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**Research Article**

# Using soil amendments and mycorrhiza to improve chemical properties of degraded calcareous soil and yield of sorghum in dryland

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**Abstract**

Optimized use of calcareous soil in dryland areas needs to begin with rehabilitation efforts using soil amendments, including organic fertilizer and biochar. This study aimed to determine the effects of soil amendments and mycorrhizal biofertilizers on the chemical quality of calcareous soils to increase the yield of sorghum on dry land. The study was conducted at the experimental garden of the Agricultural Extension Center located in Oelnasi Village from April to August of 2023. Two factors studied were soil amendment and mycorrhizal biological fertilizer, both of which were arranged in a randomized block design. The parameters observed were soil chemical properties, plant N and P nutrient uptake, and sorghum yield. The results showed that the application of cow dung, rice straw compost, and corncob biochar improved the chemical quality of calcareous soil. The application of corncob biochar significantly reduced soil pH from 7.85 to 7.19 and increased soil organic C to 2.55% C, followed by treatment with cow dung and rice straw compost. Other soil chemical properties, i.e., N, P, K, and soil CEC, also improved, which differed from the control treatment. The mycorrhizal biofertilizer provided also improved the chemical properties of calcareous soil. The application of mycorrhizal biofertilizer increased the N and P uptake of sorghum plants by 3.79% dry weight$^{-1}$ and 2.18% dry weight$^{-1}$, respectively, as well as increased sorghum yields, respectively by 4.04 t ha$^{-1}$, 3.97 t ha$^{-1}$ and 3.87 t ha$^{-1}$, higher than the control which only achieved 2.32 t ha$^{-1}$.

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## Introduction

Soils spread across East Nusa Tenggara Province, especially in the West Timor region, are generally classified as young soils such as Renzina, Inceptisol, Grumosol, Alfisol, and Vertisol (Subardja et al., 2014). These lands are mostly formed in geological formations in the form of limestone. Soils formed on limestone rock formations are known as calcareous soils which are characterized by high calcium carbonate ($CaCO_3$) content which greatly influences the physical and chemical properties of the soil as well as plant growth (Taalab et al., 2019).

Plants that grow on calcareous soil generally experience nutrient deficiencies, especially phosphorus (P), because most of the P in the soil is fixed by $CaCO_3$ ions and exists as calcium phosphate deposits, which are difficult for plants to provide. The low availability of P nutrients greatly limits plant growth because P is an essential nutrient for plants. The nutrient P is directly involved in all physiological processes of plant life and is utilized by plants from the germination phase vegetative phase to the generative phase of the plant (Budi and Sari, 2015).

A significant cereal crop other than corn that is dominantly cultivated on calcareous soil in the West Timor region is sorghum (*Sorghum bicolor* L.) Moench). Sorghum is a potential cereal crop because all parts of the plant have economic value. Even though it has high economic potential, its development is still limited compared to corn plants. Sorghum is a type of plant that is suitable for development on dry land because it is very adaptable to dry climate conditions and can grow on soil with low fertility levels. Apart from climate factors, one of the problems with dry land in the Kupang Regency area is the physical condition of the land, which is unproductive and dominated by calcareous soil.

Efforts to increase the productivity of calcareous soil at the farmer level have so far been carried out with inorganic fertilizer (NPK fertilizer). This inorganic fertilization often has to be done at high doses to get a significant plant response. Taalab et al. (2019) stated that the application of inorganic fertilizer (NPK fertilizer) at normal rates often does not provide optimal plant results in terms of quantity and quality.

Therefore, it is necessary to optimize the use of degraded calcareous soil as cultivation land by mechanical means to improve the quality of the soil. The right mechanical approach to improve the quality of calcareous soil so that it is productive is to use soil amendments and biological fertilizers. The right mechanical approach to improve the quality of calcareous soil so that it is productive is to use soil amendments and biological fertilizers. Various studies have proven that soil amendments have dual functions, namely as a source of organic carbon, as well as a source of nutrients, and to rehabilitate degraded soil (Celestina et al., 2019; Matheus et al., 2023). Several studies have shown that improving the physical, chemical, and biological properties of soil is more successful with organic amendments like compost, manure, and biochar than with mineral supplements (Mensah, 2015; Martinez et al., 2018).

The weakness of conditioning is the quality, especially the relatively low amount of nutrient content, so the amount required is relatively large (>10 t $ha^{-1}$); and the nutrient release process is slow, so there is no synchronization between nutrient availability and plant needs (Glaser et al., 2015; Matheus et al., 2017; Nobile et al., 2022). Mycorrhizal biofertilizers can be used with soil amendments to help boost plant nutrient availability and absorption and overcome the limitations of soil amendments. Fungi known as mycorrhizae, can form symbiotic relationships with plant roots. They play a crucial role in enhancing plant resistance, preserving soil fertility by promoting the uptake of N, P, and K nutrients, enhancing water absorption, and enhancing resistance to drought (Rani and Chozin, 2015). Mycorrhizal fungi promote plant uptake of nutrients and inhibit soil-borne diseases, hasten organic matter mineralization, enhance soil structure, and generate growth-promoting compounds (Bolan, 2014). Farida and Chozin (2015) stated that maize treated with mycorrhiza resulted in higher maize growth and yield compared to maize treated without mycorrhiza.

It would need creativity to use soil amendments and mycorrhizal biological fertilizers to boost dry land productivity and enhance the quality of calcareous soil. This study aimed to assess how different soil amendments and mycorrhizal biofertilizers affect the chemical characteristics of the soil, plant, and sorghum yield and the uptake of phosphate and nitrogen by the plants grown on calcareous soils.

## Materials and Methods

The study was carried out at the Agricultural Extension Center's experimental farm in Oelnas Village, Kupang Regency, East Nusa Tenggara, Indonesia, from April to August 2023. This research location is located at 10º09"N and 123º45"E. The land used in this experiment is degraded moorland characterized by a rocky surface and thin solum (<15 cm). The soil used in this experiment is Renzina soil, characterized by calcareous soil. Soil analysis results showed that the soil at the study site has the following chemical properties: pH $H_2O$ = 7.95, organic C = 1.85%, total N = 0.11%, available P = 4.26 ppm, exchangeable K = 0.37 me 100 $g^{-1}$ soil and cation exchange capacity (CEC) = 16.78 me 100 $g^{-1}$ soil.

This study used a two-factor randomized block design. The first factor was the type of soil amendment, which consisted of four treatments, namely: no soil amendment (P0), cow dung (P1), rice straw compost (P2), and corncob biochar (P3). The second factor was mycorrhizal biofertilizer, with two treatments, namely, without mycorrhizal biofertilizer (M0) and with mycorrhizal biofertilizer (M1). The amendment material used in this research came from agricultural waste in the form of cow dung and rice straw, which was composted for three months and completely decomposed. Corncob biochar was obtained by pyrolysis of corncobs at 400ºC for 4 hours. Table 1 displays the chemical makeup of the soil amendment utilized in this experiment.

Table 1 demonstrates the variations in soil amendment quality. On average, the three types of soil amendments have an alkaline pH (pH>8) due to the relatively high alkaline cation content. The process source of the raw materials and the production process largely determine the quality of soil conditioner materials. Cow dung and rice straw compost were given at a dose of 10 t $ha^{-1}$, while biochar was given at a dose of 5 t $ha^{-1}$. Mycorrhizal biofertilizer as a treatment was given at a dose of 10 g $plant^{-1}$. NPK fertilizer as the independent variable was given at the same dose of 150 kg $ha^{-1}$. There were 32 experimental units because the treatment was repeated three times. The size of each experimental plot was 2 x 5 $m^2$. The experimental land used in this research measures 60 x

14 m. The experimental area was then divided into three blocks as replications. Each block was divided into experimental units, with the size of each unit being 2 x 5 m. The total treatment units were 48 experimental units. The indicator plant tested in this research was the Ulumbu variety sorghum plant, with a 100 x 20 cm planting distance. The chemical characteristics of the soil after the experiment, i.e., pH (pH meter), organic C (Walkley and Black method), total N (Micro Kjeldahl method), and total P (Bray-2 method), were the variables observed in this study. Sorghum yield, soil total K and soil cation exchange capacity (extraction technique with 1N $NH_4OAc$), soil N, and soil P. Plant samples were collected 50 days after planting (DAP) during the maximal vegetative phase in order to analyze the total N and total P in the plants.

Table 1. Chemical compositions of soil amendment used for the study.

| Parameter | Cow dung (P1) | Rice straw compost (P2) | Corncob biochar (P3) |
|---|---|---|---|
| pH $H_2O$ | 8.13 | 8.03 | 8.82 |
| Organic C (%) | 9.87 | 10.90 | 13.65 |
| Total N (%) | 0.74 | 0.86 | 0.44 |
| C/N | 11.33 | 13.42 | 27.62 |
| $P_2O_5$ (%) | 1.74 | 1.54 | 0.59 |
| $K_2O$ (%) | 1.52 | 0.42 | 1.42 |

Determination of N and P uptake by sorghum using the following equation: nutrient uptake = nutrient content (%) x dry weight (g). Analysis of variance was used to examine the data from the observations (ANOVA) followed by Duncan Multiple Range Test (DMRT) to evaluate the trial treatments' averages.

## Results and Discussion

### *Soil chemical properties*

After the trial, there was often no significant interaction (p>0.05) between the application of soil amendments and mycorrhizal biofertilizers on the chemical quality of the soil. The application of both mycorrhizal biofertilizer and single-factor soil amendment had a highly significant (p<0.01) impact on the thin-solum soil's chemical quality. The results of soil chemical quality analysis after sorghum harvest on calcareous soil for each individual factor treatment are shown in Table 2.

### *Soil pH*

An important indicator of soil chemical fertility is soil pH. This is because the availability of nutrients in the soil is reflected by soil pH, as is the activity of soil organisms and plant growth as well (Zhang et al., 2019). The soil at the experimental location reacted slightly alkaline (pH 7.85), due to the large soil parent material being limestone, which contains calcium carbonate compounds ($CaCO_3$), which can inhibit the availability of phosphate because P is bound by Ca ions. The results of statistical analysis (Table 2) show that the degree of soil acidity (pH) decreased in the treatment of corn cob biochar (P3), reaching a pH of 7.19 compared to the application of cow dung (P1) and rice straw compost (P2), which were on average pH reaches. This is because biochar applied to calcareous soil is more resistant to weathering, so it can last longer, promoting ion exchange in the soil. The treatment of cow dung (P1) and rice straw compost (P2) which were added to the soil, also significantly reduced the pH due to the role of humus compounds in assisting ion exchange to encourage changes in pH. Reducing the pH towards neutral will facilitate the exchange of soil ions to provide nutrients for plant growth. According to Zhang et al. (2012), the effect of adding organic material can influence changes in soil pH depending on the maturity level of the added organic material and the type of soil. Soil amendment materials that are applied to the soil will further decompose or mineralize, releasing minerals in the form of basic cations (Ca, Mg, Na, K), which cause the concentration of $H^+$ ions to increase, resulting in a decrease in pH. The treatment of providing mycorrhizal biofertilizer (M1) significantly reduced pH to a greater extent (pH 7.35) and was significantly different from the treatment without mycorrhizal biofertilizer (M0). A decrease in soil pH can be due to the ability of mycorrhizal fungi to produce organic acids and can increase the population of other microorganisms in the soil that can stimulate ion exchange in the soil (Mustafa et al., 2015; Han et al., 2016).

### *Organic C*

Because it can improve the soil's capacity to bind and absorb nutrients and water, decrease nutrient leaching, increase soil granulation, and serve as an energy source for soil organisms, soil organic carbon, or organic C, is essential to soil fertility (Hoffland et al., 2020). By the end of the experiment, there were variations in the concentration of soil organic C, as indicated by the results of the statistical analysis (Table 2). In comparison to the other treatments, the biochar treatment greatly increased the amount of organic carbon in the soil and had a statistically significant effect. Application of biochar significantly increased soil organic C by 2.55%, higher than cow dung (2.33% C) and rice straw compost (2.37% C). This is because the carbon fraction in biochar is resistant to decomposition, so it is able to change the composition of the main constituent fractions in the soil. The buffering ability of the soil against the leaching of N, P, and K nutrients is positively increased by the presence of biochar as a carbon source in the soil. It raises the soil's capacity for cation exchange. Biochar comprises a variety of organic compounds, including organic acids, which aid in the release of nutrients, in addition to stable organic C (Matheus et al., 2017; Martinez et al., 2018). The supply of biochar can also significantly change the internal properties of the soil (Han et al. 2016).). Treatment with mycorrhizal biofertilizer (M1) also significantly increased soil organic C higher compared to the treatment without mycorrhizal biofertilizer (M0). This is because soil organic matter can be broken down by mycorrhizal fungi, which are found in the root zone.

Table 2. Soil chemical characteristics after sorghum harvest due to application of soil conditioner and mycorrhizal biofertilizers on calcareous soils.

| **Treatment** | **pH $H_2O$** | **Organic C (%)** | **Total N (%)** | **Available P (ppm)** | **Exchangeable K (ppm)** | **Cation Exchange Capacity (me 100 $g^{-1}$)** |
|---|---|---|---|---|---|---|
| Types of soil amendment: | | | | | | |
| − No amendment (P0) | 7.85 a | 1.65 c | 0.16 b | 6.46 b | 52.35 b | 16.27 b |
| − Cow dung (P1) | 7.39 b | 2.32 b | 0.23 a | 7.67 a | 69.68 b | 28.11 a |
| − Rice straw compost (P2) | 7.34 b | 2.37 b | 0.23 a | 7.62 a | 64.13 b | 28.07 a |
| − Corncob biochar (P3) | 7.19 c | 2.55 a | 0.22 a | 8.19 a | 72.76 b | 29.97 a |
| Mycorrhiza biofertilizer: | | | | | | |
| − No mycorrhiza (M0) | 7.43 b | 2.18 b | 0.20 b | 7.19 b | 63.73 b | 24.82 b |
| − With mycorrhiza (M1) | 7.35 a | 2.26 a | 0.22 a | 7.79 a | 66.23 a | 26.39 a |

Notes: The numbers followed by similar letters in the same column induicate no significant difference according to DMRT.

***Total N of soil***

Based on the results of the soil analysis at the end of the experiment (Table 2), the soil N content differed significantly between the soil amendment and vesicular-arbuscular mycorrhiza (VAM) treatments. Soil conditioner treatments such as manure (P1), rice straw compost (P2), and biochar (P3), were able to increase total soil N higher and significantly different compared to the control (P0), which only reached 0.17% N. Zhang et al. (2019), the increase in N nutrient concentration in the soil is determined not only by fertilization but also by the breakdown of organic matter. The use of soil amendments increases the availability of organic C in the rhizosphere environment, which is the main determinant of the amount of nitrogen produced (Gyapong and Ayisi, 2015; Cai et al., 2019). Additionally, the statistical analysis results (Table 2) demonstrate that, compared to not applying mycorrhizal biofertilizer (M0), the application of mycorrhizal biofertilizer (M1) boosted the soil's total nitrogen content at the conclusion of the trial. This is suspected to be the role of mycorrhizal fungi through hyphae, which are able to expand the absorption of nutrients stored in micropores. Mustafa et al. (2015) stated that mycorrhizal fungi are also known to interact synergistically with $N_2$-fixing bacteria, and root nodule formation increases when alfalfa plants are inoculated with Glomus.

***Available P***

The highest available P concentration with an index of 8.19 ppm was found in biochar soil conditioner (P3) and was not significantly different from the manure (P1) and rice straw compost (P2) treatments. However, it is significantly different from the control treatment (Table 2). The increase in available P at the end of the experiment was due to the role of sourced soil conditioner materials, which were applied and experienced mineralization so that they could release or liberate P from micellar bonds, which were trapped by calcium carbonate ions ($CaCO_3$). This is consistent with Martinez et al. (2018), who observed an increase in P after the application of rice straw compost compared to no compost. The same was observed in mycorrhizal biofertilizer treatment (M1), which showed that mycorrhizal biofertilizer application (M1) significantly increased soil available P by 7.79 ppm, which was higher and significantly different compared to the no mycorrhizal treatment (M0). Because mycorrhizal fungi infect the sorghum root system to enable it to absorb nutrients, calcareous soil has a higher P content. This is in line with the findings of Mustafa et al. (2015), who discovered that applying 30 doses of fluorescent bacteria and arbuscular mycorrhizal spores boosted P absorption by 107% (24.40 ppm) in comparison to the control treatment of 11.77 ppm. According to Mustafa et al. (2015), the functional principle of mycorrhiza is to infect the root system of the host plant and form an intensive network of hyphae so that mycorrhizal plants can increase their ability to absorb nutrients, especially the element P.

***Exchangeable K***

The application of soil amendments (biochar, cow dung, and rice straw compost) considerably impacted the available K content. It differed significantly from the reference treatment (no amendments), according to the results of the statistical analysis (Table 2). This demonstrates that soil supplements, which might include macronutrients like soil nutrient K that are advantageous to plants, are derived from organic material that has undergone mineralization. Abdillah and Widiyastuti (2022) found that the use of rice straw compost and agro-industrial waste can improve soil chemical quality, namely K availability and K uptake by rice plants. Mycorrhizal biofertilizer treatment (Table 2) showed a significant difference in soil K content at the end of the experiment. Application of mycorrhizal biofertilizer (M1) increased available K by 66.23 ppm, more than without mycorrhiza (M0), where available K concentration was 63.73 ppm. The increase in available K is thought to be due to the role of soil mycorrhizal fungi in mineralizing the soil into nutrients readily available to sorghum plants.

***Cation exchange capacity of the soil***

One of the most significant chemical characteristics of the soil is its cation exchange capacity (CEC), which influences the availability of nutrients for plant roots. The application of cow dung (P1), rice straw compost (P2), and biochar (P3) as soil amendments resulted in soil CEC values of 28.11, 28.07, and 29.97 me 100 g soil$^{-1}$, respectively. These values were substantially greater than those of the treatment without amendment (16.27 me 100 g soil$^{-1}$).

The role that humus plays in the breakdown of soil conditioner materials is linked to the rise in CEC values in calcareous soil. According to Abel et al. (2021), the use of compost and rice husk biochar increases soil CEC considerably because organic material can improve cation exchange and adsorption capacities. This occurs because the breakdown of organic matter creates humus, or organic colloids, which are a source of negative soil charge and allow water and nutrients to be present on the soil’s surface. As the content of organic matter in the soil decreases, humus (organic colloids) as a source of negative charge in the soil also decreases, so the exchangeable positive charge (cations) also decreases (Arif et al., 2020; Chen et al., 2023).

The single-factor treatment of mycorrhizal biofertilizer also had an effect on increasing the CEC of Vertisols. The treatment of providing mycorrhizal biofertilizer (M1) significantly increased soil CEC by 26.39 me 100 g soil$^{-1}$, higher than without mycorrhiza (M0), which had a low soil CEC value (24.82 me 100 g soil$^{-1}$)

***N uptake and P uptake by sorghum***

It is known that the application of mycorrhizal biofertilizer and soil amendments did not significantly interact ($p>0.05$) according to the findings of the analysis of variance. Each factor showed results with significant effects ($p<0.05$) on N and P uptake by sorghum plants 50 days after planting. The results of statistical analysis showed that treatment with soil amendment, types of cow dung (P1), rice straw compost (P2), and corncob biochar (P3) significantly increased the uptake of N and P nutrients by sorghum plants (Table 3). The trend of increasing N and P nutrient uptake by sorghum plants shows the real contribution of soil amendments, which can increase the physical fertility of the soil so that plant roots can easily and freely absorb nutrients in the soil.

The findings suggest that adding soil amendments made of organic materials to thin-solum soil can significantly improve the soil's characteristics and boost nutrient uptake. By enhancing the chemical characteristics of the soil, soil amendments provide a conducive atmosphere for crop production, plant nutrition, and growth (Dida and Etisa, 2019). The same author states that applying organic fertilizer greatly increases sorghum's ability to absorb nutrients. These results are in accordance with research by Fosu-Mensah et al. (2016), Abel et al. (2021), and Teshome et al. (2023), who found that the application of organic fertilizer and biochar together with NPK fertilizer significantly increased total nutrient uptake.

Mycorrhizal biofertilizer treatment also showed significant differences in the N and P nutrient uptake of sorghum plants. The treatment with mycorrhizal biofertilizer (M1) showed higher N and P nutrient uptake and was different from without mycorrhizae (M0). The increase in plant absorption of N and P nutrients is due to an increase in the external network of mycorrhizal hyphae, which infects the plant roots and thus expands the area of root uptake of water and nutrients. In addition, the very fine size of the root hair hyphae allows them to penetrate the finest pores in the soil so that the hyphae can absorb water in conditions of very low soil water content.

Table 3. N uptake and P uptake of sorghum plants 50 days after planting.

| **Treatment** | **N uptake** | **P uptake** |
|---|---|---|
| | **(% dry weight of the plant$^{-1}$)** | |
| Types of soil amendment: | | |
| – No amendment (P0) | 2.76 b | 1.04 b |
| – Cow dung (P1) | 3.68 a | 2.40 a |
| – Rice straw compost (P2) | 3.92 a | 2.34 a |
| – Corncob biochar (P3) | 3.78 a | 2.20 a |
| Mycorrhiza biofertilizer: | | |
| – No mycorrhiza (M0) | 2.23 b | 1.56 b |
| – With mycorrhiza (M1) | 3.79 a | 2.18 a |

Greater water uptake by mycorrhizal plants will also bring in nutrients such as N, P, and K, so nutrient uptake by plants will increase. Utomo et al. (2017) reported that plants infected with mycorrhizae were able to absorb higher P elements compared to plants that were not infected. The high P absorption by plants infected with mycorrhizal was caused by mycorrhizal hyphae, which secreted phosphatase enzymes so that P bound in the soil would be dissolved and available for plants. These results are in accordance with research by Adeyemi et al. (2020), who found that roots infected with mycorrhiza were able to increase the absorption of $NH_4^+$ and $NO_3^-$, while mycorrhizal could increase plant resistance in conditions of water shortage through increasing nutrient absorption, leaf transpiration, and water use efficiency.

***Sorghum yield***

The analysis of variance results indicated that the components of sorghum yield, such as seed weight per plant (g), 1,000 seed weight (g), and sorghum yield (t ha$^{-1}$), were significantly affected ($p<0.05$) by the kind of soil amendments and mycorrhizal biofertilizer.

***Seed weight***

Measuring seed weight per plant is needed to predict plant productivity. The results of measuring the dry seed weight of plant$^{-1}$ are presented in Figure 1.

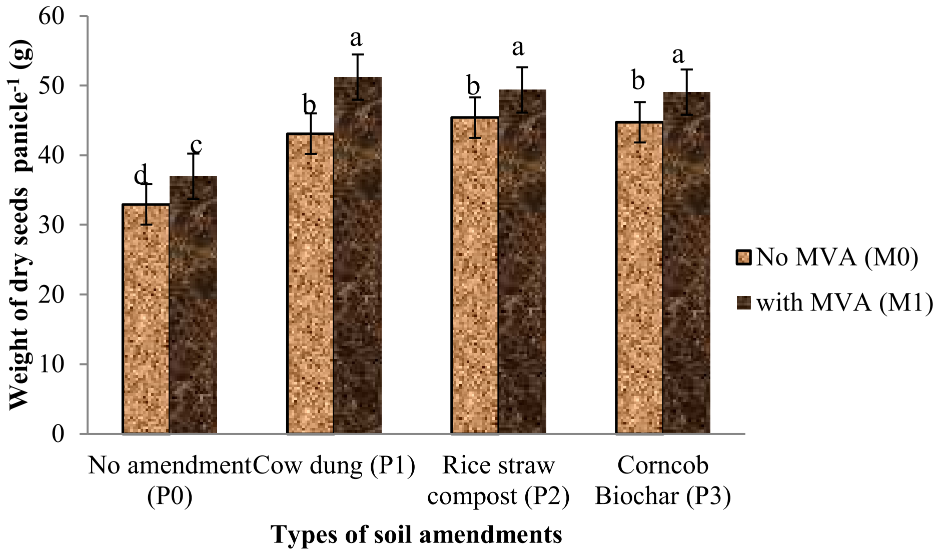


Figure 1. Weight of dry sorghum seeds.

Figure 1. shows that there is an interaction, which means that the two factors tested, namely the type of soil conditioner and the application of mycorrhizal biological fertilizer, mutually influence the dry seed weight of the plant. The soil conditioner treatments of cow dung (P1), rice straw compost (P2), and biochar (P3) applied with mycorrhizal biofertilizer (M1) were not significantly different and gave higher plant seed weights compared to other combination treatments. This is because soil amendments that are applied simultaneously with the application of mycorrhizal biological fertilizer can increase plant nutrient uptake, especially P elements, thus speeding up seed filling.

***Weight of 1,000 seeds***

The weight of 1,000 seeds is also one of the yield component parameters related to the potential yield of a plant, especially cereal plants. The measurement results of the weight of 1,000 seeds are shown in Figure 2. The research results showed that there is an interaction between the type of soil conditioner and mycorrhizal biofertilizer. The treatment of cow dung (P1), rice straw compost (P2), and corncob biochar (P3) applied with mycorrhizal biofertilizer (M1) showed that the weight of 1,000 seeds was not significantly different and was higher, compared to the other treatments. This proves that the types of soil conditioner and mycorrhiza applied to calcareous soil can increase nutrient availability for plants to produce more sorghum seeds.

***Sorghum yield***

Figure 3 shows an interaction between the type of soil conditioner and mycorrhizal biological fertilizer on sorghum yield. The existence of this interaction shows that the two factors tested have an influence together. The type of soil conditioner treatment applied with mycorrhizal biological fertilizer has a significant effect on sorghum productivity in calcareous soil. The productivity of sorghum treated with cow dung followed by VAM (P1M1) and rice straw compost followed by VAM (P2M1) was not significantly different and showed higher productivity, respectively 4.04 t ha$^{-1}$ and 3.97 t ha$^{-1}$, but tends not to be significantly different from the application of corncob biochar and mycorrhizal biofertilizer (P3M1), which gave a yield of 3.87 t ha$^{-1}$. These results are consistent with Kurniasari et al. (2023), who obtained sorghum productivity with the application of manure reached 3.74 t ha$^{-1}$, higher than without manure, which only reached 2.32 t ha$^{-1}$. Furthermore, Rani and Chozin (2015) stated that the increase in dry-shelled corn yield with the addition of mycorrhizal fungi occurred because plants infected with mycorrhiza through their external hyphal network were able to expand the area of root absorption so that the plants received sufficient nutrient supply for growth and increased yields (Sharif et al., 2014).

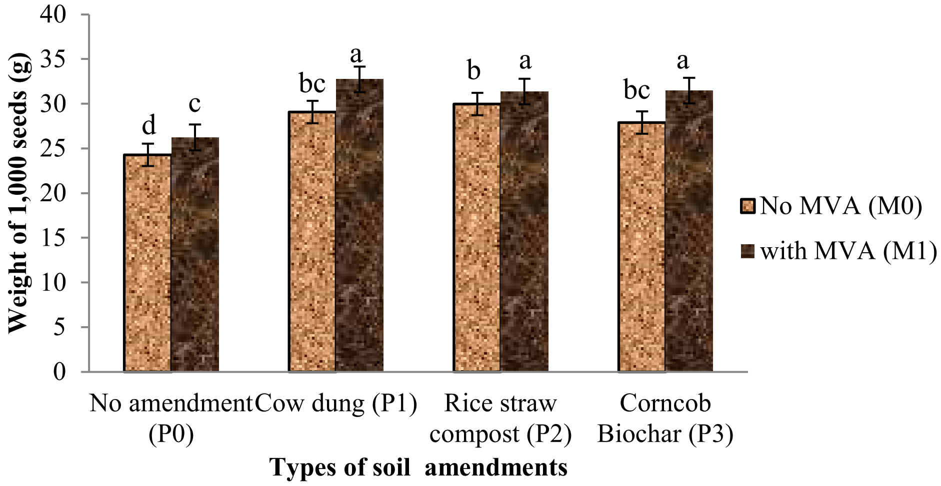


Figure 2. Weight of 1,000 seeds of sorghum.

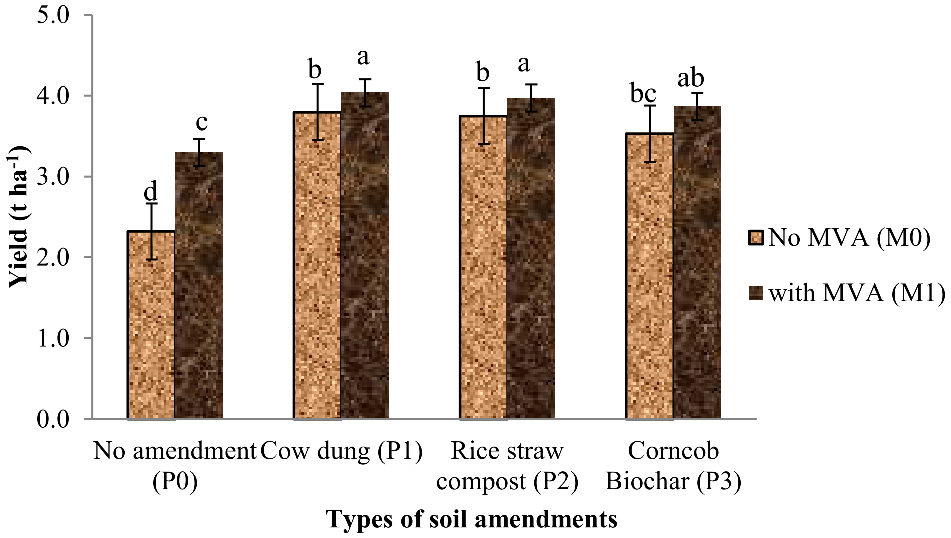


Figure 3. Sorghum yield.

Furthermore, according to Adeyemi et al. (2020), plants infected with mycorrhizal fungi will cause the root reach to expand due to the presence of mycorrhizal hyphae, so the nutrients absorbed by the roots will affect the plant roots. Providing mycorrhiza is thought to improve the condition of the media and also support nutrient absorption. The continuation of the symbiosis between plants and mycorrhiza will affect the plant's metabolic processes and can influence the formation of new roots. The large number of new roots with high membrane permeability will be beneficial for the process of root colonization by mycorrhiza. Mycorrhiza also has a high auxin content, which allows increased root growth (Adeyemi et al., 2020). This illustrates that the productivity of unproductive soils, such as the soil of this research site with thin solum, can be increased by providing soil amendments and biological fertilizers (Celestina et al. 2019).

## Conclusion

Soil amendments and mycorrhiza have effectively increased the chemical properties of calcareous soil (pH, C org, N, P, K, and CEC), N, P uptake, and sorghum yield. It was noted that the soil amendment types of cow dung (P1), rice straw compost (P2), and corncob biochar (P3) showed extraordinary potential in increasing nutrient (N, P) uptake and yield of sorghum. The use of mycorrhiza also significantly increased nutrient uptake (N, P) and sorghum yield. The results of this research indicate that using organic amendments (cow dung, straw compost, and biochar) in the long term can increase the productivity of calcareous soil for developing food crops on dry land.

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