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Soil Health under Cover Crops *Mucuna bracteata* and Sweet Potato in Oil Palm Intercropping Systems

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ABSTRACT

Cover crops have an important role in the sustainability of oil palm plantations, since their role in protecting the soil from rainwater impact, maintaining soil moisture, contributing soil organic matter, and other important roles for soil organisms. Smallholder oil palm farmers have chosen to plant production crops between newly planted oil palm rows, one of that is sweet potato. The study aimed to compare the health of soil planted with Mucuna bracteata with that planted with sweet potato on immature oil palm land. The study was carried out in Sumatera Utara Province, Indonesia. Data were analyzed using a t-test of SPSS 27. The results showed that soil respiration, soil fauna population, biomass amount, soil exchange K, N and P nutrient uptake of oil palm leaves were significantly different between the two treatments, with higher values found in M bracteata plot. Microbial populations, C-organic content, N, P soil content and K uptake of oil palm leaves were not significantly different in both. The result is that planting Mucuna bracteata on immature oil palm land provides a better contribution to soil health than sweet potato plants. Sweet potato plants have the potential to be productive ground cover plants on immature oil palm lands. It was suggested to conduct similar research with the duration and frequency from sweet potato planting of more than one planting cycle in a year to obtain its effect on the generative growth of oil palm plants.

Keywords: Biological activity, oil palm, soil fauna, soil nutrients

INTRODUCTION

The area of oil palm plantations in Indonesia continues to increase, the Central Statistics Agency of Indonesia noted that the area has reached 16.83 million hectares. The status of unproductive plants on smallholder plantations is 1.09 million hectares, large private plantations (Private estates) are 981 thousand hectares and large national companies (government estates) 39 thousand hectares. Unproductive oil palm plants cannot be harvested for 30 to 36 months. In this phase, there is an empty area between oil palm trees of around 60-75%, this area requires ground cover so that the land is protected from erosion and washing during rain, suppresses evaporation, maintains humidity, adds organic matter, maintains aggregate stability, and is a source of life for soil organisms. Generally, unproductive oil palm land is planted with leguminous cover crops (LCC), the LCC that is popularly used by Indonesian farmers is *Mucuna bracteata* (Corley and Thinker, 2016) .

Mucuna bracteata is a perennial plant, that creeps and spreads quickly from each node, in 4 weeks it can grow up to 4 m. The thick main stem and pseudo taproot can penetrate up to a depth of 3 meters, large dark green trifoliate leaves measuring 14 cm x 10 cm (Goh and Chiu, 2007). Research on the characteristics of soil covered with *M. bracteata* and without cover crops on flat and sloping land has been conducted, the results show that the organic matter content on flat land without cover crops is 1.98% and on land covered with *M. bracteata* 2.58%. On sloping land without cover crops, the organic matter content is 1.44% and on land covered with MB 2.22%. The organic matter content on flat and sloping land covered with *M. brateata* increased, 30.43% and 53.53% respectively. The increasing in organic matter content is followed by an increasing in N content in the soil (Sakiah *et al*., 2017; Sakiah *et al*., 2018). *M. bracteata* contributes in organic matter and N nutrients to the soil, from dry litter produced by 4-year-old *M. bracteata* cover, under full sunlight reaches 13 tons ha^{-1} $year^{-1}$, while *M. bracteata* under oil palm cover survives for 8 years but the litter produced is 40% lower than *M. bracteata* growing in open areas (Corley and Thinker, 2016). Manorama *et al*. (2021) reported that conventional oil palm cultivation experienced as 4% decrease in soil organic carbon over a period of 6 years, accompanied by a decrease in the availability of nutrients in the soil.

Building oil palm plantations using *M. bracteata* as cover crops requires great effort and funds for planting and maintenance. This is a problem faced by smallholder plantations due to limited business capital, so that empty areas between oil palm plants are planted with various types of production plants to increase income. Morphological similarities of plants and farmers' finances are considerations when choosing intercrops, sweet potatoes (*Ipomea batatas*) have the same growth type as *M. bracteata*, namely growing creeping with a tendril system that spreads quickly horizontally on the ground, the leaves are simple and arranged in a spiral with a 2/5 phyllotaxies pattern (Huaman, 1992). Sweet potato tubers are known as food ingredient that sold well in local and global markets. In terms of food and health, sweet potato tubers are known as functional foods and their tips are used to develop cosmetic ingredients (Young *et al*., 2022) since it is rich in carbohydrates, protein, carotenoids, flavonoids, anthocyanins, phenolic acids and minerals (Alam, 2021). The main result of *M. bracteata is litter* (Dissanayaka *et al*., 2024) while sweet potatoes produce tubers that have economic value. Kassali (2011) reported that sweet potato cultivation has economic value and is profitable even with small capital input.

Ground cover plants can come from legumes or non-legumes, the type of plant chosen also associates in forming an ecosystem that in turn will disturb soil health and has the potential to become a competitor for the main crop if not considered properly. The desired properties of ground cover as reported Fageria *et al*. (2005) and requirements in national regulations (Minister of Agriculture, 2016) found in sweet potatoes. Land used and soil cultivation are important factors that affect soil health (Sheibani and Ahangar, 2013). How is the health of the soil after planting sweet potatoes between rows of oil palms? Based on our reference search, very few studies were found that reported this. This study aimed to compare soil health after planting sweet potatoes and *M. bracteata* among rows of immature oil palm, soil health variables observed are microbial population, soil fauna, soil respiration, fresh biomass of ground cover plants, C-organic content, N, P and K content of soil and absorption of N, P and K of oil palm leaves. This study is expected to be a consideration in selecting ground cover plants during the immature oil palm period to support sustainable oil palm plantations.

MATERIALS AND METHODS

Experimental site

The field study was conducted in Sinah Kasih Village, North Sumatra, Indonesia. The soil classified as Kandiudults based on Center for Soil and Agroclimatic Research (2000). Nutrient tests of N, P and K were conducted at Analytical Laboratory, Indonesian Oil Palm Research Institute. Soil biological properties were tested in The Soil Biology Laboratory, Universitas Sumatera Utara, Indonesia.

Research design and hypothesis

This study compared the results between two different treatments. Treatment I, namely sweet potatoes planted between oil palm trees, treatment II, namely *M. bracteata* between oil palm rows. The research hypothesis is H_0 = There is no difference in microbial population, soil fauna, soil respiration, fresh biomass of ground cover plants, C-organic content, N, P and K content of soil and absorption of N, P and K of oil palm leaves in plots planted with sweet potatoes with those planted with *M. bracteata* between oil palm rows. H_1 = There is a difference in microbial population, soil fauna, soil respiration, fresh biomass of ground cover plants, C-organic content, N, P and K content of soil and absorption of N, P and K of oil palm leaves in plots planted with sweet potatoes with those planted with *M bracteata* between oil palm rows.

Research plot

There are 20 research plots measuring 6 m x 10 m located between oil palm trees, 10 plots planted with sweet potatoes, in one plot planted 120 sweet potato cuttings from sari variety, planting distance 50 cm x 100 cm. The other plots totaling 10 plots, planted with *M. bracteata* before planting oil palm. Oil palm trees in one plot number 3 trees, DP Topaz 3 Asian Agri variety aged 11 months. The distance between plots is 1.5 m.

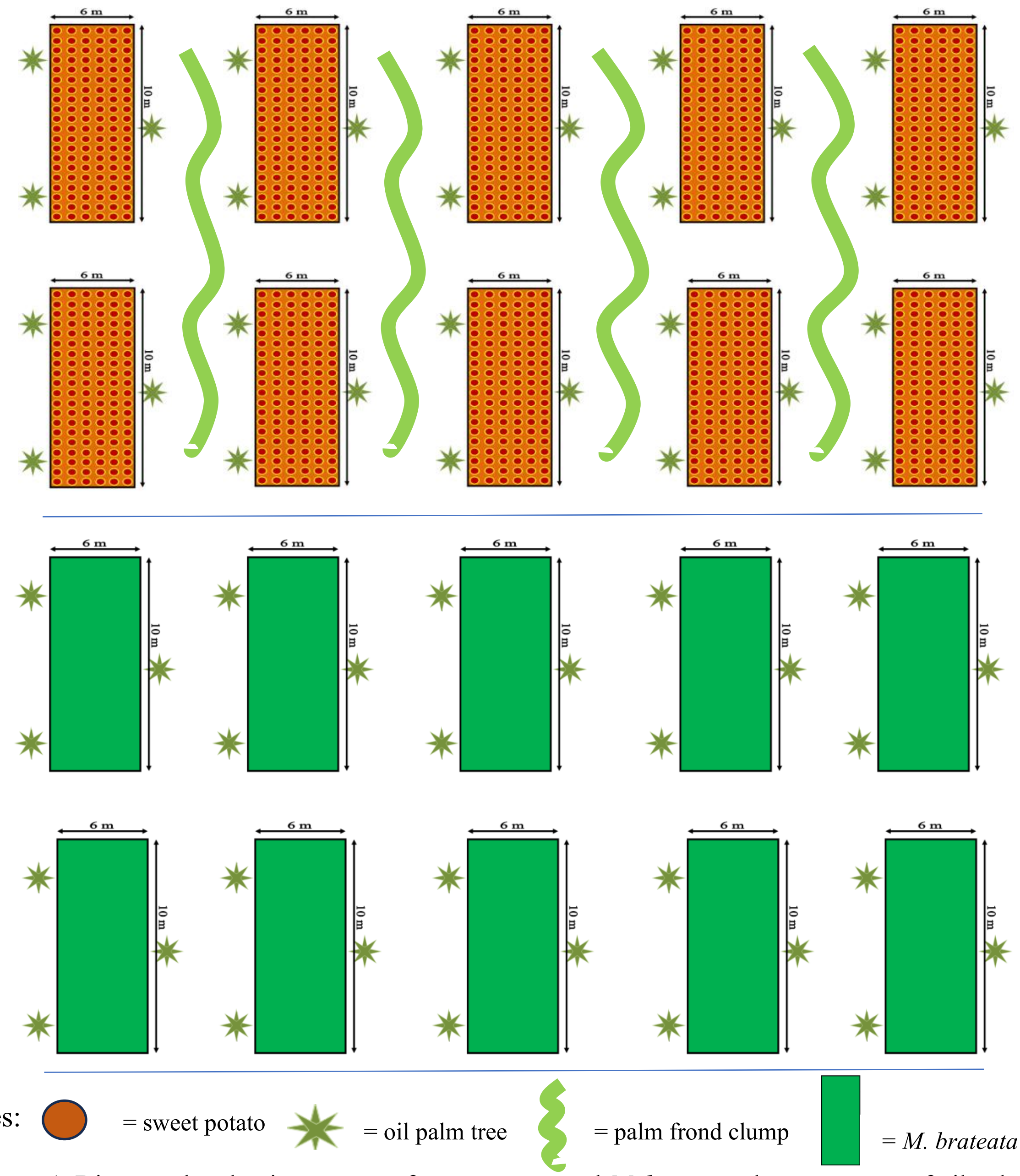

Figure 1. Diagram the planting pattern of sweet potato and *M. bracteata* between rows of oil palm

Figure 2. Sweet potato planting plot between rows of oil palm trees

Soil sampling

Composite soil samples were taken diagonally, from each plot as 5 sample points; soil samples are taken at a depth of 0-20 cm using a soil drill, the soil samples are then mixed evenly and taken 1 kg for each plot then put into a plastic bag and given a marker label, this soil sample is used for N, P, K, C-organic parameters. Testing of soil biological properties using fresh aggregate soil that is taken using a hoe (Canadian Society of Soil Science, 2007), the soil is taken from a depth of 0-20 cm then put in plastic packaging to be tested in the laboratory.

Measurement of carbon (C), nitrogen (N), phosphorus (P) and potassium (K) on soil

Soil organic C content was measured using the Walkley and Black method (Sullivan and Moore, 2019). The soil N measured in this study was total N using the Kjeldahl method (FAO, 2021), P-available by Bray II Spectrophotometry method, K-exchange by Atomic Absorption Spectrophotometer (AAS) method extracted with 1N Ammonium Acetate pH 7.

Measurement of nitrogen (N), phosphorus (P) and potassium (K) on leaves of oil palm

Levels N, P and K on leaves were analyzed by wet destruction H_2SO_4 H_2O_2. The N analysis method is Titrimetric, Spectrophotometric method for P and AAS method for K.

Measurement on microbial population

The enumeration was conducted by plate counting technique from a series of dilutions of each sample. Ten g of fresh soil was put into Erlenmeyer containing 95 mL of physiological solution (8.5 g NaCl in 1L distilled water) then shaken for 30 minutes. One mL of pure culture was put into a 10 mL test tube containing 9 mL of physiological solution (resulting in 100 times or10^{-2} dilution). It was shaken for one minute and one mL of 10^{-2} dilution was taken for dilution of 10^{-2}. Dilution process was continued until the dilution 10^{-8} was reached. Then the culture was incubated for three days. After incubation, the number of microbes was counted using Quebec colony counter. The number of microbes was calculated using Equation (1):

$\sum colony\ mL^{-1} = \sum colonies\ x\ dilution\ factor$ ……………..(1) (Elfiati and Susilowati, 2019)

Soil respiration

Soil respiration was measured with Jar method as utilised by Elfiati and Susilowati, 2019, fresh samples of 100 g, 5 mL of 0.2N potassium hydroxide (KOH), and 10 mL water were incubated in 1000 mL vial for two weeks at 28-30ºC. At the end of the incubation period, two drops phenolphthalein was added to KOH beaker until a red solution was formed. HCl was added into the red solution until the red color disappeared and at that point, the volume of HCl used in the titration was recorded. Afterward, two drops of methyl orange were added into the solution until yellow color was formed. The solution, then was re-titrated with HCl to form pink color and the required HCl volume was recorded. A control vial with no soil was included in the incubation to correct for the CO_2 in the Jar at the initiation of the incubation. The amount of respiration (R) (in mg CO_2 100 g^{-1} day^{-1} was calculated using Equation (2):

$$R = \frac{(a-b)\ x\ t\ x\ 120}{n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where: a is the volume of HCl used for titration (mL), b is the volume of HCl used for; titration of the blank/control (mL), t is the normality of HCl; n is the incubation time in days (Anderson, 1982).

Population of soil fauna

Fauna trapped with the Berlese-Tullgren Funnel (Smith *et al*., 2008), fresh intact soil samples were inserted into the Berlese Tullgren Funnel. The labeled glass tube was filled with 70% Alcohol as high as 4 cm and then placed under the funnel hole. The funnel cover was installed, the light in the funnel was turned on, the soil was incubated for 24 hours. The fauna collected in the glass tube was inserted into a petri dish filled with 70% alcohol using a dropper. Furthermore, counting and identification were carried out under a microscope.

Biomass of *M. bracteata* and sweet potato.

Biomass measurements were carried out gravimetrically. Cover crop biomass was taken from 1m x 1m sample plots of 3 plots in the research plot. The samples were weighed, and their wet weight (g m-2) was recorded. Furthermore, the biomass was oven-dried at 70ºC for 24 hours, then placed in a desiccator. The dry weight of the biomass was weighed and recorded.

Statistical analysis

The average observation results were obtained from 10 replications on the *M bracteata* plot and 10 replications on sweet potato plot. To answer the hypothesis, the observation results were tested using a t-test using SPSS 27, the testing criteria were:

H0: $\mu 1 = \mu 2$, H0 is accepted if the sig value (2-tailed) > α (0.05)
H1: $\mu 1 \neq \mu 2$, H1 is accepted if sig (2-tailed) > α (0.05)

RESULTS AND DISCUSSION

The data of soil and leaves palm oil observation were analyzed by using t-test at 5% confidence interval in SPSS v.27. The requirement in this test applies if the Sig value (2-tailed) <0.05, then the hypothesis H0 (no difference) is accepted and H1 (there is a difference) is rejected. The recapitulation of data analysis is listed in Table 1.

Table 1. Results of t-test analysis

Parameters		Sig value (2-tailed)		Conclusions	
Soil Biology	Microbial population	0.258	> 0.05	H_0 accepted	no difference
	Soil Fauna	0.009	< 0.05	H_0 rejected	difference
	C-organic	0.514	> 0.05	H_0 accepted	no difference
	Soil respiration	0.005	< 0.05	H_0 rejected	difference
	Biomass	0.004	< 0.05	H_0 rejected	difference
Nutrients in soil	N	0.809	> 0.05	H_0 accepted	no difference
	P	0.353	> 0.05	H_0 accepted	no difference
	K	0.020	< 0.05	H_0 rejected	difference
Nutrients in Leaves	N	0.039	< 0.05	H_0 rejected	difference
	P	0.000	< 0.05	H_0 rejected	difference
	K	0.400	> 0.05	H_0 accepted	no difference

Table 1 shows that there was no difference in microbial population, organic C, N and P levels in soil and K in oil palm leaves between sweet potato plot and the *M bracteata* plot. While for soil fauna population, soil respiration, fresh biomass of cover crops, soil exchange K and N and P in oil palm leaves were different in both plots. This difference demonstrates that soil fauna are sensitive to their environment. Soil fauna respond to environments that undergo soil cultivation or technical cultural activities, such as plots planted with sweet potatoes, as a disturbance to their survival. This has implications for the role of each soil organism in its community. The sub-section below explains this in more detail.

Soil biological properties

The average population of microbes, soil fauna, soil respiration, biomass of cover crops and C-organic are presented in **Table 2**.

Table 2. Soil biological properties after planting cover crops

Plot	Microbial population (10^5CFU.ml^{-1})	Soil fauna (individual.m^{-2})	Soil respiration (mgCO$_2$ day^{-1}m^{-2})	Biomass of cover crops (ton. ha^{-1})	C-organic (%)
Sweet Potato	5	20	70	4.09	0.75
Mucuna bracteata	8.4	300	134	5.5	0.70

Microbial population

The utilization of empty space between immature rows of oil palm as a sweet potato planting plot has lasted one planting cycle, namely planting seedlings to harvest for 4 months. The population of soil microbes at a depth of 0-20 cm has been observed, the results show (**Table 1**) the population of soil microbes in sweet potato plot is no different from the *M bracteata* plot that has been planted before, the development of microbes under sweet potato plants comparable with microbes under the *M. bracteata* that are commonly used as cover crops for oil palm plantations. Agyei *et al*. (2024) reported plant diversity had minimal impact on microbial populations. Sarkar *et al*. 2022 emphasized that microbes are living creatures that are responsive to changes in surrounding environment and environmental stress conditions. Ma *et al*. (2022) stated that the microclimate is ecologically significant mediating the soil microbial population, the most closely related being temperature, pH and N. Sweet potato plants as a substitute for *M. bracteata* are thought to produce a microclimate similar to *M. bracteata* environment so that the presence of sweet potatoes is not a limiting factor for the development of soil microbes. Research results from Sapalina *et al*. (2022) strengthens that the intercropping system has the potential to increase soil biological activity; indicated by the bacterial population in Sorghum and Casava intercropping being higher than the bacterial population in *M. bracteata* cover crop land. Soil microbes play an important role in various soil processes. Sheibani and Ahangar (2013) reported that microbes regulate carbon and nitrogen cycles and provide nutrients for plants. Bacteria and fungi are essential in the conversion of plant residues to soil organic matter, increasing aggregate stability, cation exchange capacity, water holding capacity, water infiltration, and soil porosity.

Soil Fauna

The soil fauna in *M. bracteata* plot and sweet potato plot were observed, significant differences were found in the number of individuals and their diversity, that was greater in *M. bracteata* plot (300 individuals m^{-2}) compared to sweet potato plot (20 individuals m^{-2}). The fauna found in the *M. bracteata* plot were the families *Sciaridae, Uropodidae, Dictynidae, Miturgidae,* and *Haplozetidae*, while in sweet potato plot there were only two families, namely *Sciridae* and *Dictinydae*. This difference is thought to be since *M. bracteata* plot has more natural environment, minimal soil cultivation, while in sweet potato plot, soil cultivation was carried out in the form of making beds during planting, manual weeding and hilling at sweet potato planting point to initiate tuber formation, allowing the soil mesofauna to move and relocate to a natural environment. Kladivko (2001); Agyei *et al*. (2024); Cassani *et al*. (2021) and Chamorro Martinez (2022) stated The soil organism community is greatly influenced by soil cultivation activities, which can fundamentally alter the physical and chemical environment of the soil. Soil organisms then respond to these changes, with larger organisms being more sensitive to environmental changes. Land changes from natural systems to production systems reduce the abundance and richness of soil fauna (Sheibani and Ahangar, 2013). These negative effects were stronger when conversion occurred in tropical and subtropical locations and when natural systems were replaced by agricultural land, grasslands and grazing. The highest declines in abundance were recorded in omnivores and predators (Chiappero *et al*., 2024)

Micro, meso and macro soil fauna are biological actors of various processes in the soil, they have different roles and abilities in decomposing biomass residues. Mesofauna plays a role in breaking down coarse organic matter, swallowing and digesting some of litter eaten (Creamer *et al*., 2022). Some of the litter becomes small pieces then it is easily to access microbes (Hopwood *et al*., 2021). Litter processing in mesofauna digestion can increase microbial activity in the short term, activity then decreases so that in the long term feces decompose more slowly than the original litter (Frouz, 2018). Soil mesofauna and soil organic matter have a significant correlation (Chamorro Martinez, 2022). Cassani *et al*., (2021) reported that litter decomposition rate by micro-meso-macrofauna was higher and left the lowest litter, the opposite for microfauna, namely the lowest decomposition rate and the highest litter residue. Soil fauna also affect the distribution of organic matter in the soil profile and determine whether litter decomposes on the soil surface, that substantially affects the microbial community and decomposition rate (Frouz, 2018).

Soil organic carbon and biomass of cover crops

Soil organic carbon is an important instrument in assessing soil fertility and health. Soil organic carbon is in line with soil organic matter (Sullivan and Moore, 2019). In sustainable agriculture-plantation practices, soil organic matter content is often used as a benchmark, its role is so complex in influencing the physical, chemical and biological properties of the soil. Based on the data analysis that has been carried out, there is no difference in soil organic carbon content, the *M. bracteata* plot has a carbon content of 0.70% and sweet potato plot 0.75%. In line with the statement from Blanco-Canqu *et al*. (2015) that the amount of carbon contributed by cover crops to the soil depends on the amount of biomass, the length of time the land is covered by cover crops and initial soil carbon content.

The main source of soil organic carbon actually comes from the biomass of fallen or dead land cover vegetation that returns to the soil. This study showed the fresh biomass produced from *M. bracteata* (5.5 Mg ha^{-1}) is significantly different from the biomass of sweet potatoes (4.09 Mg ha^{-1}), the biomass of *M. bracteata* plot is 34.47% higher than sweet potato plot. The biomass measured in this study is the stem, root and leaf, excluding sweet potato tubers. In essence, the amount of cover crop biomass of a land reflects the potential for organic material to be recycled then contributed to the soil. Organic material that has been decomposed to a size of <0.001mm acts as a soil colloid that has the ability to exchange cations and retain water greater than clay. Cations sourced from organic materials are important nutrients for plants, namely NH^{4+}, K^+, Ca^{2+} and Mg^{2+}.

Soil Respiration

Soil respiration is the amount of CO_2 produced from the activity of living organisms in the soil. The activity of soil organisms is not limited to the decomposition of organic matter alone, other activities including ammonification, nitrification, mineralization, aggregation, bioturbation and incorporation also involve soil organisms (Creamer *et al*., 2022). Soil respiration showed a significant difference, in *M. bracteata* plot (134 mgC-CO_2 $day^{-1}m^{-2}$) was 91.43% greater than soil respiration in sweet potato plot (70 mgC-CO_2 $day^{-1}m^{-2}$). It is related to observations in *M. bracteata* plot that showed higher microbial populations, soil fauna and cover crop biomass than the vine test plot. USDA, (2014) stated that soil respiration is a measure of carbon dioxide released from the soil by microbes, soil fauna and plant roots. Raich and Tufekciogul (2000) reported, no predictable differences in soil respiration were found between vegetated and unvegetated soils, between forested and vegetated soils, or between pasture and vegetated soils. Some factors such as temperature, water availability, and substrate properties that simultaneously influence organic matter production and consumption are more important in controlling overall soil respiration rates than vegetation type in most cases. Vegetation influences soil respiration through the microclimate it creates, the quantity of detritus supplied to the soil, the quality of that detritus, and the overall root respiration rate.

Table 2. Nutrients of N, P and K in soil and leaves after planting of cover crops

	Soil			Leaves		
Plot	N_{total} (%)	$P_{available}$ (ppm)	$K_{exchangeable}$ (me 100^{-1} g)	N %	P %	K %
Sweet Potato	0.064	31.505	0.283	3,319	0.1965	1.752
Mucuna bracteata	0.068	43.758	0.582	3.135	0.1666	1.586

Soil N, P and K levels and their absorption by leaves

Nitrogen, phosphorus and potassium are some macronutrients needed by plants in large quantities. Soil is a supplier of nutrients for plants, but soil is dynamic as the nutrients contained in the soil so that the amount of nutrients absorbed by plants is limited. Biotic and abiotic environmental factors also affect the availability of nutrients for plants, including human intervention in managing agroecosystems. Observations on soil N-total, P-availabe and K-exchangeable have been carried out, the results showed that N-total and P-available in the *M. bracteata* plot were not significantly different from sweet potato plot, but significantly different in soil exchangeable K. The level of exchangeable K was higher in *M bracteata* plot than the exchangeable K in sweet potato plot.

Nutrients absorbed by plants are distributed and stored in their tissues, to leaves, stems, roots, fruits and other parts. The results of the analysis showed that N and P in oil palm leaves in *M. bracteata* plot were significantly different from N and P in sweet potato plot, but K in the leaves was not significantly different in both plots. N and P nutrients in oil palm leaves were greater in sweet potato plot than in sweet potato plot, but K nutrients were greater in oil palm leaves in the *M. bracteata* plot than in sweet potato plot.

CONCLUSION

Soil health in *Mucuna bracteata* covered field was better than sweet potato, indicated by soil respiration, soil fauna population, biomass amount, soil exchange K, N and P nutrient uptake of oil palm leaves were higher in *M. bracteata* covered field. Those five soil fauna families were found, in total 300 individuals per m^2, soil respiration was 91.43% and biomass was 34.47% higher in *M. bracteata* covered field than sweet potato covered field. The financial considerations of smallholders when oil palm is not yet producing; sweet potato is the option as a productive ground cover. It was suggested to conduct similar study with the duration and frequency from sweet potato planting of more than one planting cycle in a year to obtain the effects on the generative growth of oil palm plants.

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