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Research Article

The conversion of monoculture sugarcane to a tree-based agroforestry system increases total carbon sequestration and soil macrofauna population

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Abstract

Vegetations accumulate carbon (C) from the atmosphere in the form of tree biomass, producing litter which then becomes the main input of soil organic matter. The accumulation of soil organic matter provides food and energy for soil macrofauna to help maintain soil fertility. Total C accumulation is affected by land use changes which can then reduce soil ecosystem and ecological functioning. This study examined the impact of land use conversion from monoculture sugarcane to a tree-based agroforestry system. The results showed that the land use changes affected soil texture, bulk density, soil organic matter, and total C sequestration. The total C sequestration under 5 years old sengon (*Paraserianthes moluccana*) agroforestry system was almost double that of total C sequestration 2 times or even 5 times ratooned monoculture sugarcane (*Saccharum officinarum*). The lowest IVI of soil macrofauna was detected under 1-year-old sengon agroforestry system before it was getting lowered under a longer period of cultivation, whilst the highest population was detected under 5 years old Sengon. Multivariate analysis, which was employed to detect the impact of land use changes, could cluster and group the effect of treatments based on selected variables such as soil physical, chemicals, and soil macrofauna structure and diversity, which accounted for 97.75% of the total variance. There was a strong relationship between the abundance of *Formicidae* sp. and *Carabidae* sp.

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Introduction

Climate change is one of the consequences of increasing global temperature, which is mainly due to the increase of greenhouse gas concentration in the atmosphere, in the form of CO_2, N_2O, and CH_4 (IPCC, 2006; Darung et al., 2018). This is caused by the growth of human activities on burning fossil fuels, the establishment of an industrial area that emits pollutants, the development and building of infrastructure in agricultural areas, and land use conversion from the forest into other uses (Al Qassam and Prayogo, 2018; Ginting and Prayogo, 2018). The adoption of agricultural practices using a large number of chemicals and fertilizers affects climate change and global warming (Lasco et al., 2004; IPCC, 2006). Mitigation and adaptation scenario needs to be employed through optimizing biomass accumulation which allows carbon captured mechanism from the atmosphere, known as carbon sequestration, to anticipate those global warming effects. Increasing carbon capture has now become one of the important topics in achieving sustainable development goals agenda (IPCC, 2006; Hairiah et al., 2021; Prayogo et al., 2021) and carbon trading mechanism (Sutaryo, 2009). This can be achieved following increasing tree establishment on the land through land use conversion from arable/shrub/pasture to plantation/multi-purpose tree species using an agroforestry system or even to forest ecosystem (Lasco et al., 2004; Butarbutar, 2009; Prayogo et al., 2021). Nowadays, various agroforestry system has been introduced to wide communities as an alternative system to achieve low carbon emission and sustainable farming (Lasco et al., 2006) and to maintain ecological function (van Noordwijk et al., 2000; van Noordwijk et al., 2011; Hairiah, 2018). Planting trees outside forest areas becoming popular and attracted many researchers (Vieira et al., 2008; Sari et al., 2011; Ishaq et al., 2020; Prayogo et al., 2021).

The area of Kedungkandang district in Malang, from the period 1990 to 2010, was dominated by intensive sugarcane (*Saccharum officinarum*) plantation before that area was converted into a sengon (*Paraserianthes moluccana*) agroforestry system. Sugarcane carbon storage has been reported to accumulate carbon at 4.3 Mg C ha^{-1} to 17.5 Mg C ha^{-1} on average (Suman et al., 2008; Anaya and Huber-Sannwald, 2014). This value was only about 5% of the carbon storage in the forest ecosystem, which can reach about 254 Mg C ha^{-1} to 325 Mg C ha^{-1} (Lusiana et al., 2005; Hairiah, 2018). However, in 2010, as a result of the decrease in sugarcane yields and due to the outbreak of pests and disease, along with massive fluctuation in the sugarcane price and the decreasing soil fertility, people shifted their agricultural practices to the sengon tree-based agroforestry system as an alternative way to secure their income.

The sugarcane monoculture system is very profitable for farmers and the sugar industry because it reduces production costs by 30-40%. But the productivity of sugarcane under multi-ratooning decreases by 30-50% every year due to a decrease in soil quality both physically and chemical (nutrient content). Soil degradation has been the result of long-term monoculture of sugarcane (Ghayal et al., 2011); however, this system potentially emits CO_2 under the risk of fire hazards on slash and burn practices (Pannosso et al., 2011). The effect of sugarcane conversion into an agroforestry system was rarely informed, particularly on their change in carbon storage at above and below ground biomass. Previous research on sugarcane plantations was focused on the soil nutrients effect (Lindell and Kroon, 2010; Pancelli et al., 2015). Nowadays, farmers prefer to cultivate various tree species to optimize their farming system and increase their income (Prayogo et al., 2021)

The main tree species that attracted farmers to be cultivated is sengon (*Paraserianthes moluccana*), which was established under a monoculture system or combined with other crops such as cassava (*Manihot utilissima*) or chilies (*Capsicum frutescens*). Sengon is selected because of its simple land management and required low maintenance, no need for regular irrigation and fertilization, and a short period of harvesting time, which is approximately around 5-7 years, and plays an important role in increasing farmer income (Krisnawati et al., 2011). Sengon known as a legume tree, produces a large quantity of organic matter biomass through its falling leaves and its litter or branches decomposition (Wahyudi and Sudin, 2013). This tree, when cultivated under an agroforestry system, can provide captured free nitrogen fixation following symbiotic processes and accumulate a great quantity of organic matter on the soil surface (Orwa et al., 2009). This is one of the benefits, such as those achieved in intensive monoculture patterns. In terms of social, economic, and cultural aspects, tree-based agroforestry systems are superior to intensive monoculture patterns because they are able to attract more labor and increase local people's income, create a cooperation system and togetherness between communities when the tree mature, and ready for harvest (Mutuo et al., 2005; Mayrowani and Ashari, 2011; Wahyudi and Sudin, 2013) and rehabilitate degraded soil properties (Ishag et al., 2020; Suprayogo et al., 2020)

Soil macrofauna has a significant role in improving the functional properties of the soil (Nusroh, 2007; Suin, 2012). They have a diverse role in their habitat and play an important role in maintaining soil fertility through organic matter changes and decomposition processes, nutrient distribution, and increased soil aeration (Prayogo et al., 2019). Soil macrofauna population dynamics depend on environmental factors that support it, both in the form of food sources, competitors, predators, and the physical-chemical environment (Sugiyarto et al., 2007). But unfortunately, research on the increase in organic matter content due to changes in the planting pattern of sugarcane into sengon-based agroforestry is very rare.

Differences in land use and management will affect the population and composition of soil macrofauna. Intensive tillage, fertilisation, and monoculture cultivation in conventional farming systems can cause a significant reduction in soil macrofauna biodiversity (Prayogo et al., 2019). This is in line with that stated by Susilo et al. (2005) that the activity of various soil macrofauna is known to be related to the dynamics of organic matter and soil nutrients. Each soil fauna group can be used as a bio-indicator because the presence of soil fauna is highly dependent on soil biotic and abiotic factors (Sugiyarto, 2000). However, those impact on changes in structure and composition of soil macrofauna is rarely informed due to their relationship with total carbon sequestration.

Therefore, this study was directed to obtain more information about changes in carbon storage and its effect on increasing the abundance of soil macrofauna in the upper part of the soil surface in terms of sugarcane monocultures conversion to sengon

(*Paraserianthes moluccana*)-based agroforestry using 2 times ratoon of monoculture sugarcane, 5 times ratoon of monoculture sugarcane plot compared to sengon monoculture at ages of 1 year, 3 years, and 5 years old.

Materials and Methods

Research site

The research was conducted in Kedungkandang District of Malang, East Java, Indonesia, which is located at 112^{o}36'14" - 112^{o}40'42" East and 07^{o}36'38" - 08^{o}01'57" South. Climatic conditions show an average temperature of about 24 °C with a humidity of 72.6%. The average annual rainfall reaches 2,279 mm, with the lowest average in August and the highest in January, with the highest number of rainy days, which is 19 days. The land use systems studied are presented in Figure 1. They consisted of 2 and 5 times ratooned sugarcane monoculture compared to 1, 3, and 5 years sengon tree-based (*Paraserianthes moluccana*) agroforestry system. Each land use system was replicated 3 times, and the area of the plot of each treatment was within the size of 100 m x 20 m.

Experimental design

Soil sampling and analysis

The method used for sampling and soil analysis was a systematic random sampling method consisting of 5 land use systems with three replications. Soil parameters measured were total organic C, soil bulk density, soil particle density, soil pH, soil texture, and soil porosity. Soil pH was determined with 1:1 soil water suspension.

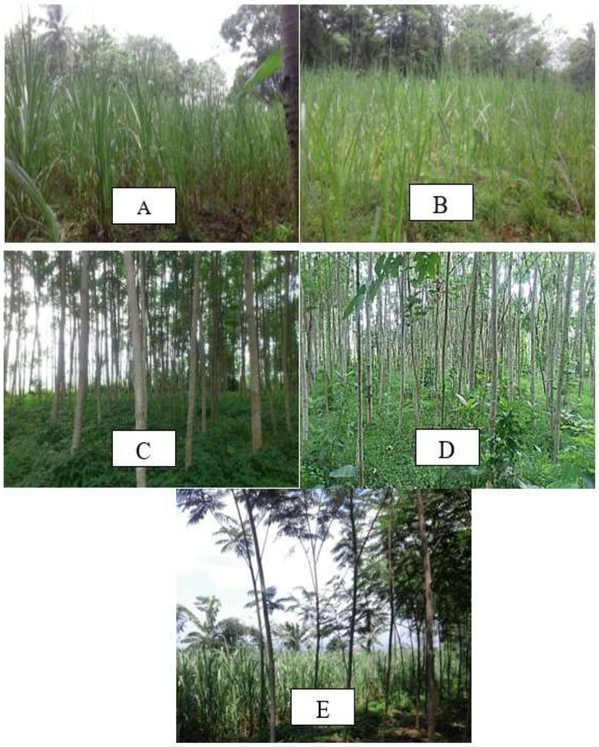

Figure 1. Land use systems of the study area: (a) 2 times ratooned sugarcane monoculture (b) 5 times ratooned sugarcane monoculture, (c) 1-year-old sengon-based agroforestry system, (d) 3 years old sengon-based agroforestry system, and (e) 5 years old sengon-based agroforestry system.

Soil organic carbon content was determined using the Walkley and Black method by titrating the soil samples with $FeSO_47H_2O$ (FAO, 2019). Soil bulk density and particle density were determined using soil cores samples which were collected using stainless steel metal rings with the size of 6 cm in height and 5 cm in diameter, inserted into the soil to a depth of 0-30 cm. Soil cores were oven-dried at 105 ˚C for 24 hours. Bulk density was calculated by dividing the mass of soil by the core volume, and gravimetric moisture content was calculated as the mass of water in the soil sample per mass of the oven-dried soil. Soil particle density was determined using the mass of soil divided by dry soil volume, whilst soil porosity was calculated from the ratio between soil bulk density divided by soil particle density (Smith, 2000; Ronbinson et al., 2022). Soil texture was determined following a pipette method. The soil physical and chemical analysis was conducted at the Soil Department Laboratory, Faculty of Agriculture, Brawijaya University, Malang.

Biomass, necromass, and carbon storage measurement

Measurement of above-ground plant biomass reserves for the Sengon-based agroforestry system was carried out by creating observation plots using a standard method that measured carbon stocks in various pools (tree vegetation, understorey), necromass, and soil. Location and determination of carbon stock observation plots for tree vegetation were based on the method developed by Hairiah et al. (2011) based on IPCC (2000) report. The observation plot was made within the size of 100 m x 20 m by placing the north to the south direction at the selected location. The subplots measurement were conducted within the size of 20 m x 40 m to measure vegetation with a diameter of 5 cm to 30 cm. The size of the subplot was enlarged to 100 m x 20 m if the plots contained vegetation with a diameter >30 cm. The total tree biomass was estimated using the allometric equation developed by Chave et al. (2005) as follows:

$$(AGB)\ est = \pi * \exp(-1.499 + 2.148 \ln(D) + 0.207 (\ln(D))\ 2 - 0.0281 (\ln(D))$$

where:

AGB est = above ground biomass estimation (kg)
D = tree diameter at the breast height: 1.3 m from the soil surface

The destructive method was used to take samples of understorey biomass as they had a diameter of <5 cm, including herbs, scrub, and grasses (Hairiah et al., 2011), which were taken using a subplot within the size of 0.5 m x 0.5 m with three replications. Necromass that is part of a dead tree on the soil surface was calculated using a standard formula to determine wood volume. Necromass collection was carried out within this subplot. There were two types of necromasses, including woody necromasses (i.e., branches, twigs) and non-woody necromasses (i.e., leaves, grass, seedling). The roots contribution to carbon sequestration was determined using a shoot/ratio which was about 0.21-0.25 (Mokany et al., 2009; Yusuf et al., 2014). The sugarcane biomass was collected by destructive sampling using a sample within an area of 2 m x 2 m when the sugarcane biomass had achieved the mature stage.

Soil macrofauna population and diversity

Observation of soil macrofauna in this study was carried out using the pitfall trap method, in which those sampling points were determined randomly on the plot by making a hole of the size of the trapping glass. The trapping glass containing 4% formalin was inserted into the hole until the glass surface was in a parallel position with the soil surface. The traping glasses were left for 24 hours before the trapped soil macrofauna were identified in the laboratory to classify their order and family name. The soil macrofauna identification was conducted at the Plant Pest and Disease Laboratory, Faculty of Agriculture, Brawijaya University, Malang. Abundance describes the large number of individuals occupying a location. Species abundance used for research data analysis refers to the number of individuals of a species found in a particular location (plot). The frequency (F) of a soil macrofauna species indicates the frequency with which certain soil macrofauna species are found in one place. The frequency of finding soil macrofauna species can be calculated by the following formula:

$$\text{F (frequency)} = \frac{\text{number of spesies detected in plots}}{\text{number of all plots}}$$

The diversity of soil macrofauna was calculated using the Shannon-Wiener Diversity Index (H’) formula as used by Ayuke et al. (2009) and Wibowo et al. (2021) as follows:

$$H' = -\Sigma\ pi \ln pi$$

$$Pi = \frac{ni}{N}$$

where:

H ' = Shannon-Wiener species diversity index
ni = number of individuals of the with species
N = number of individuals of all species

The Pielou evenness index (E) shows the degree of evenness of abundance of each species (Ayuke et al., 2009; Wibowo et al., 2021). The Pielou evenness index is expressed by:

$$E = \frac{H'}{\ln N}$$

where:

E = evenness index of the Pielou species
H ' = Shannon-Wiener species diversity index
N = number of species found

The E value ranges from 0-1. A value close to 0 indicates that there are dominant species in the community. If the value is close to 1, it indicates that all species have almost the same level of species evenness or there is no dominance of a particular species. The similarity index shows the level of community similarity between 2 different types of stands. The community similarity value (Similarity index) between stand types was calculated using the Sorensen community index value (S) as used by Ayuke et al. (2009) and Wibowo et al. (2021) as follows:

$$S = \frac{2J}{(a+b)} x100\%$$

where:

J = number of species found in habitats a and b
a = number of species found in habitat a
b = number of species found in habitat b

Sorensen community index ranges from 0-1, which if the value is close to 1 indicates that the level of community similarity between habitats is high, and if it is close to a value of 0, it indicates that the level of species similarity between habitats is low (Wibowo et al., 2021). The Importance Value Index (IVI) of soil macrofauna species that dominate the standing community was calculated using the formula of Prayogo et al. (2021): IVI = FR + KR + DR, where IVI = Importance Value Index, FR = relative frequency, KR = relative density and DR = relative dominance. The higher the importance of a species, the higher the level of control in the community concerned.

Data analysis

Data were subjected to Analysis of Variance (ANOVA) followed by Duncan's test at a 5% level of significance. Besides, correlation tests were also conducted to determine the relationship between parameters. The results of the correlation test were continued with multivariate analysis using Canonical Variate and Biplot approach under the application of GenStat Discovery 10th Edition to produce a 2-dimensional graph.

Results and Discussion

Soil properties and characteristics

The results of ANOVA showed that changes in land use from sugarcane monoculture to sengon tree-based agroforestry significantly ($p<0.05$) affected soil texture, especially the silt and clay fractions, soil bulk density, pH, and soil organic C (Table 1). There was no significant difference ($p>0.05$) in the percentage of sandy fraction in all treatments, with the values ranging from 29 to 34%. The silt fraction in the 3 years old sengon-based agroforestry system was the highest, almost 2 x higher than the silt fraction in the 5 years old sengon-based agroforestry system. However, this was the opposite of the clay fraction status, where the clay fraction in the 3 years old sengon-based agroforestry system was the lowest among all treatments. Data presented in Table 1 clearly indicate that the dominant soil fraction was the silt fraction.

Table 1. Effect of land use change on several soil properties.

Land Use	**Soil Texture (%)**			**Soil Bulk Density ($g\ cm^{-3}$)**	**Soil Particle Density ($g\ cm^{-3}$)**	**Soil Porosity (%)**	**Soil pH**	**Soil Organic C (%)**
	Sand	**Silt**	**Clay**					
T2	34	57 ab	9 ab	1.05 a	2.49	53.41	4.63 a	1.31 ab
T5	33	62 ab	5 ab	1.14 ab	2.28	46.93	5.03 a	1.59 c
S1	29	59 ab	12 ab	1.37 c	2.43	52.26	4.72 a	0.99 a
S3	30	69 b	1 a	1.26 bc	2.42	50.41	5.43 ab	1.51 bc
S5	32	49 a	19 b	1.18 ab	2.42	47.93	5.60 b	1.40 b

Notes: T2 (2 times ratooned sugarcane), T5 (5 times ratooned sugarcane), S1 (1-year-old sengon), S3 (3 years old sengon), S5 (5 years old sengon). The numbers in the column followed by the same letters show no significant difference based on Duncan's test level of 5%.

For comparison, previous research on intensive sugarcane plantation areas in the Martinho region, Brazil, showed that the percentage of clay fraction was 69%, 13% of silt, and 18% of sand (Galdos et al., 2009). Meanwhile, soil texture under 2 times ratooned sugarcane consisted of 75% of clay, 22% of silt, and 3% of sand. Soils under the sugarcane plantation in the City of Guariba, Sao Paulo, Brazil, had 60% of clay, 10% of silt, and 30% of sand (Barrios et al., 2017).

The developments in soil texture can be influenced by soil fauna. Living organisms such as ants, worms, and rodents carry out soil particles to the surface and mix organic matter with minerals. The holes are made to help circulate water and air, increase chemical weathering, and accelerate soil formation and development. In the process of decomposition of organic matter, it will produce organic acids, which are primary agents to decompose rock and minerals, which allow soil particles to easily break down into smaller sizes. In addition, the greater number and density of roots will accelerate the physical crushing so that finer fractions will be formed quickly (Arifin, 2011). The 5 years old sengon-based agroforestry system had higher soil bulk and particle density values than that of the 3 years old sengon, 1-year-old sengon, and 2 times or 5 times ratooned sugarcane. The difference in soil bulk and particle density values is caused by a different content of organic matter and soil texture. At 2 times ratooned sugar cane had soil bulk density at the value of 1.05 $g\ cm^{-3,}$ which increased to 1.14 $g\ cm^{-3}$ at 5 times ratooned sugarcane (Table 1). The results of this study had a similar value when compared to the previous research in the Martinho area, Brazil, with a soil depth of 0-10 cm at 2 years replanted before soil sampling.

The soil had a soil bulk density value of 1.10 g cm^{-3} (Galdos et al., 2009) which was comparable to the soil bulk density of 6-year treatment sugarcane at the value of 1.12 g cm^{-3} of sugarcane cultivation in a conventional system, with and without burning, raised the soil bulk density to 1.39 g cm^{-3} and 1.21 g cm^{-3} which was lower than the soil bulk density under pasture (1.43 g cm^{-3}) (Borges et al., 2018). The effect of sugarcane ratooning on soil physical properties has been rarely informed, if any; the previous study was more focusing on the changes in soil chemical aspect (Pancelli et al., 2015).

Soil acidity is a condition that allows mineral nutrients to be optimally absorbed by plant roots. The optimal pH value for supporting plant growth is between 6.5 to 7 (Sudomo and Handayani, 2013). The pH value of 2 times ratooned sugarcane was 4.63, while 5 times ratooned sugarcane was 5.03 (Table 1), which is indicated in slightly acidic conditions, which was lower than those pH values when it was compared to the pH of sugarcane plantations in the Bukidnon area, Philippines, which is at 5.23. Soil pH sugarcane plantation of Guariba and Minas Gerais in Brazil reaches 5.30 (Da Rocha Junior et al., 2014). The pH value in this study at 1-year-old sengon, was 4.72 and increased significantly ($p<0.05$) at the age of 3 years where the pH value reached 5.43 and 5.60 at 5 years old Sengon agroforestry system, respectively. Soil pH at Slamparejo, Jabung, Malang under the sengon/Falcata plantation at the age of 3 to 6 years old were 5.65 and 5.7, respectively (Khalif et al., 2014) was comparable to the value of soil pH in this study. Another study showed that, at a depth of 0-30 cm, the value of soil pH at sengon-based agroforestry ranged between 6.28-6.81, which was not significantly different to soil pH under pine-based agroforestry and monocultures at Mrayan-Ngrayun, Ponorogo (Parwi et al., 2022). The difference in the pH value of the land use of sugarcane monocultures and sengon-based agroforestry can be influenced by the method of soil cultivation and fertilisation.

Soil management and soil organic matter inputs play important roles in the changes in soil pH along with the activities of soil microorganisms. The availability of soil organic C can be influenced by how much inputs are supplied into the system, such as inorganic fertilisers or soil amendments. The existence of a sufficient level of soil organic matter can provide a source of carbon, improve soil aggregate stability, increase the ability of soil to store water, soil nutrients, and CEC, and reduce soil bulk density (Mindawati et al., 2010). Changes in land use from sugarcane monocultures to sengon-based agroforestry systems significantly affected soil organic C content ($p<0.05$). The highest soil organic C value was found in the 5 times ratooned sugarcane plot with a value of 1.59%, followed by the 3 years old sengon-based agroforestry system with a value of 1.51%, the 5 years old sengon-based agroforestry system of 1.40%, the 2 times ratooned sugarcane system with a value of 1.31% and 1-year-old sengon-based agroforestry system about 0.99%. There is a change in the increase in the soil organic C by 20%. The average value of soil organic C obtained at 1-year-old sengon-based agroforestry plot was 0.99% which increased by 80% at the 3 years old sengon-based agroforestry plot to about 1.51% and the 5 years old sengon-based agroforestry system was at 1.40% (Table 1). Organic sugarcane cultivation in the Cerrado biome-Brazil causes changes in soil carbon at a value of 2.3 %, which was higher than that of the burning sugarcane practices (1.3%) (Borges et al. 2018). This burning sugarcane soil organic value was comparable to the value of soil organic at 5 years old sengon-based agroforestry system in this study. The size of the soil organic C is strongly influenced by the input of organic matter inputs from litter in situ and understory as well as fallen leaves and crop residues that were not transported out of the system.

Carbon sequestration

The conversion of land use from sugarcane monoculture to sengon-based agroforestry systems resulted in significant changes ($p <0.05$) in the amount of litter biomass, understory biomass, and litter thickness). The highest litter biomass + necromass was found in 3 years old sengon plot at about 0.138 Mg ha^{-1}, then followed by the 5 years old sengon of 0.083 t ha^{-1}, and the 1-year-old sengon of 0.068 Mg ha^{-1}. The accumulation of litter and necromass in the two plots was not different ($p<0.05$) with the 2 times monoculture ratooned sugarcane of 0.084 Mg ha^{-1} and 5 times of ratooned sugarcane of 0.063 t ha^{-1} (Table 2). This yield was much lower than the input of litter in sengon + coffee + taro agroforestry in Slampangrejo village, Jabung (Khalif et al., 2014). The highest understory of vegetation biomass on sengon was found in 5 years old sengon with a value of 0.078 Mg ha^{-1}, then followed by 3 years old monoculture sengon of 0.065 Mg ha^{-1}. The lowest was detected at 1-year-old sengon plot of 0.044 Mg $ha^{-1,}$ which was only significantly different ($p<0.05$) from the 2 times ratooned sugarcane plot of 0.026 Mg ha^{-1} (Table 3).

The increase in vegetation biomass on land is thought to be due to the changes in land management. The low amount of biomass in sugarcane monoculture land is due to intensive land management by clearing weeds off the soil surface, while in sengon-based agroforestry plot, weeds were not cleared. The lowest above-ground biomass carbon stocks were found in 1 year old sengon plot at the value of 10.89 Mg C ha^{-1}, which was 50% lower than 2 times ratooned sugarcane which was equal to 25.82 Mg C ha^{-1}, followed by 5 times ratooned sugarcane of 25.43 Mg C ha^{-1} and 3 years old sengon of 26.32 Mg C ha^{-1}. From these results, it can be concluded that carbon sequestration under the sugarcane plot in this study was twice higher than the sugarcane sequestration in Isabel, Philippines, which accumulated 10.61 Mg C $ha^{-1,}$ and in Leyte was about 13.1 Mg C ha^{-1}. Meanwhile, the carbon stock in Bukidnon, Philippines, under sugarcane plantation accumulated carbon sequestration of 19.78 Mg C ha^{-1}, which is still lower than the results of the research in this study. The carbon stock in the sengon in Mindano, Philippines, at the age of 5 years has carbon sequestration of about 34.02 Mg C ha^{-1} (Lasco, 2002). Meanwhile, the carbon stock in Prigen Subdistrict, Pasuruan Regency, on a monoculture sengon, with the age of 4 years can reach a value of 47 Mg ha^{-1} (Sari et al., 2011), which was 50% lower than hose value of 5 years old sengon agroforestry in this study, to about 84.80 Mg ha^{-1}. The tree carbon stock of the community forest which was dominated by sengon/falcata tree (*Paraserianthes falcataria* L. Nielsen) at Julagajaya Village in 1, 2, 3, 4, 5, and 6 years old stand were at 29.2, 33.5, 36.0, 39.1, 33.1, and 56.9 Mg ha^{-1}, respectively (Elias and Wistara, 2009), which was within the range of *P. falcataria* trees carbon stock in Philippine to accumulate 32.50 t ha^{-1} (Malayao and Mendoza, 2013). However, those values were lower almost twice than the value of carbon of stock of sengon tree system in this study. Moreover, when the diversity and the population of sengon/falcata trees increased and those systems were combined with the multistorey coffee system, their carbon stock could have amounted to 92 Mg C ha^{-1} (Labata et al., 2012), which was comparable to 4 years old *P. falcataria* stands in Manupali watershed in Bukidnon, Philippines (Shively, 2003).

Table 2. Impact of treatments on litter, necromass, understory, root biomass, soil C-stock, and total C sequestration across land use.

Land use	**Litter + Necromass (Mg C ha^{-1})**	**Understory biomass (Mg C ha^{-1})**	**Above-ground plant biomass (Mg C ha^{-1})**	**Root biomass (Mg C ha^{-1})**	**Soil C stock (Mg C ha^{-1})**	**Total C sequestration (Mg ha^{-1})**
T2	0.084 ab	0.026 a	25.43 b	6.35 b	13.75 a	45.64
T5	0.063 a	0.043 ab	25.82 b	6.45 b	18.13 b	50.50
S1	0.068 a	0.044 ab	10.89 a	2.72 a	13.56 a	27.28
S3	0.138 b	0.065 b	26.32 b	6.58 b	19.03 b	52.13
S5	0.083 ab	0.078 b	55.49 c	13.87 c	16.52 ab	86.04

Notes: T2 (2 times ratooned sugarcane), T5 (5 times ratooned sugarcane), S1 (1-year-old sengon), S3 (3 years old sengon), S5 (5 years old sengon). The numbers in the column followed by the same letters show no significant difference based on Duncan's test level of 5%.

Sengon tree (*P. falcataria*) as a typical fast-growing tree species, accumulates more biomass and carbon than slow-growing species for the same period of time (Sales et al*.,* 2004). However, fast-growing species typically have lower wood density and thus contain less carbon than the wood of slow-growing species (Lasco and Pulhin, 2009). The carbon stock at the root system could be estimated using an average root-shoot ratio of root biomass to the main stem ranging from 0.1324-0.4172 (mean 0.25), while the root-shoot ratio of root carbon mass trees to the above-ground carbon mass of trees ranged from 0.0794-0.2132 (mean 0.14) and root shoot ratio of the carbon mass of the tree roots to the main trunk ranged from 0.0983-0.3017 (mean 0.20). That value was derived from the experiment under *Accacia mangium* tree plantation at Parung Panjang-Bogor (Elias et al., 2010).

The root biomass of sengon agroforestry system in this study after 5 years of planting was 13.87 Mg C ha^{-1}, which was comparable to the root biomass estimation of *A mangium* at the diameter of 15-20 cm, resulting in root biomass carbon stock of 11.05 Mg C ha^{-1} (Elias et al., 2010). The difference in carbon stocks at each research location can be due to different plant ages and the number of trees in each agroecosystem. The older the age of a tree and the greater the number of populations, the more carbon stock which had been accumulated is becoming greater (Tresnawan and Rosalina, 2002; Lasco and Pulhin, 2003). The carbon stock stored in the soil did not show a significant difference, except for the land use of 5 times ratooned sugarcane for 18.13 Mg C ha^{-1} and 3 years old sengon, which was sequestered biomass to about 19.03 Mg ha$^{-1,}$ which was significantly different ($p<0.05$) from other land uses. The results of the measurement of carbon stocks were higher than the results of soil carbon stock research conducted in Minas Gerais, Brazil, which resulted in carbon storage at a soil depth of 0-10 cm of 10.28 Mg ha^{-1}, and research conducted in Ribeirao Preto, Sao Paulo State, Brazil, which obtained carbon stock at a depth of 0-5 cm was 14.4 Mg ha^{-1} and at a depth of 5-10 cm was 14.3 Mg ha^{-1} (Segnini et al., 2013). When the organic sugarcane system is implemented, the soil carbon stock could reach 25 Mg C ha^{-1} (Borges et al., 2018). The difference in the amount of carbon stock in the soil at a depth of 0-10 cm from some of these areas can be due to land cultivation, fertilisation intensity, processing of crop residues, and so on.

The high amount of carbon stored in the soil in sugarcane land use can be related to the presence or absence of land preparation and intensive cultivation, which could modify the decomposition process (Patricio, 2014). Under an organic sugarcane system in a Cerrado Oxisol-Brazil, soil physical properties can be enhanced by increasing organic carbon content in which, favouring water infiltration and retention (Borges et al., 2018).

Diversity, abundance, and similarity of soil macrofauna

Diversity, abundance, and similarity of macrofauna due to changes in land management from sugarcane to sengon presented in Table 3 show that land changes from sugarcane to sengon increased the density of individuals per hectare, especially the increase in diversity (H'), abundance (R) and similarity (E) of macrofauna observed, especially for the 1-year-old sengon which had the highest value. The value decreased in the 3 and 5 years sengon plots. The changes in land management have been reported to impact soil macrofauna structure and diversity in the agroforestry system (Prayogo et al., 2019) and soil microbes under a sugarcane system (Ghayal et al., 2011). A significant reduction in IVI value has been detected on S1 (1-year-old sengon) compared to other land use, whilst the greatest was under 2 times ratooned sugarcane system (Table 3). Soil macrofauna observed in this study consisted of various family groups such as a) *Carabidae* sp.*,* (b) *Thomisidae* sp.*,* (c) *Acrididae* sp.*,* (d) *Gryllidae* sp. etc. (Figure 2).

Table 3. Population, diversity index, similarity index, and evenness index of soil macrofauna across land use system.

Land use	Population (ha^{-1})	H '	S	E	IVI
T2	3800.00±1928.73	1.03±0.20	1.20±0.26	0.62±0.04	97.62
T5	3133.33±1270.17	1.20±0.14	1.27±0.03	0.72±0.04	85.91
S1	3633.33±862.17	1.44±0.15	1.39±0.19	0.81±0.05	69.80
S3	6000.00±2325.94	0.91±0.28	1.14±0.34	0.53±0.12	86.66
S5	6733.33±2324.51	1.02±0.02	1.12±0.04	0.59±0.03	84.80

Notes: T2 (2 times ratooned sugarcane), T5 (5 ratooned sugarcane), S1 (1-year-old sengon), S3 (3 years old sengon), S5 (5 years old sengon), (±) SE (Standard Error). The column in the table followed by the same letter show no significant difference based on Duncan's test level of 5%. H' = Diversity index, S = Similarity index, E = Evenness index , IVI = Important Value Index.

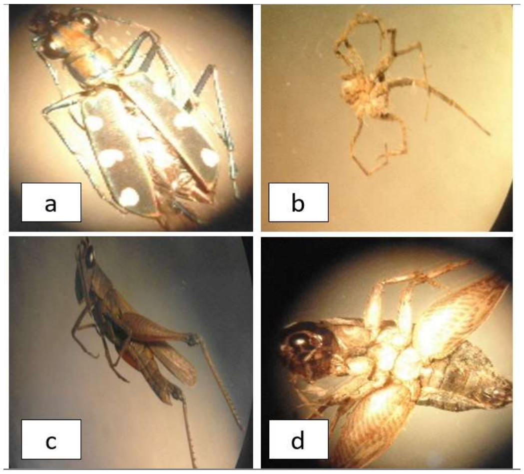

Figure 2. (a) *Carabidae* sp.*,* (b) *Thomisidae* sp.*,* (c) *Acrididae* sp.*,* (d) *Gryllidae* sp.

Multivariate analysis

Though the principal components analysis is important to determine the relationship amongst the group of soil macrofauna and understand their magnitude and direction (Torres-Salinas, 2013), CVA Biplot was adopted (Figure 3). It was verified that the first principal component analysis axis (CVA-1) responded to 97.75% while the second principal components analysis axis (CVA-2) was compounded by 1.52% of the total variance, cumulative percentage of both CVA-1 and CVA-2 in 100% of the total variance. CVA-1 accounted for the above parameters, which successfully split the effect of the treatments along the X axis. This figure indicates that the group of *Formicidae* sp. has a strong correlation and similar magnitude or direction to *Carabidae* sp. (upper position), while *Ochteridae* sp., *Thomisidae* sp., *Gryllidae* sp., and *Culisidae* sp. were in the opposite direction (lower position). *Acrididae* sp. had a different magnitude and direction, which were not similar to those both above group. It showed that the conversion of sugarcane to a sengon tree-based agroforestry system did not affect the structure of all families of soil macrofauna. Organic cultivation is characterized by promoting greater biodiversity of the microbiota and soil fauna, as well as by improving fertility and maintaining biological pest control (Borger et al., 2018). Ants are good ecological indicators because of their vast population and abundance. They are largely found under different geographic locations, sensitive to environmental or land use changes (Siquera et al., 2016). This study is in line with the finding from Siquera et al. (2016), which identified that *Formicidae* had a greater abundance (26%) compared to *Aranae* (13%) under the intensive cultivation of sugarcane.

Using the selected parameters of soil and macrofauna indices, CVA was also employed to distinguish and cluster the treatments. Figure 4 shows that there was an overlapping one to each other between S1 and T2, and T2 and S5, but not for S1 and S5, which were not overlapping at all.

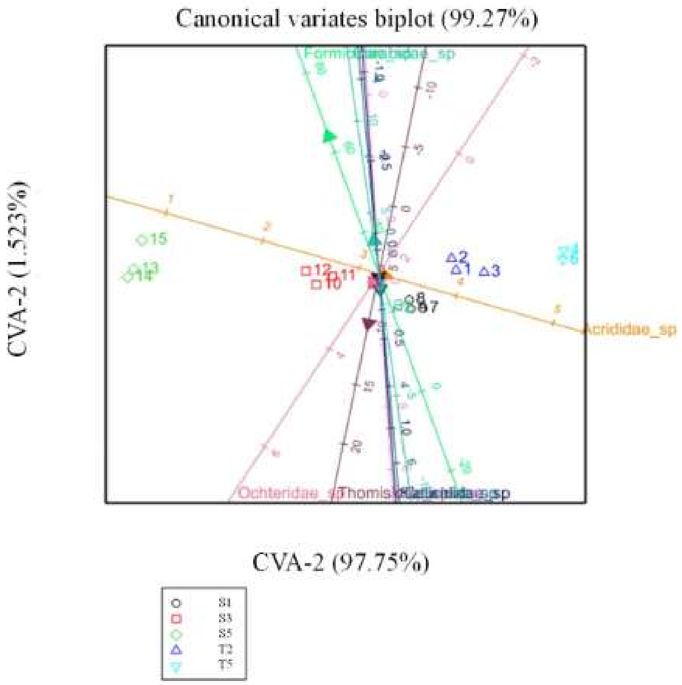

Figure 3. Biplot analysis of the macrofauna group.

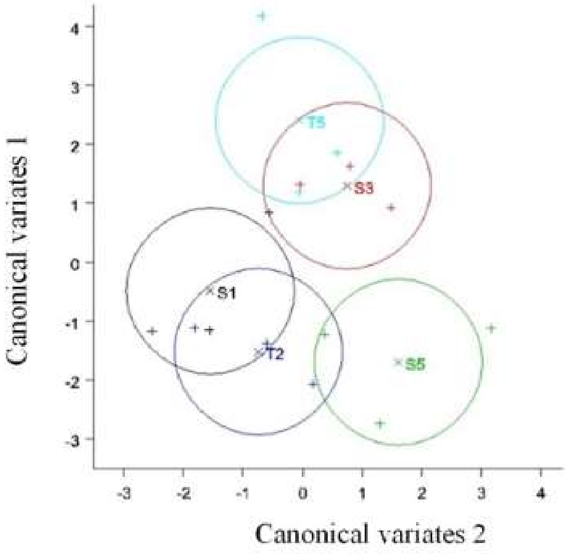

Figure 4. CVA analysis of the effect of land use conversion.

Those three treatments were separated and had a gap to S3 or T5 treatments which overlapped one to another. When the treatments were overlapping, it can be concluded that those treatments were not significantly different based on selected multivariate parameters, and when there were not overlapping, the conclusion was the opposite. Using PCA analysis, the result of previous findings (Menandro et al., 2019) showed that Formicidae, Oligochaeta, and Coleoptera were substantially influenced by sugarcane straw removal management. Sugarcane straw removal management was inducing direct impacts on soil macrofauna population and bridging synergistic effects on the changes in macrofauna communities along with altering soil chemical and physical attributes (Menandro et al., 2019).

Conclusion

Sengon tree (*Paraserianthes moluccana*)-based agroforestry system has some advantages in improving carbon sequestration due to the accumulation of biomass, surface litter, and necromass as well as the soil carbon storage and root biomass contribution. At 5 years of planting, total carbon sequestration was almost twice compared to carbon sequestration at 2 times ratooned sugarcane (*Saccharum officinarum*) system. Soil macrofauna population was influenced by the conversion of land use even though there were only small changes in their diversity, similarity, and evenness value. The increase in soil macrofauna population did not directly impact greater soil porosity. The effect of land use could be determined by CVA and Biplot assessment which was grouping and clustering each land use separately. Soil macrofauna under the family of *Formicidae* sp. have a similar magnitude and direction to the family of *Carabidae* sp., which means they have strong relationship approaches that can be used as tools to determine the impact of different management of agroforestry systems on the abundance and diversity of soil invertebrates

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