Asia-Pacific Journal of Science and Technology :Volume :30 Issue :05 Article ID :APST-30-05-11 Research Article

Asia-Pacific Journal of Science and Technology

https//:www.tci-thaijo.org/index.php/APST/index

Published by Research and Innovation Department,
Khon Kaen University, Thailand

Beneficial Microbes (BMs) in organic fertilizer increased the yield of eggplant watered with laundry waste: Exploiting BMs bioremediation and growth promoting potentials

Jomar L. Aban[1*], Analyn V. Sagun[1], and Jenilyn A. Asirot[1]

[1] Don Mariano Marcos Memorial State University, Bacnotan, La Union, 2515, Philippines
*Corresponding author: jaban@dmmmsu.edu.ph

Received 22 August 2024
Revised17 January 2025
Accepted 30 April 2025

Abstract

Beneficial microorganisms (BMs) are naturally occurring soil microbes that are inoculated in organic fertilizers to amplify their abilities to decompose organic matter and make macronutrients readily available to plants. Aside from BMs' ability to enhance biodegradation, they are also found to bioremediate toxins in the environment. This study was conducted to determine the effect of BMs in organic fertilizer on the vegetative development and yield of eggplants. Using a true experimental design, 210 eggplant seedlings were grown in pots using a randomized complete block design. The average height growth and plant vigor index were highest in eggplants grown in organic fertilizer with beneficial microbes (OFBM) soil media. When laundry waste was used instead of tap water, the eggplants grown in OFBM media produced comparable results, proving potential bioremediating activities by these beneficial microbes. Two significant discoveries were recorded. First, that eggplants grown in OFBM show enhanced growth and fruit production, and second, that the use of laundry waste as irrigation results in comparable yields to those watered with tap water due to the bioremediation capabilities of the BMs. These findings imply that integrating waste materials like laundry water in agricultural practices could promote sustainable farming and soil health by reducing waste while enhancing crop yields. The study recommends practical applications of using laundry waste to irrigate crops grown in OFBM media, promoting ecological sustainability and resource efficiency in agricultural production.

Keywords: Agricultural innovation, Beneficial microorganisms, Biotechnology, Increased production, Organic agriculture

1. Introduction

As a developing country, the Philippines is struggling to sustain the agricultural needs of its population. The current population of the Philippines in 2024 is more than 119 million. With this huge number, agricultural scientists are concerned about how to sustain the survivability of the population while protecting biodiversity. According to research, the scale of human growth explosion contributes to the substantial loss of biodiversity. Several solutions have been proposed to increase food production while protecting the environment [1]. These include: sustainable farming practices, precision agriculture, agroforestry, crop diversification, and the development of climate-resilient crop varieties.

There has been an increase in the reckless use of chemical fertilizers in conventional farming to increase agricultural production. The overuse of chemical fertilizers brings potential hazards to the environment, including loss of macronutrients, a drop in microbial activity, soil fertility reduction, and pollution of bodies of water, land, and air. [2]. The proposed use of organic fertilizer in agricultural production has become unappealing to some farmers due to a drastic decrease in agricultural yield caused by slow nutrient release to support crops in a short time [3]. However, published data shows an increased crop yield when using organic fertilizer. For instance, the technical efficiency of organic fertilizer in rice in Bangladesh [4]. The use of organic fertilizer created higher flower and root yield on *Panax*, a valuable herbal plant used in Chinese medicine [5]. Organic and biological fertilizers also increased the biomass and yield of various agricultural crops while improving the physicochemical properties of soil [6].

Microorganisms have been vastly studied due to their importance in the soil and in plants. Microbes such as bacteria and fungi are well-known decomposers of organic matter. They exist in the soil to ensure that nutrients found in all organic matter, including dead plants and animals, are recycled back to the soil and made available for plant nutrient assimilation. Soil microbes are considered invisible managers of soil fertility because they play a pivotal role in various biogeochemical processes, including carbon, nitrogen, and phosphorus cycles, to maintain soil health [7].

Lugtenberg et al. [8] suggested mechanisms of microbial action on the plant host. These include (a) release of plant growth-promoting factors, (b) degradation action to release specific plant nutrients in organic matter, and (c) microbial plant growth regulation and stress control. The microbes, the soil, and the plants evidently show a tripartite interaction for nutrient acquisition and enhanced plant growth for sustainable agriculture [9].

While it is crucial to address agricultural crop production using organic fertilizer and naturally occurring soil microbes, another critical environmental problem continues to exist. Laundry wastes that is perpetually generated by residential houses cause inevitable water pollution. As the population increases, the risk of water contamination due to wastewater becomes more prevalent. Laundry wastewater contains pollutants such as surfactants, phosphates, and heavy metals that can significantly impact the physiology of microorganisms, potentially affecting their biophysiological capabilities. To address this, the bioremediating potential of microbes is further exploited. Beneficial bacteria can thrive in reduced fertilizer environments while promoting nutrient activation, improving plant growth under stress. Beneficial microbial consortia can enhance soil fertility and inhibit pathogenic organisms, thereby indicating that their physiological adaptations to contaminants in wastewater may enhance their effectiveness in breaking down harmful compounds. Heavy metals and other waste from detergents are common wastewater, and bioremediation from water and soil relies heavily on microbes [10]. Heavy metals present in laundry detergents, such as lead, cadmium, and mercury, can be phytotoxic, leading to inhibited plant growth, reduced nutrient uptake, and alterations in physiological processes. However, once broken down or transformed by beneficial microorganisms in organic fertilizers, these harmful compounds can potentially be restructured into less toxic forms or sequestered, allowing plants to assimilate essential micronutrients that contribute to their growth and overall health. According to Kapoor et al. [11], the remediation process done by microorganisms is considered a clean, effective, and safe way to detoxify wastewater.

In a nutshell, beneficial microorganisms (BMs), including various bacteria and fungi, play a crucial role in sustainable agriculture by enhancing soil fertility and plant health. These microorganisms facilitate the decomposition of organic matter, making macronutrients readily available for plant uptake. Specifically, they release plant growth-promoting factors such as phytohormones, which stimulate root development and improve plant vigor [2]. Additionally, BMs engage in symbiotic relationships with plant roots, helping plants resist environmental stressors while enhancing nutrient absorption. The cycling of essential nutrients such as carbon, nitrogen, and phosphorus—mediated by soil microbes—provides a stable nutrient base conducive to plant growth [7]. Furthermore, BMs have demonstrated potential for bioremediation, especially in tackling environmental pollutants like those found in laundry wastewater. Laundry wastes often contain surfactants, phosphates, and heavy metals that pose significant risks to ecosystem health. Research has shown that specific BMs can degrade these contaminants via enzymatic activities, transforming harmful compounds into less toxic forms that are more easily assimilated by plants [4]. By leveraging the capabilities of BMs in both promoting plant growth and remediating wastewater, this study aims to explore the efficacy of BMs in organic fertilizers applied to eggplants watered with laundry waste. Finally, the increasing generation of household laundry waste poses a significant threat to the environment due to the pollutants it contains, which can contaminate water sources and disrupt local ecosystems. Addressing this issue is crucial as integrating bioremediation methods in agricultural practices not only mitigates the impact of wastewater on soil health but also transforms these wastes into valuable resources that enhance plant growth and productivity [11].

In this present study, the researchers investigated the beneficial microorganisms found in organic fertilizers and examined the BMs' abilities to not only retain soil health and fertility but also to bioremediate the laundry waste introduced to the soil to water eggplants. The researchers determined whether the BMs have the ability to maintain or increase the yield of eggplant even when these plants were exposed to laundry waste treatments. The researchers chose eggplant because it is known for its versatility in culinary applications and rich nutritional profile, being recognized as a significant crop in the Philippines. It is also cultivated in various regions due to its adaptability to different climatic conditions. The country produces approximately 80,000 tons of eggplants annually, making it one of the primary vegetable crops grown for both local consumption and export. With rising demand for healthy and flavorful vegetables, the consumption of eggplant in the Philippines continues to grow, as it is a staple in many traditional dishes and is recognized for its potential health benefits, including antioxidant properties and dietary fiber content.

The researchers sought to determine the effect of laundry waste on eggplant grown in agricultural soils applied with BM-activated organic fertilizers. Specifically, average height growth, the number of marketable fruits and weight of eggplant fruit were measured to find out how the beneficial microbes present in the organic fertilizer would bioremediate the laundry waste and reconfigure the unwanted, even potentially toxic, components of laundry waste and convert them into nutrients that can be assimilated by plants.

2. Materials and methods

2.1 Theoretical mechanisms of action by beneficial microbes

Figure 1 shows the theoretical mechanisms of action by the beneficial microorganisms contained in the organic fertilizer through the bio-activator technology of the ELR (Eliseo R. Ruiz) Family Trading Company.

The bio-activator technology allowed the use of naturally occurring soil microbes in greater quantity to synergistically work together to increase their decomposition role. As these microbes produce enzymes and other extracellular exudates, they can convert organic wastes such as leaves, fruit peelings, vegetable wastes, organic solid wastes and other biodegradable wastes into organic fertilizer. It is also speculated that these beneficial microbes found in organic fertilizer have the ability to perform bioremediation activity. This means when laundry waste in applied to soils amended with organic fertilizers containing these beneficial microbes, these microbes will reconfigure the molecular structure of harmful compounds found in laundry waste and transform these compounds in macronutrients that are readily assimilated by plants [7-11].

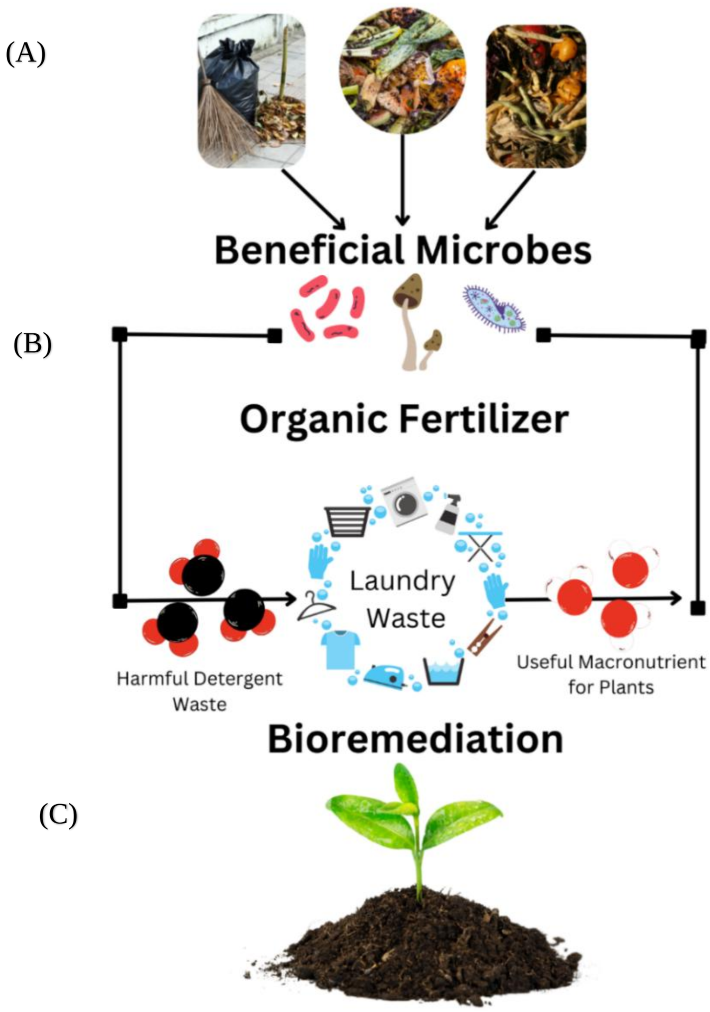

Figure 1 Theoretical mechanism of action by the beneficial microbes in organic fertilizer. (A) Wastes are turned into fertilizer by beneficial microbes. (B) Beneficial microbes transform harmful detergent waste to useful macronutrients for plants. (C). Increased nutrients in soil also increase plant growth and productivity.

2.2 Research design

This research utilized true experimental design. True experimental design is operationally defined as having four elements: manipulation, control, random assignment, and random selection [12]. These elements were satisfied in the present experimental research. The negative control group did not receive any fertilizer application. Consequently, the positive control group received chemical fertilizer application but were not watered with laundry waste. Manipulation was done by applying different levels of laundry waste to the treatment groups. Eggplant grown in pots was randomly assigned through a random complete block design setup. All 210 eggplants grown in various replications per treatment per block were randomly selected.

2.3 Control and experimental treatment groups

Table 1: Fertilizer application and tap/wastewater application per treatment.

Treatment Group	Water Application	Fertilizer Application
T0 – Negative Control	100% tap water	No fertilizer applied
T1 – Positive Control 1	100% tap water	100% chemical fertilizer*
T2 – Positive Control 2	100% tap water	100% OFBM**
T3 – Experimental Group 1	25% laundry waste***	100% OFBM
T4 – Experimental Group 2	50% laundry waste	100% OFBM
T5 – Experimental Group 3	75% laundry waste	100% OFBM
T6 – Experimental Group 4	100% laundry waste	100% OFBM

*The chemical fertilizer applied was based on the eggplant package of technology from Agricultural Training Institute – Department of Agriculture, Philippines, and was also based on soil requirement; ** OFBM – organic fertilizer with beneficial microbes; *** laundry waste application – 25% laundry waste means 25 mL of laundry waste was diluted to 75 mL tap water; 50% laundry waste means 50 mL of laundry waste was diluted to 50 mL tap water; 75% laundry waste means 75 mL of laundry waste was diluted to 25 mL of tap water

2.4 Eggplant seed growing, selection and seedling production

Eggplant seeds were randomly selected and were grown in seedbeds for four weeks by growers from the Department of Agriculture, Philippines. A single variety (var. Calixto) of randomly chosen eggplant seedlings was procured from these growers (> 4 weeks old) and were transplanted in polyethylene bags. Approximately 5 gallons of soil volume were placed in bags. The topsoil from the study site was scooped and placed into the bags. The potting media used in the study included the topsoil from the study site, homogenously mixed with carbonated rice hull. Rice hull served as a bulking agent in the soil [13]. A soil expert was consulted for the bagging and soil preparation of all the treatment groups. For T1 (positive control), complete fertilizer (14-14-14) at 10g per pot was applied and was covered lightly with soil. For the treatment groups (T2-T6), 200 g of organic fertilizers with beneficial microbes (Plantmate, Philippines) were applied per bag.

2.5 Transplantation and maintenance

Prior to transplantation, the polyethylene bags were initially irrigated. One seedling was planted per bag. The plant in the polyethylene bag was watered directly into the soil contained in the bag using the drench technique. The bag was watered well at least one inch per week. Tap water was used for all the control groups. Meanwhile, wastewater was used for all the experimental groups, but in different proportions corresponding to the treatment group specification. Weeds were removed two to three times during the growing season, or as necessary. Mulching was practiced to minimize weed growth and maintain uniform soil moisture. Manual removal of damaged leaves and shoots was done to manage the spread of pests and diseases. No pesticides were applied during experimentation.

2.6 Harvesting

Mature fruits, which are shiny and still soft, were harvested. All fruits were harvested, including those that are deformed and damaged. Those without damages and deformations were considered marketable fruits. There were six harvesting periods within two to six months after planting.

2.7 Laundry waste collection and storage

Household laundry wastes were used to water the treatment groups in the study. 100% laundry waste is operationally defined as the wastewater generated while washing clothes (primary washing), including the wastewater generated after the 1st and 2nd rinsing. The present document did not specify the exact composition of the laundry waste as it utilized commercially available detergents, which can vary significantly in formulation. By not identifying specific brands or types, the research maintained a broader applicability to typical household laundry practices, acknowledging that households frequently use a mix of commonly available products. This general approach allows for the findings to be relevant to a wide audience, rather than confined to particular detergents or chemicals that may not be universally used. However, the laundry waste generated was presumed to contain sand, grit, lint, oil, grease, heavy metals, and various detergent waste, and the high concentration of these unwanted materials can contaminate the environment and affect the lives of humans and biota in aquatic systems [14]. All laundry wastes were stored using 200L blue plastic drums. These wastes were stored for no more than a week and were used to water the experimental treatment groups. Approximately 1 L of water was used per bag. Therefore, about 120 L was used to water the 120 seedlings for T3 to T6, which were watered every week for six months.

2.8 Data collected / agronomic attributes measured

The following agronomic attributes were measured: (1) average height growth; (2) total number of fruits; (3) total number of marketable fruits; (4) total fruit weight; (5) total marketable fruit weight. The agronomic traits were measured as follows:

Average height growth. This is the final height minus the initial height of the eggplant, measured in cm. The height was measured from the base of the main step to the tip of the terminal bud of the eggplant using a ruler.

The initial height was measured right after transplanting. The final height was measured 120 days after transplanting.

Total number of fruits. This is the total number of all fruits collected per treatment group per harvest time.

Total number of marketable fruits. This is the total number of all fruits without damages and deformation.

Total fruit weight. This is the total weight of all fruits collected per treatment per harvest time. This was measured in (g).

Total weight of marketable fruits. This is the total weight of fruits without damage and deformation. This was measured in (g).

2.9 Statistical analysis

The statistical analysis involved conducting a one-way analysis of variance (ANOVA) to determine significant differences among the various treatment groups based on the number and weight of fruits produced. Following the ANOVA, Tukey's multiple pairwise-comparisons test was employed as the post-hoc analysis to identify which specific groups exhibited statistically significant differences from one another. To verify ANOVA assumptions, including normality and homogeneity of variances, residual analysis was performed using normal Q-Q plots and Levene's test, ensuring that the data met the necessary criteria for the validity of the ANOVA results.

Specifically, the data on average height growth of eggplants were presented using Quest Graph box plot visualization and normal Q-Q plot to verify the assumption through residual analysis. Standard deviation was presented as error bars. The minimum, the median [box], and the maximum value were displayed in the box plot.

Meanwhile, the data on the total number of fruit and total weight were presented using Microsoft Excel Chart Builder – Custom Combination (Stacked Column – Line). A stacked column chart was used to visualize the first through the sixth harvesting period. A line graph was used to project the total yield from the first to the last harvesting period. Chart elements were added, including axes, gridlines, legends, and data labels. The data labels provided numerical data for each harvesting period and the total yield of the harvest. Before one-way analysis of variance was performed, the number of fruits and the weight of fruits were assumed to have 10 replications. Using the true value for harvested yield as the standard, the value deviated by +1 per replication for the number of fruits and by +100.00 per replication for the weight of fruits. This was done since no replication was available for the data on the total yield (number of fruits and weight of harvest).

The one-way analysis of variance (ANOVA) was calculated using Quest Graph ANOVA Calculator [15]. Using this software, ANOVA was used as an extension of the independent two-sample t-test to analyze differences among the different treatment groups. The ANOVA uses the F-statistic and its corresponding *p*-value to find out whether the data comes from the same population. A significant *p*-value suggests that some of the group means were different. Being an omnibus test statistic, a post-hoc analysis is required to determine which specific groups were statistically significantly different from each other. Tukey's multiple pairwise comparisons are used in assessing the mean difference between specific pairs of groups.

3. Result and discussion

3.1 Average height growth of eggplants

The average height growth of eggplants was measured because this agronomic attribute is a core part of the plant's ecological strategy. Published data suggest that the average plant height is strongly correlated with other agronomic and eco-physiological traits such as life span and time of maturity. This attribute is also a crucial factor that determines a plant's ability to compete with light [16].

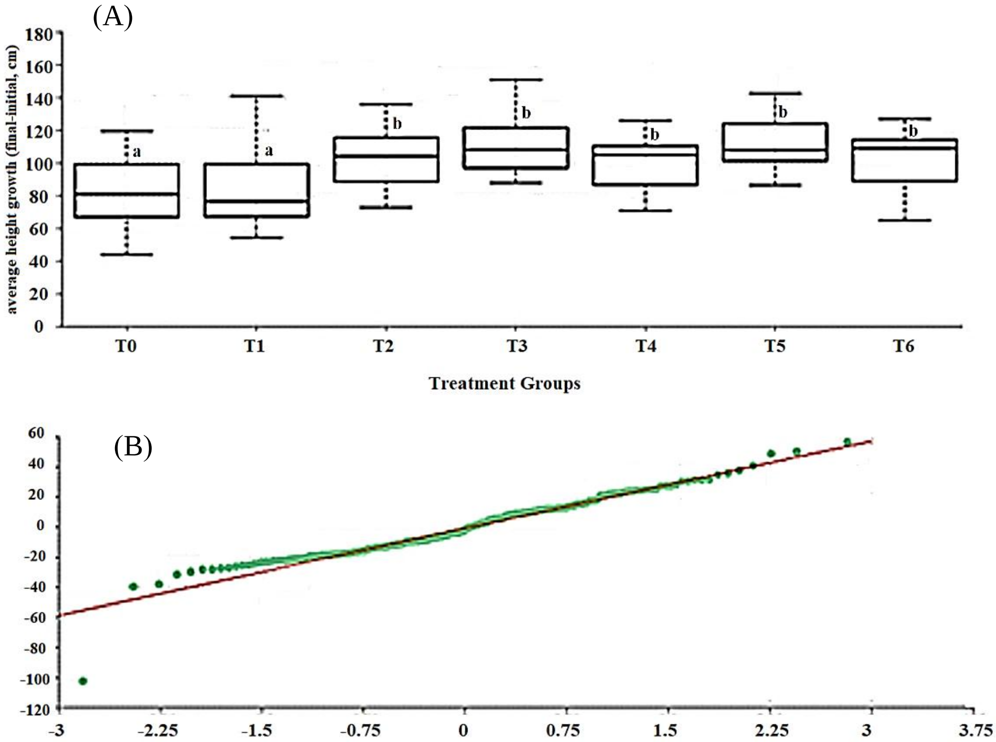

Figure 2 Average height growth of eggplants (cm). (A) Box plot visualization of average height growth (final-initial) showing significant difference using Tukey's multiple pair comparison test. Means with different letters are significantly different (α level of significance = 0.05). Standard deviation is presented as error bars. The minimum, the median [box], and the maximum value are presented. ANOVA summary result: F- statistic = 11.8407; *p*-value = 2.2298e-11. (B) Normal Q-Q plot to verify assumptions through residual analysis.

The average height growth of eggplants through box plot visualization and Q-Q plot verification is presented in Figure 2. The T5 formulation, that is, 75% laundry wastewater to organic fertilizer with beneficial microbes (OFBM) amended soils, has the highest numerical mean height of eggplants (mean = 111.85$\pm$15.27). This value is comparable to all the other OFBM amended treatment groups applied with 100% tap water (T2) or varying laundry waste formulations, T3 (25%), T4 (50%), and T6 (100%), respectively. All the OFBM treatment formulations, regardless of the type of water treatment applied, were significantly higher than the T0 negative control (no fertilizer) and the T1 positive control (chemical fertilizer application). This result is indicative of the superior performance of the OFBM treatments in terms of the average height growth of eggplants. It is implied further that the beneficial microbes in the organic fertilizer were able to transform the unwanted detergent residues and even potentially toxic compounds found in laundry waste into useful compounds that facilitated the increased growth of eggplants, making these plants significantly healthier vegetatively than the negative control group. The study demonstrated that eggplants grown in OFBM experienced significant height growth, even when irrigated with increasing concentrations of laundry waste. Meanwhile, the height of eggplants was comparable to that of those watered with laundry waste, up to 75%, indicating that the beneficial microorganisms effectively mitigated any potential phytotoxicity of the detergent residues, leading to maintained growth performance. This suggests that BMs present in organic fertilizer can enhance both plant resilience and growth, reaffirming their role as vital components in sustainable agriculture even under challenging environmental conditions.

Several published studies show that beneficial microbes affect plant height. In the study of Wang et al. [17] discovered that after growing wheat in reduced fertilizer application condition, beneficial bacteria helped in the activation of nutrients and promote the growth of wheat. Porter et al. [18] suggested the mechanism by which beneficial microbes promote growth. The BMs ameliorate abiotic and biotic stress sources in plants. As these microbes make the stressful environment more tolerable in plants, the plants have a greater opportunity for enhanced vegetative growth and development. Santoyo et al. [19] further emphasized that the consortia of beneficial microbes promote diversity and improve soil fertility. As a result, they inhibit the growth and infective action of microbial pathogens, therefore improving plant growth.

These previously established findings were supported by the present study. The eggplants grown in abiotic stressful conditions through the application of laundry waste did not seem to be an issue for the growth of eggplants because of the presence of beneficial microbes in the organic fertilizer applied to the soil media. The BMs can produce antagonistic compounds, such as hydrolytic enzymes [20], that hydrolyze the unwanted detergent compounds into nutrients utilized by the eggplants.

3.2 Total number of fruits

The total number of fruits is a measure of yield. At harvest, the yield is the primary function of the number of fruits [21]. The total number of fruits was determined as the eggplants were affected by different types of water and fertilizer application.

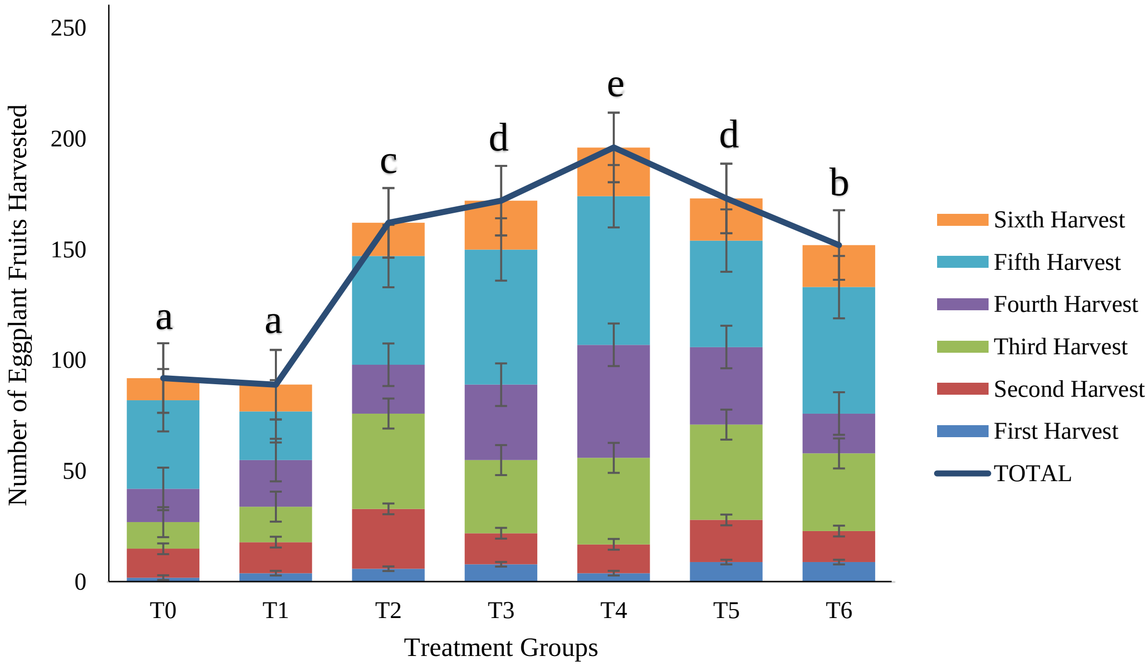

Figure 3 Total number of eggplant fruits for six harvesting periods through stacked column-line chart visualization. The line graph provided visualization of the total number of eggplant fruits from the 1st to the 6th harvesting period. ANOVA summary result: F-statistic = 1409.1818, *p*-value = 4.0095e-65. Means with different letters are significantly different (α level of significance = 0.05) using Tukey's multiple pair comparison test.

Figure 3 presents the total number of eggplant fruits for six harvesting period. The eggplants watered with 50% laundry waste inoculated in OFBM soil media (T4) appeared to have the greatest number of fruits produced (total number of fruits = 196). The T4 laundry waste formulation is significantly higher than all the control and other treatment groups. The eggplants subjected to the T3 (total number of fruits = 172) and the T5 (total number of fruits = 173) laundry waste formulations also produced a significantly greater number of eggplant fruits than the chemical fertilizer amended soil (T1 total number of fruits = 89), the OFBM amended soil (T2 total number of fruits = 162), and the negative control (T0 total number of fruits = 92) which received 100% tap water, respectively.

The productivity and the quality of agricultural crops are affected by the inoculation of plant growth promoting bacteria and other beneficial microbes. In the study of Emmanuel and Babalola [22], they explained that despite the strong evidence of high yield increase and crop quality due to the application of beneficial microbes, there is still a gap in understanding the exact mechanism of action by these microbes. The BMs may enhance the production of health promoting phytochemicals by their plant host. The use of BMs in the study of Porter et al. [18] also increased the fruit number of their host crop by pacifying the effect of environmental stress of their host plant. The effectiveness of BMs is also due to their capacity to colonize the roots of their host make their host persistently thriving in their environment [23] that eventually leads to increased fruit produced.

In the present study, the increase in the number of eggplant fruits is apparent in plants grown in OFBM soils. The number of eggplant fruits grown in OFBM soils were further improved when these plants were watered with laundry waste. It is theorized that the production of enzymes by these beneficial microbes triggered the catalysis reaction, such as enantio- or regioselective hydrolysis, causing the reduced production of detergent by-products, leading to reduced environmental pollution and an improved value to the nutrient products that were readily assimilated by the eggplants [24]. The BMs acted as good catalysts, increasing the rate of their bioremediating role in repackaging waste detergent compounds into useful forms. The highest fruit number was observed at 50% laundry waste because this concentration likely provided an optimal balance between nutrient availability and potential toxicity. At 50%, the BMs in the organic fertilizer can effectively bioremediate the harmful compounds present in the laundry waste, converting them into usable nutrients for the plants, which enhances fruit production. In contrast, at 100% laundry waste, the concentration of potentially phytotoxic substances may overwhelm the BMs' capacity to neutralize the toxins, leading to reduced growth and fruiting, while at 25%, the nutrient concentration may be insufficient to fully leverage the bioremediation capabilities of the microbes.

3.3 Total number of marketable fruits

The total number of marketable fruits is a measure of yield quality. The number of quality fruit collected were observed to be affected by OFBM application and laundry waste utilization.

The total number of marketable fruits is presented in Figure 4. After 6 harvesting periods, the eggplants grown in (T2) formulation (OFBM amended soil watered with 100% tap water) provided the greatest number of marketable fruits (n = 117). The second-best formulation was (T4) (OFBM amended soil watered with 50% laundry waste), which provided the second-highest number of marketable fruits (n = 100). These two treatments, together with the three other treatments ((T3) n = 88; (T5) n = 94; (T6) n = 88) that utilized laundry wastes produced a significantly greater number of fruits than the negative control ((T0) n =52) and the chemical fertilizer positive control ((T1) n = 57). These data revealed that the beneficial microbes in the organic fertilizer improved the quality of eggplants produced. Moreover, when laundry waste is applied to water the OFBM-amended soil, the eggplants are still able to produce more fruits than the eggplants watered with tap water that were grown in soils without fertilizer application and in soils that received chemical treatment, respectively. It is notable that those eggplants grown in OFBM watered with 100% tap water have a greater number of marketable fruits than those eggplants grown in OFBM watered with laundry waste.

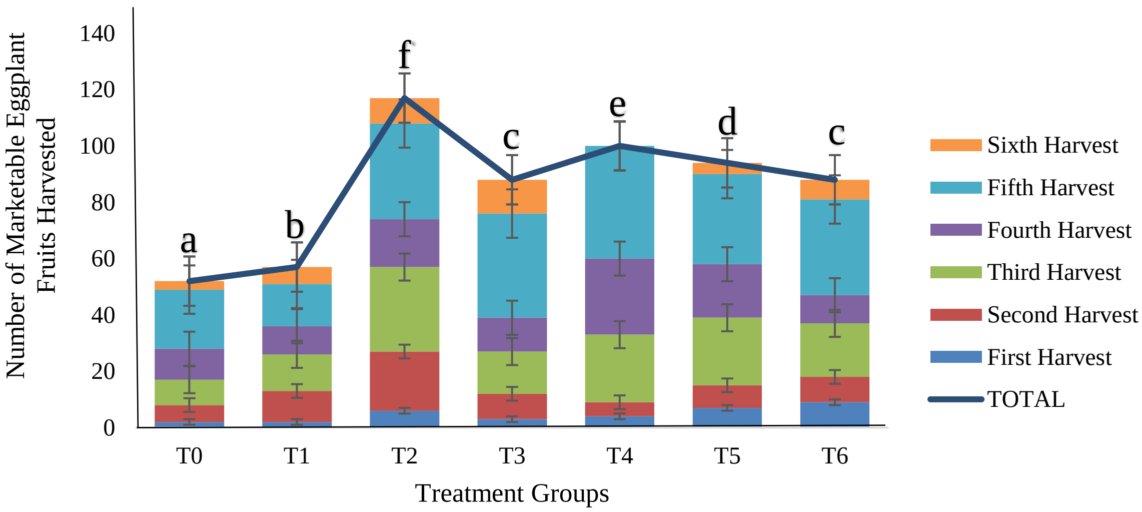

Figure 4 Total number of marketable eggplant fruits for six harvesting periods through stacked column-line chart visualization. The line graph provided a visualization of the total number of marketable eggplant fruits from the 1st to the 6th harvesting period. ANOVA summary result: F-statistic = 439.2078, *P*-value = 2.071e-49. Means with different letters are significantly different (α level of significance = 0.05) using Tukey's multiple pair comparison test.

The greater marketability of eggplants exposed to tap water compared to those irrigated with laundry waste can be attributed to several factors. Tap water likely provides a cleaner, non-toxic environment that is conducive to healthy plant growth and development, resulting in higher-quality fruits. In contrast, while laundry waste can contain organic nutrients, it may also include residual detergent compounds that can be harmful or phytotoxic to the plants, leading to reduced fruit quality. The presence of these potentially harmful substances in laundry waste could affect the texture, color, and taste of the fruits, making them less marketable. If the BMs were not able to completely neutralize the harmful effects of these detergent compounds during the fruiting stage, it would suggest that their effectiveness in bioremediation may have limitations, particularly when high concentrations of wastewater are involved.

The eggplants grown in OFBM soils not only had the greatest number of fruits produced but also the greatest number of quality and marketable fruits. According to Hirt [25], beneficial microbes in soils facilitate the creation of a healthy soil environment so that plants may produce quality fruits for healthy human consumption. Similar published reports indicate how beneficial microbes, specifically *Trichoderma*, modulated the physiological processes in strawberry plants, affecting food production and fruit quality [26]. Recruiting beneficial microbes also alters the soil microbial community to create an essential symbiotic resistance in plants and improve plant disease resistance [27]. As a result, the number of fruits and their quality are increased. Organic cultivation with beneficial microorganisms noticeably promotes microbial biodiversity in the soil, affecting aroma, fruit quantity, and fruit quality [28].

While BMs can enhance growth and nutrient uptake, excessive laundry waste can still impose stress on the plants, potentially leading to lower fruit marketability. Thus, it would imply that, under certain conditions, exposure of eggplants to laundry waste could indeed reduce their marketability, emphasizing the need for careful management of wastewater application to optimize both plant health and fruit quality.

3.4 Total weight of fruits

The total weight fruits are also a measure of yield. The total weight of fruits appeared to differ based on different fertilizer application and water treatment.

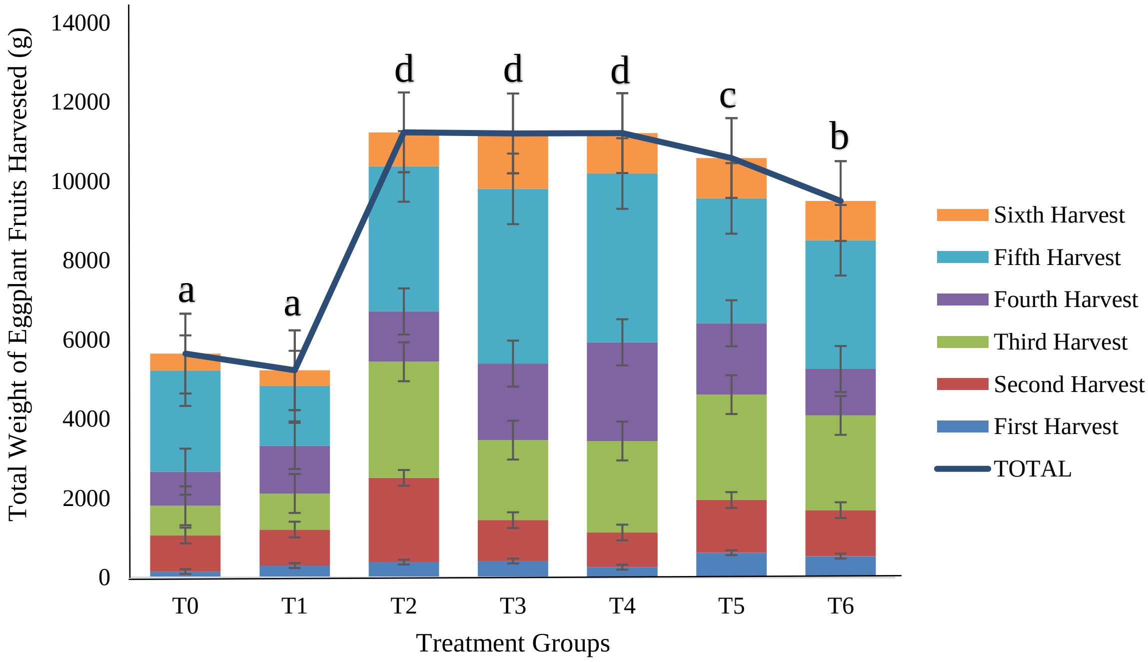

Figure 5 Total weight of eggplant fruits for six harvesting periods through stacked column-line chart visualization. The line graph provided visualization of the total weight of eggplant fruits from the 1st to the 6th harvesting period. ANOVA summary result: F-statistic = 580.8107, *P*-value = 3.7678e-53. Means with different letters are significantly different (α level of significance = 0.05) using Tukey's multiple pair comparison test.

The total weight of fruits after six harvesting periods were presented in Figure 5. The eggplants grown in OFBM-amended soils watered with 25% waste water ((T3) total weight = 11,207 g) and 50% waste water ((T4)total weight = 11215 g) have the greatest weight of total fruits produced. These two experimental groups were comparable to the eggplants grown in OFBM-amended soils watered with 100% tap water (T2 total weight = 11,234 g). The post hoc analysis for the weight of fruits revealed that the treatments with 100% tap water (T2), 25% laundry waste (T3), and 50% laundry waste (T4) did not show significant differences in terms of fruit weight. This suggests that these treatments produced similar results, indicating that watering with a moderate amount of laundry waste (up to 50%) can effectively support fruit development without compromising weight. However, as the percentage of laundry waste increases to 75% (T5) and 100% (T6), the analysis demonstrated a statistically significant reduction in fruit weight compared to the 25% (T3) and 50% (T4) treatments. This decline in weight at higher concentrations suggests that excess laundry waste may introduce detrimental factors, such as phytotoxic compounds or nutrient imbalances, into the growing environment. The presence of higher concentrations of contaminants typically found in laundry wastewater may inhibit healthy fruit growth and development. From a general implication perspective, these findings highlight an important balance in utilizing laundry waste for agricultural practices. While lower concentrations (up to 50%) can be beneficial and serve as a partial alternative to tap water, excessive application of laundry waste could adversely affect fruit weight and overall quality. Therefore, it is essential to adopt carefully calibrated practices that consider the concentration of laundry waste used, ensuring it remains within a range that optimally supports plant growth while avoiding the risk of significantly reducing product quality.

Tahiri et al. [29] assessed the role of plant growth-promoting beneficial microbes. Like the result of the present study, they also found that fruit weight was improved when plants were subjected to beneficial microbes' inoculation. The researchers found an enhanced sugar and protein content on BM inoculated plants, proving the positive effect of BMs on plants' fruit weight. A different approach was discovered by Li et al. [30]. They noticed a boosted number of beneficial microbes in organic fertilizer after fumigation. This led to improved soil nutrients and BMs enzyme activity, culminating in increased yield. In this present study, the beneficial microbes may also have increased the sugar and protein content of eggplants grown in OFBM soils, causing the production of heavier fruits. Furthermore, the beneficial microbes' ability to reconfigure waste compounds in laundry detergents may have caused comparable results on eggplants watered with tap water and eggplants watered with laundry waste when both treatments are grown in organic fertilizer-amended soils inoculated with beneficial microbes.

3.5 Total weight of marketable fruits

The total weight of marketable fruits is a measure of yield quality. The total weight of marketable fruits was significantly affected by OFBM application and laundry waste treatment.

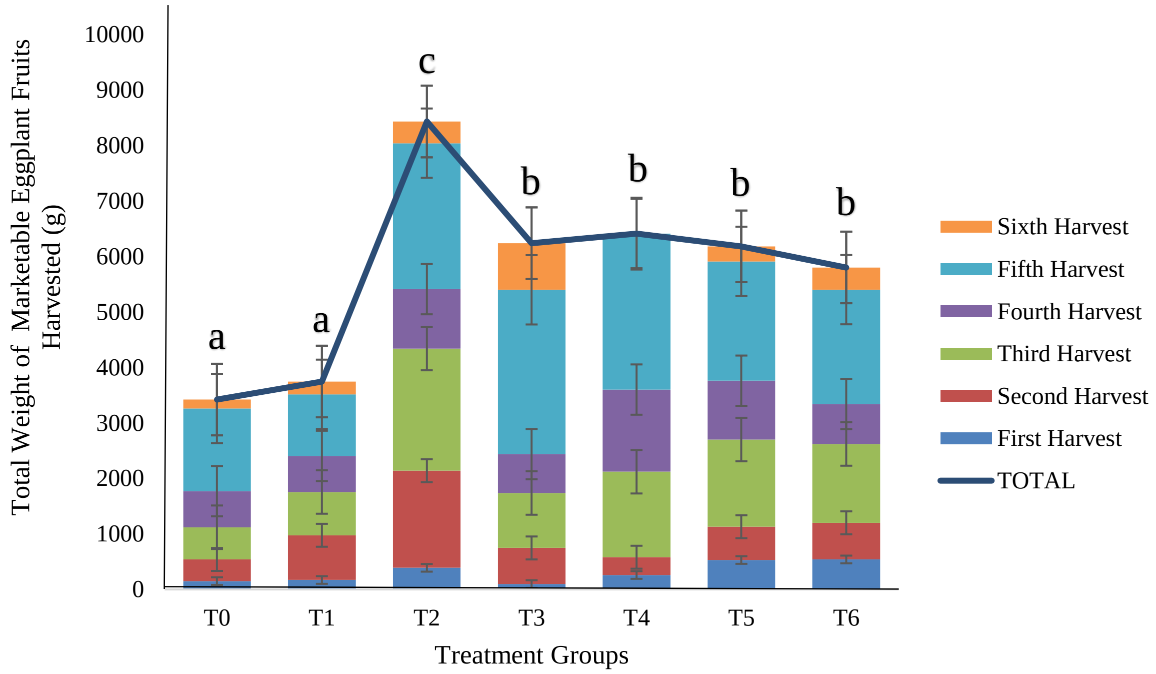

Figure 6 Total weight of marketable eggplant fruits for six harvesting periods through stacked column-line chart visualization. The line graph provided visualization of the total weight of marketable eggplant fruits from the 1st to the 6th harvesting period. ANOVA summary result: F-statistic = 238.4457, *P*-value = 2.4537e-41. Means with different letters are significantly different (α level of significance = 0.05) using Tukey's multiple pair comparison test.

The data in Figure 6 is the total weight of marketable eggplant fruits after six harvesting periods. It can be observed that the greatest weight of marketable fruits was obtained in eggplants grown in OFBM-amended soils watered with 100% tap water (T2) total weight of marketable fruits = 8429 g). Meanwhile, eggplants grown in OFBM-amended soils watered with various levels of laundry waste have a comparable weight in the total marketable fruits produced ((T3) =6237 g; (T4) = 6410 g; (T5) = 6180 g; (T6) = 5800 g, total weight of marketable fruits, respectively). These experimental treatment groups produced greater mass of marketable fruits than the negative control ((T0) total weight of marketable fruit = 3420 g) and the chemical fertilizer positive control group ((T1) total weight of marketable fruit = 3745). However, it must be noted that the eggplants grown in OFBM-amended soil watered with 100% tap water have a heavier total number of marketable fruits than the eggplants grown in OFBM-amended soil watered with various levels of laundry waste.

The data in Figure 6 is the total weight of marketable eggplant fruits after six harvesting periods. It can be observed that the greatest weight of marketable fruits was obtained in eggplants grown in OFBM-amended soils watered with 100% tap water (T2) total weight of marketable fruits = 8429 g). Meanwhile, eggplants grown in OFBM-amended soils watered with various levels of laundry waste have a comparable weight in the total marketable fruits produced (T3) =6237 g; (T4) = 6410 g; (T5) = 6180 g; (T6) = 5800 g, total weight of marketable fruits, respectively). These experimental treatment groups produced greater mass of marketable fruits than the negative control ((T0) total weight of marketable fruit = 3420 g) and the chemical fertilizer positive control group ((T1) total weight of marketable fruit = 3745). However, it must be noted that the eggplants grown in OFBM-amended soil watered with 100% tap water have a heavier total number of marketable fruits than the eggplants grown in OFBM-amended soil watered with various levels of laundry waste.

Eggplants grown in OFBM-amended soil watered with 100% tap water produce a heavier total number of marketable fruits due to the superior quality of the water, which is free from contaminants and harmful residues found in laundry waste. This clean water ensures consistent nutrient availability without introducing phytotoxic substances that can inhibit plant growth. Additionally, tap water supports optimal microbial activity in the OFBM, enhancing nutrient cycling and overall plant health. In contrast, higher concentrations of laundry waste may cause stress to the plants, limiting their ability to produce high-quality fruits. This combination of better growing conditions and reduced stress leads to greater fruit weight and marketability in eggplants irrigated with tap water. Laundry waste can still be effectively applied in lower concentrations to maintain a heavier total number of marketable fruits, as the beneficial microbes present in OFBM can help mitigate potential negative effects by bio-transforming harmful detergent residues into nutrient forms that are usable by the plants. Applying laundry waste at a controlled level allows for the advantages of organic matter enrichment and improved soil health, while minimizing the risk of phytotoxicity, thereby supporting the growth of healthy, marketable fruits.

Published studies indicate the effect of beneficial microbes to the marketable weight quality of fruits. The quality of blue berry fruits was enhanced when plants were supplemented by beneficial microbes' consortium [31]. Also, the yield and quality of tomato was also affected beneficial bacterial inoculants in an organic field [32]. Even under field conditions, beneficial microbes were also helpful in increasing the yield and fruit quality of tomatoes [33]. Undoubtedly, the weight of marketable fruits was improved by the subjection of eggplants to organic fertilizer inoculated with beneficial microbes as observed in the result of the present study. The result of this present study agrees with the result of Aban et al. [34] where beneficial microbes in organic fertilizer was also observed to help the vegetative growth of eggplants in waste-stressed environment. The eggplants under field experimentation had significantly greater number of branches, and SPAD-based nitrogen estimation potentially due to the bioremediating effects of beneficial microbes in organic fertilizer. Therefore, it is possible to enhance organic agricultural production through beneficial microorganisms and waste-water utilization [35].

3.6 Implications of significant findings

Overall, the study revealed that eggplants watered with laundry waste showed remarkable growth and yield when cultivated in soil amended with BMs. Specifically, eggplants in treatments with up to 75% laundry waste exhibited comparable average height and plant vigor to those receiving tap water, indicating that the BMs effectively mitigated the negative impacts of potential toxins in the laundry waste (T1, T2, T5). The total number of fruits and their weight were significantly higher in the BMs-amended treatments, further demonstrating the positive influence of these microbes in facilitating nutrient transformation from waste into assimilable forms for the plants (T3, T4, T5). Additionally, the enzymatic activity of the BMs was pivotal in reconfiguring harmful detergent compounds into beneficial macronutrients, which played a critical role in promoting plant health and yield under otherwise stressful conditions. This evidence collectively supports the assertion that both BMs and laundry waste can be harnessed synergistically to enhance agricultural productivity while addressing environmental waste issues. Despite the positive effects observed with BMs and laundry waste, the study indicated a decline in productivity at higher concentrations of laundry waste, particularly at the 100% laundry waste treatment. Eggplants subjected to this treatment showed reduced growth and yield compared to those receiving lower percentages of laundry waste, suggesting potential phytotoxicity or nutrient imbalance caused by excessive detergent residues. This finding emphasizes the importance of optimizing laundry waste application to ensure that the benefits of BMs are maximized without exacerbating negative effects on plant health.

The findings of this study highlight the potential role of BMs in not only improving crop yields but also in contributing to sustainable agricultural practices and environmental remediation. By utilizing organic fertilizers enriched with beneficial microbes, farmers can enhance soil health, increase nutrient availability for crops, and reduce dependency on chemical fertilizers, which have been shown to degrade soil quality and contribute to water pollution [2], [4]. Moreover, the ability of BMs to bioremediate contaminants, such as those found in laundry wastewater, presents a dual benefit: alleviating the environmental burden of wastewater while simultaneously enhancing plant growth [10], [14]. This bioremediation process involves the microbial transformation of harmful compounds into less toxic or even beneficial forms, ultimately leading to improved water quality and soil fertility [11], [24]. Such practices align well with the principles of regenerative agriculture, which seeks to improve biodiversity, soil health, and ecosystem resilience, promoting a more sustainable and productive agricultural system capable of meeting the food demands of a growing population while safeguarding the environment [1], [8].

The implications of the findings underscore the dual benefits of utilizing BMs in sustainable agricultural practices and environmental remediation. The study demonstrates that BMs in organic fertilizers not only improve the yield and growth of eggplants but also facilitate the breakdown of toxic components found in laundry wastewater. This bioremediation occurs through a variety of mechanisms: first, BMs produce extracellular enzymes such as cellulases and ligninases that break down complex organic compounds into simpler molecules, transforming them into forms that plants can use as nutrients [10]. Additionally, certain bacteria can alter the chemical structure of surfactants in laundry detergents, reducing their toxicity and enhancing their assimilation by plants [11]. The presence of BMs also promotes a diverse microbial community in the rhizosphere, which further contributes to nutrient cycling and enhances soil structure through improved aggregation and moisture retention [1]. Through these mechanisms, BMs provide a sustainable alternative to traditional agriculture methods, reducing the dependency on synthetic fertilizers and mitigating the environmental impact of wastewater [8]. Thus, adopting BMs not only enhances crop production but also addresses crucial issues of pollution and soil degradation, aligning agricultural practices with the principles of regenerative farming that protect and restore ecological systems [14].

4. Conclusions

In conclusion, the study demonstrated that eggplants cultivated in soil amended with organic fertilizer containing BMs and watered with laundry waste achieved significant growth and yield improvements compared to control groups. Specifically, eggplants receiving up to 75% laundry waste showed comparable height, number of fruits, and total fruit weight to those irrigated with tap water. However, at 100% laundry waste, a notable decrease in productivity was observed, indicating a threshold beyond which the phytotoxic effects of concentrated detergent compounds may inhibit plant growth. Thus, the results confirm that organic fertilizer with BMs can effectively utilize laundry waste as an irrigation source, provided that concentrations are optimized to prevent adverse impacts on eggplant production.

In the future, conducting field trials across diverse agroecological settings can be conducted to validate the laboratory findings. Exploring the long-term impacts of incorporating BMs in agricultural systems will be crucial to understanding their sustainability and efficacy over time. Moreover, further studies should investigate the specific microbial strains that exhibit the strongest bioremediation and growth-promoting properties, allowing for the development of tailored microbial inoculants that farmers can use based on their specific soil conditions and crop types. In terms of real-world applications, this research suggests that integrating BMs into routine agricultural practices could help transition farmers from traditional chemical fertilizers to more sustainable and environmentally friendly approaches, particularly in regions facing water scarcity and pollution issues. Additionally, developing training programs for farmers on the use of organic fertilizers enriched with BMs could enhance their adoption and spread across agricultural communities. Ultimately, this research contributes to a paradigm shift towards regenerative agriculture, where waste materials are repurposed, soil health is restored, and crop productivity is maximized without compromising environmental integrity.

5. Ethical Approval

The study protocol received a Certificate of Exemption from Ethics Review by a PHREB (Philippine Health Research Ethics Board) – accredited institution (RETC code: 2022-261-Organic Eggplant Production-Aban).

6. Acknowledgements

The authors wish to thank Don Mariano Marcos Memorial State University for the funding support of this research study.

7. References

[1] Crist E, Mora C, Engelman R. The interaction of human population, food production, and biodiversity protection. Science. 2017; 356(6335):260-264.

[2] Pahalvi HN, Rafiya L, Rashid S, Nisar B, Kamili AN. Ecofriendly tools for reclamation of degraded soil environs. J Biofertil Biopestic. 2021; 2:1–20.

[3] Wan LJ, TianY, He M, Zheng YQ, Lyu Q, Xie RJ, Ma YY, Deng L, Yi SL. Effects of chemical fertilizer combined with organic fertilizer application on soil properties, citrus growth physiology, and yield. Agriculture. 2021;11(12):120-127.

[4] Salam MA, Sarker MNI, Sharmin S. Do organic fertilizer impact on yield and efficiency of rice farms? Empirical evidence from Bangladesh. Heliyon.2021;7(8). e07731.

[5] Li J, Yang Q, Shi Z, Zang Z, Liu X. Effects of deficit irrigation and organic fertilizer on yield, saponin and disease incidence in *Panax notoginseng* under shaded conditions. Agric Water Manag. 2021; 256:107-156.

[6] Meddich A, Oufdou K, Boutasknit A, Raklami A, Tahiri A, Ben-Laouane R, Ait-El-Mokhtar M, Anli M, Mitsui T, Wahbi S. Baslam, M. Use of organic and biological fertilizers as strategies to improve crop biomass, yields and physicochemical parameters of soil. In: Meena R, editors. Nutrient dynamics for sustainable crop production, Singapore: Springer. 2020;11: 247–288.

[7] Sathya A, Vijayabharathi R, Gopalakrishnan S. Soil microbes: The invisible managers of soil fertility. Microbial inoculants in sustainable agricultural productivity. Funct Appl. 2016; 2:1–16.

[8] Lugtenberg BJ, Malfanova N, Kamilova F, Berg G. Plant growth promotion by microbes. Mol Microbiol. 2013; 1:559-573.

[9] Das PP, Singh KR, Nagpure G, Mansoori A, Singh RP, Ghazi IA, Kumar A, Singh J. Plant-soil-microbes: A tripartite interaction for nutrient acquisition and better plant growth for sustainable agricultural practices. Environ Res J. 2022; 214:113-821.

[10] Saeed MU, Hussain N, Sumrin A, Shahbaz A, Noor S, Bilal M, Aleya L, Iqbal HM. Microbial bioremediation strategies with wastewater treatment potentialities–A review. Sci Total Environ. 2022; 818:1517-1554.

[11] Kapoor RT, Danish M, Singh RS, Rafatullah M, HPS AK. Exploiting microbial biomass in treating azo dyes contaminated wastewater: Mechanism of degradation and factors affecting microbial efficiency. J Water Proc Eng. 2021; 43:102255.

[12] U. S. Department of Health and Human Services. Module 2: Research Design – Section 2. The Office of Research Integrity's website, 2024.

[13] Kim YS, Cho SH, Lee HS, Lee GJ. Composting and fertilizing characteristics of poultry manure mixture with compressed expansion rice hull as bulking agent. J Korea Org Resour. 2020;28(4):5-13.

[14] Assiddieq M, Darmayani S, Kudonowarso W. The use of silica sand, zeolite and active charcoal to reduce BOD, COD, and TSS of laundry waste water as a biology learning resources. J Pendidik Biol Indones. 2017;3(3):202-207.

[15] AAT Bioquest, Inc. Quest Graph™ ANOVA Calculator. AAT Bioquest. 2024.

[16] Moles AT, Warton DI, Warman L, Swenson NG, Laffan SW, Zanne AE, Pitman A, Hemmings FA, Leishman MR. Global patterns in plant height. J Ecol. 2009;97(5):923-932.

[17] Wang J, Li R, Zhang H, Wei G, Li Z. Beneficial bacteria activate nutrients and promote wheat growth under conditions of reduced fertilizer application. BMC Microbiol. 2020; 20:1-12.

[18] Porter SS, Bantay R, Friel CA, Garoutte A, Gdanetz K, Ibarreta K, Moore BM, Shetty P, Siler E, Friesen ML. Beneficial microbes ameliorate abiotic and biotic sources of stress on plants. Funct Ecol. 2020;34(10):2075-2086.

[19] Santoyo G, Guzmán-Guzmán P, Parra-Cota FI, Santos-Villalobos SDL, Orozco-Mosqueda MDC, Glick BR Plant growth stimulation by microbial consortia. Agron J. 2021;11(2):2-19.

[20] Elnahal AS, El-Saadony MT, Saad AM, Desoky ESM, El-Tahan AM, Rady MM, AbuQamar SF, El-Tarabily KA. The use of microbial inoculants for biological control, plant growth promotion, and sustainable agriculture: A review. Eur J Plant Pathol. 2022;162(4):759-792.

[21] Elfving DC, Schechter I. Fruit count, fruit weight, and yield relationships in 'Delicious' apple trees on nine rootstock. Hortic Sci. 1993;28(8):793-795.

[22] Emmanuel OC, Babalola OO. Productivity and quality of horticultural crops through co-inoculation of arbuscular mycorrhizal fungi and plant growth promoting bacteria. Microbiol Res. 2020; 239:126-569.

[23] Romano I, Ventorino V, Pepe O. Effectiveness of plant beneficial microbes: overview of the methodological approaches for the assessment of root colonization and persistence. Front Plant Sci. 2020; 11:487940.

[24] Ramesh A, Devi H, Chattopadhyay P, Kavitha S. Commercial applications of microbial enzymes. In: Arora N, Mishra J, Mishra V, editors. Microbial enzymes: roles and applications in industries. Microorganisms for sustainability, Singapore: Springer. 2020;11: 137–184.

[25] Hirt H. Healthy soils for healthy plants for healthy humans: How beneficial microbes in the soil, food and gut are interconnected and how agriculture can contribute to human health. EMBO Rep. 2020; 21(8): e51069.

[26] Lombardi N, Caira S, Troise AD, Scaloni A, Vitaglione P, Vinale F, Marra R, Salzano AM, Lorito M, Woo SL. *Trichoderma* applications on strawberry plants modulate the physiological processes positively affecting fruit production and quality. Front Microbiol. 2020; 11:522-584.

[27] Wang Y, Teng Y, Zhang J, Zhang Z, Wang C, Wu X, Long X. Passion fruit plants alter the soil microbial community with continuous cropping and improve plant disease resistance by recruiting beneficial microorganisms. PLoS One. 2023;18(2): e0281854.

[28] Sangiorgio D, Cellini A, Spinelli F, Farneti B, Khomenko I, Muzzi E, Savioli S, Pastore C, Rodriguez-Estrada MT, Donati I. Does organic farming increase raspberry quality, aroma and beneficial bacterial biodiversity. Microorganisms. 2021;9(8):1617.

[29] Tahiri AI, Meddich A, Raklami A, Alahmad A, Bechtaoui N, Anli M, Göttfert M, Heulin T, Achouak W, Oufdou, K. Assessing the potential role of compost, PGPR, and AMF in improving tomato plant growth, yield, fruit quality, and water stress tolerance. J Soil Sci Plant Nutr. 2022:1-22.

[30] Li Q, Zhang D, Song Z, Ren L, Jin X, Fang W, Yan D, Li Y, Wang Q, Cao A. Organic fertilizer activates soil beneficial microorganisms to promote strawberry growth and soil health after fumigation. Environ. Pollut. 2022; 295:118653.

[31] Yu YY, Xu JD, Huang TX, Zhong J, Yu H, Qiu JP, Guo JH. Combination of beneficial bacteria improves blueberry production and soil quality. Food Sci Nutr. 2020;8(11):5776-5784.

[32] Lee SK, Chiang MS, Hseu ZY, Kuo CH, Liu CT. A photosynthetic bacterial inoculant exerts beneficial effects on the yield and quality of tomato and affects bacterial community structure in an organic field Front Microbiol. 2022; 13:959080.

[33] Pérez-Rodriguez MM, Pontin M, Lipinski V, Bottini R, Piccoli P, Cohen AC. *Pseudomonas fluorescens* and *Azospirillum brasilense* increase yield and fruit quality of tomato under field conditions. J Soil Sci Plant Nutr. 2020; 20:1614-1624.

[34] Aban JL, Sagun AV, Asirot, JA. Improving eggplant growth and development by using beneficial microbes in organic fertilizers: Exploring the bioremediating effects of microbes in laundry waste. Proc Int Acad Eco Environ Sci. 2024;14(3):115-128.

[35] Aban JL, Sagun AV, Asirot JA. Enhancing organic agricultural production through beneficial microorganism and waste-water utilization technology: A concept project and futures thinking approach. J Bio Envr Sci. 2024;24(3):72-79.