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Bio-physico-chemical Soil Characteristic: Intensive Tillage vs. No Tillage

Reni Ustiatik[1,4,✉], Ayu Putri Ariska[3,4], Resa Kharisma Ramadhan[2], Novryanti Rizqi Aziz[3], Syamsu Ridzal Indra Hadi[1], R Muhammad Yusuf Adi Pujo Nugroho[3], Maydella Vista Putri Rinandy[3], M Taufik Hidayat[1], Wikan Agung Nugroho[2], Syahrul Kurniawan[1]

[1] Soil Science Department, Faculty of Agriculture, Universitas Brawijaya, Malang, INDONESIA.
[2] Study Program of Agroecotechnology, Faculty of Agriculture, Universitas Brawijaya, Malang, INDONESIA.
[3] Study Program of Soil and Water Management, Faculty of Agriculture, Universitas Brawijaya, Malang, INDONESIA.
[4] International Research Centre for the Management of Degraded and Mining Lands, Universitas Brawijaya, Malang, INDONESIA.

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Corresponding Author:
✉ reni.ustiatik@ub.ac.id
(Reni Ustiatik)

ABSTRACT

Soil tillage has both positive and negative impacts on soil quality and crop productivity. Efforts to reduce the negative impacts of intensive soil tillage are urgently needed. This study aims to analyze the impact of intensive soil tillage on soil fertility parameters (pH, available-P, organic-C, soil compaction, aggregate stability, and soil biodiversity). This research was conducted in two land uses: agriculture and forest land. The research design was descriptive-explorative through surveys and direct field observations. The sample points were determined using stratified random sampling with 3 replications (24 samples). Parameters analyzed in this study were soil compaction, aggregate stability, soil pH, soil available-P, and soil biodiversity (total microbial, soil meso-and-macrofauna). The results showed that intensive tillage affected the soil microbial population, aggregate stability, pH, and available-P ($p<0.05$). The negative impact of intensive soil tillage reduced total soil microbes by 59.37%. The soil macro and mesofauna found at the study site were earthworms and mycorrhizae, which had a higher density on non-tillage land, with trees as the main vegetation. This encourages efforts to introduce conservation soil tillage to maintain soil biodiversity before more severe damage occurs.

1. INTRODUCTION

The population growth in Indonesia is predicted to increase by 1.4% during 2020-2030, which will increase the demand for food by 1.4% (World Bank, 2022). The agricultural sector is forced to meet these needs by implementing various efforts, one of which is agricultural intensification to obtain optimal production (Dinas Pertanian dan Pangan Kabupaten Demak, 2022). Agricultural intensification is carried out in various ways, one of which is soil tillage to create a suitable growing environment for plants (Dinas Pertanian Kabupaten Buleleng, 2019).

Soil tillage has both positive and negative impacts on soil quality and crop productivity. The positive impact of soil tillage is that it helps prepare the soil for planting and weed control, but excessive (intensive) soil tillage negatively impacts soil quality and increases soil erosion (Liu *et al*., 2021). Weidhuner *et al*. (2021) reported that intensive soil tillage decreased the percentage of medium aggregates, aggregate stability, aggregate-bound carbon (C) and nitrogen (N) in the topsoil. Intensive soil tillage also disrupts the microbial community in the soil, causing changes in nutrient cycling due to changes in the physical structure and distribution of organic matter that affect the biological activity of soil microorganisms (Smith *et al*., 2016; Kraut-Cohen *et al*., 2020).

Intensive soil tillage is still widely practiced because it is considered to create a good growing environment in the root zone of plants (Harahap *et al*., 2018). On the contrary, Weidhuner *et al*. (2021) reported that intensive soil tillage did not significantly affect crop yields. However, previous studies have reported that not all soil tillage have negative impacts, with conservation tillage reported to reduce soil erosion, maintain soil moisture, increase fertility, and preserve soil quality in the long term (Tillage *et al*., 2023). The selection of tools and techniques for soil tillage (plowing) also affects the physical properties of the soil such as moldboard and rotary plows, where soil tillage using moldboard plows has higher soil porosity, bulk density, and rice productivity compared to soil tillage using rotary plows (Manik *et al*., 2017). Long-term increases in soil bulk density can be problematic as they lead to increased soil compaction and reduced soil porosity, particularly for water and air circulation in the soil (Mobilian & Craft, 2022).

Efforts to mitigate the negative impacts of intensive tillage are required to prevent further soil degradation. Site-specific analysis of soil tillage impact is also necessary to formulate solutions that can prevent soil degradation, especially in the university research station as the university is leading in innovation. Previous studies have analyzed the effect of tillage on soil properties, but not specifically in university research station. The objective of this study is to analyze the impact of intensive soil tillage on soil fertility parameters, including pH, P-availability, C-organic, soil compaction, aggregate stability, and soil biodiversity. The results can serve as a guide for improving tillage practices in order to prevent further soil degradation.

2. MATERIALS AND METHODS

2.1. Study Site

This study was conducted in February-June 2023. The sampling location was located in two land uses (Figure 1), namely agricultural area with intensive tillage at Experimental Field of Faculty of Agriculture, Universitas Brawijaya, Jatimulyo, Malang City (7°56'22.05" S and 112°37'2.75" E) and Perhutani Coban Rondo Area (no tillage), Malang Regency (7°52'21.71" S and 112°28'59.20" E). Soil order in Jatimulyo experimental farm is Inceptisol and the land is an intensively cultivated agricultural land. Commonly used tillage tools are tractors and hoes. Moldboard plowing was conducted two to three times per year. As the place has technical irrigation that allows for a four-time plant rotation annually (e.g., rice, maize, maize, shallot), the practice has been conducted since 2019. Other annual crops that are planted as the main commodities cultivated on this area beside rice, maize, and shallot are melon, chilies, tomatoes, eggplants, and cucumbers. The intensive tillage cause soil degradation in the land. There is crop rotation in this experimental farm but there is no fallow period.

The soil order identified in the Perhutani Coban Rondo area is Andisol. This land was selected as a control to compare the effects of intensive soil tillage on soil fertility parameters. The primary vegetation consists of pine trees and understory plants, such as grasses. This land has not undergone any soil tillage, crop rotation, or fallow periods, and is a natural pine forest that grows without human intervention. According to geological map sheet Malang and Turen, both sites are composed of the same parent materials which are pyroclastic material from volcanic eruption. Inceptisol in Jatimulyo is Qptm which is deposit of volcanic tuff: coarse-fine tuffs, pumiceous and andesitic fragments while Andisol in Coban Rondo is Kawi-Butak volcanic (Qpkb) formation which is volcanic breccia, lava, tuff and lahars. Lahar is mixture of water and rock fragments flowing down the slopes of a volcano and enters a river valley.

Figure 1. Soil sampling location

2.2. Research Design

The research design was used a descriptive exploratory through survey and direct observation in the field. Determination of soil sampling points was carried out using a stratified random sampling method with 12 replicates in each land use (a total of 24 samples). The control of this study was forest land (no-tillage area) in Coban Rondo.

2.3. Analysis of Soil Physical Properties

2.3.1. Aggregate Stability

Soil aggregate samples were collected at a depth of 0-20 cm, with 3-5 aggregates per sample, and stored in a plastic bottles. Aggregate stability was analyzed using the Vilensky method. The soil aggregates were dripped with water until the aggregate crushed or broke, and the number of water droplets required for ~~e~~breaking the aggregate was counted and classified according to the aggregate stability index classification system by Balai Besar Litbang Sumberdaya Lahan Pertanian (2006).

2.3.2. Soil Compaction

Soil compaction measurement was conducted at a depth of 0-20 cm using a penetrometer. The penetrometer needle was inserted three times at each sample point. The needle tip area used was 0.25 cm^2 and the spring compression was 50 N/cm. The penetrometer scale was recorded and calculated using Equation [1].

$$P = \frac{F \times g \times p}{L} \quad [1]$$

where P is penetration resistance, F is total force; g is gravity, p is spring compression (N/cm^2), L is needle tip area (cm^3).

2.4. Analysis of Soil Chemical Properties

2.4.1. Soil pH

Soil pH analysis using the electrometric method for air-dried soil samples. Soil samples were weighed as much as 10 g and 10 mL of distilled water were added, then mixed throughly using shaker for 60 minutes and precipitated for 24 hours. After settling, the sample was measured using a pH meter.

2.4.2. Soil available-P

Analysis of soil available-P was used Bray I (pH <6.5) and Olsen (pH>6.5) methods. The samples used were air-dried samples. Two grams of soil samples were mixed with 20 mL of $NaHCO_3$, then mixed using shaker for 2 h (Olsen Method) and 5 min (Bray 1 Method). The samples suspension were then filtered using Whatman filter paper. Ten milliliters of the filtered solution were added 20 mL of distilled water and 8 mL of phosphate reagent. The mixture was alllowed to settle for 20 min then measured using a UV-Vis Spectrophotometer at a wavelength of 882 nm.

2.4.3. Soil Organic Matter

Soil organic matter (SOM) analysis was conducted using hydrogen peroxide (H_2O_2) 30% method. Soil samples were collected (5 g) and added 5 mL of 30% H_2O_2 solution gradually until the sample stopped bubbling. The samples were then ovened for 24 h at 105 °C and SOM were calculated using Equation [2] (Desiani, 2019).

$$SOM = \frac{soil\ fresh\ weight}{soil\ oven{-}dreied\ weight} \times 100\% \quad [2]$$

2.5. Analysis of Soil Biological Properties

2.5.1. Enumeration of Soil Microbial Population

Soil microbial population enumeration was performed using a pour plate method and microbial population was calculated using a total plate count (TPC) method. Soil samples were weighed (5 g) and suspended into 45 mL of

0.85% NaCl (8.5 g NaCl + 1 L distilled water). The sample suspension was collected (1 mL) and mixed with 9 mL 0.85% NaCl solution (dilution 10^{-2}) then continued until dilution 10^{-5}. About 0.1 mL of dilution 10^{-5} were inoculated onto nutrient agar (NA) medium (2 g NA + 100 mL distilled water) (Cappuccino & Welsh, 2018). The inoculated media were incubated for 24 h then the forming colonies were calculated according to Equation [3].

$$Colony\ Forming\ Unit = \sum Colony \times \frac{1}{dillution\ factor} \quad [3]$$

2.5.2. Enumeration of Soil Macro and Mesofauna Density

Soil macro and mesofauna were enumerated at a depth of 0-20 cm. The number and types of species were recorded from a minipit sizing of 40×40×20 cm.

2.5.3. Measurement of Litterfall Density

Litterfall density was measured using a 50 × 50 cm frame. The litterfall was collected and weighed (g).

2.5.4. Mycorrhizal Spore Density

Mycorrhizal spore density enumeration was conducted using wet sieving methods. Soil samples were weighed (100 g), then sieved using multilevel sieves with sizes: 2 mm, 500 ηm, and 45 ηm. The soil collected in the 45 ηm sieve was then put in a beaker glass and added 5-10 mL of 60% sugar solution (60 g sugar in 1000 mL distilled water) and 200 mL of distilled water. The soil was then centrifuged at 2500 rpm for 5 min. The solution was then rinsed with distilled water to remove the sugar solution. Spore observation was done using a microscope at 100-400x.

2.6. Data Analysis

The obtained data were subjected to a normality test using Shapiro Wilk's. The data that were not in normal distribution were transformed using Log10 then subjected to a pair T-test for determining the effects of the applied management on the measured parameters. The impact soil tillage on soil fertility were determined using Principal Component Analysis (PCA). Data were statistically analyzed using R-studio.

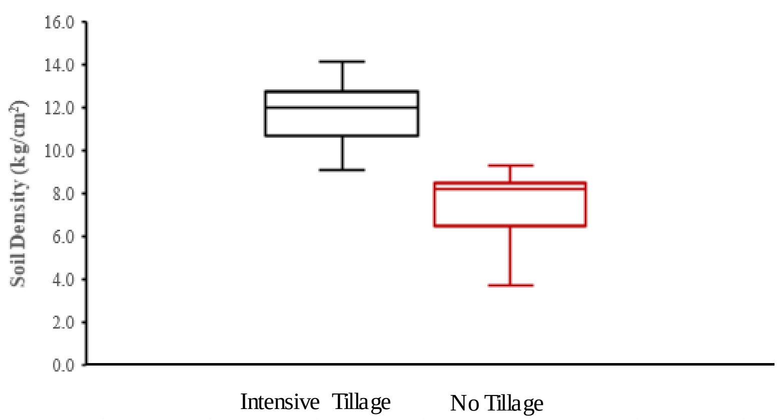

Figure 2. Soil compaction in two different land uses

3. RESULTS AND DISCUSSION

3.1. Soil Physical Properties

3.1.1. Soil Compaction

The results of the study indicate that soil compaction was higher in the intensively cultivated field compared to the no-tillage field (Figure 2). The results of the t-test indicate that tillage had no significant effect on soil compaction in the study plots (p>0.05) as the soil order was different. However, it should be noted that soil compaction was 36.82%

higher in intensive tillage than in no tillage. Previous study revealed that intensive tillage can lead to an increase in soil compaction, as it reduces soil pores and increases soil bulk density, resulting in higher penetration resistance (Badalíková, 2010).

3.1.2. Soil Aggregate Stability

The aggregate stability index in the no tillage is lower than in the intensive tillage. This is mainly due to the soil order in the no tillage, which is Andisol, resulting in a low aggregate stability index (refer to Figure 3). The t-test results indicate that intensive tillage had a significant effect on the aggregate stability index ($p<0.05$), with varying values observed in the study sites. The aggregate stability index in the intensive tillage is more uniform, ranging from stable (80-200) to very stable (>200), while the aggregate stability index in no tillage is more diverse, consisting of all aggregate stability classes. This finding does not support the idea that intensive tillage increases aggregate stability. The low aggregate stability of soil in no tillage is primarily due to the Andisol soil order. Andisol soils contain a significant amount of short-range-order (SRO) and organo-metal complexes, which have low inter-particle bonds, resulting in lower aggregate stability (Candan & Broquen, 2009).

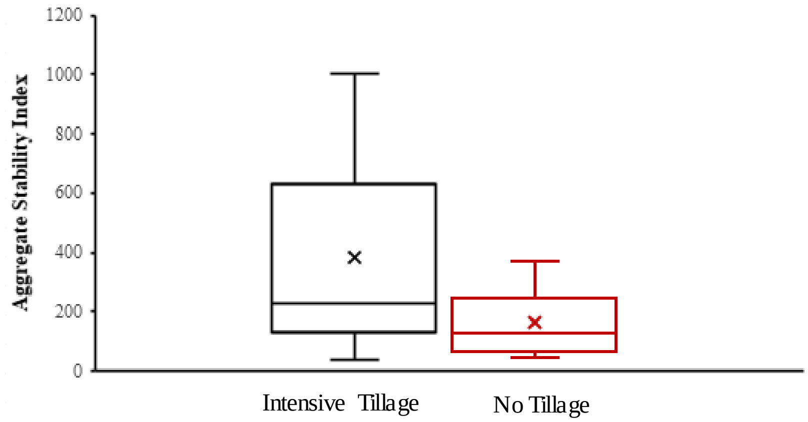

Figure 3. Aggregate stability index in two different land uses

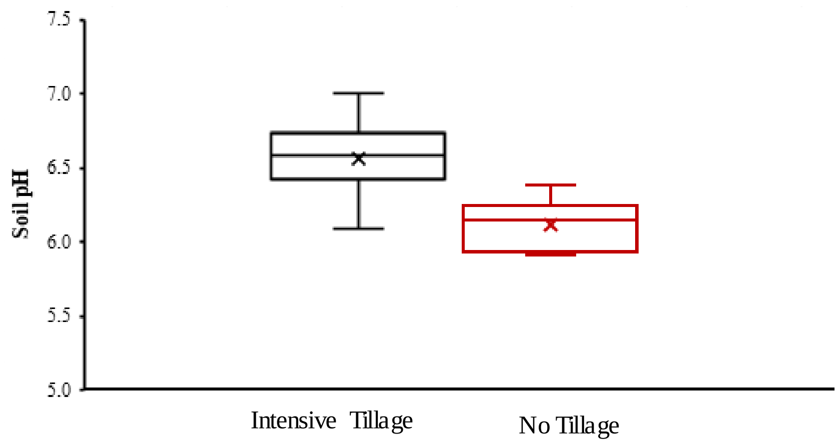

Figure 4. Soil pH in two different land uses

3.2. Soil Chemical Properties

3.2.1. Soil pH

The pH values in no tillage are lower than those in intensive tillage, primarily due to the soil order in no tillage is Andisol, which is characterized by low soil pH (Figure 4). The results of the t-test showed that intensive soil tillage affected soil pH values ($p<0.05$). In intensive tillage, the pH values were more variable, ranging from slightly acidic to neutral (6.0-7.0), while in no tillage, the soil pH tended to be uniformly slightly acidic (5.9-6.4). Andisol soils have a low pH because they are composed of highly weathered volcanic ash, which releases acid (H^{+}) and contributes to the decrease of pH (Arifin *et al*., 2022).

3.2.2. Soil Available-P

The available-P content in no tillage is lower compared to intensive tillage. This is due to the lower pH value and the soil order (Andisol), which has a high P retention (Figure 5). The t-test results indicate that intensive soil tillage affects the available-P content in this study ($p<0.05$). The available-P content in intensive tillage tends to be consistently high, ranging from 15.90-52.55 mg/kg (Figure 5), while in no tillage, it varies from low to high, ranging from 5.0-15.60 mg/kg. The high availability of P in intensive tillage is mainly due to the intensive agricultural practices in the area, which consistently use inorganic fertilizers as a source of P. In contrast, the acidic conditions in no tillage result in the binding of the P element by aluminum (Al) and iron (Fe). This is in line with Siswana *et al*. (2019),who reported that the high solubility of Al and Fe in acidic soils leads to the binding of P ions by Al and Fe, forming P compounds that are unavailable to plants. Moreover, Anda *et al*. (2021) stated that the mineralogical properties of allophane and imogolite in Andisol provide a higher reactive surface area, ranging from 700-1000 m^2/g. As a result, the minerals fix P and form P compounds such that they are unavailable for plants.

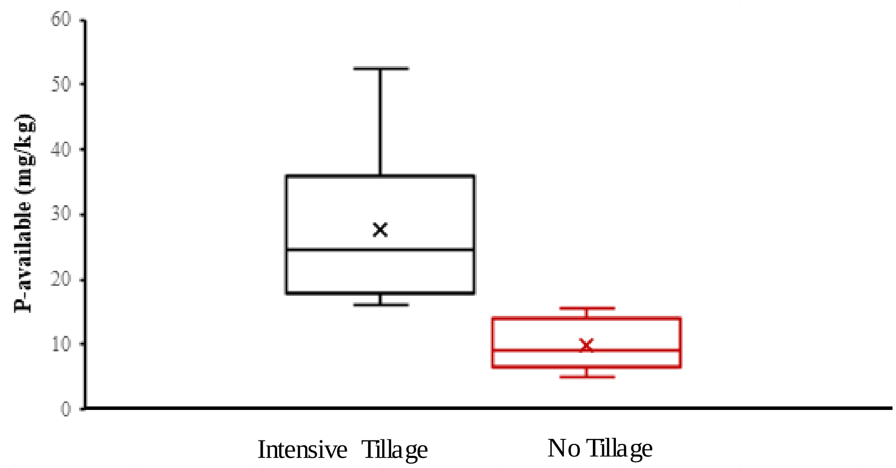

Figure 5. Soil available-P in two different land uses

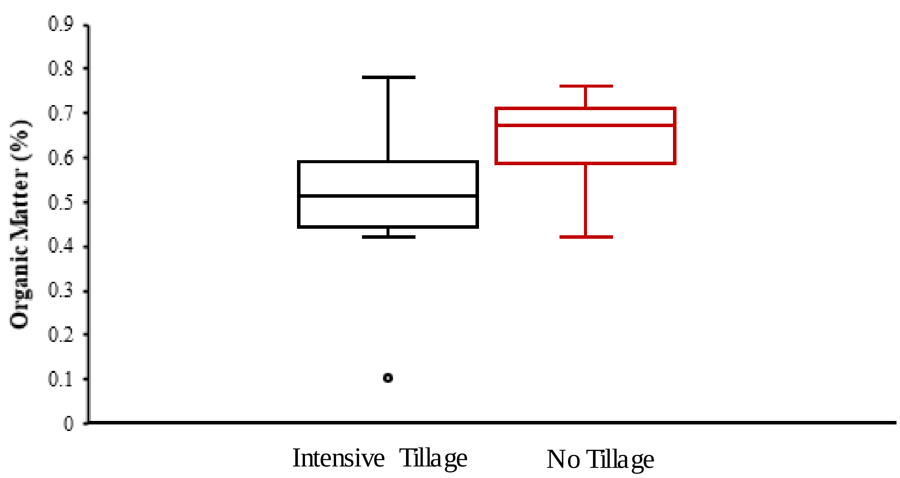

Figure 6. Soil organic matter in two different land uses

3.3. Soil Biological Properties

3.3.1. Soil Organic Matter

The soil organic matter content in no tillage is 27.03% higher than that in Jatimulyo (Figure 6). This difference is attributed to the absence of intensive soil tillage and higher vegetation diversity in no tillage compared to intensive tillage. The t-test results indicate that tillage did not significantly ($p>0.05$) affect soil organic matter content in this study. This is because organic matter content is more influenced by the input of organic matter from plant biomass (litterfall) (Qiu *et al*., 2023).

3.3.2. Total Soil Microbes

Total microbes in no tillage were 59.37% higher than in intensive tillage (Figure 7). This is due to the absence of soil tillage and the high content of organic matter which causes the availability of substrates and nutrients for microbes. The macro and meso soil fauna found in this study were earthworms (Figure 8) and mycorrhiza (Figure 9). Soil fauna meso-and-macro densities were found to be higher in no-tillage land. The t-test results showed that intensive soil tillage had an effect on total soil microbes ($p<0.05$). According to Bhattacharyya *et al.* (2022), the difference in total soil microbial population in different land use is due to differences in organic matter input to the soil. The survival of soil microbes is highly dependent on the quality and availability of organic matter. In addition to organic matter, soil tillage is reported to alter the composition and diversity of bacterial and fungal communities in the soil (Guan *et al*., 2022). This illustrates that intensive soil tillage reduces total soil microbes. More conservative tillage to maintain soil biodiversity is needed before further damage occurs.

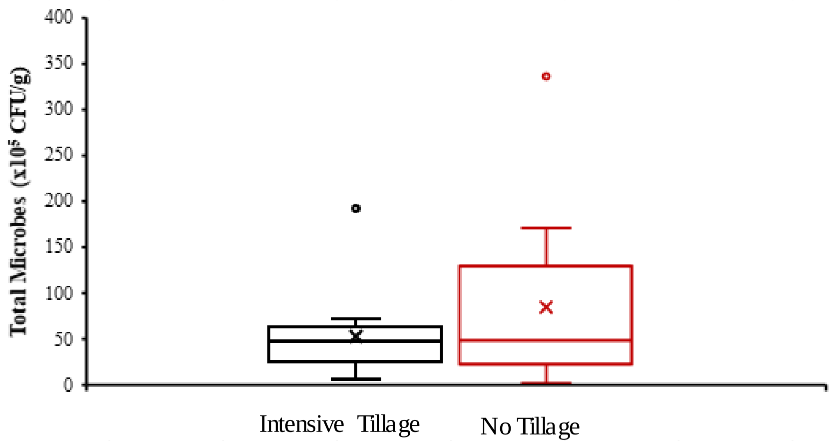

Figure 7. Total microbial population in two different land uses

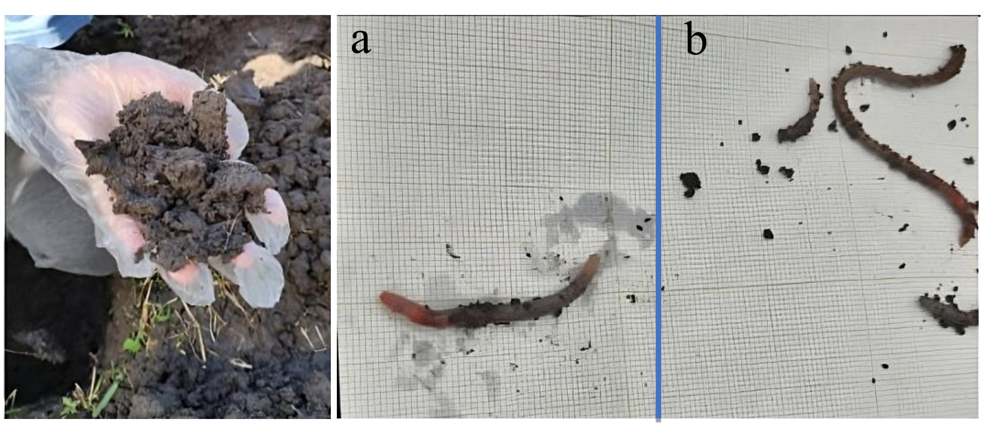

Figure 8. Earthworm observation in two different land uses: a) intensive tillage; b) no tillage

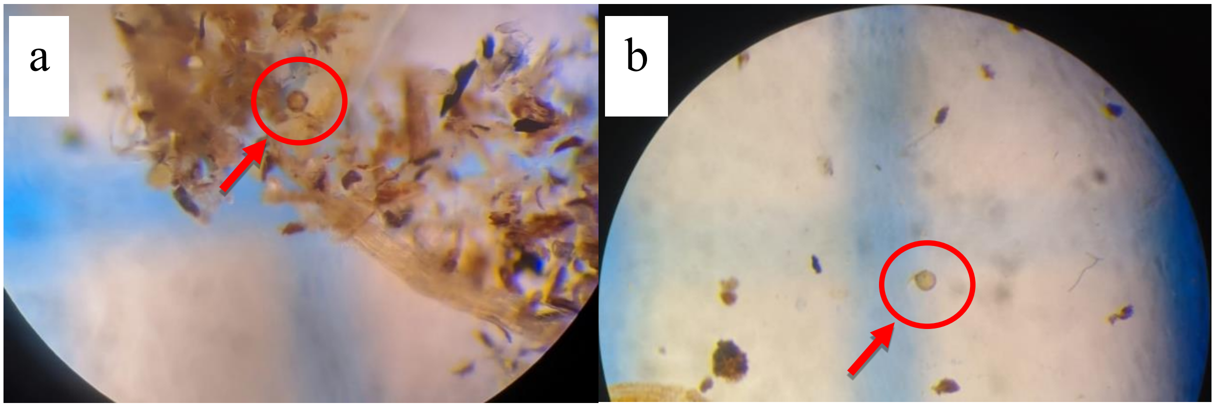

Figure 9. Observation of mycorrhizal spores in two different land uses: a) no tillage; b) intensive tillage

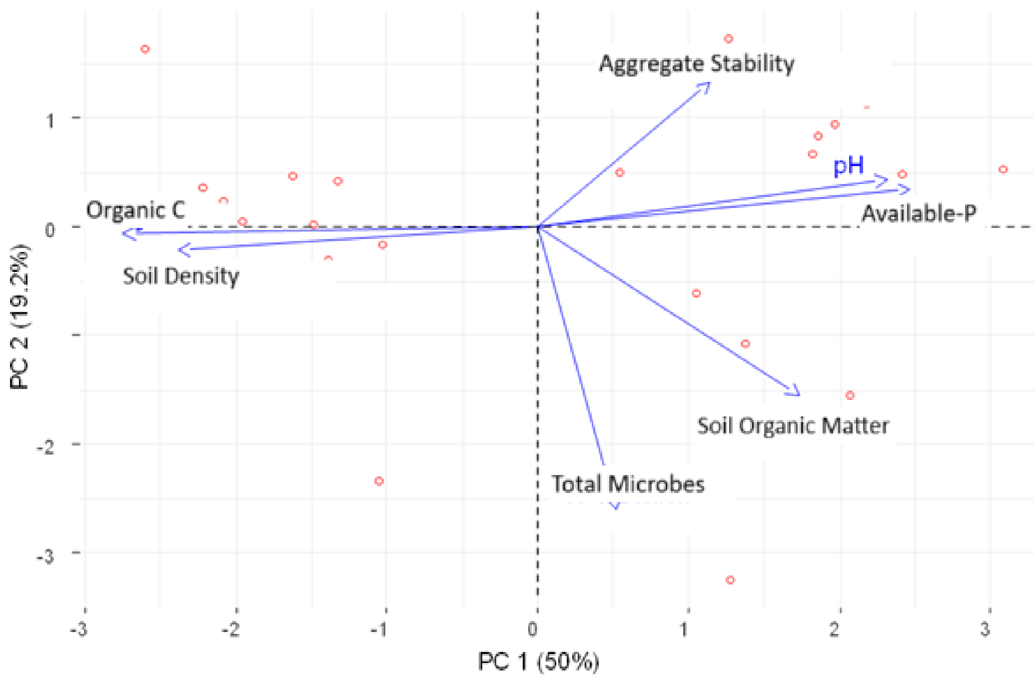

Figure 10. Biplot of Principal Component Analysis (PCA)

3.4. Impact of Soil Tillage on Soil Fertility

Principal Component Analysis (PCA) results show that the soil fertility parameters most affected by intensive soil tillage are aggregate stability, pH and available-P (Figure 10). Soil tillages have a significant impact on soil aggregate stability. Increased soil tillage intensity will decrease aggregate stability. More intensive soil tillage can disrupt soil structure and destroy soil aggregates (Weidhuner *et al.*, 2021). The impact of soil tillage on soil pH can vary depending on prevailing climatic conditions, soil type, and management factors (Busari *et al.*, 2015). Some studies have reported that soil tillage can increase soil acidity, while others have found no significant effect on soil pH (Neugschwandtner *et al.* 2014; Yuan *et al.* 2022). Soil tillage can affect the distribution and availability of P in the soil. Physical changes due to tillage, such as changes in water holding capacity, pore size distribution, bulk density and aggregate stability, can indirectly affect P availability in the soil (Xomphoutheb *et al.*, 2020).

4. CONCLUSION

Intensive soil tillage affected total soil microbial population, aggregate stability, pH and soil available-P. Intensive soil tillage decreased total soil microbes (59.37%). The negative impact of intensive soil tillage is an increase in soil density that reached 36.82%. Overall, intensive soil tillage increase soil compaction and reduce soil biodiversity. More conservative tillage to maintain soil biodiversity is urgently needed before further damage occurs.

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