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EFFECT OF LONG-TERM CASSAVA CULTIVATION ON THE MORPHOLOGY AND PROPERTIES OF SOILS IN LAMPUNG, SOUTHERN SUMATRA, INDONESIA

* Didin Wiharso[1], Afandi[2], Priyo Cahyono[3], Supriyono Loekito[4], Naomasa Nishimura[5] and Masateru Senge[6]

[1,2] Faculty of Agriculture, Lampung University, Indonesia; [3,4] PT. Great Giant Food, Indonesia; [5] Faculty of Applied Biological Science, Gifu University, Japan; [6]Gifu University Laboratory, Ltd. Union, Japan

*Corresponding Author, Received: 12 Nov. 2020, Revised: 28 Dec. 2020, Accepted: 22 Jan. 2021

ABSTRACT: Cassava is easily cultivated and very tolerant of various soil conditions. It can be planted almost anywhere, in various types of soil, even in marginal soil where other food crops are difficult to grow properly. However, imposing higher productivity for two decades clearly reduced the quality of the soil. The aim of this study is to determine the influence of long-term cassava planting (> 20 years) on the morphology and properties of the soil, compared to mixed gardens which were rarely tilled, at 14 test sites in 10 locations in Lampung, South Sumatra, Indonesia. Cassava cultivation over a period of more than 20 years was seen to make the soil color brighter in both layers of soil which, in turn, affected the other soil properties. Cassava cultivation for more than 20 years caused the surface horizons at half of the test sites to change from crumbs to angular blocky and granular. The physical properties of the soil that was cultivated with cassava plantations for more than 20 years did not differ significantly from those of the mixed garden soil which was rarely tilled. However, a tendency was seen for the water available pores (WAPs) to decline. Cassava cultivation for more than 20 years greatly reduced the soil organic carbon (at a critical value of 0.01) and significantly reduced the soil pH, soil-CEC, and exchangeable bases (at a critical value of 0.1). However, the long-term cultivation of cassava did not affect the base saturation, although there was a change in the number of exchangeable bases and the CEC of the soil.

Keywords: Cassava cultivation, Mixed garden, Crumb, Angular blocky, Soil Morphology, Soil Properties

1. INTRODUCTION

Cassava (*Manihot esculenta*) is an important agricultural commodity for Lampung Province. In 2015, 29% of the harvest area and 34% of the production in Indonesia were located in Lampung Province [1]. Cassava productivity doubled in the two decades from 1995 to 2015 from 11.94 to 26.45 tonnes per hectare. The higher productivity, however, is expected to have decreased the quality of the soil because of the additional nutrient uptake.

Cassava is one of the most widely planted crops in the world. It performs the best in soils of a friable nature by permitting the expansion of tubers [2]. Cassava is easily cultivated and very tolerant of various soil conditions. It can be planted almost anywhere, in various types of soil, even in marginal soil where other food crops are difficult to grow properly. Cassava can produce fair yields where other crops fail [3]. Suyamto and Howeler [4] stated that cassava cultivation can lead to both nutrient depletion and soil erosion; these conditions are more serious than those created by other food crops under similar conditions. Cassava plants are often regarded as the cause of high levels of erosion. This happens because cassava plants are frequently planted on steep slopes, generally planted with wide spacing, and have slow initial growth so that it takes a long time to cover and protect the soil from raindrops. Odemerho and Avwunudiogba [5] showed that monoculture planting of cassava led to more severe soil erosion than polyculture planting.

Cassava is usually planted by poor farmers in tropical regions with minimum inputs. The repetitive production of cassava under these conditions can lead to soil nutrient depletion. Cassava cultivation on slopes can also cause severe erosion if the crop is not properly managed [6]. Cassava is increasingly attractive as an energy crop due to its high rate of CO2 fixation, high water-use efficiency, high carbohydrate content, and superior starch conversion ratio for ethanol compared with other crops [7].

Many people are convinced that cassava production leads to soil degradation, and some governments do not encourage cassava cultivation because it causes serious erosion and nutrient depletion [8]. Cassava grows all over the tropics in a great variety of soils, but is mainly found in Ultisols, Oxisols, and Entisols, which are generally found in the tropics, cassava is planted in the poorest soils, such as those located on eroded slopes or in characterized by low soil fertility. In

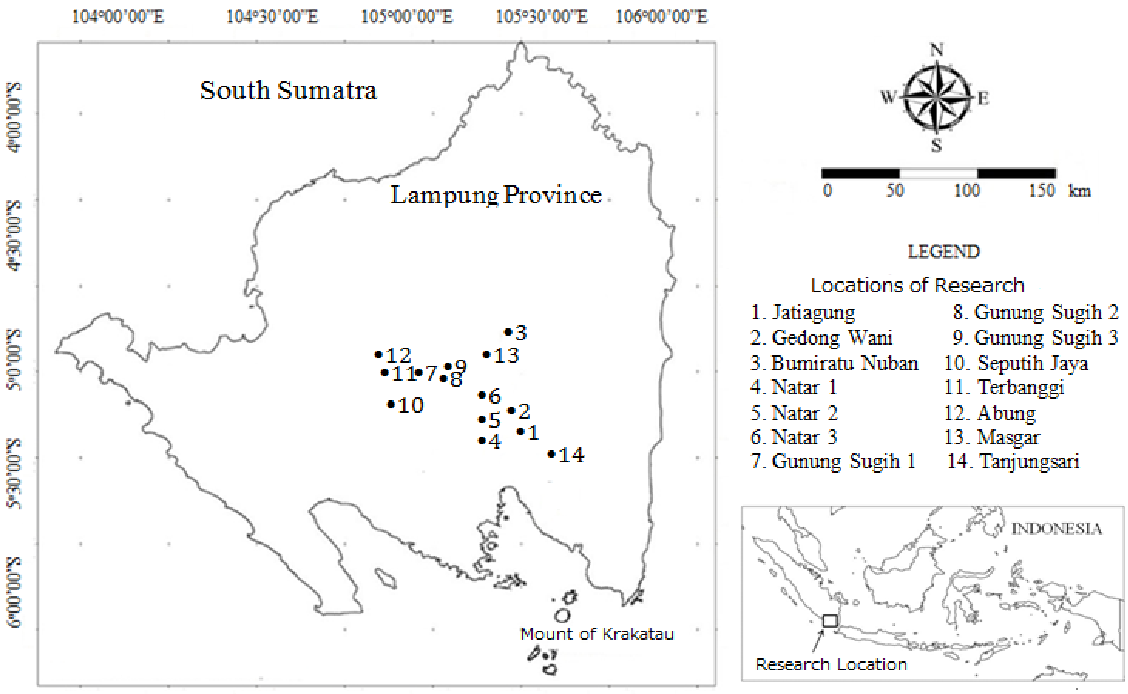

Fig.1 Locations of research sites in Lampung Province, Southern Sumatra

many places with extremely sandy soils, where other crops cannot grow. Based on this feature, many people mistakenly believe that cassava does not require high soil fertility or respond to fertilization [6].

Cassava is often cultivated on tilled plots, traditionally on mounds and ridges with the use of hand hoes or tractor-driven implements. These two conditions alter the soil structural parameters; soil turbulence increases its vulnerability to erosion, and soil compaction degrades the soil properties as a result of frequent machine movement under the conventional tillage system, affecting plant growth [8]. The soil structure is a very important part of soil morphology that can be used as a key indicator for assessing soil quality. It is often recognized that a poor soil structure is a common cause of soil physical problems [9, 10]. Therefore, monitoring the soil structure, especially on cultivated land, is very important, because the soil structure affects the physical, chemical, and biological processes that support the soil's life functions [11, 12].

Besides being cultivated for cassava plants, the soil close to farmers' houses is usually used in yards, commonly referred to as mixed gardens. The gardens are planted with coffee and fruit trees as well as herb plants for medicine. These gardens generally provide shade for the house and reduce the air temperature so it is not too hot. Mixed garden soil is usually not tilled, so it can be referred to as conservation tillage. Conservation tillage is efficient for reducing soil degradation, but it affects the soil physical properties and leads to soil compaction, negatively impacting root production. Thus, it is rarely adopted by cassava cultivators [13].

No-tillage (NT) increases the soil penetration resistance, and results in a greater accumulation of dry matter in the stems and planted cuttings than in the roots. The data suggest that increased soil penetration resistance under NT can decrease the growth of cassava roots and induce the stems and planted cuttings to serve as storage organs [14].

To produce well and sustainably, the areas of cassava cultivation need to be periodically monitored and evaluated to see whether long-term cassava cultivation is helping to maintain the productivity of the soil or is accelerating the process of land degradation.

The aim of this study is to determine the influence of long-term cassava planting (> 20 years) on the morphology and properties of the soil compared to that of mixed gardens in Lampung, South Sumatra, Indonesia.

2. MATERIALS AND METHODS

This research was conducted in Ultisols [14] and focused on soils where cassava was cultivated for more than 20 years in South Sumatra. The soil in mixed gardens was adopted as a comparison or control. Some of the types of trees that are usually planted in mixed gardens are mahogany (Swietenia macrophylla), coconut (Cocos nucifera), Robinson

Table 1 Differences in chemical properties of soil surface horizon between cassava and mixed garden soils

Soil property	Number of sites	Cassava soil		Mixed garden soil		P-value	Test results
		Mean	StDev	Mean	StDev		
Soil pH	9	4.35	0.316	4.75	0.59	0.090	*
Org-C (%)	14	1.25	0.48	2.31	1.00	0.001	**
CEC of soil (cmol kg^{-1})	9	5.81	1.45	7.48	2.16	0.073	*
Exch. bases (cmol kg^{-1})	9	2.00	1.05	3.18	1.41	0.063	*
Base saturation (%)	9	35.80	17.70	42.7	12.1	0.347	ns

Expl.: *Significant at critical value 0.10; **Significant at critical value 0.01; ns = not significant

coffee (Coffea liberica), bamboo (Bambuseae), mango (Mangifera indica), Chinese petai (Leucaena leucocephala), melinjo (Gnetum gnemon), jengkol (Archidendrom pauciflorum), rambutan (Nephelium lappaceum), and teak (Tectona grandis). Besides these trees, banana trees (*Musa sp*) are usually planted in mixed gardens. The soil cultivated with cassava plants is conventionally plowed before planting, while the soil in mixed gardens is generally not tilled. In addition to being tilled, cassava plantations are generally fertilized with nitrogen, phosphorus, and/or potassium, and sometimes with organic fertilizers, while in mixed gardens, soil fertilization is generally never done. The both soil surfaces of casaba fields and mixed gardens are flat.

Soils were sampled at eight locations in Central Lampung Regency: Bumiratu Nuban, Masgar, Gunung Sugih 1, Gunung Sugih 2, Gunung Sugih 3, Seputih Jaya, Terbanggi, and Abung, and six locations in South Lampung Regency: Tanjungsari, Jatiagung, Gedongwani, Natar 1, Natar 2, and Natar 3 (Fig. 1). In areas with cassava plantations, the farmers live with mixed gardens around their homes. The locations determined as the research sites lie in the plain physiography with generally flat to gentle topography [15]. As the parent materials are old (from Late Tertiary to Early Quarternary), the soils have generally weathered and in a mature stage of development. They are characterized by a thick solum and red soil in the subsoil horizon, as well as low pH and a low soil Cation-exchange capacity (CEC). Small profiles (pits) were dug at each site of the research area to a depth of about 70 cm. The soil profiles were described according to the Soil Survey Manual [16]. The soil color was determined in the field by the Munsell Soil Color Chart and the soil strength by a Pocket Penetrometer. Undisturbed soil samples were taken by sample rings, while disturbed soil samples were taken from each soil layer by a shovel. As for the physical properties, the bulk density, soil porosity, and permeability were analyzed. The soil chemical properties that were analyzed include soil pH (by pH meter), organic-Carbon [17], soil-CEC, and exchangeable bases (1 N Acetic Ammonium buffered until pH 7.0 and then measured by Atomic Absorption Spectrophotometer). Data were analyzed by using T-Test.

3. RESULTS AND DISCUSSION

3. 1 Soil Chemical Properties

Soil organic matter is easily influenced by changes in land use or land cover. In temperate regions, such as northwest China, the conversion of land use from forest to agricultural has caused the soil organic carbon content to drop dramatically to only 45% of its initial condition. [18]. The same is true of Iran [19]. In locations with a tropical humid climate, deforestation, land clearing, or land conversion from conservation areas, such as forests, annual plantations, and mixed plantations, to areas for food crops, such as cassava cultivation, has clearly resulted in greater degradation of organic matter than in regions with other climates.

The soil chemical properties are more easily influenced by the impact of changes in land cover than the soil physical properties. Among the soil chemical properties, the soil organic matter (SOM) or the soil organic carbon (SOC) is the property most likely to be affected by changes in land cover. Table 1 shows the differences in the organic carbon content between cassava and mixed garden soils; the range in or distribution of the organic carbon content on cassava soil is generally below that of mixed garden soil. The average SOC of cassava soil is 1.25%, classified as low, while that of mixed garden soil is 2.31%, classified as moderate [20, 21]. The results of a statistical analysis showed that the SOC values between

Fig.2 Cassava cultivation (upper) and mixed gardens (lower) in Gunung Sugih, Central Lampung

Fig.3 Soil profiles of cassava cultivation (upper) and mixed gardens (lower) in Gunung Sugih, Central Lampung

cassava and mixed garden soils were significantly different at the 0.01 level with a P-value of 0.001. The low organic carbon content will affect the other physical and chemical soil properties; therefore, it is very important that it be improved. Increasing the SOC is beneficial for restoring degraded soils with major potential impacts on crop yields, food security, and the wellbeing of smallholder farmers [22- 24].

In mixed gardens, the canopy is dense and litter covers the soil; thus, it is difficult for sunlight to reach the soil surface. As a result, the soil organic matter is more sustainable because the low soil temperatures are not enough to oxidize the soil organic matter. With more moist soil conditions, the soil temperature regime is not too hot, the atmosphere tends to darken, and the process of forming humus from litter decomposition is more likely to occur than in cassava soil where the canopy tends to be more open. Humus generally accumulates in the soil at cooler temperatures than at warmer temperatures [25].

Differences are also seen between cassava and mixed garden soils in terms of other chemical properties, such as the soil pH, soil CEC, and exchangeable bases. The differences are quite significant at the critical value of 0.1. Meanwhile, the value of base saturation is not significant, although there is a tendency for long-term cassava cultivation to bring about a reduction in the percentage of base saturation.

The soil in the research area was derived from parent materials which had accumulated from the tertiary age (Pliocene) to the beginning of the Quaternary period (Pleistocene), namely, around one million years ago [15]. In older soils, the source of the negative charge is highly dependent on the negative charge from the soil organic matter, because clay minerals are generally dominated by low-charged clay minerals, such as kaolinite and sesquioxide [26]. The reduced content of the soil organic matter in cassava soil, characterized by a reduced organic carbon (Table 1), results in soil with a reduced negative charge, as indicated by the lower soil CEC in cassava soil than in mixed garden soil. The lower soil CEC in cassava soil results in the lower adsorption of soil colloids to soil cations, so that the number of exchangeable bases decreases. Table 1 shows that the average amount of exchangeable bases in cassava soil (2.00 cmol kg^{-1}) is lower than that in mixed garden soil (3.18 cmol kg^{-1}).

The reduction of exchangeable bases in cassava soil can be caused by the process in which they are released from the sorption complex, dissolve in the soil solution, and eventually disappear through leaching phenomena. Regardless of the loss of exchangeable bases, they will be replaced by aluminum cations which are a potential source of

Table 2 Soil color distribution for cassava and mixed garden soils on As and B horizons

No.	Research site	Cassava soil		Mixed garden soil	
		A-Hor	B-Hor	A-Hor	B-Hor
1	Jati Agung	10 YR 3/2	10 YR 4/4	10 YR 3/2	10 YR 4/6
2	Gedong Wani	7.5YR 3/4	7.5YR 5/8	7.5YR 3/2	7.5YR 5/6
3	Bumiratu Nuban	10YR 4/2	10YR 5/4	7.5YR 3/4	7.5YR 4/6
4	Natar 1	5YR 3/2	5YR 4/4	5YR 3/2	5YR 4/4
5	Natar 2	5YR 3/2	5YR 4/4	5YR 3/2	5YR 4/4
6	Natar 3	5YR 3/2	5YR 4/4	5YR 3/2	5YR 4/4
7	Gunung Sugih 1	10 YR 3/4	10YR 5/8	10 YR 2/2	10 YR 4/6
8	Gunung Sugih 2	10 YR 3/4	10YR 5/8	10 YR 2/2	10 YR 4/4
9	Gunung Sugih 3	10 YR 3/3	10YR 6/8	10 YR 2/2	10 YR 4/4
10	Seputih Jaya	10YR 4/4	10YR 5/2	10YR 3/2	10YR 5/6
11	Terbanggi	7.5YR 4/4	7.5YR 5/6	10YR 3/2	10YR 5/6
12	Abung	10 YR 3/4	10 YR 4/6	10YR 3/4	10YR 4/6
13	Masgar	5 YR 3/3	5YR 4/4	5YR 3/2	5YR 4/4
14	Tanjungsari	7.5YR 3/4	7.5YR 5/6	7.5YR 3/4	5YR 5/6

soil acidity. The exchangeable Al will release H^+ ions into the soil solution; consequently, the soil pH will decrease. This is the process by which the soil pH of cassava soils decreases during long-term cultivation.

In principle, the percentage of base saturation describes the proportion of the number of exchangeable bases against the CEC of the soil. Therefore, even though the percentages of base saturation are equal, the amounts of exchangeable bases and the CEC of the soil could actually be different. An understanding of this helps explain why the difference between the values of the base saturation in cassava and mixed garden soils is not significant. Although the percentage of base saturation in cassava soil is not significantly different from that in mixed garden soil, the number of exchangeable bases is lower than that in mixed garden soil. According to Djaenudin et al. [21] and Hardjowigeno [20], the base saturation of cassava soil is classified as being in a “low” category, while that of mixed garden soil is classified as being in a “medium” category.

3. 2 Morphology of Soils

3. 2. 1 Soil color

The cultivation of cassava over a long period has been seen to lead to increasingly bright colors of the soil; therefore, the color of the cassava soil was brighter than that of the mixed garden soil (Fig. 3). Figure 4 shows the brighter colors of cassava soil characterized by higher values and chroma (v/c), distributed especially in the A horizon.

The dark color of soil has long been associated with a high organic matter content and high native fertility [27], and vice versa. The brightness of the soil color of cassava soil is closely related to a reduced soil organic matter content compared to mixed garden soil. This is indicated by the results of a statistical analysis which showed that the difference in organic carbon between the cassava and mixed garden soils of the A horizon was very significant at a critical value of 0.01 (Table 1).

The brighter color of the soil (v/c, 3/4 compared to 2/2) (Fig. 4 and Table 2) indicates the significantly reduced soil organic matter content. This, in turn, results in a decrease in the soil chemical properties, particularly in the exchangeable bases, CEC of the soil, and pH (Table 1). The soil property that is most quickly affected by a reduced amount of soil organic matter is the CEC of the soil, especially in old soils, because the clay minerals have been dominated by low activity clay or low negative charges [26].

Soil color that becomes brighter can be used as an indicator of the decreasing soil organic matter content. A decline in soil organic matter over a long time will affect the soil structure, especially the surface horizon, where 50% of the soil structure in the soil surface horizon has changed from crumbs to angular blocky or granular (Table 3). Organic materials that function as adhesives, from peds and larger soil structures in sufficient quantities, form a soil structure called crumbs.

Table 3 Shape of soil structure on A and B horizons of cassava and mixed gardens soils

No.	Research site	Shape of soil structure			
		Cassava soil		Mix garden soil	
		A-Hor	B-Hor	A-Hor	B-Hor
1	Jatiagung	Cr	sab	Cr	sab
2	Gedong Wani	Cr	ab	Cr	ab
3	Bumiratu Nuban	gr	ab	Cr	ab
4	Natar 1	Cr	ab	Cr	ab
5	Natar 2	Cr	ab	Cr	ab
6	Natar 3	Cr	ab	Cr	ab
7	Gunung Sugih 1	ab	ab	Cr	ab
8	Gunung Sugih 2	ab	ab	Cr	ab
9	Gunung Sugih 3	ab	ab	Cr	ab
10	Seputih Jaya	Cr	sab	Cr	ab
11	Terbanggi	Cr	sab	Cr	ab
12	Abung	ab	ab	Cr	ab
13	Masgar	ab	ab	Cr	ab
14	Tanjungsari	gr	ab	Cr	ab

Cr = crumb; ab = angular blocky; sab = subangular blocky

With a crumbly structure, the soil can provide optimal water and air for plant growth.

3. 2. 2 Soil structure

The results of the description for the small profile or pit indicate that there have been differences in the shape of the soil structure, especially on the surface horizon, between the cassava and the mixed garden soils (Table 3). Of the 14 small profiles that were described, the form of five profiles (35.7%) was angular blocky in structure, while that of two profiles (14.3%) was granular in structure. The other profiles (50%) had the soil structure of crumbs, such as those found in the mixed garden soil.

A decrease in organic matter seems to generally be caused by the oxidation process [28] and to be a linear function of erosion. The oxidation process of organic matter, the movement of soil particles and organic matter from the surface layer to the sub-surface layer, and the transport of soil particles and organic matter through erosion and runoff that work together, cause an increasingly severe process of soil degradation. Moreover, the imbalance between the organic carbon transported from agricultural land and the organic carbon returned to the soil further reduces the soil organic carbon and eventually damages the soil. Besides the cassava tubers which are transported out of the field as a result of harvesting, cassava leaves are generally used as animal feed, while the cassava stems are used as seeds for the next planting process and as firewood. Thus, just a very small amount of biomass is returned to the soil.

Land use and its associated management, such as crop sequencing, fertilization, soil conditioning, drainage, and irrigation, are the most important and direct ways that the soil structure and properties are affected, through their impact on destruction forces and aggregate forming processes [29, 30, 31, 32]. Land use significantly influences the stability and size distribution of soil aggregates by changing the SOM in the soil and the size fractions by high cultivating intensity or a management-related hydro-regime [33]. The results of Zhao et al. [33] are in line with the results of this study, namely, that the cultivation of cassava with a more open canopy and periodic tilling before planting has resulted in changes in the shape of the soil structure on the surface horizon from crumbs to angular blocky or granular.

Increasing the soil pore space due to tillage and providing a more open canopy from the start of tillage until the cassava plants are young, allow sunlight to directly hit the surface of the soil; consequently, the microclimate in the soil surface layer becomes warmer. Furthermore, this will create an atmosphere more conducive to the oxidation process of soil organic matter and, as a result, the soil organic matter content will be further reduced. As explained in the previous paragraph, a decrease in organic matter will cause chunks and soil structures to rupture because the bonds have weakened. In the rainy season, with an average annual rainfall of more than 2000 mm, fine soil particles and soil organic matter are easily detached and transported by runoff at the soil surface and are also leached into deeper layers.

Table 4 Differences in physical properties of soil surface horizon between cassava and mixed garden

Soil property	∑ Data	Cassava soil		Mixed garden soil		P-Value	Test results
		Mean	StDev	Mean	StDev		
Bulk density (g cm^{-3})	14	1.25	1.14	1.29	0.16	0.474	ns
Soil strength ($kgf.cm^{-2}$)	10	1.55	0.66	1.63	0.71	0.798	ns
Total porosity (%)	9	52.59	5.58	51.26	5.93	0.460	ns
Fast drainage pores (%)	9	20.20	15.60	21.60	15.80	0.873	ns
Slow drainage pores (%)	9	5.71	2.78	5.83	2.41	0.933	ns
Available water pores (%)	5	9.91	3.90	13.27	6.01	0.284	ns
Soil permeability (cm/hour)	6	11.10	10.30	7.98	8.20	0.574	ns

ns = not significant

Farmers, in general, are aware of the importance of sustainable agriculture, but are looking for the easiest and most economical methods as they are mostly concerned with the necessities of daily life. They rarely practice soil conservation, such as returning harvest waste and applying organic materials to agricultural land, because they lack the funds that would be required to cover expenses for soil conservation efforts. Thus, farmers are generally reluctant to apply organic material because it would involve greater production costs due to the large volume.

3. 3 Soil Physical Properties

The soil physical properties in cassava and mixed garden soils are shown in Table 4; they are not significantly different, even though each soil has been treated with a different cultivation for more than 20 years. Nevertheless, the average available water pores (AWPs) in cassava soil was lower (9.9%) than that in mixed garden soil (13.3%).

Another physical property that tends to be different is soil permeability, where the average permeability of cassava soil is higher (11.1 cm/hour) than that of mixed garden soil (8.0 cm/hour). This is related to the average total porosity in cassava soil (52.6%) which is higher than that in mixed garden soil (51.3%). Regular tillage of cassava soil before replanting causes the soil structure to become more open and creates greater macropore space; consequently, the bulk density (BD) decreases. Conversely, the percentage of total pore space increases. After several months of planting, the soil structure becomes rearranged by the movement of the clay particles that fill the macropore space. This causes the small structures to combine into larger ones and to become denser, so that the percentage of macropore space decreases and the BD begins to increase again. Although the BD increases again, it will not be as dense as the BD in mixed gardens that are barely plowed.

3.4 Long-term Effect of Cassava Cultivation on Soil Properties

This research focuses on the changes in soil properties in cassava fields and mixed gardens

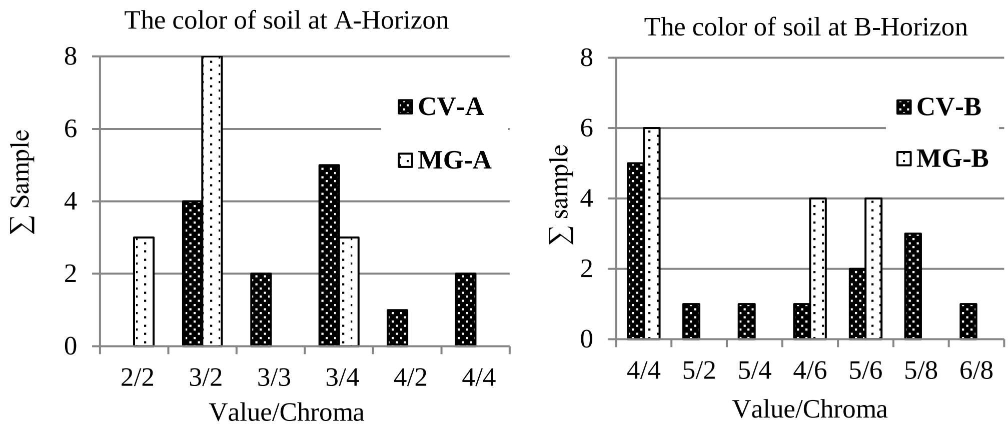

Fig.4 Differences in value and chroma between cassava and mixed garden soils

during long-term cultivation, where the canopies of the cassava fields were more open than those of the mixed gardens, especially after the soils were tilled until the plants reached 3-4 months of age.

The impact of tillage is the increase in macropore space, the surface area of the chunks of soil, granules, and peds which are directly related to air, light, and the heat of the sun; consequently, the oxidation process of organic matter will be higher. In addition to oxidation, the loss of organic matter also occurs through splash erosion, surface flow, and erosion. As a result, the organic matter content in the soil will be less and less. The decrease in the soil organic matter in cassava cultivation land is the main problem noted in this study. This decrease, in turn, will cause damage or a decrease in other soil properties, such as the soil structure, soil color, soil CEC, soil pH, and interchangeable bases, which will affect the decrease in nutrients.

The canopies are denser in mixed gardens, so that sunlight does not generally fall on the soil surface. The number of leaves that die and fall to the surface form a layer of litter which gets thicker and thicker. This layer of litter has a high capacity for water absorption and retention. Furthermore, coupled with an atmosphere that tends to darken because of the difficulty of sunlight penetration due to the density of the plant canopy, creating a cooler microclimate is conducive to humus formation and a reduced oxidation rate of organic matter. The absence of splash erosion and the high water absorption of the litter cause an increase in infiltration capacity such that the water collected at the soil surface, which will become runoff, decreases and erosion decreases. The reduced oxidation of organic matter and the loss of organic matter through erosion and surface runoff bring about more stable conditions of the soil organic material. In turn, this will make the soil structure more stable and decrease the soil chemical properties to be reduced. Finally, more of the nutrient content in the soil can be conserved.

4. CONCLUSION

Cassava cultivation over a long period causes changes in the soil morphology, especially the soil color and soil structure in the topsoil. Generally, the color of the soil becomes lighter and the structure of the soil changes from crumbs to angular blocky or granular.

Cassava cultivation significantly reduces the soil organic carbon (at a critical value of 0.01), soil pH, soil CEC, and exchangeable bases (at a critical value of 0.1) in the topsoil. However, long-term cassava cultivation does not affect base saturation. Similarly, cassava cultivation has no significant effect on the soil physical properties, although there is a tendency for a decrease in the available pore space.

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