Jurnal Manajemen Hutan Tropika, *28*(2), 119–127, August 2022
EISSN: 2089-2063
DOI: 10.7226/jtfm.28.2.119

Scientific Article
ISSN: 2087-0469

The Dynamic of Functional Microbes Community Under Auri (*Acacia auriculiformis* Cunn. Ex Benth) Agroforestry System

Enny Widyati, Mohamad Siarudin, Yonky Indrajaya*

Research Center for Ecology and Ethnobiology, National Research and Innovation Agency (BRIN),
Jalan Raya Jakarta-Bogor Km. 46, Bogor, Indonesia 16911

Received September 28, 2021/Accepted June 15, 2022

Abstract

Microbes are important rhizosphere constituents for providing nutrients in the soil. This study analyzes the dynamic of soil functional microbes' populations on land managed as an agroforestry (AF) system. The AF system consists of a 2-years old auri tree combined with several crops, i.e., wild grasses, peanuts (Arachis hypogaea), pigeon pea (Cajanus cajan), and maize (Zea mays). Soil samples were collected from each rhizosphere and then analyzed for their chemical properties such as N, P, K, pH, and C organic contents. The population of functional microbes was observed by isolation of the non-symbiotic N-fixer microbes (BNF), the cellulose-degrading microbes (CDM), and the phosphate solubilizing microbes (PSM) in their selective media. The total soil sugars were also tested for root exudates. The results showed that in an auri agroforestry system, the kind of crops determines the content of the soil organic material that is turned-offer into the soil. This affects the population structure and functional microbial abundance in the rhizosphere. Furthermore, microbial colonization in the rhizosphere affects plants in producing root exudates. Then, root exudates shape the structures of the microbial community, as well as an influence among inhabitants in defining mineralization of soil organic matter, nutrient availability, and trees performance.

Keywords: *Acacia auriculiformis, agroforestry system, soil microbes*

**Correspondence author, email*: *yonky.indrajaya@brin.go.id*

Introduction

Agroforestry is defined as "any land-use system, practice or technology, where woody perennials are integrated with crops and animals in the same land management unit, in some form of spatial arrangement or temporal sequence" (Atangana et al., 2014). Agroforestry may combine agricultural and forestry technologies to produce more productive, profitable, and sustainable land-use systems (Puri & Panwar, 2007). By integrating the agriculture and forestry sector, agroforestry is natural resource management that is ecologically dynamic, as it may increase biodiversity and sustainable production (Sobola et al., 2015). Furthermore, agroforestry is viewed as an effective means of maintaining or even increasing crop and tree productivity in line with promoting other ecosystem functions and services (Rivest et al., 2013). Moreover, Abebe et al. (2013) argue that agroforestry ecosystems, characterized by the coexistence or succession of trees and crops, depend on human action to remain stable. Human activity plays a central role in regulating these interactions and enhancing productivity toward selected goals by converting physical, chemical, and biological processes into beneficial crops and wood production inputs. Agroforestry systems are alternative options for sustainable production management. These systems contain trees that absorb nutrients from deeper layers of the soil and leaf litter that help improve the soil quality (Notaro et al., 2014). The agroforestry system is a closed ecosystem that optimally facilitates nutrition retention in soil and hence can be utilized by crops.

By promoting a closed system with internal recycling of nutrients, whereby nutrients are accessed from lower soil horizons by tree roots and returned to the soil through leaf fall, agroforestry systems enhance soil nutrient pools and turnover and reduce reliance on external inputs (Smith et al., 2013).

Auri (*Acacia auriculiformis* Cunn. Ex Benth) is an evergreen tree with a short forked bole and heavily branched (Islam et al., 2013). It is recognized as a potential tree species for fuelwood due to its high biomass productivity and caloric value (i.e. > 4,500 calory g^{-1}) (Kataki & Konwer, 2002). Singh et al. (2014) reported that auri is one of the eco-friendliest species for fuelwood since it may reduce the emission of pollutants and may grow in degraded lands. Because of its advantages, this species is commonly planted in degraded lands for land rehabilitation and fuelwood supply to people living surrounding the degraded lands using an agroforestry system.

Qin et al. (2017) reported that soil microorganisms perform many soil biological processes. The presence of an abundant and diverse soil microbial community is essential to sustain the productivity of an agroecosystem. Notaro et al. (2014) reported that differences in litter quality between the tree and crop components in agroforestry systems promote spatial diversity in enzyme activities and microbial functioning. Tree effects on microclimate enhance this spatial variation. Several studies have recorded that there is a positive relation between microbial diversity, enzyme activity, and soil stability in agroforestry alley cropping systems, attributable to differences in litter quality and quantity, and root exudates (Araujo et al., 2012; Bardhan et al., 2013; Beuschel et al., 2020; Guillot et al., 2021).

Hitherto, there is still a lack of study on the population of microbes under an auri agroforestry system with different crops. This study aims to analyze the dynamics of soil functional microbes that play an important role in providing soil nutrients on land planted by the auri agroforestry system continuously until 2 years.

Methods

This study was conducted from April to August 2017 in an agroforestry land-use system dominated by auri located in Labuhan Badas Village, Sumbawa Island, West Nusa Tenggara. The elevation of the study area is ± 40–65 m above sea level with annual precipitation of ± 1,200 mm and an average temperature of 30 °C. The soil type of the study area is litosol. The agroforestry system consists of a 2-years old auri tree combined with several crops, i.e., wild grasses, peanuts (*Arachis hypogaea*), pigeon pea (*Cajanus cajan*), and maize (*Zea mays*). The cropping patterns observed in this study were 5 treatments, namely: auri monoculture, auri + wild grass, agroforestry of auri + peanuts, agroforestry of auri + pigeon bean, and agroforestry of auri + maize.

Soil sampling Soil samplings were conducted in the rhizosphere zone at a 50–100 cm radius from the stems, with 0–20 cm depth. For each treatment, three samples were randomized selected of 25 trees. Each soil sample was collected after compositing three sampling points at each tree (Pansu & Gautheyrou, 2006).

Soil analysis Some soil properties determining microbes population, such as C organic content and pH or that influenced by soil microbes such as N, P, and K contents were analyzed. To measure root exudates, soil samples (due to root exudates released into the soil not deposited within the root tissue); were collected from each rhizosphere tree at a depth of 0–20 cm using a shovel with a depth marker (0–30 cm). In the first step, a hole of 40 cm × 40 cm × 40 cm was made, and on the rhizosphere side, we collected soil-free fine roots from the surface to a depth of 20 cm for approximately 1 kg. The soil samples were transferred to the laboratory in cooler boxes and then were analyzed using the High-Performance Liquid Chromatography (HPLC) method to examine the soil sugar amount (Pansu & Gautheyrou, 2006). This compound is the dominant root exudate and the main food source for soil microbes in the rhizosphere.

Microbes isolation Following van Elsas et al. (2006), the rhizosphere communities were observed by calculating through the Most Probable Number (MPN) method for Nitrogen Fixing Bacteria (BNF), and a plate count method for Cellulose Degrading Microbes (CDM) and Phosphate Solubilizing Microbes (PSM). Initially, 10 g of each soil sample was soluted into 90 ml of physiological solution (NaCl 0.85% m v^{-1} in aquadest) (standard as 10^{-1} solution). Afterward, 1 ml dilution was serially diluted into 10 ml sterilized aquadest (10^{-2}) until 10^{-7}. Then 1 ml of the last special three series spread on petri dishes, in duplicate, on the following selective media: dilution of 10^{-5} to 10^{-7} on Carboxy Methyl Cellulose (CMC) agar for CDM enumeration, 10^{-4} to 10^{-6} on Pikouvskaya Agar for PSM calculation, and 10^{-3} to 10^{-5} on Brilliant Green Lactose Bile Broth for NFB cultivation. Colonies surrounded by transparent circles were counted as CDM on CMC and PSM on PA, as they are capable of consuming either cellulose for CDM or phosphate source for PSM. The number of colonies was calculated after seven days of isolation. Seven days is considered as the life cycle of the bacteria. After seven days is presumed that all target microbes to be analyzed are dead. Therefore, if until the 7th day the microbes could not be found, it means that they do not exist in the samples.

Data analysis Data were analyzed using SPSS to identify the effects of treatments through the analysis of variance (ANOVA). Duncan's multiple range test (DMRT) will further analyze treatments that significantly impact the 95% confidence level.

Results and Discussion

Soil properties Results from soil analysis show that agroforestry treatment with different crops under 2-years auri stand positively affects C-organic, P-available, non-symbiotic N-fixing bacteria, and total soil sugars. In addition, agroforestry treatment may also positively affect soil pH and the population of other functional microbes (e.g., CDM and PSM). However, agroforestry has no effect on the total P, K, and N in the soil (Table 1).

The best treatment for increasing soil organic matter (SOM) production is grasses, followed by pigeon pea and maize. Grass treatment followed by pigeon pea may also improve the soil pH and P-available (Table 2). SOM provides the main source for food and energy, and settlement for soil microbes in the soil. SOM will be decomposed by degrading microbes into simpler substances. That is shown with the highest population of CDM among other functional microbes in that site. One of the substances derived from SOM decomposition is carbonates that increase soil pH. SOM is also mineralized into nutrients, such as P available in soil (Table 2), showing that P available is significant due to crops under the auri stands forming an agroforestry system.

The total of soil sugars (Table 2) also significantly improved due to the understorey crops that are short-lived plant release photosynthate, including soil sugars. Soil sugars represent the root exudates in the rhizosphere.

Jurnal Manajemen Hutan Tropika, *28*(2), 119–127, August 2022
EISSN: 2089-2063
DOI: 10.7226/jtfm.28.2.119

ISSN: 2087-0469

Table 1 ANOVA results of the effects of treatments on soil properties

Variables of soils		Sum of square	df	Mean of square	*F* value	Sig.	
C organic	Between Groups	4.719	4	1.180	14.233	0.000	**
	Within Groups	.829	10	0.083			
	Total	5.548	14				
pH	Between Groups	1.068	4	0.267	5.374	0.014	*
	Within Groups	.497	10	0.050			
	Total	1.565	14				
N	Between Groups	.097	4	0.024	0.493	0.741	ns
	Within Groups	.489	10	0.049			
	Total	.586	14				
P available (ppm)	Between Groups	55.466	4	13.867	7.722	0.004	**
	Within Groups	17.956	10	1.796			
	Total	73.423	14				
P total	Between Groups	1,671.333	4	417.833	0.324	0.856	ns
	Within Groups	12,910.000	10	1,291.000			
	Total	14,581.333	14				
K	Between Groups	.287	4	0.072	0.030	0.998	ns
	Within Groups	23.524	10	2.352			
	Total	23.811	14				
NFB (non symbiotic)	Between Groups	65.909	4	16.477	16.218	0.000	**
	Within Groups	10.160	10	1.016			
	Total	76.069	14				
CDM	Between Groups	1,128.151	4	282.038	4.992	0.018	*
	Within Groups	565.033	10	56.503			
	Total	1,693.184	14				
PSM	Between Groups	835.011	4	208.753	5.375	0.014	*
	Within Groups	388.367	10	38.837			
	Total	1,223.377	14				
Soil sugars	Between Groups	55,489.733	4	13,872.433	19.620	0.000	**
	Within Groups	7,070.667	10	707.067			
	Total	62,560.400	14				

Notes: ** very significant; * significant; ns: not significant; $\alpha = 5\%$

Widyati (2016) summarized from several sources that plants release 15−40% of photosynthesis as root exudates. Among the substances, 46−52% portion is carbohydrates (sugars, polysaccharides, etc.). The result shows that grass is the most consistent treatment in improving soil quality, followed by pigeon pea and maize. The grass is a plant with the shortest cycle, so turning organic matter into the soil occurs most quickly. The grass in this study was not harvested, so the organic material added to the soil grew more and more. In the case of pigeon peanut treatment, this crop is a low annual shrub where only the fruit is harvested. This plant is also never cleared throughout the cycle, so the amount of organic matter donated to the soil also accumulates (Poeplau, 2021). Farmers usually take the corn fruit while the remaining biomasses are left. Peanuts occupy the lowest position in organic matter contribution because the plant is harvested by removing all parts of the plant. Therefore, only a small amount of organic matter is donated to the soil (Figure 1).

In addition to contributing organic matter to the soil, according to Asaah et al. (2011), pigeon pea (*Cajanus cajan*) is a legume group that can bind atmospheric nitrogen and restores soil fertility. According to Ashworth et al. (2017), other conservation agricultural practices such as cropping rotations, animal manures, and cover crops (i.e., bio covers) can be reported, or increased soil quality for long-term agricultural production as crop residue may regulate bacterial communities.

Table 2 Soil properties of 2-years auri agroforestry system

Variable	Non-crops	Grasses	Maize	Pigeon pea	Peanuts
C-org (%)	2.92[a]	4.51 [d]	3.57 [bc]	3.84 [c]	3.12 [ab]
pH	5.92 [a]	6.70 [c]	6.24 [ab]	6.53 [bc]	6.26 [ab]
N (%)	1.67 [a]	1.86 [a]	1.89 [a]	1.74 [a]	1.82 [a]
P available (ppm)	10.36 [a]	15.69 [c]	13.33[bc]	13.46 [bc]	10.94 [ab]
P total (ppm)	182 [a]	191 [a]	207 [a]	207 [a]	185 [a]
K (ppm)	6.69 [a]	6.89 [a]	7.11 [a]	6.92 [a]	6.82 [a]
Soil sugar (mg kg^{-1})	122 [a]	177 [b]	306 [d]	210[bc]	229 [c]

Notes: Numbers followed by the same alphabet at the same row show the non-significant effect of treatments on soil properties at α = 5%

A B C D

Figure 1 Crops and understoreys: grasses (A), maize (B), pigeon pea (C), and peanut (D).

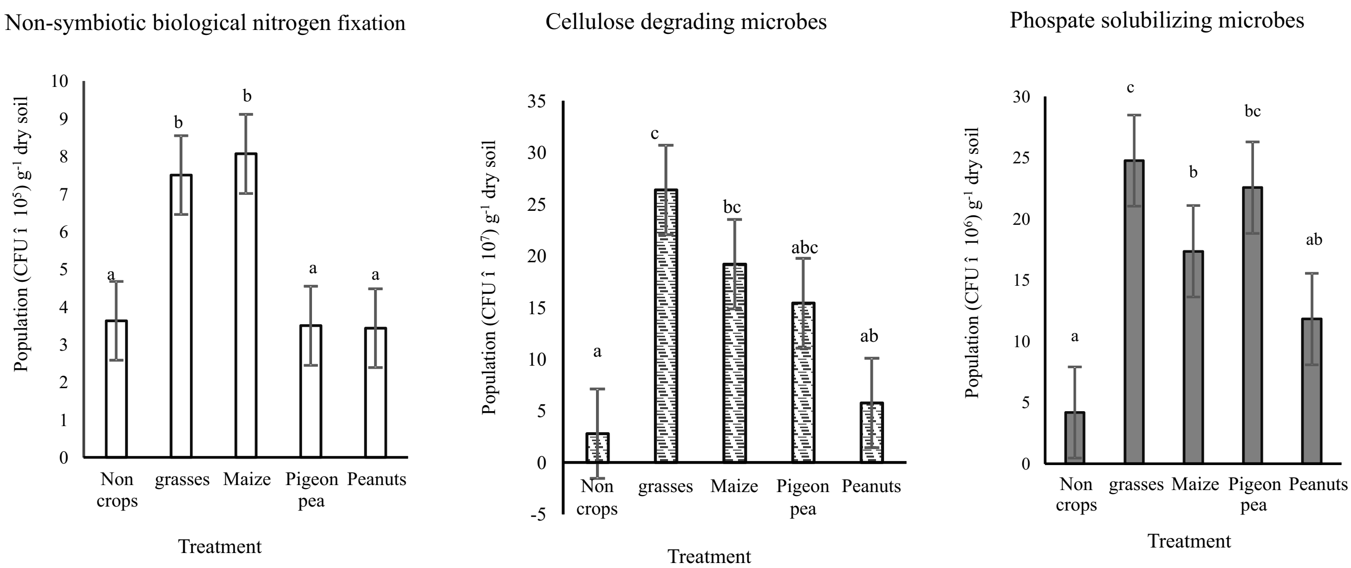

Figure 2 The abundance of functional microbes population.

The population of soil functional microbes The plantation with an agroforestry system may increase the population of soil functional microbes in the rhizosphere of auri (Figure 2). Grasses and maize (i.e., non-legume crops) may increase the population of non-symbiotic N-fixing bacteria. In contrast, legume crops (i.e., pigeon pea & peanut) do not affect the population of the non-symbiotic N-fixers. Grasses may increase the population of CDM significantly, whereas maize, pigeon pea, and peanut are indifferent. While on the PSM population, grasses also give the most significant effect, followed by pigeon pea and maize.

Plants release substances as a cocktail of various compounds that strongly depend on species (*highly species-specific*), as well as determined by specific environment status (*ecotype specific*) (Pierik et al., 2013). The best treatment for root exudates production is maize, followed by peanut and pigeon pea (Figure 3 and Table 2). That is convergent to Wolna-Maruwka et al. (2009) that maize released a huge of, both quality and quantity, root exudates recognized well for growth media of various soil fungi and bacteria. Hence, this study confirms that maize had the best non-symbiotic nitrogen-fixing bacteria and the second-best cellulose-degrading microbes (Figure 2).

Many studies reported that plant species determined soil physicochemical and soil organic quality as well as control structure and composition of soil-microbes communities (Zhang et al., 2011). Figure 2 confirms the evidence that distinct soil-microbes populations colonize different crops. Among those under auri crops, grasses had the most abundant soil functional microbes populations. This is similar to the study of Lindsay et al. (2010) that tree lots dominated by exotic grasses can increase the soil nitrate levels, where the soil microbial communities are involved in their cycling. It can be understood that grasses are the fastest group in turning over soil organic matter (Table 2) into the soil. On the other hand, grasses biomass also has the fastest decomposed by degraders. However, this is contrary to the study results of Zhou et al. (2017) that legume species form a larger soil microbial community than grasses.

Figure 4 compares the abundance of three functional microbes in the rhizosphere of the auri tree with different crops. The data presented are in the logarithmic of the actual population, so they cannot be compared between treatments. The group of CDMs has the highest logarithmic value. The log function is used to make it easier to explain in a table because they are in a really different range. Figure 2 shows that the soil at the study location has an abundance of functional microbes ranging from 10^5–10^8 colony forming unit-cfu g^{-1} of dried soil. The group of PSMs has an abundance range from 10^6–10^7 cfu g^{-1} of dry soil, while the group of BNFs has the lowest abundance (i.e., 10^5 cfu g^{-1} of dry soil).

The relation of soil, microbes, crops *Tree growth* The measurement on auri trees at 1.5 years after planting shows that the average stem diameter (10 cm above ground) was 3.95 cm while the average height was 388.5 cm. The treatments of crops did not seem to have an impact on the growth of the auri at the age of 2 years. Therefore, further observations are needed to be able to see the long-term effect of agroforestry cropping patterns on auri plants.

Root exudates production The improvement of soil properties due to agroforestry, such as the increment of SOM, pH & P-available, may increase the root exudates production that is indicated by the soil sugar availability (Table 2). Among the crop treatment, maize is consistent in improving soil properties, followed by pigeon pea and peanut (i.e., not significantly different between treatments, but significantly different with no crops treatment) (Table 1).

Table 3 shows that all soil property variables are positively correlated. If we assume that the significant relationship between soil property variables is for the correlation value of ≥ 0.55 (Taylor, 1990), thus the SOM, pH, N, P, & K determine the population of functional microbes in the soil that is managed by the auri agroforestry system. The N and K content directly determines root exudates production. In general, the root exudates were not influenced by the soil chemistry condition and the population of soil microbes.

This study demonstrated that the agroforestry system benefits the auri stand, especially by improving the soil C-org content (Table 2), and increasing nutrient availability in soil. This study confirms the previous reports that agroforestry has the ability to (1) enrich soil organic carbon

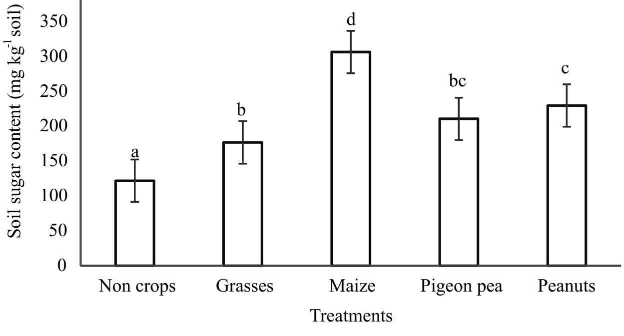

Figure 3 The soil sugar content of some crop treatments.

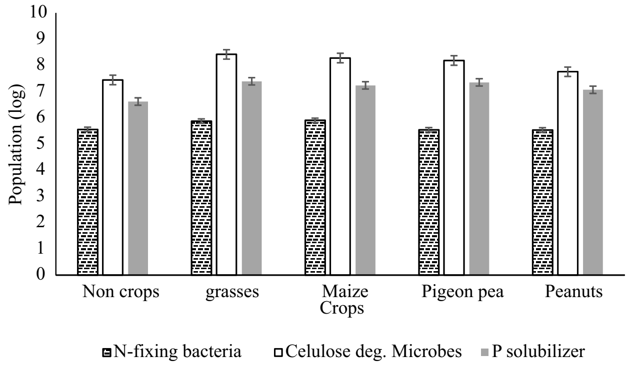

Figure 4 The population of functional microbes in the rhizosphere of auri.

Jurnal Manajemen Hutan Tropika, *28*(2), 119–127, August 2022
EISSN: 2089-2063
DOI: 10.7226/jtfm.28.2.119
Scientific Article
ISSN: 2087-0469

more effectively than monocropping systems, (2) improve soil nutrient availability and soil fertility, and (3) boost soil microbial dynamics, all of which benefit soil health (Dollinger & Jose, 2018). This is also in accordance with Notaro et al. (2014) that agroforestry systems effectively improve the nutrient cycle, increasing the microbial populations and SOM contents.

The treatment observed in this study is the effect of crop types on the improvement of soil properties. Table 1 shows that after two years, auri with an agroforestry system gives a higher organic C content, P-available content, and soil pH compared with the auri monoculture system. The crop culture treatments can increase soil pH to close to neutral. C organics content is a reflection of the SOM status in soil. SOM provides the main energy for food, energy, and settlement for soil microbes in the soil. SOM will be decomposed by degrading microbes into simpler substances. That is shown with the highest population of CDM among other functional microbes in that site (Figure 4). One of the substances derived from SOM decomposition is carbonates that increase soil pH (Table 2). SOM is also mineralized into nutrients, such as P available in soil (Table 2), showing that P available is significant due to crops under the auri stands forming an agroforestry system. An increase in soil pH is checked by SOM decomposition resulting in the release of alkaline cations as a contributor of OH-ions into the soil. Increasing the OH-ion in the soil causes an increase in soil pH (Suwarniati, 2014). Table 3 shows that the correlation between pH and organic C is very high (0.93). The increase of P also comes from the decomposition of organic matter, which produces some nutrients needed by plants, such as N, P, and K (Suwarniati, 2014). This can be seen from a very high correlation (0.99) between the organic C and the available P content (Table 3).

This study shows that the treatment did not significantly affect the N content in the soil (Table 2). This result indicates that N is one of the macronutrients required by all organisms (plants and soil microbes) in large quantities for their development and activities in the soil. The organisms will soon exploit the addition of N content in the soil. In addition, in tropical climates, the decomposition process and mineralization of organic matter in the soil is rapid, and N is a volatile element that will quickly disappear (Suwarniati, 2014). This is shown by a slightly lower correlation value (0.50) between the organic matter content to the soil N content. In this study, the N content that is not significantly different in the various understorey/crops is suspected because the planted trees are legume plants, so N content is predicted to be more dominant derived from N fixation by auri trees. Auri is one of the leguminous plants that can fix a substantial amount of atmospheric nitrogen and augment soil fertility in both monoculture and agroforestry systems (Patiram & Choudhury, 2002). The large amount of N fixed by leguminous trees causes the addition of N from the lower plants to become insignificant. This is in line with the study by Szott and Palm (1984) that in agroforestry, woody perennials can fix nitrogen. Still, the contribution of legumes varies substantially depending on soil, temperature, species, and management.

This study shows that non-leguminous maize and grass can increase non-symbiotic N-fixing microbial populations. In contrast, planting legume crop species results in the lowest population of non-symbiotic BFM, and it is not significantly different from monocultures. Therefore, it is presumed that non-symbiotic BFM fails to compete with the symbiotic BFM associated with the legume tree roots. According to Cai et al. (2009), the roots of leguminous plants (in this study are auri, pigeon pea, or peanuts) secreted canavanine. This compound acts as an antimicrobial for many rhizosphere bacteria but not rhizobia for the selection of beneficial microbes.

The functional microbial (i.e., non-symbiotic BFM, CDM, and PSM) in the agroforestry system increased in population compared to monoculture (Figure 2). The highest population of CDM and PSM was found in auri + grasses, followed by auri + maize, auri + pigeon pea, and auri + peanuts. This is thought to be closely related to the SOM content in the grass treatment having the highest organic C concentration (Table 2).

Comparing the three functional microbial groups, CDM is the dominant group, followed by PSM (Figure 4). This is thought to be related to an increase in the organic soil C content (Table 2). According to Pinho et al. (2012), the increase in organic material content benefits the microbial population because it is in a warm and humid tropical ecosystem, so their population will increase. Soil

Table 3 The correlation between soil property variable

Correlation	C-org	pH	N	P	K	BFM	CDM	PSM	Total sugars
C-org		**0.93**	**0.51**	**0.99**	0.44	**0.60**	**0.94**	**0.93**	0.10
pH			**0.50**	**0.89**	0.40	0.37	**0.83**	**0.96**	0.18
N				**0.60**	**0.78**	**0.81**	**0.70**	**0.56**	**0.76**
P					**0.57**	**0.70**	**0.99**	**0.93**	0.23
K						**0.71**	**0.68**	**0.62**	**0.89**
BFM							**0.80**	**0.50**	0.47
CDM								**0.90**	0.35
PSM									0.35
Total sugars									

Jurnal Manajemen Hutan Tropika, *28*(2), 119–127, August 2022
EISSN: 2089-2063
DOI: 10.7226/jtfm.28.2.119
Scientific Article
ISSN: 2087-0469

microorganisms are important in SOM dynamics and nutrient cycling in agroecosystems. (Ashworth et al., 2017). Increasing the microbial population will accelerate the decomposition of organic materials so that they are mineralized and utilized by plants. Therefore, organisms that cycle carbon in the soil require an organic soil cover in tropical ecosystems. As such, many studies on the effects of trees on tropical soil concentrate on the importance of organic matter (Pinho et al., 2012). According to Raj et al. (2014), soil microbes contribute to nitrogen cycling and other ecosystem processes, and soil functions contribute to ecosystem services. It maintains the population dynamics of beneficial microorganisms and improves biological nitrogen fixation in soil.

In this study, soil pH plays an important role in determining soil microbial population as well as the C organic content in the soil, indicated by the high correlation between the two variables. Referring to Grayton & Campbell (1996), an increase in pH seems to increase root exudation in grasses. The level of soil pH to neutral is the most favorable for bacteria; that is why in the second-rotation forest managed in agroforestry, bacteria have more abundance than others(Grayston & Campbell, 1996).

In this study, the root exudates analyzed focused on total soil sugar (Figure 3) because carbohydrates are the most common compounds found in root exudates. Plant roots release 5%–21% of their photosynthetically fixed carbon as soluble sugars, amino acids, or secondary metabolites to mediate the interactions between plant roots and the microbial communities in the rhizosphere (Huang et al., 2014). Plant roots are likely to attract helpful bacteria by releasing signals (root exudates), containing carbohydrates and amino acids as chemoattractants(Huang et al., 2014).

According to Grayston and Campbell (1996), variation in carbon compounds in the rhizosphere is assumed to cause the diversity of microorganisms associated with trees and their diverse functional capabilities. The substrates responsible for this distinction were carbohydrates and carboxylic acids (Grayston & Campbell, 1996). Diversification of species is also important for diversifying the features of the biomass generated and assimilated in the soil, resulting in a better nutrient mix. This may necessitate the cultivation or management of plants other than legumes (Pinho et al., 2012).

Figure 3 shows that the highest total soil sugar content was found in the auri+maize, followed by auri+peanut and auri+pigeon peaks. It is assumed that other factors could have influenced exudation patterns; hence, microbial diversity is the presence of different mycorrhizal symbionts (Grayston & Campbell, 1996). Maize is naturally an effective endomycorrhizal host.

Soil sugar content in the treatment of grass was not significantly different from the auri monoculture. In this study, the content of SOM is not a determining factor affecting the production of root exudates. The cultivar, plant species, plant developmental stage, and many environmental conditions, such as soil type, pH, temperature, and the presence of microorganisms, all influence the qualitative and quantitative composition of root exudates (Huang et al., 2014). In this study, the auri trees that became the main crop are two years old, so the development stage is not yet optimal. Therefore they are not optimal for building the rhizosphere community.

Meanwhile, the lower crops affect the microbial population (Figure 2). According to Grayston and Campbell (1996), annual herbaceous plants emit a different range of chemicals than trees. They exude more digested carbon into the soil, altering microbial community composition. Plant root exudation is also influenced by microbes established in the rhizosphere, such as fungus and bacteria; the number and identity of root-associated microbes impact plant root exudation rates(Huang et al., 2014).

Soil microbial population will affect nutrient content in the soil. Table 2 shows that N total has a relatively high value, yet it is not significantly different in all treatments (Table 2). It is presumed that N in the soil is derived from N being fixed by auri trees. As it is known, auri is a legume tree species that can fix N_2 from the air in cooperation with the bacteria that form the root nodule of rhizobium. The highest available content of phosphate is present in the grass treatment (Table 2). This is thought to be caused by the high population of solvent microbial P at the treatment (Figure 2), a micro blue capable of mineralizing both inorganic and organic phosphate.

The correlation matrix among variables of soils under different cropping systems showed a highly significant correlation coefficient (Table3). There was increased microbial activity with increased SOM levels. The microbial population is strongly influenced by organic matter content, as indicated by the result of correlation analysis with the value of 0.6 (BFM), 0.94 (CDM), and 0.93 (PSM) (Table 3). Soil microbial population is more determined by organic content, pH of available P content, and K and influenced by other microbial populations. In this study, the three microbes positively correlated from 0.80 to 0.90 (Table 3), showing synergistic interactions. Soil microbial populations are more influenced by organic matter derived from understorey/crop biomes than root exudates (Table 3). This is allegedly due to the auri trees being the initiators of microbe community formation in the rhizosphere is still 2-year-old.

Conclusion

This study concluded that crop species planted under auri trees determine the structure and composition of the rhizosphere community under the agroforestry ecosystem. It is due to different species supplying different total soil sugars into the rhizosphere, hence creating different chemical rhizosphere-soil properties. Our finding suggested that crop selection in agroforestry systems can be used to arrange strategies for specific site improvement, especially soil characteristics. This strategy will give optimum benefit in reducing fertilizer inputs. Considering that this research was conducted on 2 years old Auri agroforestry, the results of this study are relevant to the application of the short cycle (2 years) Auri agroforestry system for the development of biomass energy plantations. The application of the Auri cutting cycle for more than 2 years requires further observation.

Acknowledgment

The authors would like to thank the Research and Development Institute for Agroforestry Technology, which facilitated this research activity. We also thank our fellow technicians who have helped collect data in the field.

References

Abebe, T., Sterck, F., Wiersum, K., & Bongers, F. (2013). Diversity, composition and density of trees and shrubs in agroforestry homegardens in Southern Ethiopia. *Agroforestry Systems*, *87*(6), 1283–1293. https://doi.org/10.1007/s10457-013-9637-6

Araujo, A. S. F., Leite, L. F. C., de Freitas Iwata, B., de Andrade Lira, M., Xavier, G. R., & Figueiredo, M. d. V. B. (2012). Microbiological process in agroforestry systems. A review. *Agronomy for Sustainable Development*, *32*(1), 215–226. https://doi.org/10.1007/s13593-011-0026-0

Asaah, E. K., Tchoundjeu, Z., Leakey, R. R., Takousting, B., Njong, J., & Edang, I. (2011). Trees, agroforestry and multifunctional agriculture in Cameroon. *International Journal of Agricultural Sustainability*, *9*(1), 110–119. https://doi.org/10.3763/ijas.2010.0553

Ashworth, A., de Bruyn, J., Allen, F., Radosevich, M., & Owens, P. (2017). Microbial community structure is affected by cropping sequences and poultry litter under long-term no-tillage. *Soil Biology and Biochemistry*, *114*, 210–219. https://doi.org/10.1016/j.soilbio.2017.07.019

Atangana, A., Khasa, D., Chang, S., & Degrande, A. (2014). Definitions and classification of agroforestry systems. In *Tropical agroforestry* (pp. 35–47). Springer Netherlands. https://doi.org/10.1007/978-94-007-7723-1_3

Bardhan, S., Jose, S., Udawatta, R. P., & Fritschi, F. (2013). Microbial community diversity in a 21-year-old temperate alley cropping system. *Agroforestry systems*, *87*(5), 1031–1041. https://doi.org/10.1007/s10457-013-9617-x

Beuschel, R., Piepho, H.-P., Joergensen, R. G., & Wachendorf, C. (2020). Effects of converting a temperate short-rotation coppice to a silvo-arable alley cropping agroforestry system on soil quality indicators. *Agroforestry Systems*, *94*(2), 389–400. https://doi.org/10.1007/s10457-019-00407-2

Cai, T., Cai, W., Zhang, J., Zheng, H., Tsou, A. M., Xiao, L., …, & Zhu, J. (2009). Host legume-exuded antimetabolites optimize the symbiotic rhizosphere. *Molecular Microbiology*, *73*(3), 507–517. https://doi.org/10.1111/j.1365-2958. 2009.06790.x

Dollinger, J., & Jose, S. (2018, 2018/04/01). Agroforestry for soil health. *Agroforestry Systems*, *92*(2), 213–219. https://doi.org/10.1007/s10457-018-0223-9

Grayston, S. J., & Campbell, C. D. (1996). Functional biodiversity of microbial communities in the rhizospheres of hybrid larch (*Larix eurolepis*) and Sitka spruce (*Picea sitchensis*). *Tree Physiology*, *16*(11–12), 1031–1038. https://doi.org/10.1093/treephys/16.11-12.1031

Guillot, E., Bertrand, I., Rumpel, C., Gomez, C., Arnal, D., Abadie, J., & Hinsinger, P. (2021). Spatial heterogeneity of soil quality within a Mediterranean alley cropping agroforestry system: Comparison with a monocropping system. *European Journal of Soil Biology*, *105*, 103330. https://doi.org/https://doi.org/10.1016/j.ejsobi.2021.103330

Huang, X.-F., Chaparro, J. M., Reardon, K. F., Zhang, R., Shen, Q., & Vivanco, J. M. (2014). Rhizosphere interactions: Root exudates, microbes, and microbial communities. *Botany*, *92*(4), 267–275. https://doi.org/10.1139/cjb-2013-0225

Islam, S. S., Islam, M. S., Hossain, M. A. T., & Alam, Z. (2013). Optimal rotation interval of akashmoni (*Acacia auriculiformis*) plantations in Bangladesh. *Kasetsart Journal of Social Sciences*, *34*(1), 181–190.

Kataki, R., & Konwer, D. (2002). Fuelwood characteristics of indigenous tree species of north-east India. *Biomass and Bioenergy*, *22*(6), 433–437. https://doi.org/10.1016/S0961-9534(02)00026-0

Lindsay, E. A., Colloff, M. J., Gibb, N. L., & Wakelin, S. A. (2010). The abundance of microbial functional genes in grassy woodlands is influenced more by soil nutrient enrichment than by recent weed invasion or livestock exclusion. *Applied Environmental Microbiology*, *76*(16), 5547–5555. https://doi.org/10.1128/AEM.03054-09

Notaro, K. d. A., Medeiros, E. V. d., Duda, G. P., Silva, A. O., & Moura, P. M. d. (2014). Agroforestry systems, nutrients in litter and microbial activity in soils cultivated with coffee at high altitude. *Scientia Agricola*, *71*(2), 87–95. https://doi.org/10.1590/S0103-90162014000200001

Pansu, M., & Gautheyrou, J. (2006). *Handbook of soil analysis. Mineralogical, organic and inorganic methods*. Heidelberg: Springer. https://doi.org/10.1007/978-3-540-31211-6

Patiram, & Choudhury, B. U. (2002). *Role of agroforestry in soil health management*. Retrived from http://www.kiran.nic.in/pdf/publications/Role_of_Agroforestry.pdf

Pierik, R., Mommer, L., & Voesenek, L. A. (2013). Molecular mechanisms of plant competition: Neighbour detection and response strategies. *Functional Ecology*, *27*(4), 841–853. https://doi.org/10.1111/1365-2435.12010

Pinho, R. C., Miller, R. P., & Alfaia, S. S. (2012). Agroforestry and the improvement of soil fertility: A view from Amazonia. *Applied and Environmental Soil Science*, *2012*, 616383. https://doi.org/10.1155/2012/616383

Poeplau, C. (2021). Grassland soil organic carbon stocks along management intensity and warming gradients. *Grass and Forage Science*, *76*(2), 186–195. https://doi.org/10.1111/gfs.12537

Puri, S., & Panwar, P. (2007). *Agroforestry: Systems and practices*. New Delhi: New India Publishing Agency.

Qin, X., Wei, C., Li, J., Chen, Y., Chen, H. S, Zheng, Y., ..., & Wei, J. (2017). Changes in soil microbial community structure and functional diversity in the rhizosphere surrounding tea and soybean. *Journal of Agricultural Sciences*, *12*(1), 113. http://doi.org/10.4038/jas.v12i1.8201

Raj, A., Jhariya, M. K., & Pithoura, F. (2014). Need of agroforestry and impact on ecosystem. *Journal of Plant Development Sciences*, *6*(4), 577–581.

Rivest, D., Paquette, A., Moreno, G., & Messier, C. (2013). A meta-analysis reveals mostly neutral influence of scattered trees on pasture yield along with some contrasted effects depending on functional groups and rainfall conditions. *Agriculture, Ecosystems & Environment*, *165*, 74–79. https://doi.org/10.1016/j.agee.2012.12.010

Singh, K., Gautam, N. N., Singh, B., Goel, V. L., & Patra, D. (2014). Screening of environmentally less-hazardous fuelwood species. *Ecological Engineering*, *64*, 424–429. https://doi.org/10.1016/j.ecoleng.2014.01.013

Smith, J., Pearce, B. D., & Wolfe, M. S. (2013). Reconciling productivity with protection of the environment: Is temperate agroforestry the answer? *Renewable Agriculture and Food Systems*, *28*(1), 80–92. https://doi.org/10.1017/S1742170511000585

Sobola, O., Adeyeye, S., Amadi, D., & Thlama, D. (2015). Comparative study of organic matter content of a tropical soil under three agroforestry tree species. *Trends in Science and Technology Journal*, *1*(1), 9295.

Suwarniati, S. (2014). Pengaruh FMA dan pupuk organik terhadap sifat kimia tanah dan pertumbuhan bunga matahari (*Helianthus annuus* l.) pada lahan kritis. *BIOTIK: Jurnal Ilmiah Biologi Teknologi dan Kependidikan*, *2*(1), 58–69. https://doi.org/10.22373/biotik.v2i1.236

Szott, L. T., & Palm, C. A. (1984). Soil and vegetation dynamics in shifting cultivation fallows. *Proceedings of Symposium on the Humid Tropics* (pp. 360–379). EMBRAPA-CPATU. Retrieved from https://www.infoteca.cnptia.embrapa.br/infoteca/bitstream/doc/393167/1/CPATUDoc36v1.pdf

Taylor, R. (1990). Interpretation of the correlation coefficient: A basic review. *Journal of Diagnostic Medical Sonography*, *6*(1), 35–39. https://doi.org/10.1177/875647939000600106

van Elsas, J. D., Trevors, J. T., Jansson, J. K., & Nannipieri, P. (2006). *Modern soil microbiology*. Florida: CRC Press.

Widyati, E. (2016). Microbial community behaviour in the rhizosphere of *kilemo* (*Litsea cubeba* L. Pers) after pruning. *Jurnal Manajemen Hutan Tropika*, *22*(3), 149–157. https://doi.org/10.7226/jtfm.22.3.149

Wolna-Maruwka, A., Niewiadomska, A., & Klama, J. (2009). Biological activity of grey-brown podzolic soil organically fertilized for maize cultivation in monoculture. *Polish Journal of Environmental Studies*, *18*(5), 931–939.

Zhang, C., Liu, G., Xue, S., & Song, Z. (2011). Rhizosphere soil microbial activity under different vegetation types on the Loess Plateau, China. *Geoderma*, *161*(34), 115–125. https://doi.org/10.1016/j.geoderma.2010.12.003

Zhou, Y., Zhu, H., Fu, S., & Yao, Q. (2017). Metagenomic evidence of stronger effect of stylo (legume) than bahiagrass (grass) on taxonomic and functional profiles of the soil microbial community. *Scientific Reports*, *7*(1), 10195. https://doi.org/10.1038/s41598-017-10613-6