International Journal of Science, Technology, Engineering and Mathematics
Volume 4 Issue 2 June 2024
DOI: https://doi.org/10.53378/353072

Leafina: Potency of *Kakawate* leaves, fishbone meal and *saba* banana peel compost soil amendment to the water holding capacity of loam soil

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Abstract

In tropical regions like the Philippines, drought susceptibility is caused by high evaporation rates and poor soil water retention. To deal with this, soil amendments are crucial, enhancing soil properties to aid plant growth. In this study, LeaFiNa, a compost soil amendment composed of Kakawate leaves (KL), fishbone meal (FB), and Saba banana peels (BP) was introduced, aiming to boost soil water holding capacity (SWHC) of loam. Different LeaFiNa ratios were tested, including 3KL:1FB:2BP, 6KL:4FB:1BP, and 3KL:8FB:1BP, alongside vermicast and commercial soil amendment (neem cake) as positive controls, and plain loam soil as the negative control. Percolation method and pressure plate extraction was performed. One-way ANOVA showed a significant difference among the experimental treatments (α=0.05) in which 6KL:4FB:1BP ratio emerged with the highest SWHC of 49.60%. Meanwhile, Tukey's HSD test revealed no significant difference between 6KL:4FB:1BP and vermicast, yet a significant difference with the negative control. Moreover, the experimental treatments, particulalry the 6KL:4FB:1BP, also exhibited ideal results on other SWHC parameters such as the soil moisture content at saturation and wilting points, and in terms of gravitational water and plant available water. These findings suggest the LeaFiNa's potential in alleviating drought stress in tropical soils by enhancing water retention, offering promising outcomes for sustaining agricultural productivity in water-scarce regions.

Keywords: *soil water holding capacity, loam soil, compost soil amendment, Kakawate leaves, fishbone meal, Saba banana peels*

Article History:
Received: *May 8, 2024*
Revised: *June 8, 2024*
Accepted: *June 9, 2024*
Published online: *June 13, 2024*

Suggested Citation:
Guevarra, E.L.P, Gatchalian, C.J.L., Bueno, B.S.M., Garcia, D.L.K & Manalo, F.K.B (2024). Leafina: Potency of kakawate leaves, fishbone meal and saba banana peel compost soil amendment to the water holding capacity of loam soil. *International Journal of Science, Technology, Engineering and Mathematics*, 4(2), 51-76. https://doi.org/10.53378/353072

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1. Introduction

Areas with tropical temperatures are prone to drought stresses due to the loss of water evaporated into the atmosphere or through gravitational forces pulling the water below the soil surface (Atkinson, 2018; Stocker et al., 2023). In the Philippines, approximately 70% of its land area experiences severe cases of drought due to the incidence of extreme warm events such as El Niño (Delina et al., 2023). Globally, numerous regions also experience frequent and increased drought conditions whose cause is characterized by varying degrees of precipitation and immense water drainage. Plants receive adverse effects brought by the rapid change of climate due to weak water holding capacities of the soil (Li et al., 2021). The assessment of the levels of soil water holding capacity in soil may be a factor towards addressing drought concerns nationwide.

Soil water holding capacity (SWHC) is a key indicator of soil quality, representing the amount of water retained against gravitational forces (Olorunfemi et al., 2016). Soil properties, including SWHC, play a crucial role in regulating nutrient availability to plants, thus impacting agricultural productivity (Suleiman et al., 2017). It is particularly vital during drought conditions, where water scarcity can significantly impact crop yield (Fahad et al., 2017). Soil organic matter, considered a soil amendment, contributes to enhancing SWHC (Libohova et al., 2018). However, widespread use of chemical fertilizers in modern agriculture poses significant environmental and health hazards, affecting soil microbial activity, fertility, pH balance, pest control, and water contamination (Labajo & Pabiona, 2022; Wu, 2020). Despite their convenience, chemical fertilizers have detrimental effects on both human health and environmental pollution.

Thus, this study aimed to evaluate potency of a compost soil amendment made from Kakawate (*Gliricidia sepium*) leaves, fishbone meal, and Saba banana (*Musa paradisiaca*) peels compost to enhance the water holding capacity of loam soil. Each component of the soil amendment addresses specific nutrient requirements; Kakawate leaves balance carbon-nitrogen ratios, fishbones supplement phosphorus levels, and banana peels enrich potassium content. Moreover, these three are commonly found in households, making it accessible and easily utilized.

The research involved testing varying ratios of organic components using laboratory methods such as the 24-hour percolation and pressure plate extraction. Limitations included the availability and selection of specific organic materials rich in macronutrients and the pre-preparation of experimental setups for soil nutrient analysis. The study employed statistical tests, including one-way ANOVA and Tukey's HSD, to analyze water holding capacity.

The proposed soil amendment's efficiency was evaluated by varying NPK ratios, using readily available food and garden wastes as sustainable alternatives to chemical fertilizers. This approach aligns with RA 9003 and sustainable development goal number 11, promoting proper waste disposal and environmental practices. Additionally, the amendment meets the macronutrient requirements for soil quality and fertility, offering a cost-effective and resource-friendly option compared to commercial amendments. By increasing soil water holding capacity, the amendment aims to enhance plant growth, reduce crop loss in humid conditions, and mitigate adverse effects of water shortage, supporting goals outlined in the Harmonized National Research and Development Agenda for optimizing nutrient and water management and promoting innovative farming approaches resilient to changing climates.

2. Literature Review

2.1. Importance of soil water holding capacity

Water from the soil acts as a solvent and nutrient carrier for plants. It is one of the essential elements a plant requires to survive. This also dictates plant distribution, carbon allocation, the rate of photosynthesis, and cycles its nutrients (Cianfrani et al., 2019). Water content is an inherent trait of soil and is a concept used in many scientific and technological fields. A soil’s moisture plays a vital role as a hydrological attribute and helps in infiltration, evapotranspiration, and solute transport (Lee & Kim, 2019). The soil's water holding capacity (SWHC) provides perception into the maximum amount of water a soil can retain, it shows its capacity to supply water which is essential for plant growth support (Zhang et al., 2021). An organic matter increase is one of the ways you can increase soil water holding capacity, porosity also plays a role in improving SWHC (Pitch, 2020).

2.2. Loam soil

An average loam soil consists of approximately equal parts of soil solids, which comprise a combination of sand, silt, and clay, and pore spaces filled with water. The dimensions and arrangement of these pore spaces are influenced by the characteristics of mineral particles, including their size and shape, as well as the actions of microorganisms (Vittum, 2009). The utilization of loam soil in agricultural practices presents notable benefits stemming from its exceptional capacity to retain water and essential nutrients. These inherent attributes contribute to the establishment of a stable growth environment for plants, characterized by prolonged moisture retention and facilitated nutrient storage. Furthermore, the heightened surface area of loam soil particles amplifies nutrient absorption and retention, resulting in healthier and more productive crops (Haruna & Nkongolo, 2013).

2.3. Kakawate (Gliricidia sepium) leaves

In the Philippines, Kakawate, or Madre de Cacao, is widely cultivated due to its adaptability to various soil conditions (Villegas-Pangga & Cedillo, 2021). The Cavite agroforestry system has demonstrated the effectiveness of Kakawate leaves in soil improvement, alongside crops like coconut and coffee, reducing erosion and enhancing water retention (Parreño-de Guzman et al., 2015). Incorporating Kakawate into soil promotes faster water infiltration, decreases surface runoff, and enhances soil characteristics such as organic carbon content, microbial biomass, aggregation, water retention, and cation exchange capacity (Srinivasarao, 2011). Kakawate leaves decompose quickly, enriching the soil with nutrients like nitrogen, phosphorus, potassium, calcium, and magnesium (Baloch et al., 2015). Applying Kakawate leaves at a rate of one ton per hectare can provide significant quantities of essential nutrients, making it a valuable component of organic fertilizers. Moreover, Kakawate enhances soil productivity and crop yield in rain fed agriculture (Villegas-Pangga & Cedillo, 2021).

2.4. Fishbone

Fishbone is rich in calcium and phosphorus, with roughly 2% of the total fish weight composed of these nutrients (Ramadhani et al., 2018). Studies have demonstrated that the presence of fishbone significantly enhances soil water availability, as increased phosphorus content in soil amendments correlates with improved soil porosity and water retention (Fu et al., 2023). In soil improvement studies, compost manure containing fishbone exhibited the highest water absorption capacity among various setups, indicating favorable results (Oni et al., 2022). Additionally, fishbone have been found to have the highest moisture content among non-edible food wastes, facilitating biomass degradation and nutrient release (Islam et al., 2023).

2.5. Saba banana (Musa paradisiaca) peels

Saba bananas, a significant global food crop, are rich in fiber, potassium, and various vitamins and antioxidants (Ohagan et al., 2023). When added to compost, banana peels enhance water retention and soil structure due to their rapid decomposition, releasing nutrients quickly (Zaini et al., 2020). Given their high potassium content, banana peels serve as a valuable source of potassium for agricultural purposes, contributing to efficient waste management practices (Islam, 2019). Studies evaluating bamboo biochar production revealed a correlation between potassium content and water holding capacity, underscoring potassium's role in soil water retention (Hien et al., 2021). Despite lower usage in NPK ratios, potassium remains vital for plant physiology, emphasizing its significance in soil nutrient balance (Leigh & Wyn Jones, 1984).

2.6. The percolation method in determining soil water holding capacity

Many attempts have been made to get quantitative measures of soil water holding capacity, however, due to the intricacy and nature of soil permeability, there have been minor issues in obtaining the data. Following a few observations, it is discovered that the idea of percolation is applicable, inexpensive and a functional basis for measuring soil water holding capacity (Govindasamy et al., 2022).

The process of percolation. Based on the traditional way of implementing the percolation method, the medicinal material powder is placed in a percolation tank. Next to that, the percolation extract is acquired, and the extraction solvent is constantly added simultaneously. In terms of soil water holding capacity, filter paper is placed in a funnel then the soil sample will be measured at 100g which will then settle in the funnel. The measured 100mL of water will be gradually added to the soil sample. After that, the funnel clamp will be released and the excess water will percolate onto the graduated cylinder, while the collected water will be recorded (Estefan et al., 2013). The difference between the added water and drained water will be calculated, and the resulting soil water holding capacity will be calculated using the equation:

$$SWHC = \frac{Volume\ of\ water\ retained\ by\ soil\ (V1 - V2)}{Weight\ of\ sample\ (W)} \times 100$$

SWHC - Soil water holding capacity

V1 - Initial volume of the water

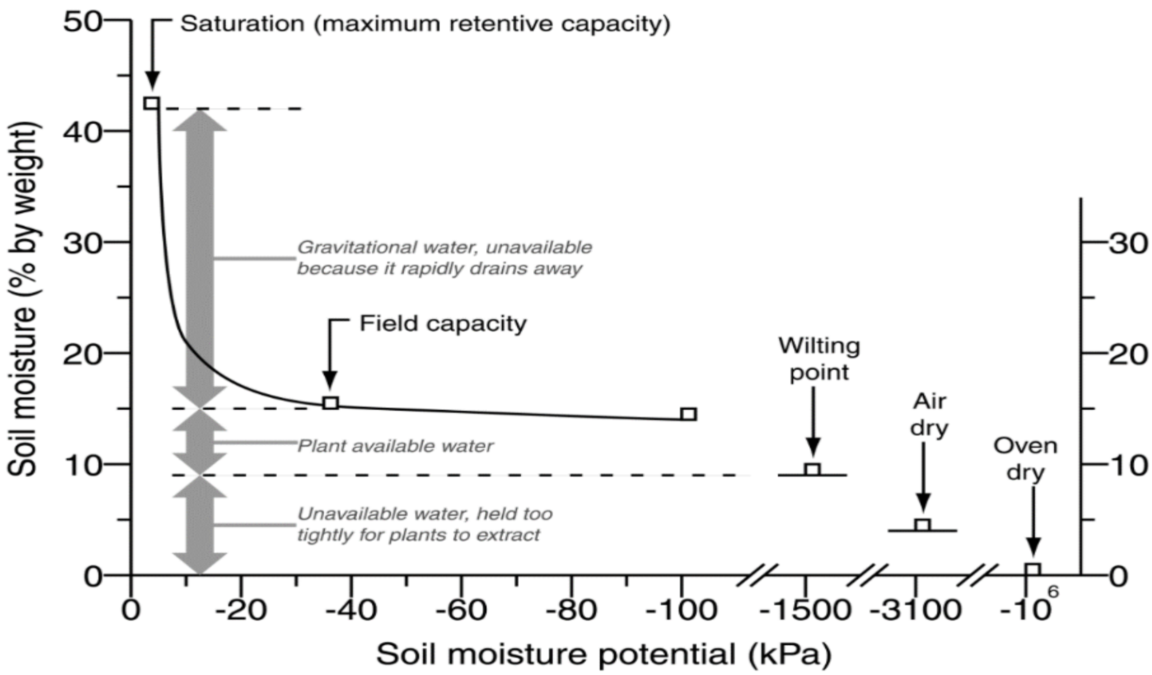
V2 - Volume of the water after the process of percolation

2.7. Phases of soil water holding capacity

Soil Water Holding Capacity (SWHC), as the capacity of the soil to retain moisture in soil macro and micropores, is correlated with pressure and gravity due to force acting on the soil. Several controlled laboratories research have used different methods, such as; Column Method (CM) where plastic columns are used to calculate the retained water, and Keen Raczkowski box Method (KM) where they used a box to saturate soil samples (Govindasamy et al., 2022). Although the results showed with studies who have used these kinds of methods were comparable for total population of soil, there is an occurrence of overestimation of water content. A prominent reason for this is that these methods do not apply any additional pressure when measuring soil’s water content. Application of pressure is essential in searching for the water content of soil types because soil has different phases according to the pressure applied (measured at kPa or Kilopascal) by gravitational force which are Saturation (SAT), Field Capacity (FC), and Wilting Point (WP). In most studies, SAT is determined to be the same as total porosity, so it is measured at 0 kPa. While Field Capacity and Wilting Point are measured at -33 kPa and -1500 kPa, respectively (Minasny & McBratney, 2017).

Figure 1

Soil moisture classes and important points on the soil moisture relationship curve



3. Methodology

3.1. Composting process for LeaFiNa components

Kakawate leaves, Saba banana peels, and fish bone meal were crushed into smaller fragments using tools like a blender and scissors to ensure consistency. During composting, each component was placed in its designated bins. The vertical composting method was employed, enclosing materials in bins with holes to oxygenate them and insulate temperature, preventing disruption from pests and odors. Varying amounts of soil were added to each bin to expedite decomposition and enhance microbial activity, maintaining a consistent ratio of 2 parts LeaFiNa to 8 parts soil. Foil was used to cover all setups for insulation.

3.2. Nutrient analysis of LeaFiNa components

Compost samples of Kakawate leaves, fishbone, and Saba banana peels underwent analysis at the Analytical Services Laboratory of the University of the Philippines, Los Baños Campus, within the Soil Physics Department. The Soil Test Kit method was employed, wherein solutions were introduced to small soil samples in test tubes for nitrogen, phosphorus, and potassium analysis. Upon reaction, which typically occurs within a few minutes, the resulting color indicates the relative acidity, salinity, or nutrient levels in the sample. Results showed that Kakawate leaves exhibited a nitrogen content of 0.20% per 1.0g of sample, while fish bone meal compost displayed a phosphorus content of 0.27% per 2.85g and Saba banana peels compost manifested a potassium content of 0.01% per 2.5g. These findings determined the suitable ratios to create LeaFiNa soil amendment across various compositions.

3.3. Preparation of experimental setups

Different proportions of LeaFiNa were determined based on the NPK content of organic components, coming up with the ratios such as 3KL:1FM:2BP, 6KL:4FM:1BP, and 3KL:8FM:1BP. Each component was carefully measured to maximize its presence in the experimental treatments, resulting in the following calculations as shown below. Significant amounts per ratio were made as these key components were used. Additionally, the soil amendments including the vermicast and neem cake were prepared in designated bins, blending them with soil at a ratio of 20 parts soil amendment to 80 parts soil.

Table 1

Weight of each nutrient per component of NPK

Sample	Mass of nitrogen per 1.0 g	Mass of phosphorus per 2.85 g	Mass of potassium per 2.5 g
Kakawate leaves	0.002g	-	-
Fishbone meal	-	0.007695g	-
Saba banana peels	-	-	0.00025g

The formula used to calculate the total weight of each component in their respective ratios:

$$Total\ Weight\ of\ Component\ (g) = \frac{(weight\ of\ soil\ sample)\ \ (weight\ of\ nutrient\ component\ in\ ratio)}{total\ weight\ of\ nutrient}$$

Therefore, the following calculations were utilized to come up with the LeaFina ratios. For the 6KL:4L:FB:1BP, 30g of Kakawate leaves was used for 0.06g of nitrogen, 14.814g of fishbone meal for 0.04g of phosphorus, and 100g of Saba banana peels for 0.01g of potassium; for the 3KL:8:FB:1BP, 15g of Kakawate leaves for 0.03g of nitrogen, 29.629g of fishbone mean for 0.08g of phosphorus, and 100g of Saba banana peels for 0.01g of potassium; and for 3KL:1FB:2BP, 15g of Kakawate leaves for 0.03g of nitrogen, 3.703g for 0.01g of phosphorus, and 200g of Saba banana peels for 0.02g of potassium.

3.4. Testing procedure

Various soil water retention parameters were measured through percolation method and pressure plate extraction to determine the saturation point, field capacity, wilting point, gravitational water, plant available water, and unavailable water.

Preparation of setups. The experiment consisted of two groups: the experimental group, comprising three LeaFiNa ratios, and the control group, including vermicast and commercial soil amendment as positive controls, and pure loam soil as the negative control. A total of 30 setups were prepared for soil water holding capacity testing using the percolation method, with 5 replicates and 1 trial. Each setup contained 50g of the mixture in a small container poured into percolation tubes. The completely randomized design ensured equal treatment probability across the 5 replicates of each treatment.

Percolation method. The cheesecloth was attached to one end of the percolation tube as a filter. The setup was arranged on a stand, with each tube labeled accordingly. Then, the soil-fertilizer mixtures were poured into the tubes, followed by the simultaneous addition of 50mL of water into each tube, with beakers placed beneath to catch any excess water. Foil was utilized to cover the top of the tubes and beakers to prevent evaporation. After 24 hours, the amount of water retained by each setup was measured to calculate its soil water holding capacity using the prescribed formula;

$$SWHC = \frac{Volume\ of\ water\ retained\ by\ soil\ (V1 - V2)}{Weight\ of\ sample\ (W)} \times 100$$

SWHC - Soil water holding capacity

V1 - Initial volume of the water

V2 - Volume of the water after the process of percolation

Phases of soil water holding capacity. Soil samples were put inside the crucibles with different variables: LeaFiNa ratios, vermicast, commercialized soil amendment, and loam soil only, filling it up to three-fourths of their capacity, packed and compressed properly. Subsequently, tap water was added to a depth of approximately 3 cm, and the setups were left undisturbed for 24 hours. The weight of the crucible plus the soil sample was recorded as the moisture retained at saturation, equating to 0-bar pressure. Using a pressure plate extractor, moisture retention was measured at field capacity (⅓ bar) and wilting point (15 bar). After drying the samples in an oven at 105°C for 24 hours, the difference in moisture retention at different pressures was calculated to determine the gravitational water, plant available water (PAW), and unavailable water, using the following formulas.

$$Soil\ moisture\ content\ (\%) = \frac{weight\ of\ wet\ soil\ (g)\ -\ weight\ of\ dry\ soil\ (g)}{weight\ of\ dry\ soil\ (g)}\ x100$$

$$Gravitational\ Water\ (\%)\ =\ Saturation\ (\%)\ -\ Field\ Capacity\ (\%)$$

$$Plant\ Available\ Water\ (\%)\ =\ Field\ Capacity\ (\%)\ -\ Wilting\ Point\ (\%)$$

$$Unavailable\ Water\ (\%)\ =\ Wilting\ Point\ (\%)$$

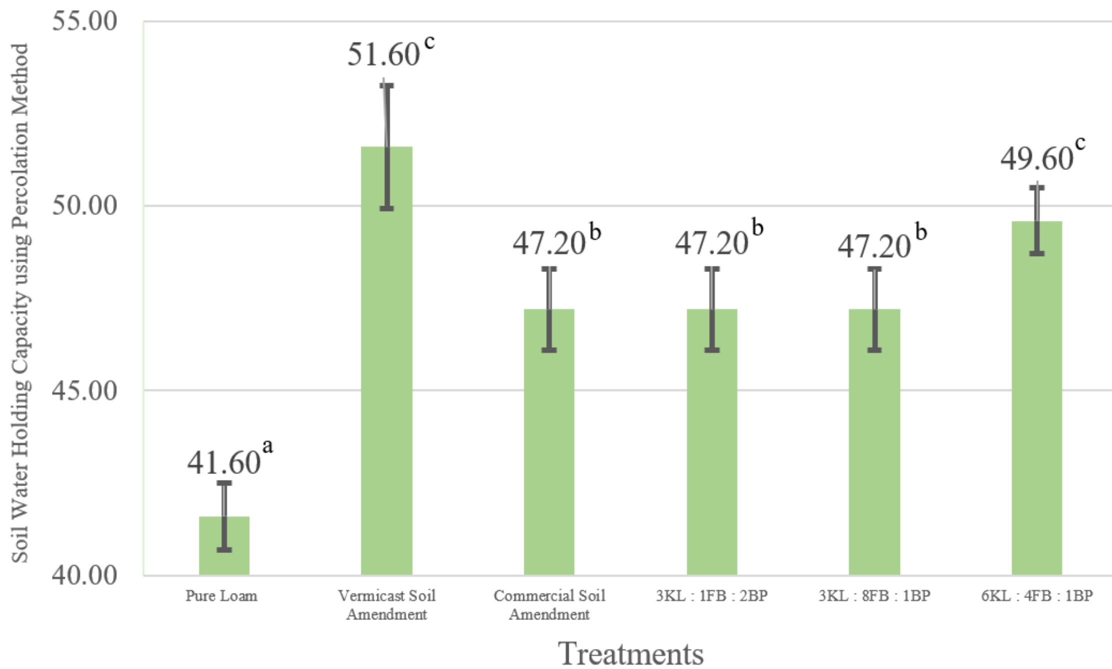
4. Findings and Discussion

Figure 2 shows the mean soil water holding capacity in terms of the water retained and lost by each treatment in the percolation method. Results showing a lower amount of water loss and a higher amount of water retained indicate a higher percentage of SWHC. This reveals that the treatment of 6KL:4FB:1BP acclaimed the highest mean percentage of SWHC among all experimental set-ups (49.6%).

Soil water retention relies on various factors such as pore structure, size distribution, shape, and continuity to mention some (Møldrup et al., 2013). Among these factors, the organic matter content plays a significant role in determining the quality of pore structure. This aspect is influenced not only by soil texture, determined by the proportions of clay, sand, and silt particles, but also by the ratio of organic matter containing essential nutrients (Munkholm et al., 2012). These nutrients contribute to sustaining healthier pores in the soil, thereby impacting its water retention capabilities. In all experimental setups, pure organic matter was used. However, from the references cited, it can be deduced that the ratio of 6KL:4FB:1BP in NPK content contained sufficient organic matter to influence the pore structure of the soil. The pore size of soil is a crucial factor affecting its water-holding capacity. Sandy soils, which are characterized by larger pores, typically exhibit low water retention capabilities. Conversely, vermicast-amended soil, along with the proposed soil amendment using the 6KL:4FB:1BP ratio, contains smaller pores, which enhance its water retention ability it creates a larger surface area for water adhesion (Josa et al., 2013).

Figure 2

Mean soil water holding capacity of different soil amendments using percolation method



Tukey's HSD determined that treatments 3KL:1FB:2BP, commercial soil amendment, and 3KL:8FB:1BP, exhibit no significant difference from each other. Meanwhile, experimental setup 6KL:4FB:1BP and the vermicast soil amendments also show no significant difference between each other. However, compared to all other set-ups, experimental setup 6KL:4FB:1BP and the vermicast soil amendment demonstrate significant difference when compared to the negative control, which is the pure loam. This highlights that experimental setup 6KL:4FB:1BP and the vermicast soil amendment possess the highest soil water holding capacity among all set-ups. Furthermore, statistical results exhibited an F-value of 42.18 with a p-value of 0.000, which is less than 5% level of significance, indicating significant differences among each other. Thus, 6KL:4FB:1BP emerges as the experimental setup with the highest soil water holding capacity.

Figure 3

Mean soil moisture content during saturation phase of different soil amendments

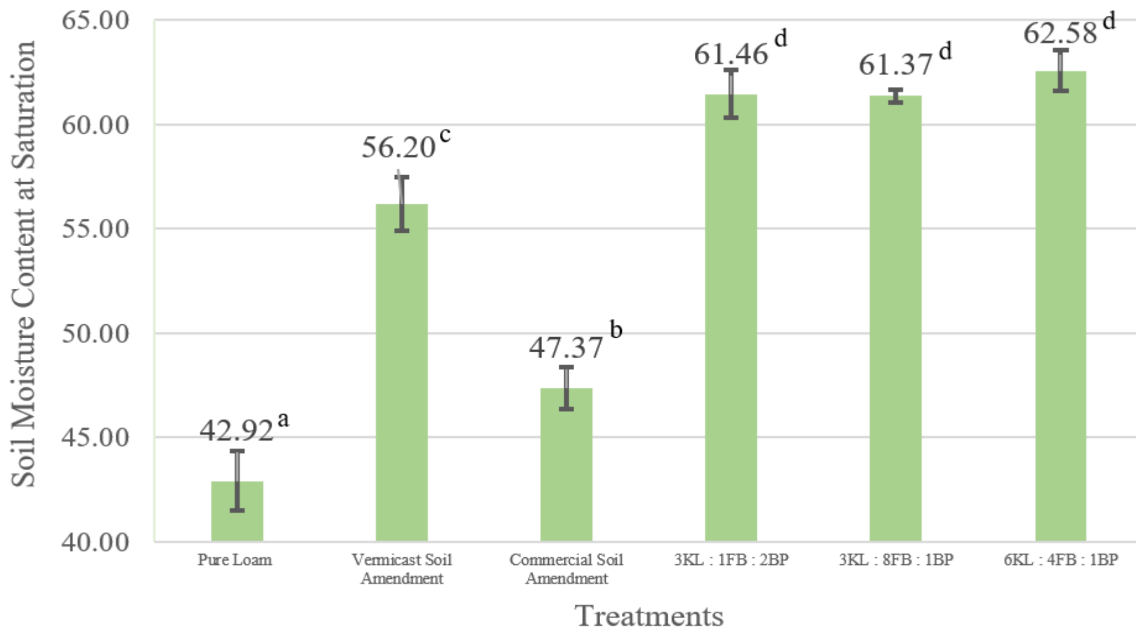
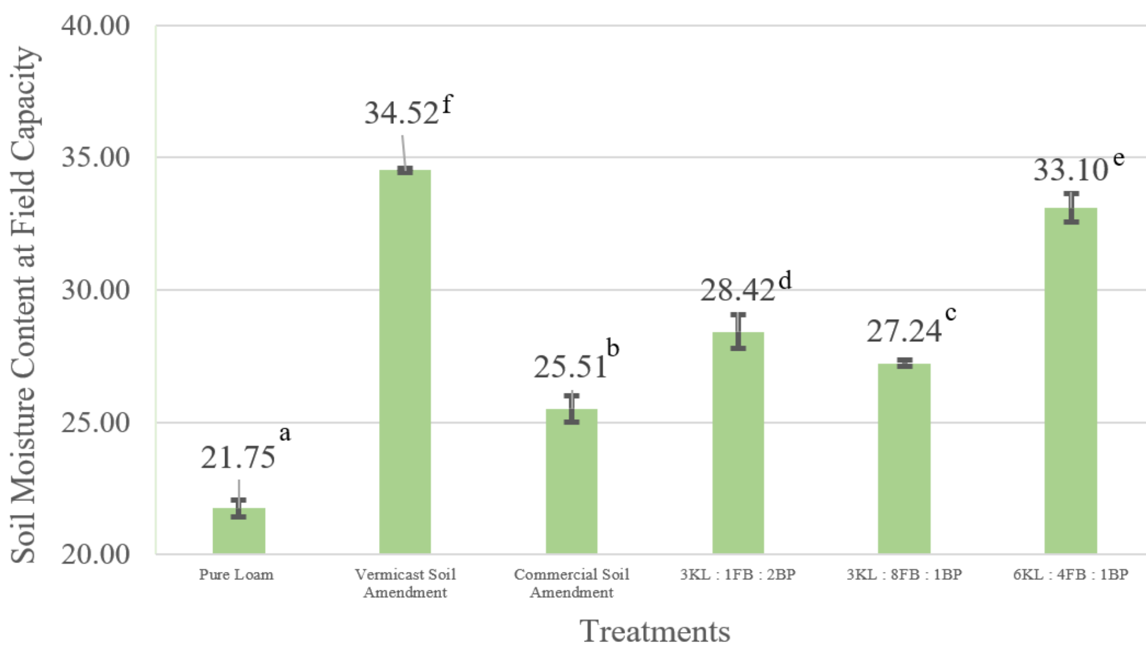


Figure 3 presents the soil content during the saturation phase of soil water holding capacity wherein 0-bar of pressure was exerted to treatments. The results indicate that the three experimental setups (6KL:4FB:1BP, 3KL:1FB:2BP, and 3KL:8FB:1BP) exhibited the highest moisture content, followed by the vermicast soil amendment, commercial soil amendment, and plain loam soil, in descending order. Statistical analysis revealed a significant difference between the groups, with an F-value of 295.572 and a p-value of 0.000, which is below the significant level of 5%. Post-hoc analysis using Tukey's HSD test indicated that the three experimental groups showed comparable effectiveness, as they belong to the same subgroup. Conversely, plain loam soil, vermicast soil amendment, and commercial soil amendment were categorized into three distinct subgroups, respectively.

These findings conclude the role of soil moisture dynamics during the saturation phase of water holding capacity. Soil water retention varies depending on the texture and structure of the soil. Following rainfall or irrigation, when the soil becomes saturated, there is a consistent and swift downward flow of water, known as drainage, caused by gravitational force (Zotarelli et al., 2019). Figure 3 illustrates that during the saturation phase, where soil moisture decreases rapidly and continuously, the experimental group demonstrated notable values of soil water retention. The observed variations in water content among setups highlight the effectiveness of compost pure organic matter in the saturation phase. Consistent with the findings of Minasny and McBratney (2018), the presence of organic matter significantly influences soil saturation dynamics, affecting water storage and redistribution mechanisms. These insights underscore the relevance of incorporating organic amendments into soil management strategies to optimize water retention and distribution for sustainable agricultural practices.

Figure 4

Mean soil moisture content at field capacity of different soil amendments



In figure 4, the analysis of the means of water content retained at a pressure of ⅓ bar using the plate extractor revealed significant results. Specifically, among the experimental setups, the 6KL:4FB:1BP exhibited the highest values, indicating higher water retention abilities during the field capacity phase of soil water holding capacity, same with the positive control vermicast. This was followed by the 3KL:1FB:2BP, 3KL:8FB:1BP, commercial soil amendment, and plain loam soil, in descending order.

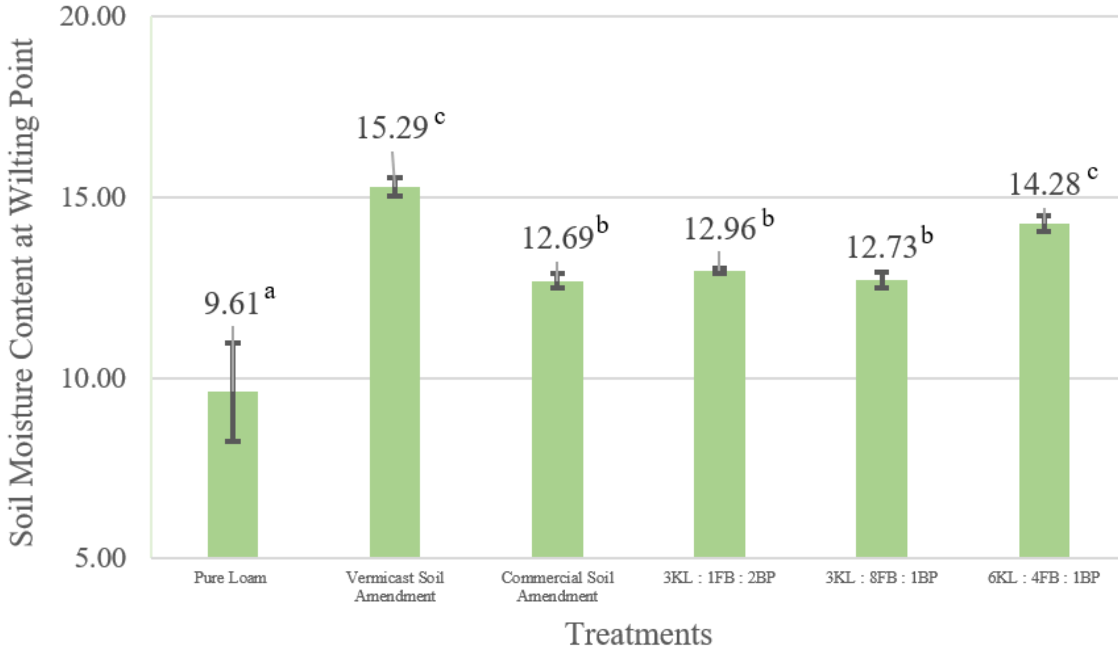
The indicated increase in field capacity in specific setups indicates their capacity to retain more water during the water absorption process, potentially leading to improved plant growth and yield. Following rapid drainage during the saturation phase, field capacity defines the maximum water retention capability of soil (Gardiner & Miller, 1998). The ideal water content for plant growth is maintained through the drainage of water from larger pores, while smaller pores retain the necessary amount of water. This process occurs because smaller pores tend to retain water after larger pores, known as macropores, have drained due to gravitational forces (Elkheir et al., 2016). Consequently, experimental setup 6KL:4FB:1BP yielded the highest soil moisture retention rate among experimental set-ups together with the positive control vermicast soil amendment demonstrating a better capacity for water retention, potentially ensuring plants with a more consistent and sustained water supply. It can be deduced that during the field capacity phase of these soil samples, their smaller soil pores, which possess the ability to withstand gravitational forces, effectively retain water through capillary action (Elkheir et al., 2016).

Additionally, the results of the Tukey's HSD test unveiled clear distinctions among all experimental setups, as each mean was assigned to distinct subgroups for this phase of soil water holding capacity. This underscores the considerable variability in water retention capabilities among the various soil treatments. Moreover, statistical results showed a F-value of 643.66 alongside a p-value of 0.000, which falls below the 5% level of significance. This indicates statistically significant differences among the experimental set-ups, further emphasizing the substantial variations in their water retention capacities.

Figure 5 presents the mean outcomes of samples subjected to a pressure of 15 bar using the pressure plate extractor. Higher values indicate greater water retention after the application of pressure. Among the experimental setups, the 6KL:4FB:1BP ratio demonstrated higher water retention abilities as well as positive control vermicast soil amendment compared to other set-ups. The statistical results yielded an F-value of 53.28 with a p-value of 0.000, which falls below the 5% significance level. This indicates significant differences among the set-ups in terms of their water retention capabilities during the phase.

Figure 5

Mean soil moisture content at wilting point of different soil amendments



The permanent wilting point marks a crucial stage in plant growth, indicating the point at which no water is accessible to the plant. Even though some water may still be present in the soil, it becomes unreachable for root absorption. At this critical juncture, plants struggle to extract water quickly enough to fulfill their water needs. Thus, higher levels of retained water at this phase signify greater soil moisture retained even at the last phase of water holding capacity (Zotarelli et al., 2019). In line with that, the 6KL:4FB:1BP ratio still demonstrated higher water retention abilities among experimental set-ups. Even though plants reach the wilting point stage, where they begin to wilt and may not recover their turgor, it can be deduced that among the different set-ups, the 6KL:4FB:1BP ratio and vermicast soil amendment retains the most significant amount of water in the soil at this stage. However, this water is typically unavailable for plants as the wilting point represents the culmination of water holding capacity. In general, water is retained in the soil's micropores at this stage, held with a tension that exceeds the plant's capacity to extract the water, making the wilting point equivalent to unavailable water (Schoonover & Crim, 2015).

The findings from Tukey's HSD test revealed distinct groupings among the experimental setups. Specifically, plain loam soil exhibited the lowest mean and stood alone in its subgroup. The commercial soil amendment, along with set-ups 3KL:1FB:2BP and 3KL:8FB:1BP, formed another subgroup with their means being second to the highest. Meanwhile, set-ups 6KL:4FB:1BP and vermicast soil amendment were grouped together in a separate subgroup, both having the highest means among all set-ups. This indicates that they possess comparable efficacy and demonstrate the most notable distinction from the negative control, in a positive way.

Figure 6

Means of gravitational water of soil amendments

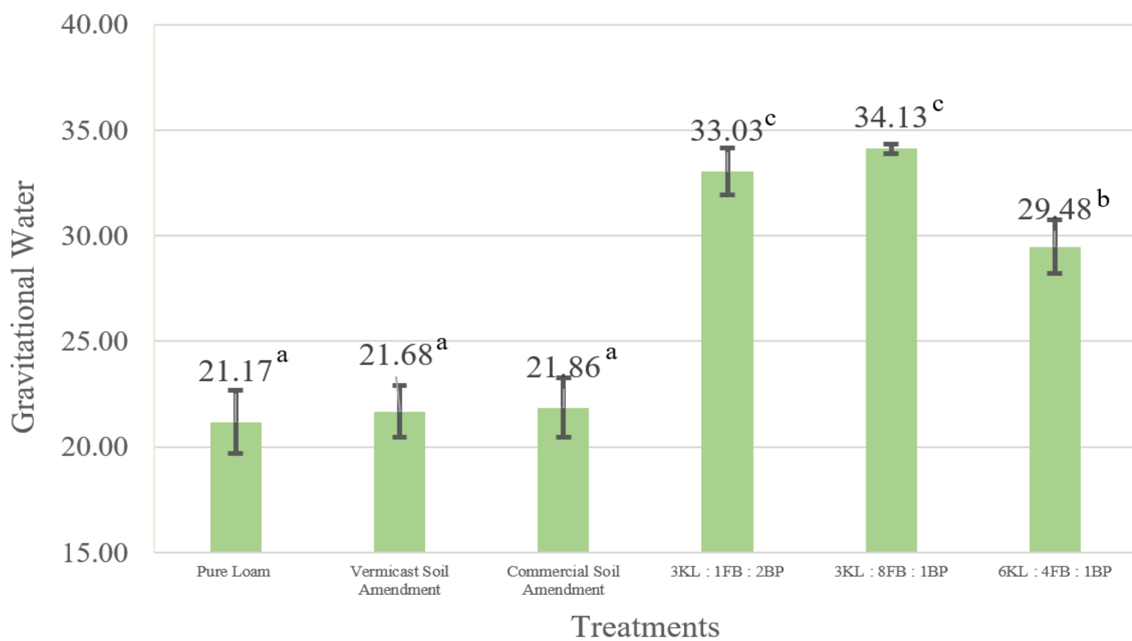


Figure 6 presents the gravitational water content of the soil samples, showcasing the water absorbed by macropores. Among all setups, experimental set-ups 3KL:1FB:2BP and 3KL:8FB:1BP exhibited the highest results, followed by setup 6KL:4FB:1BP. Conversely, plain loam soil, vermicast soil amendment, and commercial soil amendment showed minimal differences, with distinctions mainly observed in decimal points. Tukey's HSD test indicated that plain loam soil, vermicast soil amendment, and commercial soil amendment belong to the same subgroup, showing statistically similar results. In contrast, setup 6KL:4FB:1BP is isolated in a subgroup with higher values compared to the aforementioned, while both setups 3KL:1FB:2BP and 3KL:8FB:1BP are grouped together in a separate subgroup. Furthermore, the one-way ANOVA test revealed a significant difference between groups, with an F-value of 126.66 and a p-value of 0.000, falling below the predetermined significance level of 5%.

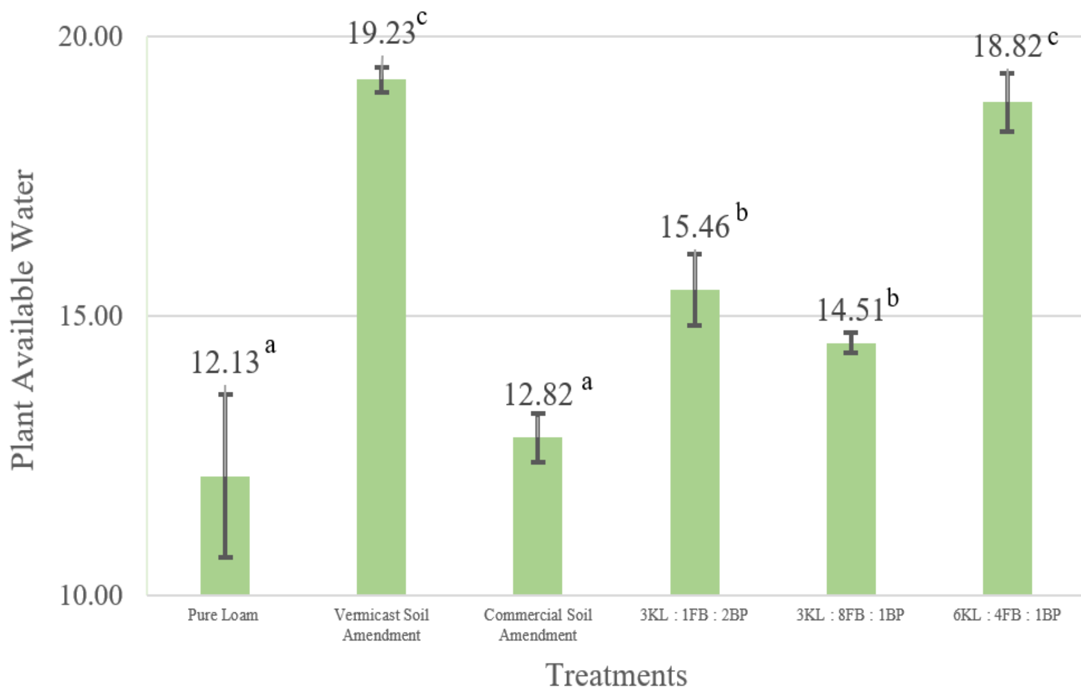
When soil demonstrates a high capacity to retain gravitational water, it signifies its ability to preserve moisture even after excess water has drained away. This attribute holds significant importance for plant growth, as it guarantees a steady and sufficient water supply to plant roots, particularly during drought periods or intervals between watering (Schoonover & Crim, 2015). The experimental setups with ratios of 3KL:1FB:2BP and 3KL:8FB:1BP, which yielded the most favorable outcomes, exhibit increased gravitational water content in soil water holding capacity (SWHC). This is advantageous for soils, as it enhances moisture retention and availability for plant roots, thereby promoting healthier plant growth (Gavrilescu, 2021). The amount of gravitational water is determined by subtracting the water content at saturation from the water held at field capacity. From the observation that experimental set-ups 3KL:1FB:2BP and 3KL:8FB:1BP showed higher averages at saturation but lower averages at field capacity, it can be deduced that their gravitational water content was higher compared to that of 6KL:4FB:1BP, as the latter yielded higher results at field capacity.

Some soils, particularly those rich in sand, may exhibit a phenomenon of having higher gravitational water but lower field capacity. This is due to the larger pore spaces between sand particles, which facilitate rapid drainage of water under the influence of gravity. Consequently, while these soils may have ample gravitational water—allowing water to move freely downwards—their ability to retain water against gravity (known as field capacity) might be compromised as the water drains away quickly, leaving the soil relatively dry. This situation commonly arises in soils characterized by poor compaction and structure (Gavrilescu, 2021). Based on this understanding, it can be inferred why set-ups 3KL:1FB:2BP and 3KL:8FB:1BP exhibited higher average water content levels at saturation but lower averages at field capacity.

Figure 7 illustrates the average soil water moisture content that is readily accessible for plant uptake, also known as Plant Available Water (PAW). It presents the disparity between soil water content at Field Capacity and Permanent Wilting Point. The findings indicate that the 6KL:4FB:1BP treatment exhibited the highest mean percentage of PAW among all experimental set-ups, reaching 18.82%.

Figure 7

Means of plant available water of different soil amendments



Commonly known as Readily Available Water (RAW), Total Available Water (TAW), or Plant Available Water (PAW), this stage denotes the point where water is exclusively accessible for plant utilization. This phase bears great significance in comprehending water holding capacity, as the water retained in micropores predominantly determines the accessibility of water for plants within the soil (Wu et al., 2018). Hence, results in figure 7 showed that the 6KL:4FB:1BP treatment demonstrated the highest average percentage of PAW, similar to the positive control vermicast, indicating its efficacy in providing sufficient water for essential metabolic processes in plants. These processes include photosynthesis, transpiration, and nutrient transport, all of which are crucial for plant health and growth. PAW directly affects plant hydration, nutrient absorption, and overall well-being. Inadequate PAW levels can result in water stress, wilting, diminished growth, and potentially plant demise (Ahluwalia et al., 2021).

The one-way ANOVA test revealed a significant difference between groups, with an F-value of 86.971 and a p-value of 0.000, which is below the predetermined significance level of 5%. Furthermore, Tukey's HSD test indicated that the commercial soil amendment and plain loam soil fall within the same subgroup, while set-ups 3KL: 1FB: 2BP and 3KL: 8FB: 1BP are grouped together in another subgroup. Interestingly, both the vermicast soil amendment and the 6KL: 4FB: 1BP setup demonstrated statistically similar results by being categorized within the same subgroup.

Upon comparing the experimental set-ups, they differ among their nitrogen content, with 6KL:4FB:1BP having the highest quantity of N. This factor may pertain to a conclusion from a similar study showing a systematic increase of yield quality for wheat with the increase of nitrogen treatment during cold-arid seasons (Wang et al., 2015). In metabolic processes, vegetative and reproductive growth and yield significantly increase upon the adequate supply of nitrogen (Chaves et al., 2014). The nitrogen content of soil is found to aid in the rate of saturation as it primarily spreads within water-filled pores, a factor influenced by the level of porosity. This is an indication of a higher water retention in soils (Indoria et al., 2017). Thus, the higher content of N in a treatment has a direct relationship on SWHC.

However, excessive nitrogen application could lead to soil acidification as well as worsen the soil environment which ultimately has a negative impact on crop growth and yield (Sun et al., 2016). According to a study by Sun et al. (2020), the optimal N application rates were based on optimal P and K application rates. Therefore, building the right equilibrium for phosphorus (P) and potassium (K) application rates in plant production, will encompass greater impacts to soil properties, leaf physiology, and crop yield in plants across different N application rates, guided by the optimal P and K application rates. (Giacometti et al., 2013). Among the three NPK application rates from a study by (Gul et al., 2015), a ratio with 75:50:30 showed the most optimal performance in terms of crop growth, yield, and yield attributes. Similar to this treatment, the ratio 6:4:1 utilizes decreasing levels within each individual NPK content.

5. Conclusion

This study concludes that treatments 6KL:4FB:1BP and the vermicast soil amendment exhibited the highest SWHC and comparable results in terms of the percolation method after 24 hours. This indicates that within the experimental set-ups, treatment 6KL:4FB:1BP shows the most favorable result. Among the six setups of soil amendments, the application of treatment 6KL:4FB:1BP yielded the highest water content in the assessment of saturation at 0 bar using the percolation process after 14 days. In addition, this was attained equally significant by 3KL:1FB:2BP and 3KL:8FB:1BP. Therefore, the amount of water at the saturation stage is the highest for these treatments. As for PAW, treatments 6KL:4FB:1B and vermicast soil amendment yielded the highest amount of water accessible for plant use, thereby exhibiting also statistically similar results.

LeaFina, particularly the treatment 6KL:4FB:1B, can be a potential candidate as a soil amendment to enhance soil water holding capacity. It serves as an efficient alternative for chemical and costly soil amendments that cause multiple environmental risk factors such as soil degradation and soil biodiversity destruction (Palansooriya et al., 2020). Along with health risks posed by synthetic fertilizers like a nitrogenous based fertilizer which when consumed in crops in excess, can cause various conditions like diabetes, and neural tube defects (Ahmed et al., 2017). This study sets the foundation for the evaluation into alternative materials for fertilizer manufacturing, with the goal of alleviating the harmful impacts linked to chemical fertilizers on human health and the environment.

Acknowledgment

The authors express sincere gratitude to Mrs. Ma. Ruby A. Mendoza, School Head of San Pablo City Science Integrated High School, for authorizing the conduct of the research study; to Dr. Victorino A. Bato, Assistant Professor 6 of Agricultural Systems Institute, University of the Philippines Los Baños, for supervising the researchers during experimentation; and to the Division of Soil Science, ASI-UPLB for allowing the researchers to utilize the needed equipment and welcoming them to the facility.

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