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WATER HOLDING CAPACITY AND SOIL ORGANIC CARBON IN TEAK (Tectona grandis Linn. F) AGROFORESTRY

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Abstract: Agroforestry is typically used to environmentally and economically optimize and efficiently use land through the diversification of commodities over time in the same field. The research objective was to assess the water-holding capacity and soil organic carbon content of land used to cultivate teak trees. This study surveyed Teak Monoculture (TM) sites aged 11 years as well as those teak that were combined with three types agroforestry – Teak-arrowroot (TA), Teak-taro (TT), Teak-cassava (TC) for each age 7 years, and 2 types of monocultures – Maize Monoculture (MM) and Paitan Elephant Grass (G). Observations on each land type, measuring 20 m by 20 m, were replicated thrice. The results showed that Teak Monoculture (TM) has the lowest soil bulk density, which is accompanied by an increase in water holding capacity. The TM land was the best with the lowest bulk density, soil porosity, field capacity water content and the highest water holding capacity, significantly different from the Teak-cassava (TC). The highest total biomass and C-biomass in monoculture teak was 440.45 Mg ha^{-1} and 202.60 Mg ha^{-1}, which are significantly different from teak produced on other land types. Soil organic carbon content decreased according to soil depth except for Teak-arrowroot agroforestry and Teak Monoculture.

Keywords: Teak agroforestry, bulk density, water holding capacity, soil organic C.
Abbreviations: TM (Teak Monoculture); TA (Teak-arrowroot); TT (Teak-taro); TC (Teak-cassava); MM (Maize Monoculture); G (Grass).

Introduction

The world population is currently around 7.9 billion and is estimated to increase to 9.3 billion by 2050 and about 11 billion by 2100 (Madkour *et al*., 2022). The increase in population will result in rising demand for wood and food, putting pressure on agricultural land and forest areas that have decreased due to the conversion to other uses. Meeting these needs would require optimizing space and time for land use. One type of land use that can meet the need for housing and food is agroforestry. According to Tully and Ryals (2017a), agroforestry is a dynamic, ecologically oriented strategy for managing natural resources that involves integrating trees into agricultural and grazing fields to boost smallholder production and diversify it for greater social, economic, and environmental advantages. Cropping patterns in agroforestry systems, on the same land unit and at the same or different times, allow the continuity of sustainable crop production diversity (Ferreiro-Domínguez *et al*., 2016; Mosquera-Losada *et al*., 2018).

These aims can be realised by combining teak agroforestry with food crops. According to Magalhães *et al*. (2013), the monoculture of five-years-old teak is a system that is more like forests for storing nutrients of cocoa teak, forestry (five-years teak), eight-years-old teak, agricultural areas (teak, cocoa, and pasture) and pasture. An agroforestry system can realise sustainable agriculture's characteristics because it can produce almost like a multistorey natural forest (Hastuti & Sufiadi, 2017). Organic carbon content is generally high in natural soils under grass or forest cover. An agroforestry system with a multi-level canopy protects the soil surface against damage caused by raindrops' kinetic energy (Idris & Mahrup, 2017; Tavares *et al*., 2018). Agroforestry plays a role in soil conservation (Yasin *et al*., 2019) to increase groundwater availability (Tully & Ryals, 2017a). Also, the intake of organic residues from falling leaves of trees and under-standing plants will function as mulch (Joslin *et al*., 2019). Their decomposition will increase organic matter content in the soil (Jacobs *et al*., 2017). Different vegetation has different abilities to anchor carbon (Singh *et al*., 2020) and interacts with the soil to produce organic matter that provides nutrients (Tully & Ryals, 2017b) and determines soil quality (Kurien *et al*., 2021).

Land management for teak agroforestry is quite fluid and heavily impacted by farmer experience. Teak was initially grown as a monoculture, but eventually farmers discovered that teak can be intercropped with food crops as an extra source of revenue. Farmers, however, encounter issues with the availability of water for food crops when managing teak agroforestry. Above ground, it is simple to see how teak agroforestry works. Below ground, however, it is more difficult to see how they affect drought sensitivity by altering the qualities of the soil. This study examined the effects of different types of teak-based agroforestry on soil bulk density, soil organic carbon, and vegetation carbon. The research objective was to assess the water holding capacity and soil organic carbon content of the teak-based land-use type. The hypothesis tested is that the type of teak agroforestry causes differences in water storage capacity and soil organic carbon.

Materials and Methods

Sampling Sites

The research was carried out from November 2020 to February 2021 in the University of Nusa Bangsa's experimental farm. The research location is administratively included in the Cogreg village area, Ciseeng sub-district, Bogor district, West Java, Indonesia. The land area of 11 ha is located between 6'25'40'SL and 106'41'05'EL. The elevation is at 150 masl, and the slope ranges from 3-8%. The soil type is Inceptisol at pH 5. The average rainfall is 2750 mm per year, and the average daily temperature is 28^{o}C with an average minimum of 23^{o}C and a maximum of 38^{o}C.

Based on observations at the research site, there were six types of land use based on teak trees (*Tectona grandis* Linn. F) aged 7 and 11 years on a land area of 11 ha. Monoculture of 11 years-old-teak took up the most land, at 7 ha. A hectare each was taken up by agroforestry of teak trees combined with other plants, which are teak with taro (*Colocasia esculent* Linn), arrowroot (*Maranta arundinacea*), and cassava (*Manihot esculenta*). The spacing for each of teak tree was 2 m x 5 m, taro 1 m x 1 m, arrowroot and cassava are 60 cm x 60 cm. Two types of non-timber monoculture land use were also found, namely maize (*Zea mays*), spaced 60 cm x 60 cm covering an area of 0.5 ha and Paitan Elephant Grass (*Axonopus compressus*) surrounding an area of 0.5 ha. At the time of observation, the intercropping plants were 3 months old. The farmers around the land cultivated intercropping plants continuously since the teak plants are planted.

The 6 types of land use observation plots were Teak Monoculture (TM), Teak and Taro combination agroforestry (TT), Teak and Arrowroot combination agroforestry (TG), Teak and Cassava combination agroforestry (TC), Maize Monoculture (MM) as control plot and Paitan Elephant Grass monoculture (G) (Figures 1 and 2). Observations were repeated three times each to obtain 18 units of observation plots. In each plot, six disturbed and undisturbed soil samples were collected. Sampling of undisturbed soil to determine of soil density was done at a depth of 0-30 cm. As much as 1 kg of disturbed soil samples were taken at a depth of 0-30 cm and 30-60 cm to determine the water content and C-organic content of the soil. Determination of soil bulk density, water content and C-organic content was carried out at the Nusa Bangsa university laboratory. Vegetation biomass and carbon content were also measured.

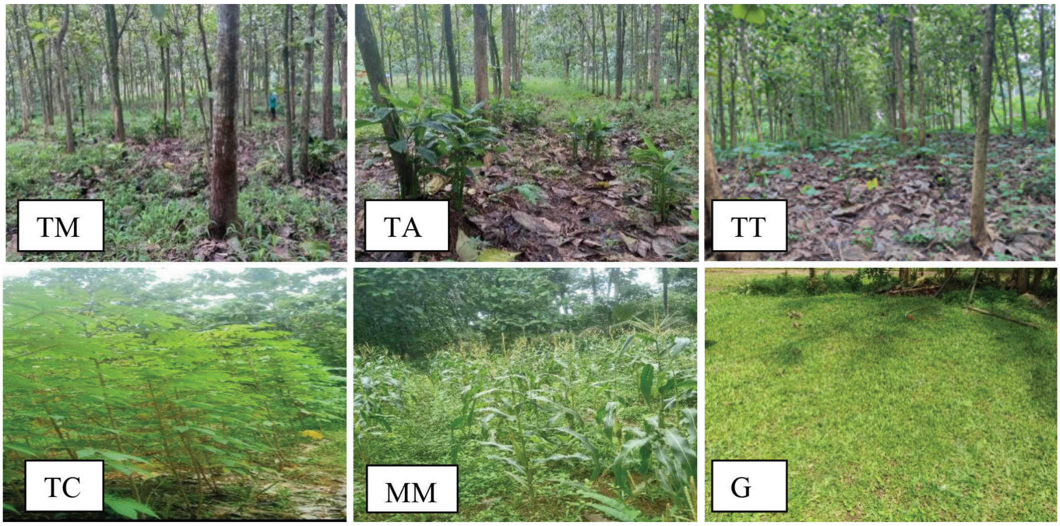

Figure 1: Plot measurement of Teak Monoculture (TM), Teak-arrowroot (TA), Teak-taro (TT), Teak-cassava (TC), Maize Monoculture (MM), Paitan Elephant Grass (G)

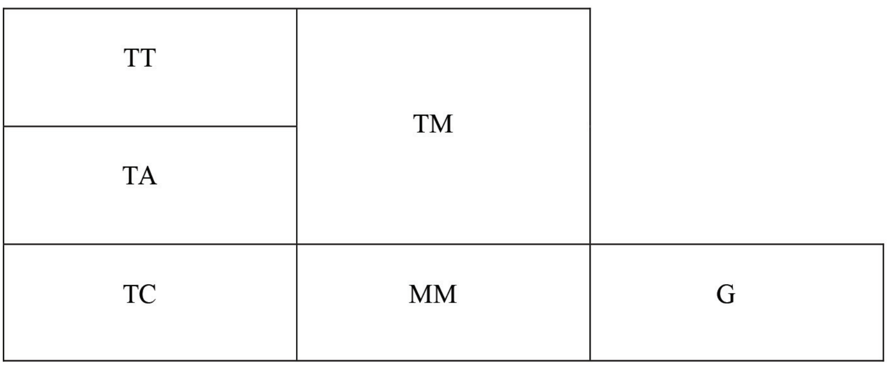

Figure 2: Planting layout and research design of Monoculture Teak (TM), Teak-arrowroot (TA), Teak-taro (TT), Teak-cassava (TC), Maize Monoculture (MM), Paitan Elephant Grass (G)

Soil Bulk Density (g cm^{-3}).

Soil bulk density was measured following the procedure of Blake and Hartge (1986). Undisturbed soil samples were taken using a ring sample with an inner diameter of 7.5 mm and a height of 4 mm. Based on soil bulk density data, the porosity (%) is calculated with the assumption that the particle density of mineral soil is 2.65 g cm^{-3}.

Soil Water Content at a Depth of 0-30 cm and 30-60 cm (%).

As much as 1 kg of soil sample was taken using a soil drill that had been marked for a depth of 30 cm and 60 cm. Water content was measured in the laboratory using the gravimetric method (Hillel, 1980).

Field Water Content Capacity (%)

The soil was saturated with water. When the water stops dripping, the soil sample is then heated at a temperature of 105^{o}C for 24 hours (Hillel, 1980).

Soil Water Holding Capacity (mm)

The water holding capacity in the soil was calculated gravimetrically by Hillel (1980). The result of the water content was multiplied by the depth of the soil and the area of the land (Masnang, 2011).

Soil C-organic (%)

Soil C-organic content at depths of 0-30 cm and 30-60 cm was determined by the Walkley and Black method described by Naelson and Sommers (1996). The soil carbon content is calculated using the equation according to BSN (2011):

$$Ct = Kd \times \rho \times \% C;$$

where:
Ct = soil carbon content (g cm^{-2})
Kd = depth of soil sample (cm)
% C organic = percentage of carbon content measured in laboratory
ρ = bulk density (g cm^{-3})
C soil = Ct x 100 … (Mg ha^{-1});

where:
C soil = soil organic content per hectare, expressed in tonnes per hectare (Mg ha^{-1})
Ct = soil carbon content (g cm^{-2})
100 = conversion factor from g cm^{-2} to Mg ha^{-1}.

Biomass and Vegetation Carbon Content.

Sampling was carried out on each plot measuring 20 m x 20 m. Vegetation biomass is measured using the allometric equation according to Brown as described by Makinde *et al.* (2017) in calculating teak biomass. The allometric equation can assess forests' ability to absorb CO_2 without having to cut down trees. The observation that is measured is dbh (diameter at breast height or diameter as high as 1.3 m from the ground). The equation to calculate biomass according to Brown (1997) for trees with a diameter of more than 5 cm is as follows:

$$Y = 0.118\ D2.53 \text{ at } D = 5\text{-}148 \text{ cm}$$

Carbon content is calculated using the equation:

$$C = 0.46 \times Y$$

where:
Y = total tree biomass (kg/tree),
D = trunk diameter at breast height (130 cm),
C = carbon content (kg/tree)

For the measurement of biomass of maize, cassava and arrowroot, 200 grams of each plant was sampled, then dried in an oven at 80^{o}C for 48 hours, then weighed to determine oven-dry biomass.

Data Analysis

Data were analysed descriptively by calculating the mean and standard deviation of each parameter. Analysis of Variance (ANOVA) was carried out to identify or test whether there are differences in land use for the parameters observed. The Tukey HSD test $P < 0.05$ was then carried out to determine if the analysis of variance shows a significant difference between variables. The statistical analysis was done using the STAR software (R-Packages 1.5 STAR 2.0.) (Statistical Tool for Agricultural Research), developed by the Department of Plant Breeding Genetics and Biotechnology, IRRI (International Rice Research Institute), Manila, Philippines.

Results and Discussion

Characteristics of Soil Physical Properties and Water Storage Capacity

Land covered by good vegetation can improve the structure of more loose soil and granular soil aggregates. More loose soil will lead to lower soil density and higher porosity. The results of statistical analysis in Table 1 show that Teak Monoculture (TM) significantly affects the bulk density, porosity, and water storage capacity of land. When compared with Teak-arrowroot (TA), Teak-taro (TT), Teak-cassava (TC), Maize Monoculture (MM), and Paitan Elephant Grass (G), TM land has lower soil density and higher overall porosity and higher water storage capacity. The soil weight in TM land was 1.19 g cm^{-3}, which is lower than the 1.27 g cm^{-3} recorded in TA, 1.32 g cm^{-3} in TC 1.45 g cm^{-3} in MM, 1.32 g cm^{-3} TT and 1.37 g cm^{-3} in elephant grass. The pattern of bulk density in Teak Monoculture is similar to the soil density in natural forests as described by (Makinde *et al*., 2017). In natural forests, the bulk density is 1.16 g cm^{-3} and 1.28 g cm^{-3} in natural grass. The bulk density of soil is an indicator of t soil compaction. Soil compaction is undesirable because it can reduce soil aeration and water holding capacity, and impedes root penetration thereby, curbing a plant's ability to harvest water.

The low bulk density of TM causes the porous surface soil layer to accelerate water movement and spread. Data in Table 1 and Figure 3 show that the level of porosity in TM is 54.91%, and it has the highest water holding capacity at 32.94 mm. TA has the next highest water holding capacity at 31.37 mm, followed by TT (30.19 mm), TC (27.27 mm), MM (30.11 mm) and G (29.10 mm). Enhancement of soil porosity can help soil aeration, thus facilitating the circulation of air and water in the ground.

Total Biomass and Carbon Biomass

The total biomass and total carbon biomass in TM were higher than the total biomass in TA, TT, TC, MM and G (Table 2). The TC land produced 175.20 Mg ha^{-1} of biomass and 80.59 Mg ha^{-1} of total vegetation carbon, which is higher compared to TA and TT. TC also has high soil organic C content (Figure 4 and Figure 5). The difference in total biomass and total vegetation carbon is because soil organic C comes from organic matter resulting from weathering of vegetation and litter and is influenced by the type of vegetation.

Table 1: Bulk density, porosity, water content field capacity dan water holding capacity on the type of land use, namely Maize Monoculture (MM), Teak-arrowroot (TA), Teak Monoculture (TM), Teak-cassava (TC), Teak-taro (TT), and Paitan Elephant Grass (G)

Land Use Type	Bulk Density ($g.cm^{-3}$)	Porosity (%)	Water Content Field Capacity (%)	Water Holding Capacity Depth 60 cm (mm)
MM	$1.32 \pm 0.10^{ab*}$	50.18 ± 3.62^{ab}	44.14 ± 2.07^{ab}	30.11 ± 2.17^{ab}
TA	1.27 ± 0.06^{ab}	52.29 ± 2.20^{ab}	49.30 ± 3.04^{a}	31.37 ± 1.32^{ab}
TM	1.19 ± 0.02^{b}	54.91 ± 0.98^{a}	44.65 ± 0.85^{ab}	32.94 ± 0.58^{a}
TC	1.45 ± 0.02^{a}	45.45 ± 0.57^{b}	39.06 ± 1.34^{bc}	27.27 ± 0.34^{b}
TT	1.32 ± 0.05^{ab}	50.33 ± 1.97^{ab}	49.25 ± 1.99^{a}	30.19 ± 1.19^{ab}
G	1.37 ± 0.15^{ab}	$48.50 + 5.81^{ab}$	35.23 ± 3.80^{c}	29.10 ± 3.49^{ab}

*Different letters along column indicate significant differences ($p < 0.05$) according to Tukey's test.

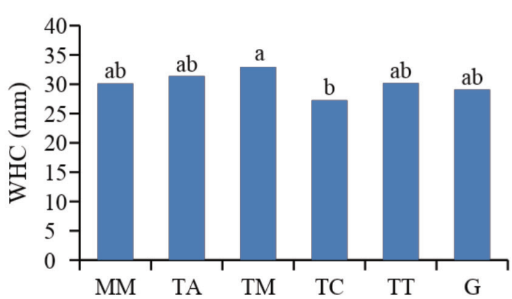

Figure 3: Water holding capacity on the type of land use, namely Maize Monoculture (MM), Teak-arrowroot (TA), Teak Monoculture (TM), Teak-cassava (TC), Teak-taro (TT), and Paitan Elephant Grass (G)

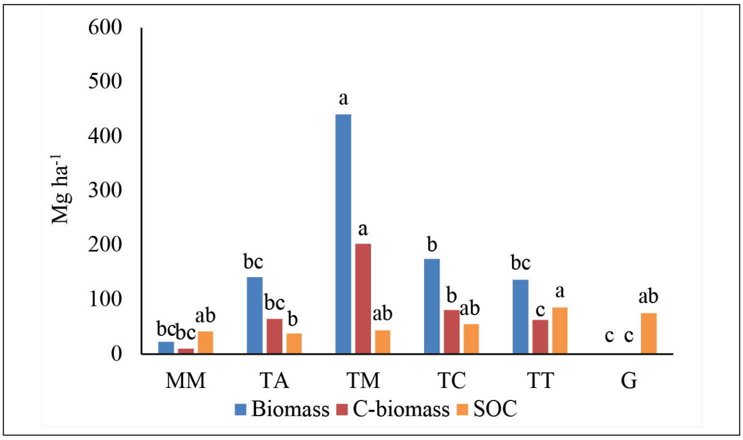

Figure 4: Biomass, biomass carbon and soil organic carbon on the type of land use, namely Maize Monoculture (MM), Teak-arrowroot (TA), Teak Monoculture (TM), Teak-cassava (TC), Teak-taro (TT), and Paitan Eephant Grass (G)

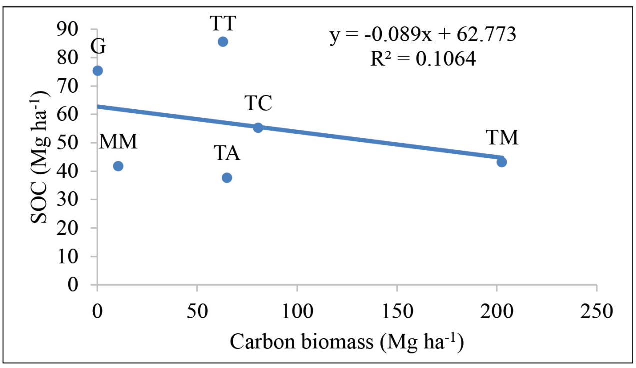

Figure 5: The relationship between biomass carbon and soil organic carbon on the type of land use, namely Maize Monoculture (MM), Teak-arrowroot (TA), Teak Monoculture (TM), Teak-cassava (TC), Teak-taro (TT), and Paitan Eephant Grass (G)

Taro plants grow well under the shade. In the TT type, although the biomass (13.67 Mg ha^{-1}) and vegetation carbon (62.86 Mg ha^{-1}) were lower than that of the TA, TC, the soil organic C content was the highest at 1.64%. This is because taro leaf litter decomposes faster due to its morphology, which is thinner and more succulent. (Bouaravong *et al*., 2017).

Biomass in monoculture teak was 440.45 Mg ha^{-1} and biomass carbon of 202.60 Mg ha^{-1} was the highest compared to biomass in TA, TC, TT, MM and G (Table 2). The high biomass carbon in TM was not closely related to the soil organic C content (Figure 5) which was 1.01% lower than the C-organic in the TT type.

Research by Santosa *et al*. (2020) showed that the carbon content in teak leaves that had just fallen from various sites was around 50.92% and Nitrogen content was 1.28% so that C/N ratio ranges in the 40s, which is very high. This results in a slow decomposition process. If the C/N ratio is high, microorganisms take a long time to degrade matter (Purnomo *et al*., 2017). Research by Yuliani and Rahayu, (2016) show that low-quality organic teak leaves have a low P content, but a high C/N ratio of 33.19, exceeding the critical limit of the C/N ratio for N and C mineralization, which is 25-30.

The results of the study by Jain and Ansari (2013) reveal that in teak plantations,

Table 2: Total biomass, C-biomass, SOC, and Total SOC on the type of land use, namely Maize Monoculture (MM), Teak-arrowroot (TA), Teak Monoculture (TM), Teak-cassava (TC), Teak-taro (TT), and Paitan Eephant Grass (G)

Land Use Type	Total Biomass (Mg ha^{-1})	Total C-biomass (Mg ha^{-1})	SOC (%) Depth 0 - 30 cm	SOC (%) Depth 30 - 60 cm	Total SOC (Mg ha^{-1})
MM	22.82 ± 1.79^{bc*}	10.50 ± 0.83^{bc}	0.79 ± 0.11^{b}	0.50 ± 0.16^{d}	41.81 ± 11.89^{ab}
TA	141.23 ± 10.51^{bc}	64.96 ± 4.83^{bc}	0.78 ± 0.10^{b}	0.83 ± 0.03^{bc}	37.75 ± 6.86^{b}
TM	440.45 ± 138.74^{a}	202.60 ± 63.82^{a}	1.01 ± 0.39^{ab}	1.11 ± 0.14^{ab}	43.21 ± 15.6^{ab}
TC	175.20 ± 52.49^{b}	80.59 ± 24.15^{b}	0.88 ± 0.36^{b}	0.78 ± 0.05^{cd}	55.30 ± 23.23^{ab}
TT	136.67 ± 36.75^{bc}	62.86 ± 16.91b^{c}	1.64 ± 0.11^{a}	1.18 ± 0.07^{a}	85.61 ± 10.32^{a}
G	0.86 ± 0.08^{c}	0.39 ± 0.04^{c}	1.32 ± 0.16^{ab}	0.85 ± 0.17^{bc}	75.39 ± 22.29^{ab}

*Different letters along column indicate significant differences ($p < 0.05$) according to Tukey's test.

aboveground biomass containing the highest carbon stock (214.7 Mg C ha^{-1}) has an average annual carbon holding capacity of 19.5 C Mg ha^{-1} year^{-1}, equivalent to 70.6 CO_2 Mg ha^{-1} year^{-1} which is much larger than secondary forest and cocoa plantations.

Soil Organic Carbon

The results showed that TT agroforestry had the most effect on soil organic carbon content (Table 2). The highest soil organic C content was at Teak-taro (TT) both at a depth of 0 - 30 cm and 30 - 60 cm, at 1.64% and 1.18%. These values are not significantly different from TM's, which are at 1.01% and 1.11% at the depth same. Soil organic C decreased according to soil depth for G, TT, TC and MM (Figure 6). According to (Ketema & Yimer, 2014; Khaki *et al.*, 2016) in general, soil organic carbon content in the top layer is higher and decreases according to soil depth.

Taro-teak agroforestry increases soil organic matter through decomposing vegetation as deciduous understorey falls to the soil surface. Soil organic C-values were higher in taro agroforestry than in cassava and arrowroot agroforestry. This can be due to the thinner taro leaves littering the ground and the higher water content in the taro leaf midrib. The soil organic C content in the Teak-arrowroot and cassava, maize and Teak Monocultures was not significantly different. As with taro, arrowroot can also grow

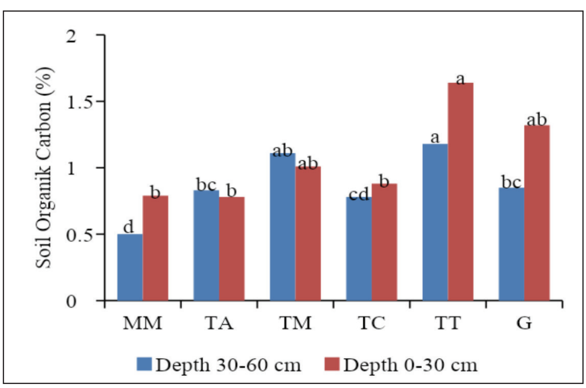

Figure 6: Soil organic carbon content at depths of 0-30 cm and 30-60 cm on the type of land use, namely Maize Monoculture (MM), Teak-arrowroot (TA), Teak Monoculture (TM), Teak-cassava (TC), Teak-taro (TT), and Paitan Eephant Grass (G)

to adapt to shade, such as under tree stands so that it has the potential to be developed on forest land (Djaafar *et al*., 2010; Sudomo *et al*., 2019). The rate of decomposition, the activity of soil microorganisms, and the amount of organic matter in the soil all have a significant impact on the level of organic carbon. The amount of soil organic matter that decomposes is greatly determined by soil temperature, moisture, and microorganism activity, which are in turn greatly dependent on the amount of plant and litter that covers the soil. In monoculture maize, the soil's surface is more open so loss of organic material and nutrients is higher, while the input or addition is less.

Agroforestry systems can maintain soil organic matter content in the top layer through weathering of litter on the soil surface (Khaki *et al*., 2016). Regular trimming of the tree canopy adds to the soil surface litter, and its decomposition maintains or adds to the soil's organic matter content. Arévalo and Martí (2020) analysed the elements in teak leaf pruning and found the highest carbon content of around 46.2%.

Conclusion

Land used for Teak Monoculture has the lowest soil bulk density, which is accompanied by an increase in water holding capacity. Teak Monoculture land was the best type with the lowest bulk density, soil porosity, field capacity water content and the highest water holding capacity, The highest total biomass and C-biomass in Teak Monoculture of 440.45 Mg ha^{-1} and 202.60 Mg ha^{-1} were significantly higher thatn other land use types. However, this was not followed by an increase in soil organic content of 1.01%, which was lower than C-organic in the type of Teak-taro agroforestry by 1.64%. Soil organic carbon content decreased according to soil depth except for Teak-arrowroot agroforestry and Teak Monoculture. Soil organic carbon at a depth of 30 - 60 cm in Teak Monoculture was significantly different from that of TC, MM and G.

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