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To cite this article: L S Aldini *et al* 2025 *IOP Conf. Ser.: Earth Environ. Sci.* **1466** 012003

Agroforestry for Reclamation of Imperata Grassland: Earthworm as indicator for soil health

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Abstract. Conversion of natural forests to agricultural land or other uses is still common in tropical regions. However, over time, when agriculture productivity decreases, land will be abandoned of fallowed by farmers. Agroforestry with dense tree canopy cover can reduce the population of *Imperata cylindrica* (alang-alang), increasing organic material input from litter and dead roots followed by a higher density of soil organisms. The purpose of this study is to evaluate the role of agroforestry in improving soil health in *Imperata* grassland by evaluating earthworm density as an indicator. This research was conducted in July-August 2024 in the Solok Regency, West Sumatra on Andisols at approximately 1500 m above sea level. We measured the microclimate, canopy cover, basal area, standing litter, as well as earthworm diversity and population density. Earthworm sampling was done using the monolith technique from TSBF (Tropical Soil Biology and Fertility). Land currently under annual crops was compared with Imperata grassland, grassland plots converted to coffee-based agroforestry systems 1-3, 4-6 or >7 years ago, old multistrata agroforestry system (AFMT), and remnant secondary forest in the same landscape. The results showed that earthworm densities were highest in AFMT, less than half as much in the *Imperata* grasslands and close to zero in currently cropped land, but also in the remnant secondary forest. Conversion of grassland to agroforestry appears to initially (1-4 years) reduce earthworm populations before they recover, but populations don't reach the AFMT level in 5-7 year old plots. A number of relationships was explored that may help understand these results. Old multistrata agroforestry system (AFMT) have a canopy cover od 47% (compared to 69% for the remnant forest) and increase humidity and reduced air and soil temperature compared to open fields. Standing litter necromass was highest in AFMT, followed by agroforestation of *Imperata* grasslands. Within these results, earthworm presence is not related to tree basal area or canopy cover, but variation in standing litter accounts for 28% of variation in earthworm numbers. Reclaiming degraded *Imperata* grassland land with an agroforestry system is effective, as it increases land cover, provides high litter inputs, and creates habitats for earthworms, thereby improving soil health.

Keywords: Degraded land, Agroforestry, Soil Quality, Belowground diversity.

1. Introduction

Land conversion from natural forest to agricultural land carried out by farmers results in a decrease of soil health due to the continuous transport of nutrients out of the system. Over time, the agriculture productivity decreases, and the land is abandoned. This situation triggers invasive plants such as *Imperata* grass to grow. *Imperata* grass grows rapidly both seeds and rhizomes, enabling it to dominate agricultural land and reduce plant productivity [1]. Land overgrown with *Imperata* grass causes a decrease in plant diversity and increases the intensity and frequency of fires, it can affect the soil nitrogen and phosphorus cycles in the system [2].

Imperata grass has fibrous roots that spread widely and penetrate deep into the soil. These root characteristics increase nutrient competition with other plant species. On the other hand, the presence of dominant *Imperata* grass can hinder the growth of other plants, thereby reducing biodiversity [3]. In addition, *Imperata* grass can also affect soil structure and C-Stock both above and belowground [1]. Syahrinudin [4] stated that land covered with *Imperata* grass has a very low soil carbon content, ranging from 5.9 to 7.6 Mg C/ha.

Low biodiversity in *Imperata* grass land can lead to a decrease in canopy cover, which affects the microclimate and organic matter input. To overcome land degradation due to the invasion of Imperata grass, agroforestry system can be considered. Agroforestry is an integrated land-use system that combines woody plants, agricultural crops, livestock, and the socio-economic aspects of the community [5]. Agroforestry has high biodiversity and canopy cover levels that cause the population of *Imperata* grass to decrease because the intensity of sunlight on the soil decreases. High canopy cover plays an important role in reducing the population of *Imperata cylindrica* grass because *Imperata* is a type of weed that thrives in open areas with sufficient sunlight [6].

Trees in agricultural landscapes can create more favorable habitats for soil biodiversity by moderating microclimates and providing a steady supply of organic matter, which serves a primary energy source for belowground diversity such as earthworm. This fosters "hot spots" of biological activity that drive numerous ecological functions essential for maintaining soil health [7]. Earthworm species and body sizes were found to be more abundant in areas with a higher diversity of tree species or in agroforestry systems. This highlights the importance of trees as a crucial element in maintaining healthy soil ecosystems and supporting biodiversity [7]. Hairiah [8] stated that land management practices that maintain litter input can preserve the vertical burrowing activities of earthworms, contributing to positive changes in soil macroporosity. These changes can enhance infiltration and reduce runoff and soil erosion. Therefore, reclamation degraded *Imperata* grass land with an agroforestry system can improve soil health and enhance environmental services. For this reason, research is needed on the reclamation of *Imperata* grass land using an agroforestry system to assess soil health, using earthworm density as an indicator.

2. Material and Method

2.1 Site Location and Research Design

This research was conducted in July - August 2024 in Nagari Sirukam and Nagari Air Dingin, Solok Regency, West Sumatra and Laboratory analysis were conducted at Agricultural Instruments Standardization Agency (BSIP) West Sumatera. A total of 32 plots were measured across various land use system (LUS): (1) PI = intensive Agriculture, (2) PE = extensive Agriculture, (3) AF0 = *Imperata* grassland before reclamation (AF0), (4) AF1 = agroforestry 1-3 years after *Imperata* grassland reclamation, (5) AF2 = agroforestry 4-6 years after *Imperata* grassland reclamation, (6) AF3 = agroforestry >7 years after *Imperata* grassland reclamation, (7) AFMT = old agroforestry, and (8) HT = remnant forest. The soils in our research are Andisols with an elevation of 1200 m above sea level (masl). The criteria used to differentiate each land use are based on the age of reclamation with the agroforestry system, the number of tree species per unit area, and the size of the basal area (the ground area occupied by trees).

Earthworm observations were carried out on the main plot measuring 20x20m by selecting plots that represented each landuse (LUS). Earthworm sampling was done using monolith technique from Tropical Soil and Biology Fertility (TSBF) in 3 depths (0-10 cm, 10-20 cm, and 20-30 cm). Earthworm sample were collected in each depths using handsorting methods.

2.2 Research variables

2.2.1. Microclimate

Soil temperature, air temperature and humidity were measured using Elitech RC-5 data logger for 1 month on each land use. Sensors were placed on trees representing each land use with 2 replications. Addittionally, canopy cover was measured in each LUS to determine the canopy density. Canopy measurements were carried out using ‘Canopyapp’ by measuring canopy cover facing upwards [9].

2.2.2. Basal Area (BA) and Diameter at Breast Height (DBH)

BA were measured on the trees with a DBH > 5cm. Tree with DBH <5 cm was considered as understorey. DBH measurements were carried out by wrapping the tape measure around a tree trunk with a height of 1.3 m. The measurement results were then converted into diameter (d) with the following formula:

$$\mathrm{d\ (cm)} = \frac{Stem\ Circumference\ (cm)}{\Pi}$$

2.2.3. Standing litter

Standing litter was measured the biomass quantity. Litter sampling was taken at the same point as the earthworm sampling point. Litter sampling was carried out using a 50 cm x 50 cm double frame. Litter thickness were measured at five points on each frame to obtain a representative data. Litter samples were then weighed to determine their fresh weight and then oven-dried at 85^0C for 48 hours for its dry weight.

2.3 The Number and Weight of Earthworms

Earthworm sampling in each point, soil depth, and LUS was carried out using the hand-sorting method. This technique is designed for undertaking a soil fauna survey using monolith based on the Tropical Soil Biology and Fertility Program (TSBF) method. Sampling was carried out using a frame size of 50 cm x 50 cm x 10 cm. Earthworms were taken at three depths for each monolith, namely 0-10 cm, 10-20 cm, and 20-30 cm. The samples of earthworms that have been obtained were then cleaned by water, counted, and weighed. Then, place an earthworm in a bottle containing 5% formalin for analysis under a microscope in the laboratory.

2.4 Statistical Analysis

In order to evaluate the role of agroforestry on improving soil health post *Imperata* invasion, we performed analysis of variance to test the difference of standing litter, earthworm population and biomass across various landuse and soil depths. If the effect was significantly different (p<0.05) then a further test of the Least Significant Difference (LSD) at the 5% level was carried out. A correlation test was conducted to determine the relationship between microclimate, basal area, litter biomass and earthworm biomass. If the relationship was significant then the predicted regression line was fitted to data. All statistical analysis was carried out using the R program version 4.4.0 [10].

3. Result and Discussion

3.1 Microclimate (Canopy cover, temperature, and Humidity)

The canopy cover in each land use showed a significant difference (p>0.05) across LUS (Figure 1A). The highest canopy cover was found in remnant forests (69%) because they have a large number of trees compared to alang alang land and monoculture agriculture which lack trees so there does not have canopy cover (0%).

Dense canopy cover could block sunlight and, reducing evaporation. As a result, the water content in the air will be high. The higher the canopy cover, the higher the humidity [11]. Remnant forests (HT) had the highest canopy cover among all land uses because forests have high basal areas. High canopy cover in the forest might be because of many species, so they have vertical arrangements and layered structures that play a very important role in regulating the microclimate, increasing biodiversity and supporting various ecological functions [12].

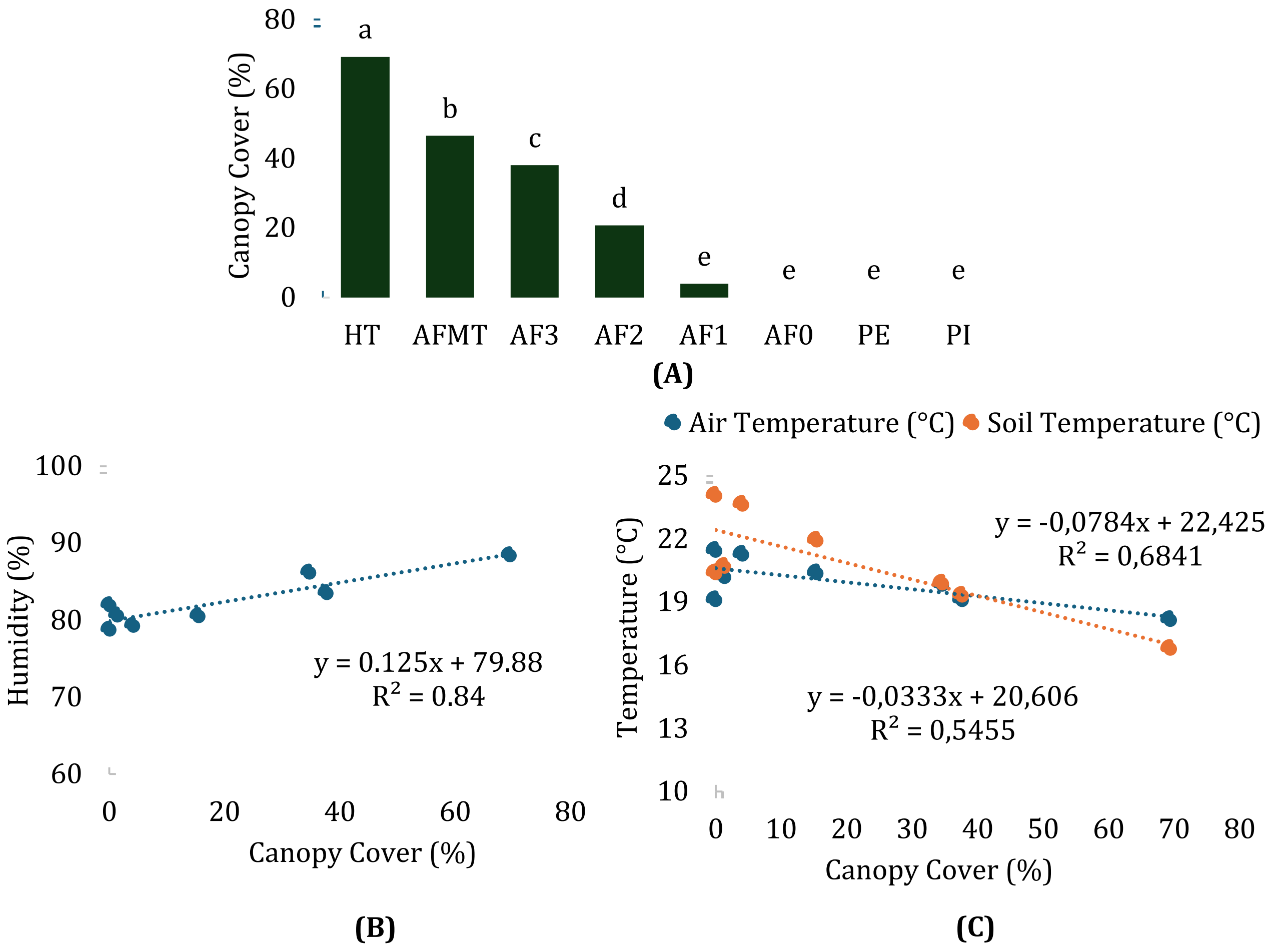

Figure 1. (A) The Variation of canopy cover in various landuse. The Relationship between; (B) Canopy cover and Humidity, and (C) Canopy cover, air and soil temperature (Note: canopy cover which has the same letter notation, is not significantly different in the Least

Significant Difference test 5% level) (PI = intensive Agriculture, PE = extensive Agriculture, AF0 = *Imperata* grassland before reclamation (AF0), AF1 = agroforestry 1-3 years after *Imperata* grassland reclamation, AF2 = agroforestry 4-6 years after *Imperata* grassland reclamation, AF3 = agroforestry >7 years after *Imperata* grassland reclamation, AFMT = old agroforestry, and HT = remnant forest).

The microclimate in a particular land use was influenced by its canopy cover. There was a negative relationship between air temperature and soil temperature, where the higher the canopy cover, the lower the air and soil temperature. High canopy cover could reduce temperature by providing shade to the land, thus reducing the intensity of sunlight, which leads to a decrease in temperature [13].

3.2 Standing Litter

Standing litter refers to all organic materials located on the soil surface (above the mineral soil), which includes various types of decomposing plant matter such as fallen leaves, branches, twigs, flowers, fruits, partially decomposed material, and roots [8].

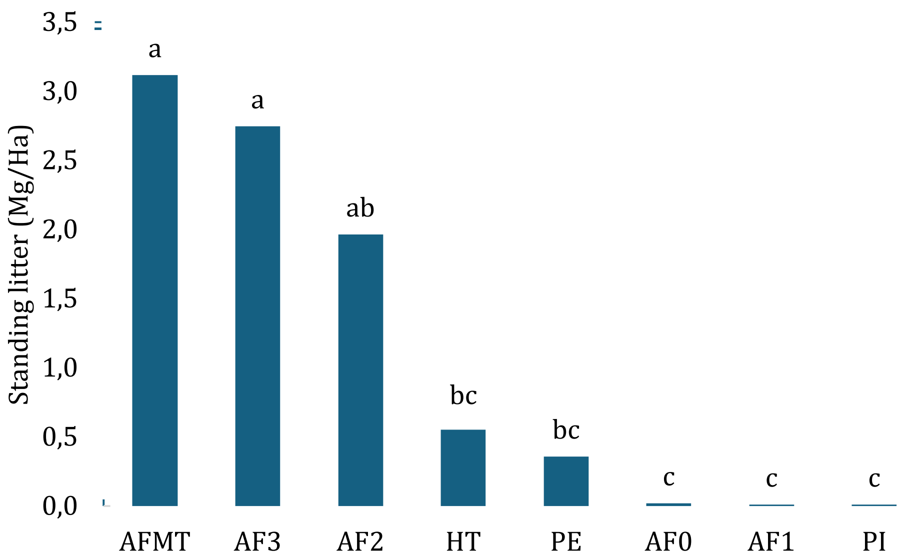

Figure 2. Standing litter in various land uses (Note: canopy cover which has the same letter notation, is not significantly different in the Least Significant Difference test 5% level) (PI = intensive Agriculture, PE = extensive Agriculture, AF0 = *Imperata* grassland before reclamation (AF0), AF1 = agroforestry 1-3 years after *Imperata* grassland reclamation, AF2 = agroforestry 4-6 years after *Imperata* grassland reclamation, AF3 = agroforestry >7 years after *Imperata* grassland reclamation, AFMT = old agroforestry, and HT = remnant forest).

Figure 3 shows that the highest standing litter was recorded in AFMT (old agroforestry) and AF3 (Imperata grassland rehabilitated for more than 7 years), each more than 3 Mg/ha, with significant differences compared to other landuses. This proves that long-term agroforestry and rehabilitation of Imperata grassland can create a stable ecosystem and supporting maximum litter accumulation. Meanwhile, AF0 (Imperata grassland before rehabilitation), AF1 (agroforestry 1-3 years after Imperata grassland reclamation), and PI (intensive agriculture) show the lowest litter biomass, less than 1 Mg/ha. This indicates that lands with poor initial conditions, new rehabilitation, or intensive management are insufficient to support litter accumulation, possibly due to high human activity or low soil fertility.

Overall, this graph illustrates that the type of land use and the duration of rehabilitation greatly affect litter biomass accumulation. Old agroforestry and long-term rehabilitation have proven to be the most effective in improving ecosystem quality through increased litter accumulation.

3.3 The Population and Biomass of Earthworm

Old agroforestry (AFMT) with a soil depth of 0-10 cm had the highest number of earthworms (370 individuals m^{-2}) compared to other land use systems and soil depths. This indicates that a more complex and older agroforestry system, with a high level of tree population that provide diverse and abundant litter inputs that provide optimal food sources and habitats for earthworms [10]. In addition, earthworms tended to be more active and have high activity at upper soil depths (0-10 cm), where the organic matter content was higher. The results of the study in Figure 3 showed that the number of earthworms tends to decrease in deeper soil layers (10-20 cm).

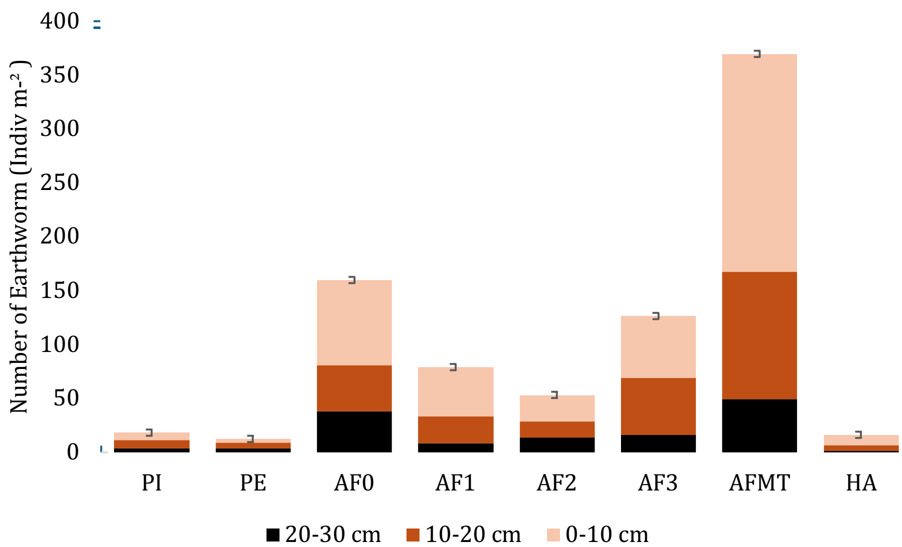

Figure 3. The population of earthworms in various land use systems and soil depths (PI = Intensive Agriculture, PE = Extensif Agriculture, AF0 = *Imperata* grassland before reclamation, AF1 = *Imperata* grassland after reclamation 1-3 years, AF2 = *Imperata* grassland after reclamation 4-6 years, AF3 = *Imperata* grassland after reclamation >7years, AFMT = old agroforestry, HT = Remnant forest)

The perennial nature of trees in agroforestry systems significantly influences the local climate and soil characteristics. By enhancing the abundance, variety, and functioning of soil organisms, trees play a crucial role in improving soil health and promoting ecosystem resilience [14].

Tree-based and non-tree-based land uses influence earthworm populations. As shown in Figure 3, intensive and extensive agricultural practices support significantly lower earthworm populations compared to agroforestry systems. This observation aligns with findings from Hairiah et al. [8], which noted that converting forests to monoculture coffee systems in Sumatra

(Indonesia) had a notable impact on the abundance and diversity of native earthworms and also affected soil physical properties.

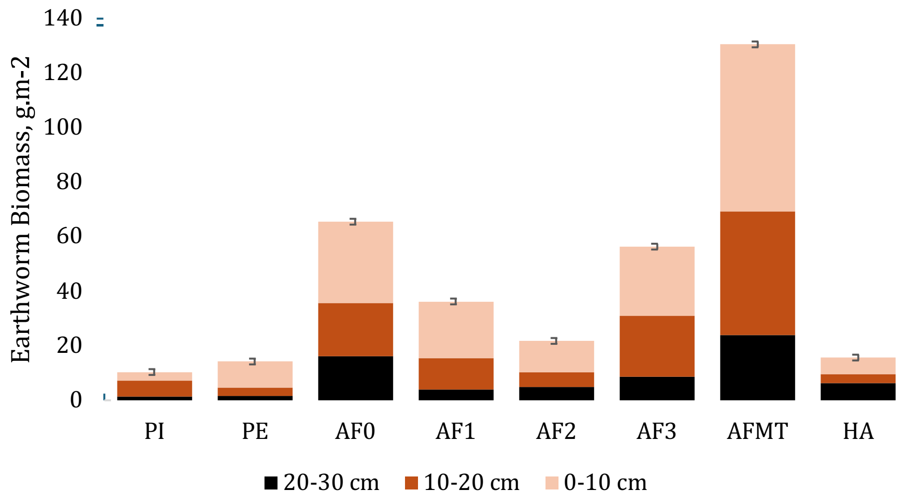

Figure 4. Earthworm biomass in various land use systems (PI = Intensive Agriculture, PE = Extensif Agriculture, AF0 = *Imperata* grassland before reclamation, AF1 = Imperata grassland after reclamation 1-3 years, AF2 = Imperata grassland after reclamation 4-6 years, AF3 = Imperata grassland after reclamation >7years, AFMT = old agroforestry, HT = Remnant forest)

The highest earthworm biomass was found in old agroforestry system (AFMT), with a value of 130.52 g.m^{-2}, which was significantly higher than in other systems (Figure 4). The high tree population in agroforestry increased the input of abundant and diverse litter, which serves as the main food source for earthworms. Litter produced by various tree species also helps enhance organic matter content and improve soil structure, creating an optimal habitat for earthworm development [15]. These results indicate that the age and complexity of the agroforestry system play a crucial role in increasing the number and biomass of earthworms. The older and more complex an agroforestry system is, the more litter input enters the soil, enriching the organic matter content and supporting earthworm life.

3.4 Relationship between Litter Biomass, Basal Area and Earthworms

Earthworm growth and activity are sensitive to changes in soil temperature and humidity. The optimal temperature for earthworm growth various depending on the species. But generally, earthworms will grow optimally in the temperature range of 17.6°C to 21.2°C [16]. Earthworms are active at stable and not too high soil temperatures, earthworms will not be active and even die if the soil temperature is too high. This high temperature can cause a decrease in earthworm biomass because earthworms will not survive if the temperature is unstable [15].

In addition to the direct effects on the microclimate, higher canopy cover is usually associated with greater litter input, such as leaves, twigs, and other plant parts that fall to the ground. This litter becomes important organic material for earthworms, because they rely on organic matter for food. Earthworms help decompose this litter into finer organic matter, which can increase soil fertility. Therefore, dense canopy cover does not only provide ideal environmental conditions for earthworms, but also increases food availability.

The results of the study showed that the higher the level of canopy cover, the more likely it is to be followed by an increase in the number of worms in the soil ($R^2 = 0.05$) (figure 5A). High levels of canopy cover reduce the intensity of sunlight entering the soil surface, thereby reducing water evaporation from the soil surface. This can maintain soil moisture levels so that soil water content is higher compared to open areas [15]. Canopy cover can also regulate soil temperature by reducing temperature fluctuations between day and night. During the day, high canopy cover reduces the intensity of sunlight reaching the soil, thus keeping the soil temperature lower. At night, the canopy helps retain heat so that the soil temperature does not drop too drastically [12]. Thus, canopy cover can produce a relatively stable microclimate with lower and more constant temperatures.

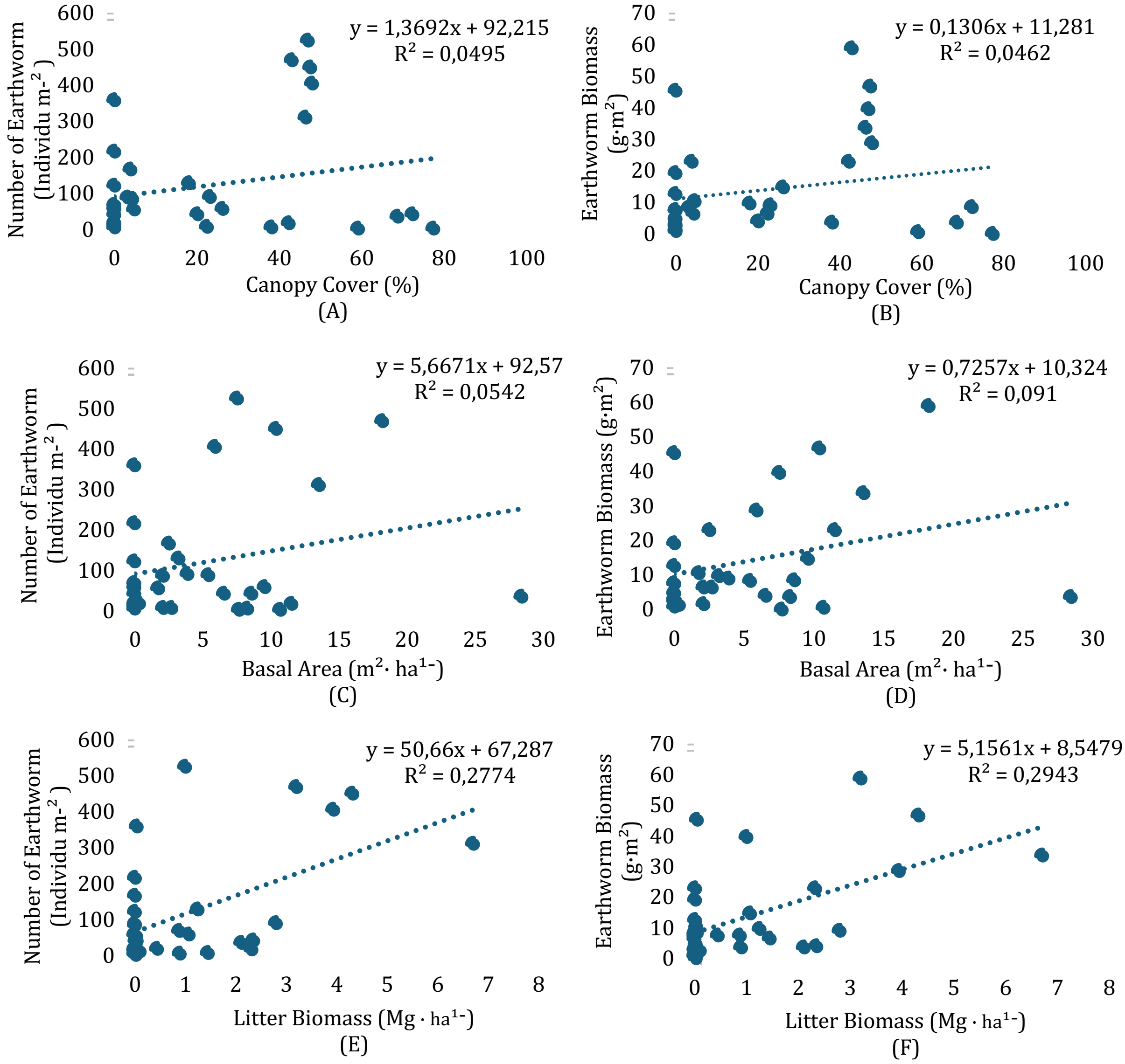

Figure 5. Relationship between Number of earthworm and Earthworm Biomass with (A),(B) Canopy Cover (C),(D) Basal Area (E),(F) Litter Biomass

Older agroforestry system usually has a complex and high tree diversity [14]. High biodiversity indicates a variety of tree and plant species in an ecosystem. The more species there are, the more diverse the structure and size of the trees. This contributes to an increase in basal area, which is the total cross-sectional area of tree trunks per hectare. A high basal area indicates a greater vegetation density, which means that the trees are denser and larger in size. As tree biodiversity increases in a system, the basal area increases, resulting in denser canopy cover. A dense canopy increases litter biomass input to the soil and can enrich the organic matter content. These conditions create an ideal habitat for earthworms, increasing the number and biomass of earthworms. Ultimately, earthworms play a role in breaking down litter and improving soil structure, which supports the health and productivity of the ecosystem as a whole. As the number and size of trees increase, they form a thicker and denser canopy layer. However, in the results of the regression analysis (Figure 5D), the basal area did not have a significant value on either the number of earthworms or worm biomass (R^2 = 0.05 and R^2 = 0.09). This shows that the basal area does not directly affect the presence of earthworms in the soil but rather litter biomass which has a greater influence (R^2 = 0.28 and R^2 = 0.30). Litter biomass that falls to the soil surface serves as the main source of organic matter to be decomposed by soil organisms, including earthworms. The decomposition process of litter produces soil organic matter and will undergo a mineralization process into important nutrients that are absorbed by the soil, which then enriches the quality of the soil. Litter that accumulates on the soil surface is an important source of organic matter for earthworms.

The high tree population in agroforestry increased the input of abundant and diverse litter, which serves as the main food source for earthworms. Earthworms eat decomposing litter, which provides a source of energy and nutrients for their growth and development. The high amount of litter from dense canopy cover increases the organic matter content in the soil [18]. Agroforestry has a higher population and biomass than monoculture land use which earthworms can improve soil health. This creates a more supportive habitat for earthworms because soil rich in litter biomass tends to have higher soil moisture and better soil structure [19]. Earthworms does not only eat litter but also help break down and mix organic matter into the soil, which improves overall soil fertility. With the large input of litter from canopy cover, the soil becomes rich in nutrients and organic matter, which supports an increase in the population and biomass of earthworms. Earthworms play an important role in improving soil structure, creating pores, and increasing the soil's capacity to store water, so they are indicators of the health of the soil ecosystem.

4. Conclusion

Old agroforestry system (AFMT) increases canopy cover and humidity as well as decreased the temperature. On the other hand it produced higher litter biomass compared to another agroforestry plot. The variety of litter inputs which indicated from the complexity of the system, serves as abundant food sources and optimal habitats for earthworms. This is indicated by the highest earthworm population in this system. Reclaiming degraded *Imperata* grassland land with an agroforestry system is effective, as it increases land cover, provides high litter inputs, and creates habitats for earthworms, thereby improving soil health. High numbers and biomass of earthworms indicate good soil conditions and could improve soil ecosystem health.

Earthworm density data collected during limited periods may not fully reflect annual population dynamics due to significant spatial and temporal variations. Factors such as geographic location, seasonality, and soil depth greatly influence earthworm activity and distribution. Seasonal changes, for instance, cause fluctuations in population as earthworms respond to moisture availability, often retreating deeper into the soil during dry periods. Additionally, land management practices like no-tillage can alter their habitat. Therefore, periodic sampling across different times and soil layers is essential for a more representative understanding of earthworm population

Acknowledgement

The authors would like to express appreciation for the financial support by Professor Grant Scheme Prof. Kurniatun Hairiah, Faculty of Agriculture, Brawijaya University (No: 03641.17/UN10.F0401/B/KS/2024) and for the research collaboration with CO_2Operate B.V, Rimbo Pangan Lestari West Sumatera, and the Research Group of Tropical Agroforestry Tropic at Brawijaya University. Thank you to Prof Meine Van Noordwijk for all valuable inputs during the fieldwork and writing up this paper.

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