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Research Article
Growth and Yield Performances of Tomato (*Solanum lycopersicum* L.) on Goat Manure Bio-Slurry Fertilization

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Abstract

Background and Objective: Tomato (*Solanum lycopersicum* L.) is among the vegetables with an ever-rising demand in Indonesia, yet national production is still lacking. Fertilization is a direct strategy to boost productivity and most productions are achieved in a high synthetic input of fertilizer farming system. This strategy promises superior growth and yield instantly, yet could result in serious drawbacks e.g., diminishing soil fertility and environmental pollution in the long term. The utilization of goat manure bio-slurry was proposed for abundance and high nutrient profile. Hence, this study reported the preparation of bio-slurry through anaerobic fermentation of goat manure and the effect of bio-slurry fertilization on several tomato growth and yield parameters. **Materials and Methods:** The research was designed as two factors randomized complete block design on the dose and frequency of the bio-slurry application on the tomato of Mutiara cultivar. The first factor is dosage of bio-slurry of goat manure and the second factor is the frequency of the goat manure bio-slurry. Each treatment was repeated 3 times, so there were 48 experimental units and a total of 144 plants. **Results:** As 75 mL L^{-1} bio-slurry at 4 times application produced the highest parameters observed in terms of plant height, root length, number of leaves, total flowers, fruit sets, fruit sugar content and fruit storability compared to the control treatment of NPK fertilization. Further analysis of the nutritional content of the bio-slurry revealed the presence of nutrients namely N, P, K, Zn, Fe and Cu which were at high levels. **Conclusion:** This study underlined the potency of goat manure bio-slurry as a means of fertilization to boost tomato productivity in a more sustainable manner.

Key words: Tomatoes, goat manure, bio-slurry, sustainable farming, fertilization

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is an important horticultural commodity because of its nutritional contents which can be useful for antioxidants, anticancer, anti-anemia etc.[1]. Tomato production in Indonesia is still low[2]. One way to increase it is with proper fertilization[3-5]. Though, some factors still persist that hamper tomato production in Indonesia[6].

Fertilization seems to be the easiest strategy to boost tomato productivity which has been done[7-10]. Unfortunately, most crop productions use synthetic fertilizer[11]. Using synthetic fertilizer will have negative effects on the environment (e.g., alteration in soil structure, reduction of soil organic content and soil water holding capacity) and cause serious land, air and water pollution[12]. To overcome this problem, it is recommended to use organic fertilizers instead of synthetic[13].

Organic fertilizers are organic substances that contain macro and micro nutrients needed for the growth and development derived from processed biological waste products such as animal manures, sewage sludge, municipal solid wastes, or food wastes[13,14]. Converting these materials into organic fertilizers would bring benefits, reducing the negative impact of unprocessed wastes on the environment[14]. Livestock such as chickens, goats, sheep, cows and pigs produce large quantities of manure daily. In integrated farming, rearing livestock along with cropping activities nearby is a beneficial circular bioeconomic. Thus, the conversion and utilization of manures into organic fertilizer can bring benefits while promoting more sustainable farming practices[13].

The conversion of animal manure into organic fertilizer is through anaerobic digestion. Conversion is achieved in a closed system and the final product is called bio-slurry[15]. This anaerobic digestion i.e., fermentation of animal manure is facilitated by countable native microbes present in manures such as *Salmonella*, *Listeria monocytogenes*, *Clostridium* spp., *Bacillus* spp., *Campylobacter* sp., *Staphylococcus* and *Streptococci*[16,17]. Some of them are pathogenic, yet, Islam *et al.*[15] found that these microbes were absent in the final product. Moreover, the anaerobic digestion of animal manures produces almost no-nutritional losses. Manures contains macro and micro nutrients such as N, P, K, Ca, Mg etc., which are mostly retained in the digestate. These ensures the biosafety and nutritional quality of bio-slurry as organic fertilizer[18,19].

In this study, goat manure was converted anaerobically into bio-slurry and used to fertilize tomatoes of the Mutiara cultivar. The treatment used was a combination of bio-slurry dosage and application frequency. The most optimal dosage was investigated based on several growth and yield parameters such as plant height, root length, number of leaves, total flowers, fruit sets, fruit sugar content and fruit storability.

MATERIALS AND METHODS

Experimental information and materials used: The study was carried out from February to May, 2022 at Mlaras, Jombang, Jawa Timur Province.

The site was on entisol soil with an elevation of 38 m above mean sea level. The materials used to produce the bio-slurry were raw goat manure, rice washing water, young coconut water, palm sugar and commercial yeast. Other materials used included tomato seed of Mutiara cultivar and NPK fertilizer which were obtained from local vendors nearby.

Goat manure digestion into bio-slurry: The digestion of goat manure into bio-slurry was carried out anaerobically by the following method. The materials prepared consisted of raw goat manure 13.5 kg, rice washing water 8 L, young coconut water 8 L, palm sugar 100 g and commercial yeast pellet 20 g. Then, all materials were mixed and placed in a 20 L sealed plastic bucket as the digestion vessel. The mixture was stirred daily and digested for 14 days until the digestate produced no more foam. The final product was called goat manure bio-slurry. For analytical purposes, the bio-slurry was analyzed for its nutrient content using the appropriate methods.

Experimental design: The experiment was designed as two factors factorial Completely Randomized Design (CRD). The first factor was the dose of bio-slurry (D) and the second factor was the frequency of bio-slurry application (F). The dose was set at four levels namely 25 mL L^{-1} (D1), 50 mL L^{-1} (D2), 75 mL L^{-1} (D3) of bio-slurry and 20 g NPK as the control treatment (D0). Concurrently, the frequency of bio-slurry application was also set at four levels: Once (F1), twice (F2), thrice (F3) and four times (F4) application. A total of 16 treatment combinations were obtained and replicated three times.

Tomato cultivation and bio-slurry treatment: Tomato seedlings were prepared until producing 3-4 leaves and subsequently transplanted into polybags. Plants maintenance were watering, staking, trimming and pest disease control. Bio-slurry application was done at the previously prescribed combinations. All tomato fruits were harvested at 90-100 days after transplanting (DAT) by picking up the fruits characterized by a minimal 80% level of hardness and hard texture.

Parameters observed: Tomato growth and yield performances were assessed on several parameters. Growth parameters observed were plant height (cm), root length (cm), number of leaves and total flowers. While yield parameters observed were fruit sets (%), fruit sugar content (% Brix) and fruit storability (days). Plant height, root length, number of leaves and total flowers were observed and measured at 84 DAT. Fruit sets were defined as the total percentage of flowers that successfully develop into fruits and calculated at 100 DAT. All fruits were harvested at no more than 100 DAT and measured for their sugar content and fruit storability. Fruit sugar content was measured by using a refractometer, while fruit storability was measured qualitatively upon any observed physical changes e.g., change in color or shape.

Statistical analysis: The data was displayed as the mean value. The data was statistically analyzed by using Analysis of Variance (ANOVA) procedure. Should there be any significance, the data was further analyzed by using the Least Significance Difference (LSD) *post hoc* Test. The significance level was set at 95% ($\alpha = 0.05$).

RESULTS

Physical and nutritional characteristics of the bio-slurry: The digestion process of goat manure into bio-slurry took 14 days to complete. Based on physical observation (Fig. 1), there were several characteristic changes before and after the digestion process. The color was darker, the viscosity was higher and the aroma was less strong in the finished slurry. There was also apparent remaining foam on the surface of the slurry. Further analysis showed a slightly higher pH at 7.5 but it was still categorized as near neutral and organic C was at a very low level.

The nutrient content of goat-manure bio-slurry was analyzed using the appropriate methods. The nutrient content analyzed included macro and micro-nutrients such as total N, C, P, K, Zn, Fe and Cu. The result of the analysis (Table 1) showed that some were found in high or very high levels (e.g., P, K, Zn and Fe), while the others were at the medium level (N) and low or very low levels (Cu and organic C).

Effect of goat manure bio-slurry on growth performances of tomato of Mutiara cultivar: Growth performances of tomato plants of Mutiara cultivar affected by the combination of goat manure dosage and frequency of application were displayed in Fig. 2. Table 1 shows growth performances in terms of plant height (cm), root length (cm), number of leaves and total flowers. The combination of 75 mL L^{-1} bio-slurry in 4 times application seemed to produce the highest performances on all parameters observed. The differences were significant in all parameters but root length and total flowers. In root length,

Table 1: Nutrient content of goat manure bio-slurry organic fertilizer

Parameter	Method	Score	Criteria
pH (H_2O, 2:1)	Potentiometer	7.5	Neutral
N-total (%)	Kjeldahl	0.41	Medium
C-organic (%)	Walkley-black	0.6	Very low
P-total (ppm)	Wet digestion (extract HNO_3 and $HClO_4$)	278	Very high
K-total (ppm)	Wet digestion (extract HNO_3 and $HClO_4$)	922	Very high
Zn-total (ppm)	Wet digestion (extract HNO_3 and $HClO_4$)	46.56	High
Fe-total (ppm)	Wet digestion (extract HNO_3 and $HClO_4$)	41.29	High
Cu-total (ppm)	Wet digestion (extract HNO_3 and $HClO_4$)	2.35	Low

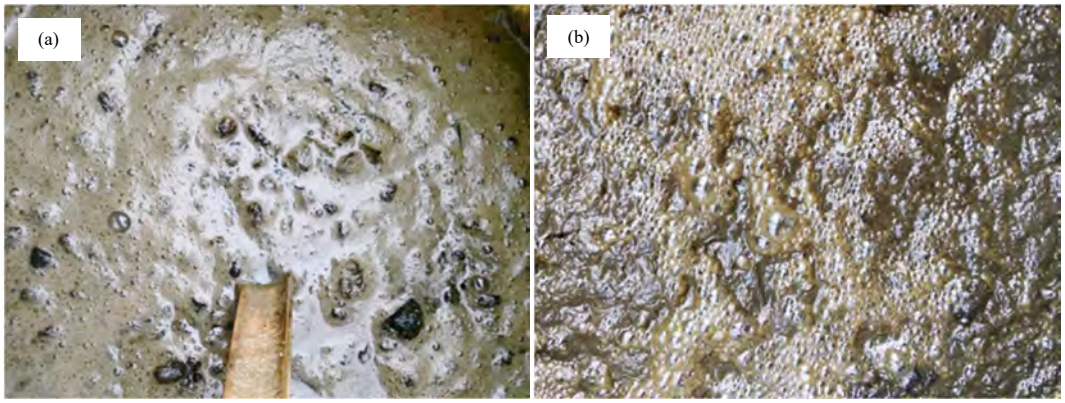

Fig. 1(a-b): Appearance of goat manure produced in this study, (a) Before and (b) After processing into bio-slurry

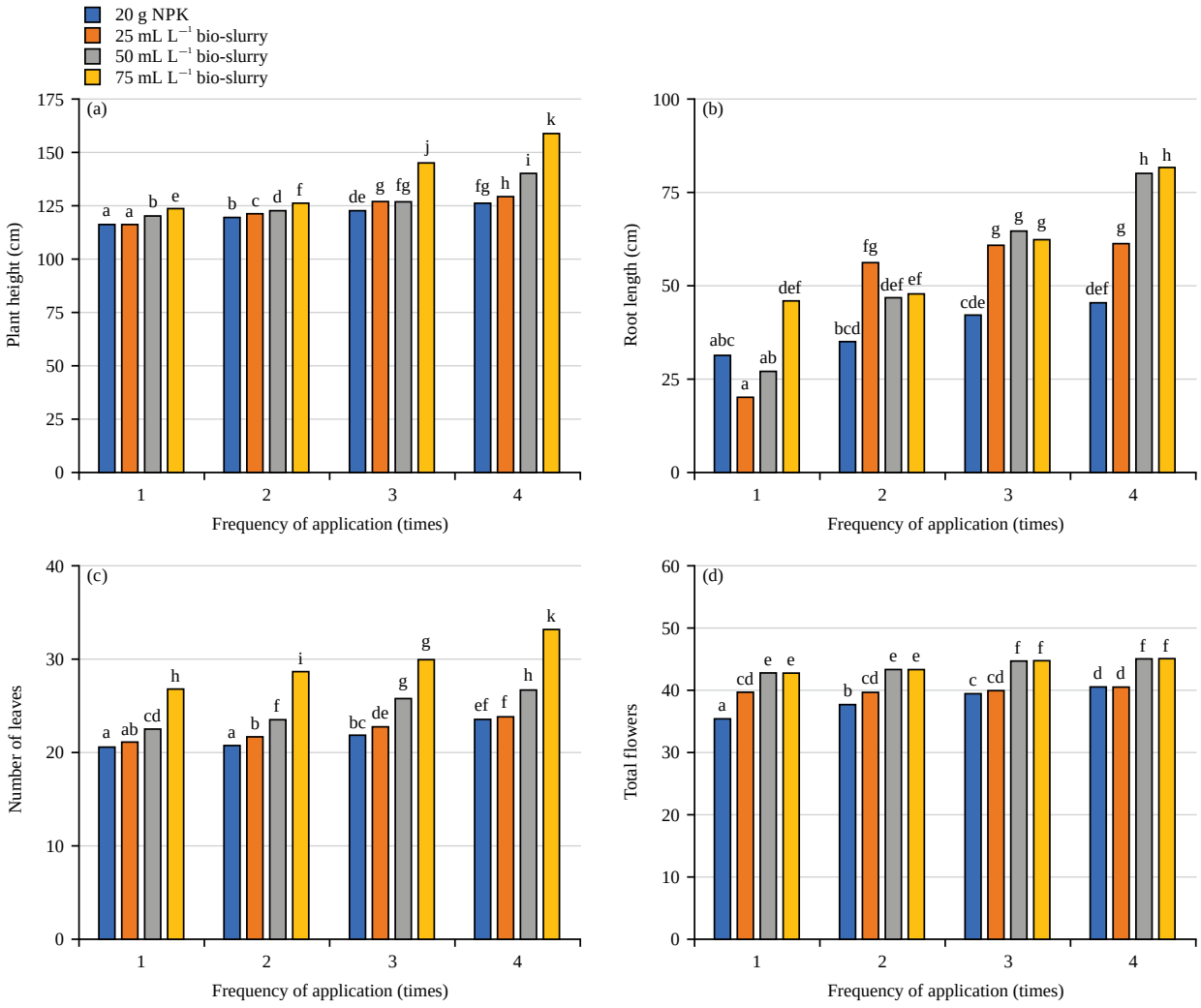

Fig. 2(a-d): Growth performances of tomato in terms of, (a) Plant height, (b) Root length, (c) Number of leaves and (d) Total flowers of Mutiara cultivar on the application of combination of goat manure bio-slurry dosage and frequency

Small letter above the diagram shown the difference based on Least Significant Difference (LSD) test at significance level 95% ($\alpha = 0.05$)

there was no difference between 75 and 50 mL L^{-1} bio-slurry at 4 times of application. While in total flowers, both 50 and 75 mL L^{-1} bio-slurry were not different either at 3 or 4 times of application. Overall, it could be concluded that the application of goat manure bio-slurry positively affected all parameters observed. Any increase in bio-slurry dosage and/or frequency would increase plant height, root length, number of leaves and total flowers. Further, the data also clearly showed that the growth performances of tomatoes were better compared to the control NPK treatment in all parameters. These results clearly indicated a positive effect of goat manure bio-slurry upon the growth performances of tomato of Mutiara cultivar.

Growth performances of tomatoes in terms of, (a) Plant height, (b) Root length, (c) Number of leaves and (d) Total flowers of Mutiara cultivar on the application of a combination of goat manure bio-slurry dosage and frequency was shown in Fig. 2. The small letter above the diagram shows the difference based on the Least Significant Difference (LSD) test at a significance level of 95% ($\alpha = 0.05$).

Effect of goat manure bio-slurry on yield performances of tomato of Mutiara cultivar: Yield performances of tomatoes of Mutiara cultivar on goat manure bio-slurry application were displayed in Fig. 3. Table 1 showed fruit sets (%), fruit sugar content (% Brix) and fruit storability (days) of tomato fruit harvested at no more than 100 DAT. Interestingly, there was not any significant interaction between the doses and frequencies of application hence, analyzed separately. The

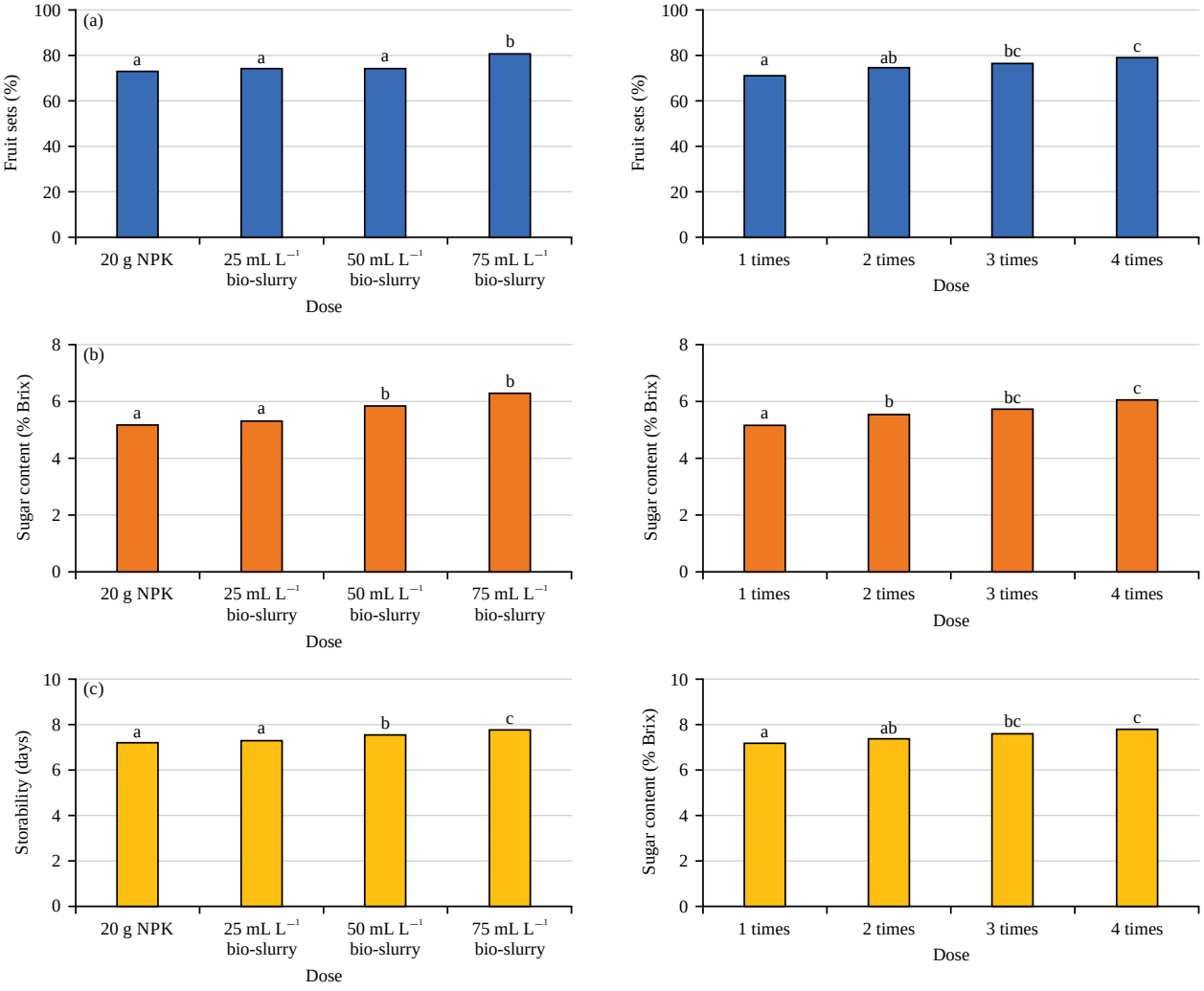

Fig. 3(a-c): Yield performances in terms of, (a) Fruit sets, (b) Fruit sugar content and (c) Fruit storability of tomato of Mutiara cultivar on the application of combination of goat manure bio-slurry dosage and frequency. Interaction is not significance, hence the diagram was made separately

Small letter above the diagram shown the difference based on Least Significant Difference (LSD) test at significance level 95% ($\alpha = 0.05$)

dose of 75 mL L^{-1} bio-slurry significantly resulted in the highest yield performances but fruit sugar content was not significantly different from that of 50 mL L^{-1} bio-slurry. Also, the frequency of 4 times bio-slurry application gave the highest yield performances, yet it did not differ significantly from that of 3 times application in all parameters. It was also notable to mention that both 75 mL L^{-1} dose and 4 times the frequency of bio-slurry gave significantly higher performances in all yield parameters i.e., fruit sets, fruit sugar content and fruit storability. Overall, their results indicated positive effects of bio-slurry application on yield performances of tomato of Mutiara cultivar.

Yield performances in terms of, (a) Fruit sets, (b) Fruit sugar content and (c) Fruit storability of tomato of Mutiara cultivar on the application of a combination of goat manure bio-slurry dosage and frequency was shown Fig. 3. The interaction is not significance, hence the diagram was made separately. The small letter above the diagram shows the difference based on Least Significant Difference (LSD) test at significance level 95% ($\alpha = 0.05$).

DISCUSSION

The ever-increasing food demand has stressed our ability to produce more crops in order to satisfy the demand. Yet, excessive use of synthetic fertilizer in long term produces more harm than benefit and hence is unsustainable. The use of organic fertilizer obtained from animal manure conversion

has become an attractive choice due to its ability to fertilize the soil and increase the yield, while minimizing the environmental risks[14]. At the same time, a mainstream question of whether such organic fertilizer could satisfy the nutrients needed by plants always arises. Plants need macro-(e.g., N, P, K and Mg) and micronutrients (e.g., Zn, Fe, Mn and Cu) for their growth and development. They serve crucial roles either as the building blocks of important macromolecules (e.g., DNA, protein, enzyme and ATP), the regulator of many physiological and biochemical processes (e.g., osmoregulation, enzyme activation, molecules translocation), cell functioning and structural integrity (e.g., cell wall synthesis, cell elongation, cell division) and many other functions[20-23]. Therefore, it was important to ensure that the fertilizer must contain the above nutrients in satisfying quantity first before its deployment into the field to substitute inorganic fertilizer to some degree[19].

A nutritional analysis had undertaken to answer that question (Table 1). The bio-slurry was characterized by high P, K, Zn and Fe, fairly medium N and low Cu content. It also had a quite normal pH (7.5) and a low amount of organic C. Even though not all nutrients were analyzed, those results indicated the presence of some important plant nutrients at satisfying levels. These would support plants' optimum growth and yield. Moreover, the pH was near neutral which satisfies the pH requirements of most plants and the presence of organic C could supplement soil organic C upon application.

It was known that the anaerobic digestion of animal manure into bio-slurry results in minimal to almost no-nutritional change[18,19]. Hence, the nutritional content of the bio-slurry depends on the raw materials i.e., goat manure that was used in this study. Goat manure contains high macronutrient content particularly nitrogen (as NO_3^- and NH_4^+) and phosphorus (as PO_3^-)[13,24]. Aside from macronutrients, goat manure also contains essential micronutrients such as Zn, Fe, Cu and Mn in satisfying levels[24]. These were in conformation with that of current data as shown in Table 1. Moreover, in anaerobic digestion, the pH tends to decrease first due to the synthesis of volatile acids, yet subsequent processes (e.g., methane synthesis, CO_2 removal and basic cations shift) that followed after would lead to protons consumption hence increasing the final pH at 7.3-9.0[18,19]. This was also in conformation with the final pH of 7.5. Goat manure also has medium[25] to high[26] organic carbon content that was reduced to a lower level due to the biodegradation of most organic matter into biogas[18] which was responsible to the low organic carbon content in the final bio-slurry product.

The application of bio-slurry into tomato plants showed consistently positive effects across all parameters. It results in significantly higher growth and yield performances compared to the control treatment where NPK (20 g) was used. Interestingly, there were two distinct patterns in the data obtained. The combination of dose and frequency of bio-slurry somehow demonstrated significant interaction on the growth parameters. Both factors synergistically contributed to the increase in plant growth, root length, number of leaves and total flowers. On the contrary, there was no significant interaction between the dose and frequency of bio-slurry on yield parameters hence fruit sets, fruit sugar content and fruit storability was separately affected by either the increase of dose and frequency of bio-slurry application.

Vegetative growth is a collective work that may contribute to the process. Put aside the genetic and other biotic-abiotic factors but nutrients, the growth and development of plants were largely affected by nutrient availability in their surroundings[9]. Plant utilizes macronutrients such as nitrogen, phosphorus and potassium as the materials to synthesize many important biological macromolecules such as DNA, RNA, proteins, enzymes, lipids etc.[20-22]. These macromolecules further serve as the main building block of plant cells and tissue, hence the more nutrients available to the plants, the better the growth performance of plants would be. This was demonstrated in the data which on the higher level of bio-slurry dosage and frequency of application resulted in better tomato growth performance in terms of plant height, root length, number of leaves and total flowers was shown.

On the other hand, the application of bio-slurry also positively affected tomato yield parameters yet the dose and frequency seemed to act separately since there was no significant interaction between them. This was very interesting because this result was quite different from that of the previous result. It seemed that in the yield parameters observed, the micronutrients play a more important than the macronutrients. Without disregarding the importance of the latter since they are already present in sufficient quantities, micronutrients on the other hand were needed by plants only in much smaller quantities, hence any increases in neither dose nor frequency did not result in a significant interaction between them[27]. The importance of micronutrients is emphasized in Liebig's law of diminishing return which the output growth and development of plants are often dictated by the compliance of the micro- instead of the macronutrients[28].

Among the micronutrient content analyzed in this work, there were Zn, Fe and Cu. The Zn plays roles as a co-factor in many metabolic-related enzymes, cell division and synthesis of important molecules such as protein, auxin and ATP[29,30]. Meanwhile, Fe takes part in photosynthesis, especially in chloroplast development and as an electron carrier, protein biosynthesis and activation of enzymes among all[31]. At last, Cu is a cofactor in many enzymes and plays many important roles in respiration, photosynthesis, lignification, metabolism, protein synthesis and auxin regulation[32].

The NPK of Mutiara brand was used as the control treatment in this study. Based on the information from the manufacturer, it contains elemental N, P and K in a ratio of 16:16:16 (% weight). N present in NO_3^- (6.5%) and NH_4^+ (9.5%), P present as P_2O_5 and K present as K_2O (NPK Mutiara). It also contains other nutrients namely Mg (0.5%, in form of MgO) and Ca (6%, in form of CaO)[33]. However, it did not contain any micronutrients. In comparison, our bio-slurry contained medium N, very high P and K and some micronutrients in the forms of Zn, Fe and Cu with varying levels. The other micro- and macronutrients, even though were not analyzed, must also be present in our bio-slurry as suggested by others[19,24,34]. Hence, in a vis-à-vis comparison, our bio-slurry is superior to NPK which was demonstrated by the data shown in this work.

CONCLUSION

Anaerobic digestion of goat manure produced bio-slurry which was rich in nutrients particularly N, P, K, Zn, Fe and Cu content in sufficient quantity. The combination of dose and frequency of bio-slurry resulted in higher growth and yield performances of tomato of Mutiara cultivar compared to NPK fertilizer. The result of this work indicated the potency of goat manure bio-slurry as the nutrient source to fertilize plants in place of inorganic synthetic fertilizer in a more sustainable farming practice.

SIGNIFICANCE STATEMENT

This study aims to determine the growth response and yield of tomato plants fed organic fertilizer derived from goat manure bio-slurry. The results of this study demonstrate the potential of goat manure bio-slurry as a source of nutrients to fertilize plants as a substitute for inorganic synthetic fertilizers in more sustainable farming practices. The results of this study need to be carried out further research on the content of microorganisms from goat manure bio-slurry fertilization.

REFERENCES

1. Vats, S., R. Bansal, N. Rana, S. Kumawat and V. Bhatt *et al*., 2022. Unexplored nutritive potential of tomato to combat global malnutrition. Crit. Rev. Food Sci. Nutr., 62: 1003-1034.
2. Yunita, R. and S. Isnaeni, 2020. Study of growth and production of tomato cultivars in response to fruit thinning at Tamansari, Tasikmalaya, West Java, Indonesia. J. Trop. Crop Sci., 7: 45-50.
3. Anisa, W.N., E.N.Afifah and R.H. Murti, 2022. Selection of tomato breeding lines based on morphological traits associated with high yield potential in double-cross population. Biodiversitas J. Biol. Diversity, 23: 2973-2980.
4. Suyadi and Rosfiansyah, 2017. The role of plant parasitic nematodes on productivity reduction of banana and tomato in East Kalimantan, Indonesia. Asian J. Agric., 1: 40-45.
5. Taberima, S., S. Prabawardani, R. Sarwom and G. Lyons, 2020. Organic fertilizer applications improve the growth of vegetable crops and chemical properties in the tailings deposition area at Timika, Papua, Indonesia. Nusantara Biosci., 12: 134-142.
6. Fakhrunnisa, E. and J.G.K. dan Sudarsono, 2018. Production of cherry tomato and beef tomato hydroponics system at amazing farm, Bandung [Indonesian]. Buletin Agrohorti, 6: 316-325.
7. Li, Y., Y. Sun, S. Liao, G. Zou and T. Zhao *et al*., 2017. Effects of two slow-release nitrogen fertilizers and irrigation on yield, quality, and water-fertilizer productivity of greenhouse tomato. Agric. Water Manage., 186: 139-146.
8. Molla, A.H., M.M. Haque, M.A. Haque and G.N.M. Ilias, 2012. *Trichoderma*-enriched biofertilizer enhances production and nutritional quality of tomato (*Lycopersicon esculentum* Mill.) and minimizes NPK fertilizer use. Agric. Res., 1: 265-272.
9. Souri, M.K., F.Y. Sooraki and M. Moghadamyar, 2017. Growth and quality of cucumber, tomato and green bean under foliar and soil applications of an aminochelate fertilizer. Hortic. Environ. Biotechnol., 58: 530-536.
10. Ye, L., X. Zhao, E. Bao, J. Li, Z. Zou and K. Cao, 2020. Bio-organic fertilizer with reduced rates of chemical fertilization improves soil fertility and enhances tomato yield and quality. Sci. Rep., Vol. 10, 10.1038/s41598-019-56954-2.
11. Wulan, D.R., D. Marganingrum and M. Yoneda, 2020. Distribution, source identification, and assessment of heavy metal pollution in the surface and pore waters of Cipeles River, West Java, Indonesia. Environ. Sci. Pollut. Res., 27: 39123-39134.
12. Savci, S., 2012. Investigation of effect of chemical fertilizers on environment. APCBEE Procedia, 1: 287-292.
13. Kurniawati, A., R.D.H. Windriyati, N.K. Wulansari, G. Toth and Z. Toth, 2021. Alternatives for circular bioeconomy in organic farming under excessive nutrients (goat manure and arbuscular mycorrhizal fungi): A case study in Indonesia. Sustainability, Vol. 13. 10.3390/su132212333.

14. Chew, K.W., S.R. Chia, H.W. Yen, S. Nomanbhay, Y.C. Ho and P.L. Show, 2019. Transformation of biomass waste into sustainable organic fertilizers. Sustainability, Vol. 11. 10.3390/su11082266.
15. Islam, M.A., P. Biswas, A.A.M. Sabuj, Z.F. Haque and C.K. Saha *et al*., 2019. Microbial load in bio-slurry from different biogas plants in Bangladesh. J. Adv. Vet. Anim. Res., 6: 376-383.
16. Bagge, E., L. Sahlström and A. Albihn, 2005. The effect of hygienic treatment on the microbial flora of biowaste at biogas plants. Water Res., 39: 4879-4886.
17. Massé, D., Y. Gilbert and E. Topp, 2011. Pathogen removal in farm-scale psychrophilic anaerobic digesters processing swine manure. Bioresour. Technol., 102: 641-646.
18. Kusuma, M. and R. Afrianisa, 2021. Initial characterization of bio-slurry as liquid fertilizer. J. Phys.: Conf. Ser., Vol. 2117. 10.1088/1742-6596/2117/1/012007.
19. Möller, K. and T. Müller, 2012. Effects of anaerobic digestion on digestate nutrient availability and crop growth: A review. Eng. Life Sci., 12: 242-257.
20. Andrews, M., J.A. Raven and P.J. Lea, 2013. Do plants need nitrate? The mechanisms by which nitrogen form affects plants. Ann. Appl. Biol., 163: 174-199.
21. Wang, F., M. Deng, J. Xu, X. Zhu and C. Mao, 2018. Molecular mechanisms of phosphate transport and signaling in higher plants. Semin. Cell Dev. Biol., 74: 114-122.
22. Wang, Y. and W.H. Wu, 2017. Regulation of potassium transport and signaling in plants. Curr. Opin. Plant Biol., 39: 123-128.
23. Hajiboland, R., 2012. Effect of Micronutrient Deficiencies on Plants Stress Responses. In: Abiotic Stress Responses in Plants: Metabolism, Productivity and Sustainability, Ahmad, P. and M.N.V. Prasad (Eds.), Springer, New York, ISBN: 978-1-4614-0633-4, pp: 283-329.
24. Mbatha, K.C., C.N. Mchunu, S. Mavengahama and N.R. Ntuli, 2021. Effect of poultry and goat manures on the nutrient content of *Sesamum alatum* leafy vegetables. Appl. Sci., Vol. 11. 10.3390/app112411933.
25. Zhang, T., L. Liu, Z. Song, G. Ren, Y. Feng, X. Han and G. Yang, 2013. Biogas production by co-digestion of goat manure with three crop residues. PLoS ONE, Vol. 8. 10.1371/journal.pone.0066845.
26. Kaur, H. and R.R. Kommalapati, 2021. Optimizing anaerobic co-digestion of goat manure and cotton gin trash using biochemical methane potential (BMP) test and mathematical modeling. SN Appl. Sci., Vol. 3. 10.1007/s42452-021-04706-1.
27. Kumar, S., S. Kumar and T. Mohapatra, 2021. Interaction between macro- and micro-nutrients in plants. Front. Plant Sci., Vol. 12. 10.3389/fpls.2021.665583.
28. Martins-Loução, M.A., T. Dias and C. Cruz, 2022. Integrating ecological principles for addressing plant production security and move beyond the dichotomy 'good or bad' for nitrogen inputs choice. Agronomy, Vol. 12. 10.3390/agronomy12071632.
29. Suganya, A., A. Saravanan and N. Manivannan, 2020. Role of zinc nutrition for increasing zinc availability, uptake, yield, and quality of maize (*Zea mays* L.) grains: An overview. Commun. Soil Sci. Plant Anal., 51: 2001-2021.
30. Sarwar, M., M.F. Saleem, N. Ullah, S. Ali and M. Rizwan *et al*., 2019. Role of mineral nutrition in alleviation of heat stress in cotton plants grown in glasshouse and field conditions. Sci. Rep., Vol. 9. 10.1038/s41598-019-49404-6.
31. Briat, J.F., C. Dubos and F. Gaymard, 2015. Iron nutrition, biomass production, and plant product quality. Trends Plant Sci., 20: 33-40.
32. Tripathi, D.K., S. Singh, S. Singh, S. Mishra, D.K. Chauhan and N.K. Dubey, 2015. Micronutrients and their diverse role in agricultural crops: Advances and future prospective. Acta Physiol. Plant, Vol. 37. 10.1007/s11738-015-1870-3.
33. Paiman, Ardiyanta, C.T. Kusumastuti, S. Gunawan and F. Ardiani, 2021. Maximizing the rice yield (*Oryza sativa* L.) using NPK fertilizer. Open Agric. J., 15: 33-38.
34. Sunaryo, Y., D. Purnomo, M.T. Darini and V.R. Cahyani, 2018. Nutrients content and quality of liquid fertilizer made from goat manure. J. Phys.: Confer. Ser., Vol. 1022. 10.1088/1742-6596/1022/1/012053.