pakistan.*
[3]*Department of Plant Breeding and Genetics, Sindh Agriculture University Tandojam, Pakistan.*

[*]**Corresponding author:** zohaib.bughio1@gmail.com

Original Research

Received:
23 March 2024
Revised:
7 October 2024
Accepted:
26 November 2024
Published online:
3 December 2024

Abstract:

Purpose: This research endeavor aimed to produce composts using banana plant leftovers (stem and leaves) and animal manures (poultry and cattle), and subsequently assess their nutrient concentrations and the resulting impact on bottle gourd growth.
Method: Two distinct composts were prepared by utilizing banana plants (stems + leaves) blended with cattle and poultry manure in cemented pits. Afterwards the prepared composts were used as soil amendments. The treatments included T_1: control, T_2: Recommended NPK, T_3: 10-ton compost 1 [Banana plants + Poultry manure], T_4: 10-ton compost 2 [Banana plants + Cattle manure], T_5: 5-ton compost 1 + 1/2 NPK, and T_6: 5 ton compost 2 + 1/2 NPK.
Results: The study revealed that composts significantly improved plant development and yield, with enhanced effectiveness when combined with NPK fertilizers. The treatments led to substantial increases in vine length (25 – 61%), branch number (25 – 72%), fruit, weight (14 – 79%), and yield (13 – 55%), with NPK treatment showing the highest gains. The N concentration doubled, while P and K concentrations increased 13-fold and 5-fold, respectively. Both sole and integrated NPK + Compost 2 applications effectively enhanced N concentration, while the highest P and K increases were observed with the sole NPK application, closely followed by the integrated approach.
Conclusion: Composting effectively recycled banana plant leftovers, cattle, and poultry manure, producing high-quality compost that significantly enhances growth, yield, and nutrient accumulation in bottle gourd. The combined use of compost and NPK fertilizers outperforms their individual application, suggesting that this integrated nutrient management strategy is ideal for optimizing bottle gourd production in low-fertility soils.

Keywords: Bottle gourd; Compost; Banana plant residues; Animal manures

1. Introduction

Soil carbon sequestration is a crucial process that captures CO_2 from the atmosphere and stores it in soil organic matter, with agriculture playing a significant role (Rodrigues et al., 2023). Pakistan generates a significant amount of agricultural waste, including crop residues and large quantities of livestock manure, which are often not properly managed or utilized. (Iqbal et al., 2007). The common practice of burning these residues harms the environment. Transforming crop and animal waste into compost and biochar presents a sustainable solution. This approach can reduce carbon emissions, enhance soil nutrients, decrease reliance on chemical fertilizers, and mitigate greenhouse gas emissions. Educating farmers about composting empowers them to create eco-friendly organic fertilizers, fostering a more sustainable agricultural practice (Gamage et al., 2023).

Modern agriculture heavily relies on chemical fertilizers to sustain crop production and obtain higher yields (Abebe et al., 2022). The rise in fertilizer usage under vegetable cultivation can be attributed to the development of highyielding and short-duration cultivars, which have driven the intensification of vegetable farming worldwide. These cultivars typically have higher nutrient demands, resulting in a substantial increase in the use of chemical fertilizers to meet their growth requirements and maximize yields (Krasilnikov et al., 2022). However, the excessive application of synthetic fertilizers by farmers has degraded soil productivity and undermined environmental sustainability (Aryal et al., 2021).

Interestingly, high prices, lower availability and associated risks of chemical fertilizers on environment drives to pursuit for alternate fertilizer sources for crop husbandry and environmental sustainability (Rahman and Zhang, 2018).

Organic manures have become increasingly popular as a source of nutrients for plants and a soil conditioner in recent years (Bhatti et al., 2021; Lashari et al., 2022). This has led to increase interest in the application of composts. Compost serves as a rich source of essential plant nutrients required for crop production and also contributes valuable organic matter to the soil (Bhatti et al., 2021). In addition to this, compost also improves soil structure, and promotes the activity of beneficial soil organisms, enhancing overall soil health and fertility (Riley et al., 2008; Rehman et al., 2023; Mohite et al., 2024).

Vegetables contribute to a balanced diet by not only giving energy, but also by offering nutrient protection in the form of minerals and vitamins (Pem and Jeewon, 2015). Because of their importance in ensuring nutritional security in the wake of escalating nutritional concerns in humans, vegetables are gaining prominence across the world (Ghosh et al., 2023). Bottle gourd (*Lagenaria siceraria*) locally known as Lauki, is widely grown cucurbit in the tropical and subtropical regions of the world (Prajapati et al., 2010). Across the globe, bottle gourd is cultivated for its fleshy fruit which used as a vegetable and it is taken up as fresh, fried or in soups. It also possesses medicinal properties i.e., lowering body cholesterol, pain and inflammation, avoids constipation and has diuretic and cardio-tonic properties (Mehboob et al., 2022). Since most vegetable crops only leave behind negligible amounts of crop residue, adding organic amendments like compost, and other forms of organic fertilizer is necessary to keep the soil's organic matter levels stable (Xu et al., 2023).

Despite the widely acknowledged global benefits of compost, Pakistan has conducted limited research into its preparation and analysis (Iqbal et al., 2007; Bhatti et al., 2021; Lashari et al., 2022). Notably, Pakistan generates more than 20 million tons of waste annually, with 60 to 65% of it being organic and biodegradable (Hashim et al., 2022). Due to limited access to disposal sites, agricultural waste is often mismanaged, leading to burning or destruction (Waqas et al., 731). Prioritizing the appropriate use and development of Agricultural Waste Management (AWM) is crucial for protecting the environment, ensuring sustainable agriculture, resilient rural regions, and productive farming. Among various methods for managing organic waste, biological decomposition of agricultural waste is considered the most effective. This research endeavor aimed to produce composts using banana plant leftovers (stem and leaves) and animal manures (poultry and cattle), and subsequently assess their nutrient concentrations and the resulting impact on bottle gourd growth.

Banana residues, cattle manure, and poultry manure were chosen for composting due to their common disposal practices, which often involve discarding them inappropriately near fields, roadsides, or landfills in Pakistan. This disposal neglects their valuable characteristics, including substantial moisture content, nutrient composition, and carbon content (Gerald and Charles, 2022; ElNour et al., 2015). Both cattle and poultry manure are nutrient-rich resources frequently wasted despite their recognized importance in enhancing soil fertility and supporting sustainable agricultural practices (Parihar et al., 2019).

2. Materials and methods

Compost preparation

The composting process was conducted using the pit method near the Greenhouses of the Department of Soil Science at Sindh Agriculture University (SAU), Tandojam, from July 2019 to December 2020. The composting pits were cemented, each measuring 1.1 m in length, 1.1 m in width, and 1.3 m in depth. Two distinct composts were prepared by utilizing banana plants (stems + leaves) blended with cattle and poultry manure in cemented pits as suggested by. In compost 1 (C1), banana residues were mixed with poultry manure and in compost 2 (C2) with cattle manure. Banana plant residues (trunk and leaves) collected from Latif Farm at SAU, Goat manure from the Livestock Management Department, Cattle manure from a local farm in Tandojam, and poultry manure from a farm near SAU Colony.

The pits were filled using a 3:1 ratio of banana plant residues to animal manure. The banana trunks and leaves were chopped into pieces no larger than 1 inch and layered 9 inches thick at the bottom of the pit. On top of the banana layer, a 3-inch-thick layer of animal manure (e.g., cattle, goat, or poultry) was added. This alternate layering continued until the pit was full. The composting material was turned every 15 days by transferring it into an empty pit to ensure aeration. During each turning, the temperature was monitored, and moisture was added when needed. The turning process lasted for five months, followed by one month for compost stabilization.

Chemical analysis of composts

The composts were subjected to air drying and then sieved through a 2 mm mesh. The values for EC and pH were determined in 1:5 (compost: water) extract by using EC and pH meters (Cox et al., 2021). The values for total carbon % were calculated by adopting the ignition loss method (Qureshi et al., 2014). Briefly, 50 grams of compost were dried at 105 °C for 6 hours. Afterwards, 10 grams of the dried compost were ignited in a muffle furnace at 650 – 700 °C for 6 – 8 hours. The cooled samples were then weighed to measure carbon content by loss on ignition.

The values for total N in composts were determined by Kjeldahl method (Bernal et al., 2009). In brief, 0.5 g of compost was digested with prescribed amount of H_2SO_4 and a catalyst mixture, followed by distillation with NaOH.

The distillate was titrated with 0.1 N HCl and the values for total N were calculated by using the prescribed formula. Total phosphorus in compost was determined by pre-digesting the samples overnight with HCl, followed by digestion with a di-acid mixture. After cooling, the volume was adjusted, and phosphorus was analyzed using a colorimetric technique with a spectrophotometer (Bernal et al., 2009). To determine potassium (K) concentration in compost, 1 g of oven-dried and dry-ashed compost was digested with 5 mL of HCl and filtered. The volume was raised, and potassium concentration was analyzed using a flame photometer (Bernal et al., 2009).

Details of field experiment

A field experiment was conducted at the experimental field of SAU, Tandojam. The climate of the study area is generally arid to subtropical, where summers are moderately hot, and winters are cool. Such a type of climate is generally preferred for Bottle Gourd cultivation. A plot of 120 m^2 (12 m $\times$ 10 m) was divided into 18 equal experimental units of 6 m^2 (2 m $\times$ 3 m). The experiment followed a randomized complete block design (RCBD) with three replications. The experimental soil was clay loam in texture, moderately alkaline in reaction (pH: 7.90), slightly saline (EC: 0.65 dS/m), low in organic matter (0.21%) and moderately calcareous (8.0%). The soil was low in total N (0.034%), available P (1.6 mg/kg) and adequate in extractable P (200 mg/kg).

Sowing and treatments

The sowing was done on 15th March 2020 where presoaked seeds of bottle gourd (Cv. Anmol-F1) were sown by employing the dibbling method, where 3 seeds per hill were sown manually by maintaining plant to plant distance of 2 feet. The experiment involved six treatments; T_1: Control, T_2: Recommended NPK (200, 150 and 100 kg N, P_2O_5 and K_2O tons/ha respectively), T_3: Compost 1 (C1, 10 tons/ha), T_4: Compost 2 (C2, 10 tons/ha), T_5: (1/2 C1 + 1/2 NPK) and T_6 (1/2 C2 + 1/2 NPK).

Agronomic observations

At the time of harvest, five plants were randomly selected from each replication for the recording of agronomic data. The number of branches was manually counted. Vine length, measured from the base to the tip of the plant, was determined using a measuring tape. For fruit analysis, the fruits from each selected plant were harvested, and their diameter was measured using a vernier caliper. Fruit length was recorded using a measuring scale, and the fruit weight was determined using an electronic balance.

Plant analysis

The leaf samples were decontaminated with 1% HCl, rinsed with distilled water and oven dried at 70 °C for 48 hours. The concentration of N was determined in leaf samples by following the Kjeldahl method, where the samples were digested with HCl and catalyst mixture followed by distillation with NaOH and titration with HCl (Estefan et al., 2013). For the determination of P and K, the samples were digested with di-acid mixture (HNO_3-$HClO_4$, 2:1) followed by cooling and filtration. The resulting filtrate was analyzed for P content using a spectrophotometer, while K concentration was determined using a flame photometer (Estefan et al., 2013).

Statistical analysis

The collected data was subjected to analysis of variance using one-way ANOVA in Statistix 8.1 software. Treatment means were separated using Fisher's least significant difference (LSD) test at a 5% probability level to determine significant differences.

3. Results and discussion

Chemical characteristics of prepared composts

The prepared composts exhibited significant variations concerning their EC and pH values. Notably, C1 displayed higher values for both parameters compared to C2 (Table 1 and Table 2). Despite these discrepancies, the values for both EC and pH remained within the acceptable range. Guidelines commonly recommend that the Electrical Conductivity (EC) of composts should not exceed 4.0 dS/m, and pH values should ideally fall within the range of 6.0 to 8.5 (Lasaridi et al., 2006). In this study, the values for both compost types analyzed were significantly lower than these specified thresholds, confirming their suitability for use as soil amendments.

Significant variation in total C content was evident between

Table 1. EC, pH and Total C values in prepared composts.

Compost	EC (dS m^{-1})	pH	Total Carbon (%)
C1	2.50 ± 0.07^{B}	7.9 ± 0.08^{B}	13.34 ± 1.32^{B}
C2	2.69 ± 0.05^{A}	8.3 ± 0.03^{A}	32.48 ± 1.42^{A}

C1: Compost 1 (Banana plant + Poultry manure), C2: Compost 2 (Banana plants + Cattle manure)
Each value is a mean ± SE (n = 4); Means followed by distinct letters describe the significant difference among various composts ($P < 0.05$).

Table 2. Total N, P, K % C:N ratio in prepared composts.

Compost	Total N (%)	Total P (%)	Total K (%)	C:N ratio
C1	0.64 ± 0.08^{B}	1.41 ± 0.21	1.45 ± 0.60	21.70 ± 3.29^{B}
C2	1.47 ± 0.04^{A}	1.46 ± 0.18	3.05 ± 1.09	22.20 ± 0.87^{A}

Each value is a mean ± SE (n = 4); Means followed by distinct letters describe the significant difference among various composts ($P < 0.05$).

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the prepared composts ($P < 0.05$), with C2 displaying a markedly higher total carbon ($32.48 \pm 1.42\%$) compared to C1 ($13.34 \pm 1.32\%$). In accordance with the Indonesian standard for organic fertilizer, mature compost should ideally contain no less than 10% organic carbon. It's noteworthy that the total carbon values obtained for the composts in this study surpass the minimum threshold required for organic waste, indicating their suitability for use as organic fertilizer.

The two compost types exhibited notable differences in their nitrogen (N), phosphorus (P), and potassium (K) content. Notably, C2 exhibited considerably higher levels of N, P, and K (1.47 ± 0.04, 1.46 ± 0.18, and 3.05 ± 1.09 respectively) compared to C1. According to recommendations, mature compost ideally should contain no less than 0.40% N, 0.1% P, and 0.2% K (Alfadlli et al., 2018). It is important to note that the NPK values recorded for both compost types exceeded the suggested ranges significantly. This indicates that both composts possess substantially higher levels of nitrogen, phosphorus, and potassium than the minimum recommended values, showcasing their richness and potential effectiveness as fertilizers.

The C:N ratio in the prepared composts varied significantly where the values found to be 6.85 ± 1.57 in C1 and 22.20 ± 0.87 in C2. According to literature, a compost should ideally possess a C:N ratio value of < 25 (Gautam et al., 2010). The C:N ratio values observed in this study fall below this recommended threshold, indicating the maturity of the composts. This suggests their suitability for utilization in agricultural fields and other applications.

Growth and yield of bottle gourd as influenced by inorganic and organic amendments

The study found that composts prepared and used in the research had a significant impact on plant development and yield ($P < 0.05$, Table 3). Interestingly, when integrated with inorganic NPK fertilizers, their effectiveness increased significantly. When compared to the control group, the addition of these various treatments resulted in remarkable improvements across multiple parameters. Vine length increased by 25 to 61%, the number of branches increased by 25 to 72%, fruit width increased by 21 to 62%, fruit length increased by 18 to 48%, fruit weight increased by 14 to 79%, and fruit yield increased by 13 to 55%. Among the treatments applied, there was a consistent trend of increment, with NPK treatment leading to the highest improvements followed by NPK + Compost 2, NPK + Compost 1, Compost 2, and Compost 1. The possible reason for such increment might be due to efficient release of nutrients from all tested nutrient sources, which contributes to improved plant development and agricultural output. Compost application enhances growth and yield by providing a slow, steady release of essential nutrients like nitrogen, phosphorus, and potassium. This continuous nutrient supply supports healthy plant development and increases productivity of bottle gourd (Taneja et al., 2024). These results are very encouraging due to the fact that the integrated application of NPK and composts not only improves growth and yield but simultaneously will also enhance soil fertility while reducing the cost of chemical fertilization. These finding agree with the findings reported previously where the positive impacts of inorganic NPK and organic fertilizers was noticed on the growth and yield characteristics of Bottle gourd (Pravallika and Panshu, 2020; Taneja et al., 2024).

Nutrient accumulation in bottle gourd leaves as influenced by inorganic and organic amendments

The supplementation of organic and inorganic amendments led to significant improvements in nutrient accumulation in leaves (Table 4). The N concentration showed a twofold increment, while the increments in P and K concentration were 13-fold and 5-fold respectively. Interestingly, the sole application of inorganic NPK and the integrated application were equally effective in enhancing N concentration, whereas the maximum enhancements in P and K concentration were achieved with the sole application of inorganic

Table 3. Influence of amendments on selected growth and yield characteristics of bottle gourd.

Treatments	Vine length (cm)	Branches per vine	Fruit width (cm)	Fruit length (cm)	Fruit weight (g)	Fruit yield (kg/plot)
T_1 = Control	351.8±1.8F	10.7±0.1F	16.9±0.1F	30.6±0.6F	652.0±2.1F	56.5±1.2F
T_2 = Recommended NPK	439.3±1.1A	16.0±0.4A	27.4±0.3A	45.3±0.5A	988.8±1.9A	82.9±0.9A
T_3 = Compost 1 @ 10 t ha^{-1}	380.2±1.3E	11.6±0.2E	21.1±0.2E	36.0±0.4E	729.3±1.6E	63.1±0.1E
T_4 = Compost 2 @ 10 t ha^{-1}	399.3±1.6D	12.5±0.2D	22.4±0.3D	38.4±0.3D	766.0±0.8D	67.5±0.8D
T_5 = Compost 1 @ 5 t ha^{-1} + half recommended NPK	413.4±1.3C	13.4±0.2C	24.7±0.2C	40.1±0.5C	827.6±1.0C	73.1±1.6C
T_6 = Compost 2 @ 5 t ha^{-1} + half recommended NPK	421.1±0.8B	14.7±0.2B	25.7±0.3B	42.3±0.4B	914.3±1.7B	78.6±0.5B

Each value is a mean ± SE (n = 3); Values with the same letter within in rows are not significantly different at p = 0.05.

Table 4. Effect of organic and inorganic applications on concentration of N, P and K in leaves of bottle gourd.

Treatments	**N %**	**P %**	**K %**
T_1 = Control	1.24±0.24D	0.13±0.01C	0.50±0.03F
T_2 = Recommended (200-150-100) NPK kg ha^{-1}	3.56±0.03A	1.57±0.24A	3.27±0.05A
T_3 = Compost 1 @ 10 t ha^{-1}	2.06±0.04C	0.11±0.01C	1.40±0.06E
T_4 = Compost 2 @ 10 t ha^{-1}	2.32±0.01C	0.22±0.01C	2.40±0.03D
T_5 = Compost 1 @ 5 t ha^{-1} + half recommended NPK	2.75±0.02B	0.65±0.01B	2.80±0.01C
T_6 = Compost 2 @ 5 t ha^{-1} + half recommended NPK	3.20±0.15A	0.88±0.02B	2.90±0.05B

Each value is a mean ± SE (n = 3); Values with the same letter within in rows are not significantly different at p = 0.05.

NPK, closely followed by the integrated application. These findings highlight the importance of appropriate nutrient management strategies for maximizing nutrient uptake and plant growth in bottle gourd cultivation. Combining organic compost with inorganic NPK fertilizers improves soil structure, moisture retention, and microbial activity while providing quick nutrient uptake (Ghimire et al., 2023). This synergy ensures better nutrient availability and accumulation in leaves, boosting plant growth and productivity (Dogbatse et al., 2021). These findings align with previous studies that demonstrate a significant increase in NPK concentration in plant leaves resulting from the individual application of NPK, compost, as well as their integrated use (Bhatti et al., 2021; Lashari et al., 2022).

4. Conclusion

Composting served as an effective approach to recycle and utilize banana plant leftovers, cattle, and poultry manure, producing composts that meet international quality standards. The application of these composts significantly improved the growth, yield, and nutrient accumulation in bottle gourd. Furthermore, the integrated application of compost with NPK fertilizers proved superior to their sole use, enhancing plant productivity and nutritional quality. Therefore, in soils with low fertility, adopting an integrated nutrient management strategy combining compost and inorganic NPK is recommended to optimize bottle gourd production and soil health.

Authors contributions

Shan Arain: Executed the field experiment and write up of Thesis (as MSc student). Muhammad Saleem Sarki: Conceived the idea of field experiment, data analysis and write up work (Main Supervisor of the student, 1st Author). Saleem Maseeh Bhatti: Conceived the idea of composts preparation and analysis, Overall management of the work and manuscript write up (Co-Supervisor 1 of the student). Zohaib ur Rehman Bughio: Helped in thesis writeup, manuscript management (formatting, latest references) and journal correspondence as corresponding author. Shahnawaz Mari: Helped in Field experiment and Thesis Writeup (Co-Supervisor 2 of the student).

Availability of data and materials

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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