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Effects of Vermicast and Arbuscular Mycorrhizal Fungi (AMF) on the Establishment of Cacao (*Theobroma cacao* Linn.) Seedlings Grown in Degraded Soil

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Abstract

Declining soil fertility poses a significant challenge for cacao production, particularly for establishing seedlings. This study investigated the potential effects of vermicast and arbuscular mycorrhizal fungi (AMF) to enhance cacao seedling establishment in degraded soil conditions. The study was conducted in a low-cost protective structure established at the Abaca Project Experimental Area of the University of Southeastern Philippines, Mampising, Mabini, Davao de Oro, from December 2018 to April 2019. Furthermore, a Completely Randomized Design (CRD) was employed with eight (8) treatments and three (3) replications with eight (8) sample plants per replicate. The following are the treatment combinations: No Application (T_1), Recommended Rate (T_2), Vermicast (T_3), AMF (T_4), Vermicast + AMF (T_5), Recommended Rate + AMF (T_6), Recommended Rate + Vermicast (T_7), and Recommended Rate + AMF + Vermicast (T_8). The results of the study reveal that the application of vermicast and AMF combined with inorganic fertilizer based on the recommended rate increased the growth and development of cacao seedlings in degraded soil in terms of plant height (16.40%), length of leaves (14.59%), the width of leaves (12.11%), number of leaves (1.26%), leaf color (41%), stem diameter, shoot weight (60%), dry matter yield (116%) and *root:shoot* ratio (63.16%) compared to control or no application. Thus, the judicious use of inorganic fertilizer, vermicast, and AMF improves the establishment of cacao seedlings in soils with degraded conditions.

Keywords: cacao, vermicast, mycorrhiza, degraded soil, the Philippines

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The *Cacao* (*Theobroma cacao* Linn.) belongs to the family Sterculiaceae and is one of the 22 species of the genus *Theobroma* (Gutiérrez-Macías et al., 2021). *Theobroma* translates as the food of God in Greeks (Perera & Smith, 2013); this made Cacao through its beans known as the raw material for making chocolate, cocoa powder, and tablea. Originally domesticated for the pulp surrounding beans, it can be eaten as a snack and fermented into mildly alcoholic beverages. As an equatorial crop (ERDB, 2015), Cacao thrives well in regions occupying the equator, like the Philippines. Being a small and wide-branching evergreen tree that is native to tropical rainforest areas, cacao thrives best in soils that are moist, nutrient-rich, well-drained, and aerated (Asare, 2005).

As a global industry, exported cacao beans had a market value of USD 8.6 billion in 2017 (Voora et al., 2019). They increased to USD 24.5 billion in 2019 with a projection of growth of 3.1% compound annual growth rate to reach a value of $30.2 billion in 2026 (Allied Market Research, 2021). As a significant commodity for the chocolate industry, the Food and Agriculture Organization (FAO) of the United Nations reported 5.7 million tons of cocoa beans produced in 2021 from 12 million harvested hectares. From this production, African countries (Ivory Coast, Ghana, Nigeria, and Cameroon) are the top producing countries contributing 70% of the global cacao beans production. Asia contributes 13%, and the Philippines ranked 25th, producing 7,009 metric tons (FAO, 2021), thereby making it one of the key player countries in global cacao bean production.

The cacao industry in the Philippines can be traced back to the Spaniard's colonization. In a 2016 industry study by the Peace and Equity Foundation, the Philippines was the first country to produce cacao beans in Asia in 1600, particularly in San Jose, Batangas. This industry study further stressed that cacao became a highly profitable commodity in the market during the 1950s since mostly commercial cacao farms and processing facilities were established, and production expanded until 1980 due to tax incentives offered by the Philippine government. Production slowed dramatically when the Republic Act No. 6657 (Comprehensive Agrarian Reform Law) and the Comprehensive Agrarian Reform Program (CARP) in 1988 were implemented. Since then, the cacao industry has faced an unstable condition not until 2006 when R.A. 7900 or the High-Value Crop Development Program was enacted, which lists the intensification of cacao production as one of its priorities, bringing a significant progression in the production and stability of the market for cacao. The crafting of the Philippine Cacao Industry Roadmap 2017-2022 provides a direction for the Philippine cacao industry. It sets targets for production and provides strategic management programs that will revitalize, reinvigorate, and sustain the productivity of quality cacao in the Philippines (DA, 2017).

Moreover, the Department of Agriculture states that the global demand for cacao beans is expected to reach between 4.7 million and 5 million metric tons in 2020, and the global industry will have a deficit of 1 million MT. Local consumption is at 50,000 MT annually, but the local supply is around 10,000 MT, making the country a net importer.

Meanwhile, the focus today is on Mindanao, the southernmost group of islands in the Philippines, which accounts for 90% of the Philippines' cacao, proving that much work still needs to be done. Despite this progress, the Philippine cacao industry significantly faced challenges. This includes low productivity, limited farmer knowledge of modern farming techniques and farm management skills, limited access to finance to purchase input supplies and quality planting material, aging trees that are past their peak cocoa pod production, the decline in soil fertility, pests, and disease outbreaks, and unavailability of potential lands for sustainable cacao production (DA, 2017).

To address these challenges, development plans and management programs must incorporate initiatives that will address the sustainability of cacao production (DA, 2017). These initiatives should include a selection of vigorous planting materials, subsidy by the government to the local cacao farmers, development of cacao-related products, establishment of markets for cacao, enhancement of facilities for cacao production, and intensification of research towards sustainable cacao production. Sustainable cacao production in the Philippines is challenged by the unavailability of potential areas that can be devoted to cacao production. Relative to this, Villason and Olguera (2020) firmly believed that the need for appropriate characterization of the soil environment is a must so that optimum levels of nutrients can be estimated, proper site-specific management programs will be designed, and suitable areas for cacao production will be known, while unsuitable areas will be managed to suit the productivity needs, such that the case of the degraded soils located in the Philippine uplands (Asio et al., 2009). In this light, these areas need to be managed through deliberate and sustainable management programs aiming to augment cacao's productivity despite the marginal conditions.

Degraded soils are those that have low nutrient availability due to low pH, high concentration of exchangeable aluminum and manganese, low base saturation and cation exchange capacity, low organic matter content, and low available phosphorus and high fixation capacity (Asio et al., 2009). Aluminum toxicity is one of the agricultural production constraints with degraded soils, reflected through inhibited root growth, stunted appearance, and lack of plant vigor (Briones, 1982). Other nutritional problems associated with degraded soils are manganese and copper toxicity, as well as phosphorus, potassium, sulfur, zinc, boron, calcium, and magnesium deficiency (Francisco, 1994). Plants also suffer from low nitrogen levels because the nitrogen-fixing bacteria are quite sensitive to low pH (Recel, 1989). The susceptibility to erosion is also an essential consideration since degraded soils occur on sloping areas and dominate highland and mountain soils that were converted from forests to agriculture (Carating et al., 2014).

Aside from the agricultural-related problems, it is also a challenge to address environmental problems and social-related conflicts in degraded areas. The improvement of the infrastructure of the Philippines, such as the establishment of farm-to-market roads, services, and government aid, reached this marginal landscape. With these aids and services, introducing sustainable management schemes such as investing in high-value commodities such as cacao is a practical consideration to augment productivity in these areas. The challenge, therefore, is to improve the degraded area's condition to complement cacao's optimum growth and development requirements (Sys et al., 1993). These require adopting strategies that will address this climo-edaphic associated problem, hence introducing the promising potential of vermicomposting and taking advantage of the symbiotic association of native microorganisms present in the soil environment.

Vermicast is the stable product of the biooxidation and stabilization process of organic material as a result of the joint action of earthworms and microorganisms. The earthworms are the agents of turning, fragmentation, and aeration where organic wastes can be broken down and fragmented rapidly by earthworms, resulting in a stable, nontoxic material with a good structure that has potentially high economic value as a soil conditioner for plant growth (Dominguez & Sabler, 1997). The wide variety of organic waste available as feedstock in vermicomposting represents a rich source of microbial diversity. Furthermore, vermicast can contain plant growth-promoting free-living nitrogen fixers, nitrifying bacteria, and plant disease-protective microorganisms (Gopal et al., 2009) and even stimulate AMF colonization in roots. Arbuscular mycorrhizal fungi (AMF), on the other hand, are soil microbes that colonize the majority of plant roots and form a connection between the plant and the substrate, assisting in the generation of plant growth hormones, increasing nutrient availability, and inhibiting root infections (Kumari et al., 2021).

The utilization of vermicast and AMF is promising due to its sustainability and practicability. Its application in the long term will enhance the quality of the soil, reduce inputs of synthetic chemicals in the soil system, and enhance microbial diversity, which in return enhances the capability of the soil to sustain the needed requirements of the crop and augment the productivity potential and quality of the soil. Using vermicast and arbuscular mycorrhizal fungi will not only enhance cacao's productivity potential but will also improve the establishment of cacao seedlings in degraded soils.

Hence, the purpose of the study is to evaluate the effect of vermicast and arbuscular mycorrhizal fungi (AMF) on the seedling establishment of cacao in a degraded soil condition. Due to the increasing demand for this commodity, it is a great challenge for farmers in marginal areas to increase the productivity of cacao, particularly in a degraded soil environment.

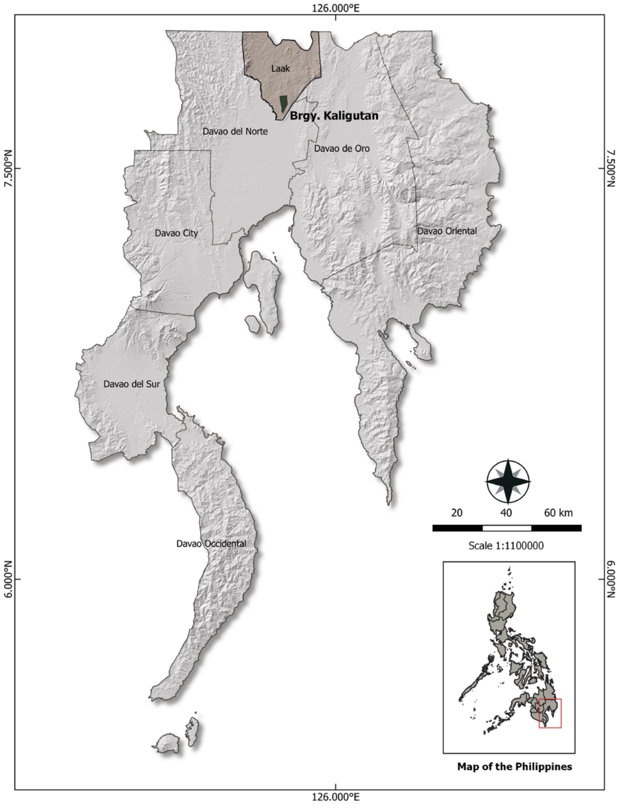
Materials and Methods

Sampling Site

The sampling site was selected through an intensive preliminary survey in the uplands of Brgy. Kaligutan in the Municipality of Laak, Davao de Oro (Figure 1). Biophysical characterization of the area shows that the site has rolling topography and type IV climatic conditions characterized by having no pronounced dry season throughout the year (Coronas, 1920) and is under intensive agroforestry land use system and management. The soil in this area belongs to the Camansa series, classified as Typic Eutropepts (Carating et al., 2014) with clay loam soil texture of the topsoil. Soil analysis reveals that this soil has an extremely acidic pH (4.0), low organic matter content (1.5%), very low phosphorus (4 ppm), and very high potassium (714 ppm).

Figure 1

Location of the Sampling Site of the Study



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Test Crop Used

The test crop used is cacao clone UF-18. Clone UF-18 is a commercial hybrid cacao registered at the National Seed Council (NSIC) that is a prominent *trinitario* hybrid highly adapted to the agro-climatic conditions in the Mindanao region. UF-18 is moderately resistant to vascular streak dieback (VSD) and tolerant to pod rot but susceptible to pod borer.

Greenhouse Experiment

The study was conducted in a low-cost protective structure established at the Experimental Area of the University of Southeastern Philippines, Tagum-Mabini Campus, Mabini, Davao de Oro, from December 2018 to April 2019. The experiment was laid out in a Completely Randomized Design (CRD) with eight (8) treatments and three (3) replications, with eight (8) sample plants per treatment per replicate. The following are the treatment combinations: *T_1 – No Application; T_2 – Recommended Rate; T_3 – Vermicast; T_4 – AMF; T_5 – Vermicast + AMF; T_6 – Recommended Rate + AMF; T_7 – Recommended Rate + Vermicast; T_8 – Recommended Rate + AMF + Vermicast.*

Soil Collection, Preparation, and Handling

A bulk sample from a 0-20 cm layer of soil was collected at the sampling site. The samples were mixed thoroughly, air-dried, and sieved through a 4 mm wire mesh screen to remove the stone and other rock fragments. Furthermore, a soil sample of about 1 kg was separated for physical and chemical analysis, and the rest was used as a medium for planting. The 1 kg soil sample was air-dried, pulverized using a wooden mallet, and sieved in a 2-mm wire mesh to get the fine earth and was sent to the Bureau of Soil's Laboratory, Department of Agriculture, Region XI, Agdao, Davao City.

Treatment Preparation and Management

There were 192 pots used in the study, which were referred to as pots in the succeeding sections. The pot had a size dimension of 10 x 12 inches, and every pot was filled with 3 kg of degraded soil. These pots were sown with cacao seeds selected based on vigor.

Five (5) days before sowing, treatments were applied based on the recommended rate of 0.01 N, 0.01 P2O5, and 0.002 K2O kg/ha/year of synthetic fertilizer and 0.5 kg/ha organic fertilizer. In contrast, AMF (Mycovam) was applied at the rate of 5 g pot-1. Plants were watered early in the morning or late in the afternoon when necessary. Weeds and insects in each pot were removed manually immediately after the emergence of weeds and when the insects were observed.

Data Gathered

Plant Height (cm). This was obtained by taking the average height of eight (8) sample plants per treatment per replication. Measurement was done from the base to the tip of the youngest developed leaves. This was done at 20, 40, 60, and 80 days after sowing (DAS).

Length of Leaves (cm). The length of the leaves was determined by measuring one representative leaf (number three from the top) per plant of eight sample plants per treatment per replication. This was based on the presumption that the third leaf from the top is fully developed. Measurement was done at 20, 40, 60, and 80 DAS.

Width of the Leaves (cm). The width of the leaves was taken from the same leaves used for the length of the leaves data by measuring and getting the mean of the eight (8) sample plants per treatment per replication. Data was gathered at 20, 40, 60, and 80 DAS.

Leaf color. The leaf color was taken from eight (8) sample plants per treatment per replication using Leaf Color Chart (LCC) by placing the middle part of the third leaf on the top of the color strips of LCC for comparison at 40, 60, and 80 DAS.

Stem Diameter (mm). The stem diameter was taken by measuring the mean of the up, middle, and below portion of the stem of eight (8) sample plants per treatment per replication using a Vernier caliper. Data were gathered at 20, 40, 60, and 80 DAS.

Seedling/Plant Biomass (grams/plant). During termination, the root and the shoot of the cacao seedlings were separated and oven-dried for one week or until the constant weight was obtained. Afterward, the weight of the root and shoot of the cacao seedlings were obtained separately. With this, the weight of the root was divided by the weight of the shoot, obtaining the root and shoot ratio. Moreover, the dry matter yield was obtained by getting the combined weight of the root and shoot.

Statistical Analysis

The data were analyzed statistically to determine the analysis of variance (ANOVA) at a 5% level of significance, and Duncan's Multiple Range Test (DMRT) was used to compare significant treatment means.

Results and Discussion

This study assessed the effects of vermicast and arbuscular mycorrhizal fungi (AMF) and recommended rate of inorganic fertilizers on the growth performance of cacao seedlings in degraded soil. The data suggests that the application of vermicast and AMF at different stages of growth had significant effects on the growth of cacao seedlings in terms of plant height, leaf length and width, number of leaves, stem diameter, leaf color, root weight, shoot weight, dry matter yield, and root-and-shoot ratio. The results imply that the growth of cacao seedlings in degraded soils can be improved by applying vermicast and AMF combined with inorganic fertilizer. This has significant implications for cacao farming and reforestation initiatives in areas with degraded soils.

General Observations

The growth performance of cacao seedlings, as shown in Figure 2, was significantly affected by the application of vermicast, AMF, and the recommended rate of inorganic fertilizer in terms of plant height at 20, 40, and 60 DAS. However, it did not become significant in the 80 days after DAS. The tallest plant height was observed in cacao seedlings applied with the recommended rate (T_2). Also, it significantly affects the length, width, and number of leaves at 20, 40, and 60 DAS but becomes insignificant at 80 DAS. The longest length was observed in cacao seedlings applied with the recommended rate + AMF (T_6). The longest width was observed in cacao seedlings applied with the recommended rate + vermicast (T_7). The highest number of leaves was observed in cacao seedlings applied with the recommended rate + AMF (T_6). The stem diameter was significant during 20 days after sowing. At 40 and 60 days after sowing, it became insignificant; however, it became significant again at 80 days after sowing. The widest measured stem diameter was observed in cacao seedlings applied with the recommended rate + vermicast (T_7). The leaf color was significantly influenced at 40, 60, and 80 DAS. The highest measured number of leaf colors was observed in cacao seedlings applied with the recommended rate + AMF + vermicast (T_8). Applying the recommended rate, vermicast, and AMF did not significantly affect the root weight.

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Figure 2

Photograph Showing Cacao Seedlings under Different Treatments Grown in a Degraded Soil

On the other hand, shoot weight was significantly affected, with the highest values observed in cacao seedlings applied with the recommended rate + vermicast (T_7). Dry matter yield was also significantly affected, with the highest yield observed in seedlings treated with the recommended rate + AMF + vermicast (T_8). In terms of root-to-shoot ratio, the lowest ratios were found in cacao seedlings applied with the recommended rate alone (T_2), as well as in combination with AMF (T_6) and vermicast (T_7). This implies good vegetation characteristics during the early successional phases.

Plant Height

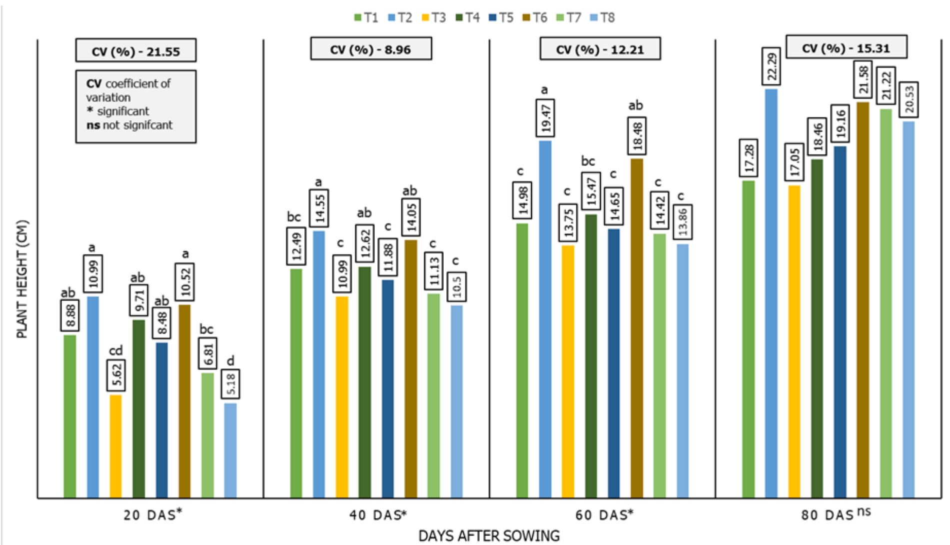
Plant height is an important parameter considered in cacao seedling production. It is one of the indicators used in evaluating the growth performance of plants grown in areas with unique agro-climatic conditions. Plant height of cacao seedlings at 20, 40, 60, and 80 DAS as affected by vermicast and AMF grown in a degraded soil is shown in Figure 3.

Results reveal that the height of cacao seedlings was significantly affected by the application of vermicast and AMF grown in degraded soil at 20, 40, and 60 DAS but did not significantly affect during 80 DAS. Cacao seedlings applied with the recommended rate (T_2) had the consistent tallest height, followed by the application of recommended rate + AMF (T_6), AMF (T_4), and control or no application (T_1). Meanwhile, shorter heights were observed on the treatments applied of vermicast + AMF (T_5), recommended rate + vermicast (T_7), vermicast (T_3), and recommended rate + AMF + vermicast (T_8).

The result clearly shows that the recommended rate maximizes the growth of cacao seedlings from 20 to 80 days after sowing (DAS) grown in degraded soil. Its effect is superior to the growth of the seedlings grown under control or without application (T_1). It can also be observed that the treatment applied in combination with the recommended rate of fertilizer and AMF (T6) had a comparable result to the recommended rate alone (T_3). This implies that the recommended rate and AMF had the potential to boost the plant height of the cacao seedlings grown in degraded soil since the fertilizer supplied the lacking nutrients. AMF colonized the root, increasing its density (Kumari et al., 2021) and enhancing the cacao seedlings' water and nutrient absorption, thereby increasing its growth and development of soils despite degraded conditions.

Figure 3

Plant Height of Cacao Seedlings Grown in Degraded Soil at 20 to 80 DAS as Affected by Vermicast and Arbuscular Mycorrhizal Fungi (AMF). Means with Common Letters and Those Without Letters are Not Significantly Different at a 5% Level of Significance



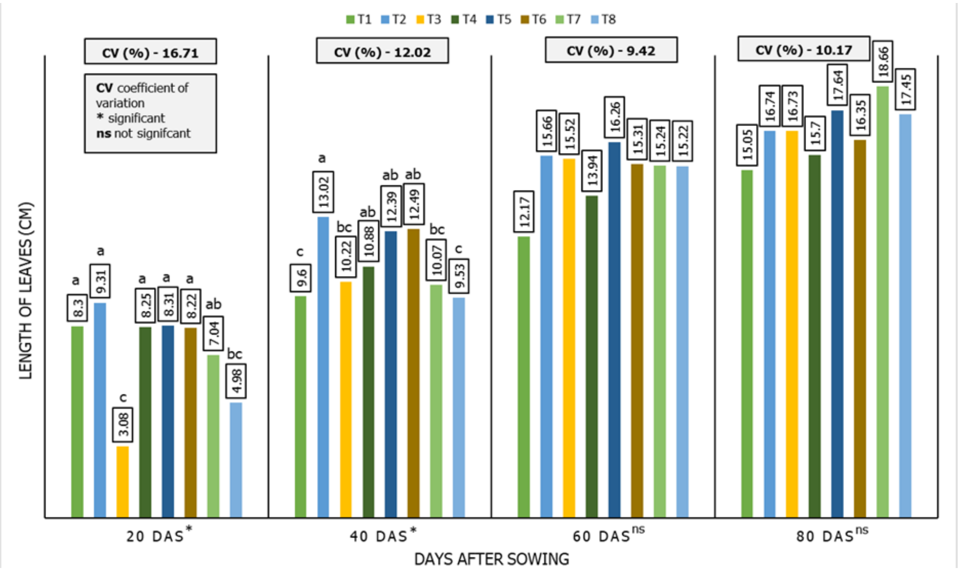
Length and Width of Leaves

Length of leaves is one of the indicators used in evaluating the vigorous appearance and or nutrition of the plant. As the length and the width of the leaves dictate the surface areas for the efficiency of the photosynthetic activity of the plant, such parameters are helpful in the visual evaluation of the quality of cacao seedlings. Figure 4 and Figure 5 show the length and width of cacao seedlings, respectively, grown in degraded soil at 20, 40, 60, and 80 DAS as affected by vermicast and arbuscular mycorrhizal fungi (AMF).

Results show that the length of leaves of cacao seedlings was significantly affected by the application of vermicast and AMF grown in degraded soil during 20 and 40 DAS but did not significantly affect during 60 and 80 DAS. Cacao seedlings applied with the recommended rate (T_2) resulted in the longest length, followed by the application of recommended rate + AMF (T_6) vermicast + AMF (T_5) and AMF (T_4). The shorter lengths were observed on the cacao seedlings applied with vermicast (T_3), recommended rate + vermicast (T_7), control or no application (T_1), and recommended rate + AMF + vermicast (T_8). The comparable effects were observed in vermicast, AMF, and the recommended rate for the number of leaves. Combining the recommended rate with AMF (T_6) and vermicast with AMF (T_5) had shown a potential effect on the length of leaves. However, combining the recommended rate, vermicast, and AMF had an inferior effect on the length of leaves.

Figure 4

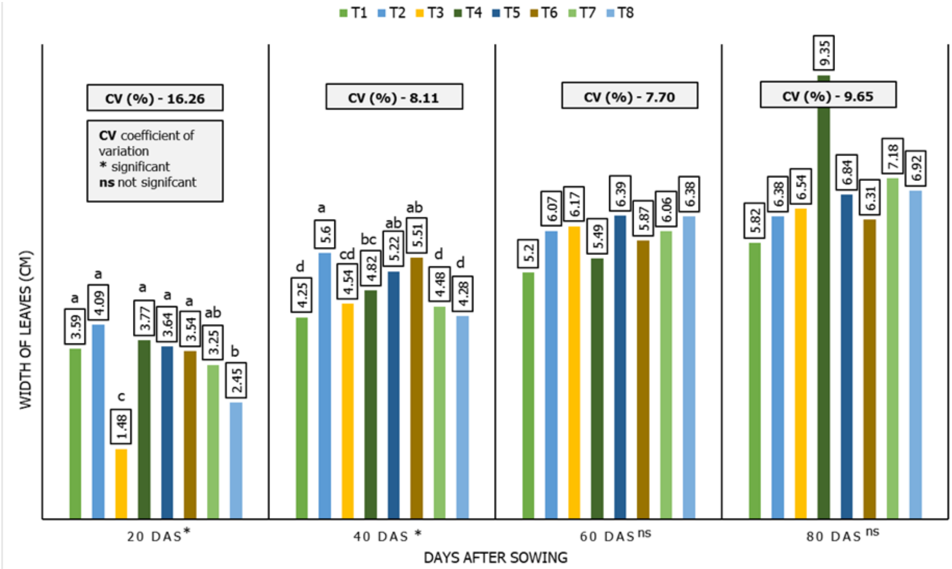
Length of Leaves of Cacao Seedlings Grown in Degraded Soil at 20 to 80 DAS as Affected by Vermicast and Arbuscular Mycorrhizal Fungi (AMF). Means with Common Letters and Those Without Letters are Not Significantly Different at a 5% Level of Significance



Meanwhile, the width of the leaves of cacao seedlings was significantly affected by the application of vermicast and AMF grown in degraded soil during 20 and 40 DAS. However, it did not significantly affect during 60 and 80 DAS. Cacao seedlings applied with the recommended rate (T_2) resulted in the widest width, followed by the application of recommended rate + AMF (T_6), vermicast + AMF (T_5), AMF (T_4), vermicast (T_3), recommended rate + vermicast (T_7), and recommended rate + AMF + vermicast (T_8). The thinnest width was observed on control or no application (T_1).

Figure 5

Width of Leaves of Cacao Seedlings Grown in Degraded Soil at 20 to 80 DAS as Affected by Vermicast and Arbuscular Mycorrhizal Fungi (AMF). Means with Common Letters and Those Without Letters are Not Significantly Different at a 5% Level of Significance



This illustrates that the application of recommended rate + vermicast (T_7) maximizes the width of leaves of cacao seedlings, and it is comparable to the control or no application (T_1). This can be attributed to the improvement of good physical condition by applying vermicast and the availability of nutrients as a result of applying the fertilizer's recommended rate. Despite having less plant height than the application of AMF, treatment applied with vermicast shows a more robust plant stand. Vermicast improves the structure, serving as the cementing agent for soil particles that form aggregates and contain nutrients released to the soil solution for plant nutrition. As such, the performance of the cacao seedlings in soils with degraded conditions was enhanced with the application of AMF and vermicast. According to Celik et al. (2004), adding organic materials of various origins to soil has been one of the most common rehabilitation practices to improve soil physical properties. AMF has been known to play a significant role in forming stable soil aggregates. Added with organic fertilizer, it is more effective in improving soil physical properties than the inorganic treatment, leaving plant growth desirable. However, since vermicast needs to undergo decomposition so that nutrients will be released for plant needs during the vegetative stage, the improved length, width, and number of leaves to treatment applied with fertilizer can be attributed to this premise.

Leaf Color

Leaf color is an important parameter considered in cacao seedling production. It reflects the general condition of the plant, whether it is healthy, has inferior growth, or manifests symptoms due to a deficiency of certain nutrients. The leaf color of the cacao seedlings as affected by vermicast and AMF grown in degraded soil is shown in Figure 6.

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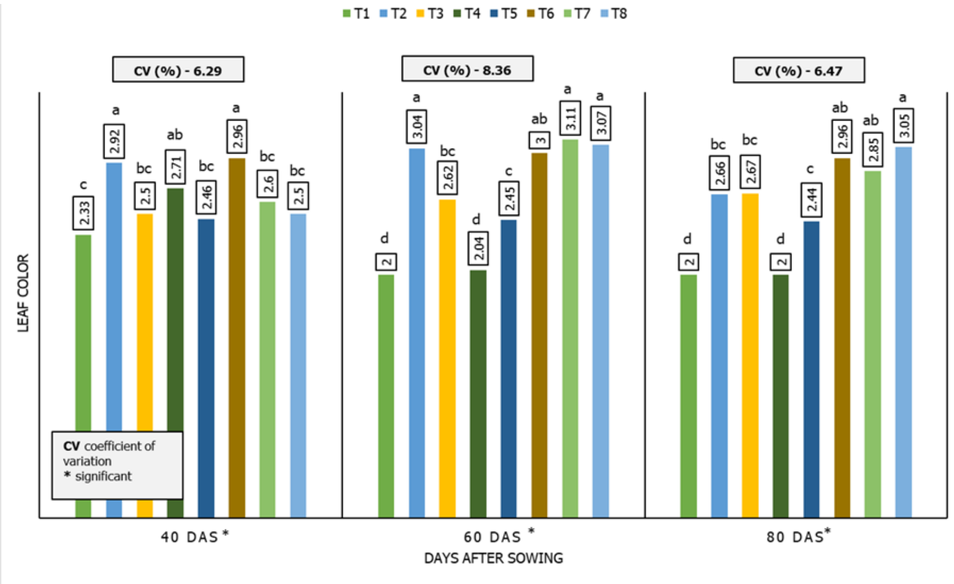
Figure 6

Leaf Color of Cacao Seedlings Grown in Degraded Soil at 20 to 80 DAS as Affected by Vermicast and Arbuscular Mycorrhizal Fungi (AMF). Means with Common Letters are Not Significantly Different at a 5% Level of Significance



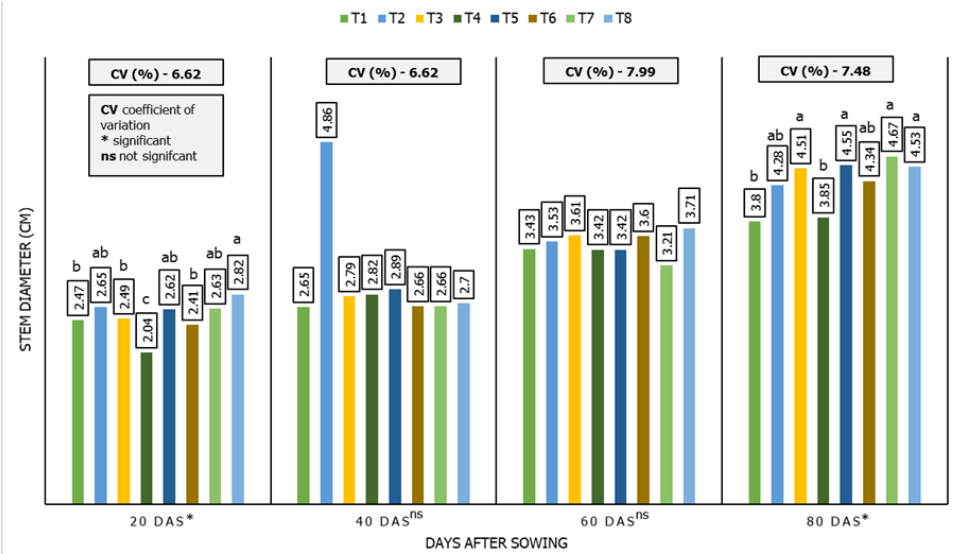
Based on the analysis, the leaf color of cacao seedlings was significantly affected by the application of vermicast and arbuscular mycorrhizal fungi (AMF) grown in degraded soil during 40, 60, and 80 days after sowing (DAS). Cacao seedlings applied with recommended rate + AMF + vermicast (T_8) resulted in the highest number, followed by the seedlings applied with recommended rate + AMF (T_6), recommended rate + vermicast (T_7), vermicast (T_3), recommended rate (T_2), and vermicast + AMF (T_6). Meanwhile, the lowest leaf color was control or no application (T_1) and AMF (T_4). The results imply that the application of the recommended rate enhances the appearance of the leaf of the plant and is superior to the control. This can be attributed to the enhanced nutrition of the soil due to the improvement of physical and chemical characteristics brought by the application of vermicast and the recommended rate, respectively.

Stem Diameter

Stem diameter is an important parameter considered in cacao seedling production. It is one of the indicators used in evaluating the stem diameter performance of the plant grown in areas with unique agro-climatic conditions. The stem diameter of the cacao seedlings as affected by vermicast and AMF grown in degraded soil is shown in Figure 7.

Figure 7

Stem Diameter of Cacao Seedlings Grown in Degraded Soil at 20 to 80 DAS as Affected by Vermicast and Arbuscular Mycorrhizal Fungi (AMF). Means with Common Letters and Those Without Letters are Not Significantly Different at a 5% Level of Significance



The result shows that cacao seedlings' stem diameter was significantly affected by the application of vermicast and AMF grown in degraded soil 20 and 80 days after sowing (DAS), but it became insignificant during 40 to 60 DAS. Cacao seedlings applied with recommended rate + vermicast (T_7) resulted in a bigger stem diameter followed by the application of recommended rate + AMF + vermicast (T_8), vermicast + AMF (T_5), vermicast (T_3), recommended rate + AMF (T_6), and recommended rate (T_2). Meanwhile, the thinnest stem diameter was observed in the plants with AMF (T_4) and control or no application (T_1).

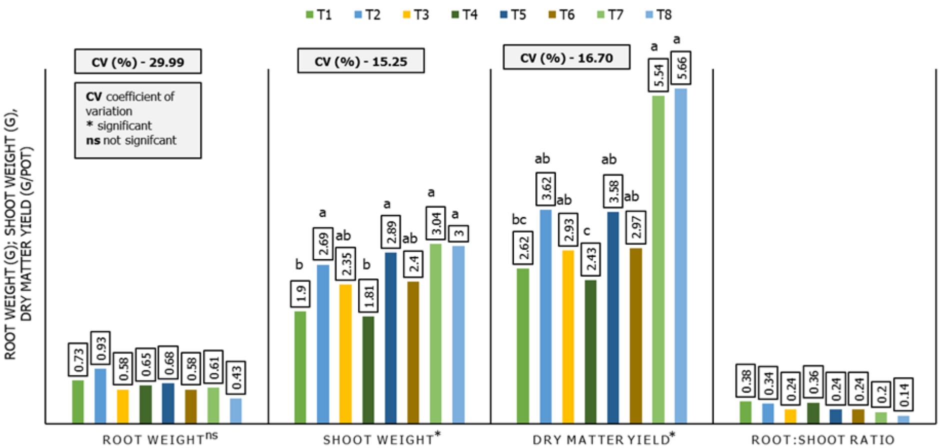
The results show that the treatment applied at the recommended rate combined with vermicast and AMF had a superior stem diameter to the other treatment. This is attributed to the cacao's enhanced nutrition due to the nutrients it contains. Celik et al. (2004) state that organic fertilizer sources were shown to have a major positive effect on soil physical properties, and according to Wu et at. (2005), biofertilizers have been identified as an alternative to chemical fertilizers to increase soil fertility and crop production in the sustainable farming.

Plant Biomass

Dry matter yield refers to the total dry matter produced which can be partitioned into root dry matter and shoot dry matter discarded with moisture content. These are used to evaluate the rooting and shooting performance of the plant grown in areas with unique agro-climatic conditions. The root weight, shoot weight, and dry matter yield of cacao seedlings affected by vermicast and AMF grown in degraded soil are shown in Figure 8.

Figure 8

Root and Shoot Weight, Dry Matter Yield, and Root:shoot Ratio of Cacao Seedlings Grown in Degraded Soil at 20 to 80 DAS as Affected by Vermicast and Arbuscular Mycorrhizal Fungi (AMF). Means with Common Letters and Those Without Letters are Not Significantly Different at a 5% Level of Significance



Results show that the root weight of cacao seedlings was not significantly affected by the application of vermicast and AMF grown in degraded soil. Cacao seedlings applied with the recommended rate (T_2) resulted in the highest root weight, followed by the application of control or no application (T_1), vermicast + AMF (T_5), AMF (T_4), and recommended rate + vermicast (T_7). Meanwhile, the lowest root weight was observed at the treatments applied with vermicast (T_3), recommended rate + AMF (T_6), and recommended rate + AMF + vermicast (T_3). Meanwhile, the shoot weight of cacao seedlings was significantly affected by the application of vermicast and AMF grown in degraded soil. Cacao seedlings applied with recommended rate + vermicast (T_7) resulted the highest shoot weight, followed by and recommended rate + AMF + vermicast (T_8), vermicast + AMF (T_5), recommended rate (T_2), recommended rate + AMF (T_6), and vermicast (T_3). Meanwhile, the lowest shoot weight was observed at the treatments applied with control or no application (T_1) and AMF (T_4).

The results indicate that the application of the recommended rate (T_3) maximizes the rooting performance of cacao seedlings. Moreover, to enhance the performance of the cacao seedlings, the application of AMF and vermicast is a potential initiative to address the fertility problem in degraded soil. Saranya and Kumutha (2011) show that plants in vermicompost with AMF increase the shoot length, root length, root biomass, and nutritional status. Meanwhile, the recommended rate + vermicast (T_8) enhances the shooting performance of the cacao seedlings. This can be attributed to the soil's nutrients due to physical and chemical improvement brought by applying fertilizer and vermicast.

On the other hand, the dry matter yield of cacao seedlings grown in degraded soil was significantly affected by the application of vermicast and AMF grown in degraded soil. Cacao seedlings applied with the recommended rate + AMF + vermicast (T_8) resulted in the highest dry matter yield, followed by the application with recommended rate + vermicast (T_7), recommended rate (T_2), and vermicast + AMF (T_5). The lowest dry matter yield was observed at the treatments applied with recommended rate + AMF (T_6), vermicast (T_3), control or no application (T_1), and AMF alone (T_4). This result clearly shows that the application of the recommended rate, vermicast, and AMF enhances the dry matter yield performance of cacao seedlings and can be attributed to the improved nutrition of the soil in terms of nutrient availability (Abad et al., 2001; Chen, 2006) and physical condition improvement.

Finally, the root:shoot ratio of cacao seedlings was significantly affected by the application of vermicast and AMF. Cacao seedlings applied with recommended rate + AMF + vermicast (T_8) resulted in the lowest ratio, followed by recommended rate + vermicast (T_7), vermicast + AMF (T_5), recommended rate + AMF (T_6), and vermicast (T_3). Meanwhile, the highest ratio was observed at the treatments applied with the recommended rate (T_2), AMF (T_4), and control or no application (T_1).

The results demonstrate that applying the recommended rate of inorganic fertilizer, AMF, vermicast, and in combination enhances the root:shoot ratio of the cacao seedlings. Results imply that the lower root-to-shoot proportion indicates a well-developed vegetative system of the plant, necessary for the photosynthetic process to occur efficiently, thereby creating photosynthates to build tissues required for the optimum growth and development of the cacao seedlings. According to Wood and Roper (2000), plants with a higher proportion of roots can compete more effectively for soil nutrients, while those with a higher proportion of shoots can collect more light energy. A large proportion of shoot production is characteristic of vegetation in early successional phases. On this note, there is clear evidence of the potential of vermicast and AMF in improving the establishment of cacao seedlings in degraded areas. Vermicast improves the soil's physical conditions and improves the soil's pH to desirable levels, while AMF enhances the root density and disease resistance of cacao plants (Borowicz, 2013).

Conclusion and Recommendation

The application of vermicast and AMF improved the growth of cacao seedlings planted in degraded soil. Thus, the judicious use of inorganic fertilizer, vermicast, and AMF improves the growth of cacao seedlings in soils with degraded conditions. Therefore, it is recommended that a field trial be done to evaluate the effect of vermicast and AMF in enhancing not only the growth but also the yield and quality of beans and other varieties of cacao.

Conflict of Interest Statement

We have no conflict of interest to disclose.

AI Disclosure

We declare that this manuscript was prepared without the assistance of artificial intelligence. Hence, the content of this paper is original.

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