Malaysian Journal of Microbiology, Vol 18(2) 2022, pp. 235-241
DOI: http://dx.doi.org/10.21161/mjm.211275

Malaysian Journal of Microbiology
Published by Malaysian Society for Microbiology
(In SCOPUS since 2011)

SHORT COMMUNICATION

Oil palm intercropping system: A potential nature-based solution to improve soil biology activities in North Sumatra plantation, Indonesia

Fadilla Sapalina*, Rana Farrasati, Dhimas Wiratmoko, Suroso Rahutomo, Heri Santoso, Eko Noviandi Ginting, Iput Pradiko and Fandi Hidayat

Indonesian Oil Palm Research Institute, 20158, Medan, Indonesia.
Email: fadillasapalina@gmail.com

Received 15 August 2021; Received in revised form 21 September 2021; Accepted 24 January 2022

ABSTRACT

Aims: Intercropping system in oil palm plantation is recognized as one of a nature-based solution as well as a promising sustainable practice. This study aimed to observe the advantages of existing intercropping system in one of North Sumatra's oil palm plantation. It is achieved by analyzing the population of soil bacteria and fungi in oil palm intercropping fields with sorghum and cassava, compared with the non-intercropping field that using *Mucuna bracteata* (MB) as a common legume cover crop in oil palm plantations.
Methodology and results: Soil samples were collected from the weeded circle and windrow area (the area between palms within the row). The results showed that the highest and the lowest soil bacteria populations were in sorghum (1.7 ± 1.4 × 10^8 CFU/g) and MB (1.7 ± 0.4 × 10^7 CFU/g), while the highest and the lowest soil fungi populations were in sorghum (4.3 ± 2.9 × 10^6 CFU/g) and cassava (2.1 ± 0.8 × 10^6 CFU/g).
Conclusion, significance and impact of study: The intercropping system in this study showed a significant difference in the bacteria population, while the fungi population had no difference compared to the non-intercropping system. The bacterial and fungi population results also indicate that the intercropping system potentially enhances the soil's biological activity as an indicator of improved soil health. It is also followed by a slightly higher soil organic carbon value in intercropping system. This research suggests that further studies should be done to identify specific soil functional microbes (nutrients fixers and solubilizers). The future research will be used as a reference for promising biofertilizer agents in supporting sustainable crop production.

Keywords: Bacteria, fungi, intercropping, oil palm, soil health

INTRODUCTION

Intercropping is a planting system with two or more types of crops cultivated on the same field (Chimonyo *et al.*, 2015). The benefit of the intercropping system is to optimize the utilization of land resources in one area to obtain a higher yield than the monoculture system. The crop combination system has also been reported to create biological stability; hence it can suppress pests-disease attacks and maintain soil fertility (Rochmah *et al.*, 2020). In addition, intercropping was reported to increase nutrients content in the rhizosphere, enhance soil microbial diversity and quantity (bacteria and fungi), soil enzyme activity, nutrient mobilization and nutrient absorption through interspecific interactions in the rhizosphere (Effendi *et al.*, 2019; Gong *et al.*, 2019; Tang *et al.*, 2019; Dang *et al.*, 2020). Intercropping can effectively increase soil fertility as shown in Zhang *et al.* (2018) study. The intercropping of broccoli and corn successfully improves the diversity of soil functional microbes and soil nutrients (N, P and K).

The intercropping system has also been applied in oil palm plantations. Several studies were conducted using various intercrops such as maize, peanut, soybean, cassava, tomato and pineapple (Fitriana *et al.*, 2019; Kusumawati *et al.*, 2019; Koussihouèdé *et al.*, 2020; Rochmah *et al.*, 2020). Kusumawati *et al.* (2019) revealed that oil palm with corn and soybean intercrops provides additional income for farmers and has no adverse effect on the vegetative growth of the main crop.

One current concern that has not been widely reported in the intercropping system is the dynamics of soil microbe diversity and population, especially soil bacteria and fungi. Soil microbes are one of the indicators that affect soil health and fertility. Microbes play an essential role in soil biogeochemical processes, increase

***Corresponding author**

ISSN (print): 1823-8262, ISSN (online): 2231-7538

the availability of nutrients in the soil, mobilize nutrients from the soil to plants and improve soil structure (Rashid *et al.*, 2016; Li and Wu, 2018). Community and soil microbial diversity are vital to maintain ecosystem biodiversity and soil health and productivity (Li and Wu, 2018). Besides, it is also reported that the transformation of microbial diversity is associated with soil physical and chemical properties (Li and Wu, 2018; Gong *et al.*, 2019; Lian *et al.*, 2019; Li *et al.*, 2020). Therefore, this study aims to analyze the soil microbes (bacteria and fungi) populations in intercropping of oil palm with sorghum and cassava compared to non-intercropping *Mucuna bracteata* (MB) as the common legume cover crop in oil palm plantation (immature stage).

MATERIALS AND METHODS

Time, location and general information of the research site

This study conducted from March to May 2021. The observed parameters are soil sampling for physical and chemical analysis, isolation and enumeration of microbial (bacteria and fungi) and statistical analysis. Soil samples were collected at three fields (block 7, 15 and 17) of oil palm plantations in Laut Tador Village, Tebing Syahbandar District, Tebing Tinggi City, North Sumatra, Indonesia (site; 30 15' 57.692" - 30 17' 22.847"N, 990 12' 47.406 - 990 13' 16.298"E). The land topography was classified as flat to undulating. This area has implemented the intercropping system for approximately one year during the immature stage of oil palm. Oil palm plantations in block 7 (*M. bracteata*) were planted in 2019, block 15 and 17 (intercropping with sorghum and cassava, respectively) were planted in 2020. Sorghum was fertilized with NPK (Nitrogen-Phosphorus-Potassium) fertilizer and Pasopati hormone, while cassava was fertilized with urea and TSP (Triple Super Phosphate) fertilizer. Fertilization of oil palm using RP (Rock Phosphate), borate and urea fertilizer. In block 15 (intercropping with sorghum), beside regular oil palm fertilization, it also combined with additional compost from empty fruit bunches and palm oil mill effluent (POME). Analysis of soil physical and chemical properties, and enumeration of microbial population were carried out at the Laboratory of Soil Science and Agronomy, Palm Oil Research Institute, Medan, North Sumatra.

Soil sampling

Soil sampling was carried out systematically in weeded circle and windrow (the area between palms within the row) from two intercropping blocks and one non intercropping block. The cash crops were sorghum (block 15) and cassava (block 17). In the non-intercropping field, *M. bracteata* (block 7) was grown as a legume cover crop. Soil samples were collected from three blocks with six sites, each site consists of three sites in the weeded circle and three sites in the windrow area (Figure 1). Sampling was done at a soil depth of 0-20 cm (200 g soil sample) (Lisnawita *et al.*, 2020). The soil samples were put into plastic, labeled and stored in cool box.

Analysis of soil physical and chemical properties

Analysis of soil physical and chemical properties was carried out as supporting data in this study. Soil physical properties consist of texture analysis and soil moisture content. Soil texture analysis was determined using a hydrometer and a modification of the Bouyoucos method (Beretta *et al.*, 2014). Soil moisture content was measured by the gravimetric method at 105 °C for 24 h in an oven (Sukhla *et al.*, 2014; Rasti *et al.*, 2020). Analysis of soil chemical properties consists of measuring soil pH and soil organic carbon (SOC). Soil pH was measured using a pH meter (Balai Penelitian Tanah, 2009), while SOC using a spectrophotometric method. A total of 0.05 g of the sample was weighed. Then, 5 mL of 1 N $K_2Cr_2O_7$ and 7 mL of H_2SO_4 were added to the sample. The mixture is boiled and allowed to stand for 30 min. Then, the mixture was diluted with distilled water to 100 mL and it was left overnight. The absorbance was measured using a UV-Visible spectrophotometer with a wavelength of 561 nm (Purbaningtias *et al.*, 2018).

Isolation and enumeration of bacterial and fungal populations

Nutrient agar (NA) is a medium used for the isolation of bacteria. It contains (g/L): peptone 5 g, HM peptone 1.5 g, yeast extract 1.5 g, NaCl 5 g, agar (Himedia) 15 g, while for isolation of fungi using potato dextrose agar (PDA) with the composition of potato infusion 200 g, dextrose 20 g, agar (Himedia) 15 g. The medium was sterilized using an autoclave at 121 °C and at pressure of 0.1 MPa for 15 min. Isolation of bacteria and fungi was performed with serial dilution method from a dilution of 10^{-1} to 10^{-8} (Damodaran *et al.*, 2013; Singh and Mishra, 2013). The last three dilutions (10^{-5} to 10^{-8}) were used to inoculate bacteria and fungi into Petri dishes using the pour plate count method (Singh and Mishra, 2013; Kannan *et al.*, 2018). Then it incubated at 37 °C for 24 h for bacteria and 27 °C for 48 h for fungi (Singh and Mishra, 2013). The enumeration of bacteria and fungi colonies in Petri dishes were counted by colony counter with 30–300 of bacteria colonies and 10-100 of fungi colonies (Saraswati *et al.*, 2007; Sornplang *et al.*, 2011).

The calculation of the total population of bacteria and fungi was refers to Saraswati *et al.* (2007) as follows:

Total population (CFU/g) = (number of colonies × df)/dw

where df, dilution factor in Petri dishes whose colonies are counted and dw, dry weight of soil sample (g) = wet weight × (1 – moisture content)

Statistical analysis

The bacteria and fungi population data were analyzed statistically using R software version 4.1.0 (R Core Team,

ISSN (print): 1823-8262, ISSN (online): 2231-7538

Malays. J. Microbiol. Vol 18(2) 2022, pp. 235-241
DOI: http://dx.doi.org/10.21161/mjm.211275

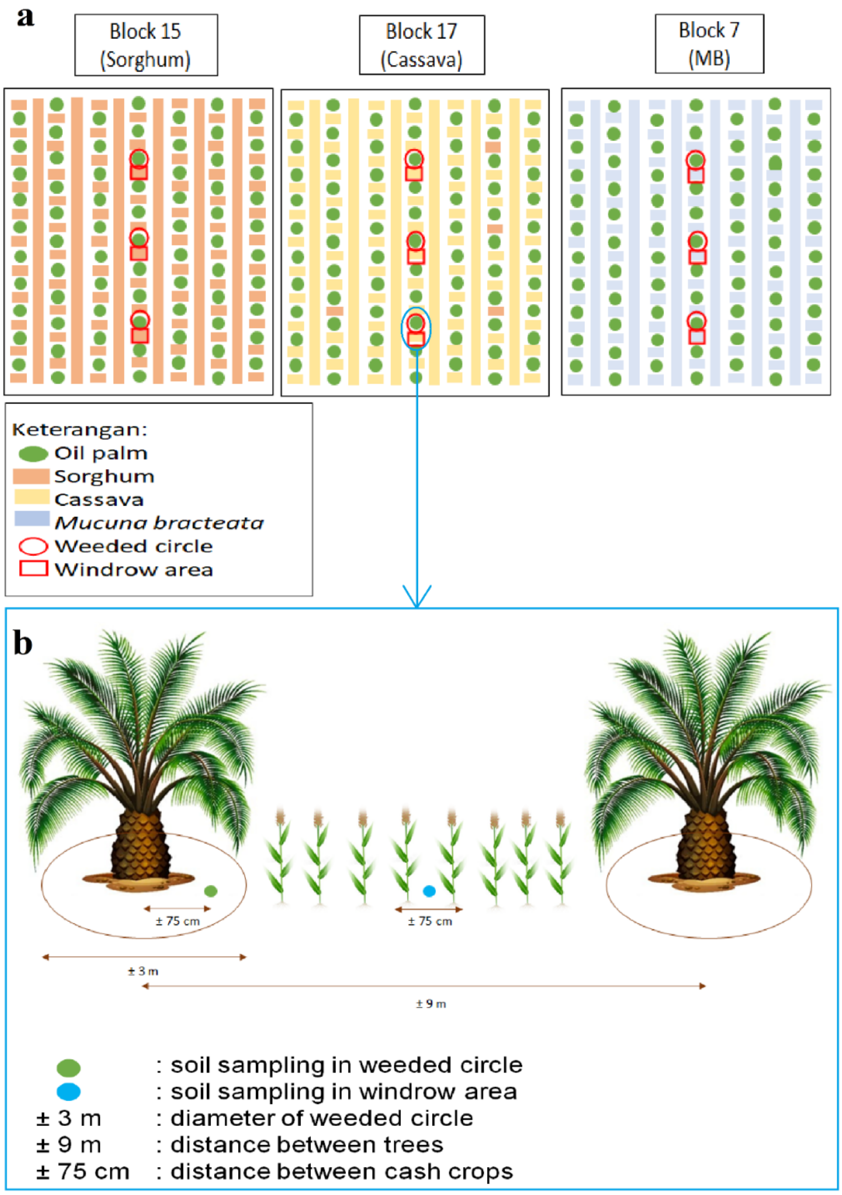

Figure 1: Sampling sites. (a) Square shows soil sampling in three blocks. (b) An example of soil sampling in the weeded circle and windrow area.

2021) with the independent-sample t-test method and the level of significance of 5% (Goh *et al.*, 2020). This analysis aims to determine differences of soil bacteria and fungi population in oil palm fields with sorghum and cassava intercropping while in the non-intercropping area using *M. bracteata* as a legume cover crop.

RESULTS

Soil physical and chemical characteristics

In general, the soil texture on intercropping and non-intercropping fields was relatively similar, although there was a slight variation. The soil texture is dominated by sandy loam texture (Table 1), with the average fractions of sand, silt and clay around 72%, 9% and 19%, respectively. The result of soil moisture content was slightly higher in the windrow area than in a weeded circle (Table 1). Soil pH in this study ranged from 5.3 to 6.3.

Soil bacterial and fungal population

In the weeded circle of MB, sorghum and cassava, soil bacteria populations were 1.7 ± 0.4 × 10^7 CFU/g, 6.7 ± 0.8 × 10^7 CFU/g and 1.7 ± 1.6 × 10^7 CFU/g, respectively. Soil bacteria in windrow area of MB, sorghum and cassava

 ISSN (print): 1823-8262, ISSN (online): 2231-7538

Malays. J. Microbiol. Vol 18(2) 2022, pp. 235-241
DOI: http://dx.doi.org/10.21161/mjm.211275

Table 1: Soil texture, soil moisture content, pH and soil organic carbon in oil palm intercropping field with several cash crops.

Sample	Soil areal	Fraction (%)			Soil texture	Soil moisture content	pH	SOC
		Sand	Silt	Clay				
Mucuna bracteata	Weeded circle	64	11	25	Sandy clay loam	22%	5.6	0.97%
	Windrow area	76	7	17	Sandy loam	25%	5.3	1.16%
Sorghum	Weeded circle	74	11	15	Sandy loam	19%	6.3	1.28%
	Windrow area	68	11	21	Sandy clay loam	22%	6.1	1.09%
Cassava	Weeded circle	74	7	19	Sandy loam	19%	5.8	1.05%
	Windrow area	76	7	17	Sandy loam	20%	5.8	1.16%
Average fraction		72	9	19	Sandy loam			

Table 2: Soil bacteria and fungi populations in oil palm intercropping field with several cash crops.

No	Sample	Soil areal	Bacteria population (CFU/g)	Fungi population (CFU/g)
1	MB	Weeded circle	$1.7 \pm 0.4 \times 10^{7a}$	$3.1 \pm 1.8 \times 10^{6a}$
		Windrow area	$1.7 \pm 0.2 \times 10^{7a}$	$3.6 \pm 1.0 \times 10^{6a}$
2	Sorghum	Weeded circle	$6.7 \pm 0.8 \times 10^{7b}$	$4.3 \pm 2.9 \times 10^{6a}$
		Windrow area	$1.7 \pm 1.4 \times 10^{8b}$	$2.2 \pm 0.3 \times 10^{6a}$
3	Cassava	Weeded circle	$1.7 \pm 1.6 \times 10^{7b}$	$2.1 \pm 0.8 \times 10^{6a}$
		Windrow area	$1.6 \pm 0.1 \times 10^{8b}$	$2.4 \pm 0.8 \times 10^{6a}$

The results of statistical analysis showed that there was a significant difference between the mean population of soil bacteria and no significant difference between the mean population of soil fungi on sorghum and cassava plants compared to MB at significant level of 5%.

were $1.7 \pm 0.2 \times 10^7$ CFU/g, $1.7 \pm 1.4 \times 10^8$ CFU/g and $1.6 \pm 0.1 \times 10^8$ CFU/g, respectively (Table 2). Based on these results, the bacteria population is similar to Pandey *et al.* (2019), which ranged from 10^6-10^8 CFU/g. The intercropping sorghum with legumes reached 3.3×10^8 CFU/g, while cassava plantations ranged from 2×10^6 to 6×10^6 CFU/g.

On the other hand, the fungi population in weeded circle with sorghum was $4.3 \pm 2.9 \times 10^6$ CFU/g, while in MB and cassava were $3.1 \pm 1.8 \times 10^6$ CFU/g and $2.1 \pm 0.8 \times 10^6$ CFU/g. In windrow area, the fungi population of MB, cassava and sorghum were $3.6 \pm 1.0 \times 10^6$ CFU/g, $2.4 \pm 0.8 \times 10^6$ CFU/g and $2.2 \pm 0.3 \times 10^6$ CFU/g, respectively (Table 2). These number are higher than soil fungi population in the intercropping field of sorghum and legumes conducted by Pandey *et al.* (2019) and Sule and Oyeyiola (2012) which are 2.7×10^5 CFU/g and 1.0×10^3-4.6×10^3 CFU/g.

DISCUSSION

Intercropping of oil palm with cassava and sorghum was carried out in this study. These two crops were chosen because cassava is one of the most important sources of food energy in many tropical countries (Benti *et al.*, 2020). In addition, sorghum can be produced with satisfactory yields and in dry and fragile ecological conditions where production of other crops is difficult (Duvvada and Maitra, 2020). Statistical analysis between sorghum and cassava compared to MB showed a significant difference for the mean value of the bacteria population. Meanwhile, the fungi population did not show a significant difference. The higher adaptability of bacteria than fungi could be one of the factors that affect this event. It is in line with the research of Gong *et al.* (2019) and Jiao *et al.* (2021), who reported that intercropping had a more significant impact on the diversity of soil bacteria rather than fungi because bacteria had a higher sensitivity for adaptability. In general, the population of soil bacteria is greater than the fungi population, Schmitz (2021) reported that one gram of soil can contain 10^7-10^8 CFU/g bacteria and 10^5-10^6 fungi CFU/g.

The soil bacteria and fungi population in the windrow area tends to be higher than in the weeded circle of oil palm. This is presumably due to relatively higher soil moisture content and SOC (soil organic carbon) in the windrow area. Soil moisture content directly affects the availability of water for plants and microbes (Yan *et al.*, 2015), while SOC is a substrate to support the growth and development of soil microbial (Araujo *et al.*, 2012). However, the soil fungi population in sorghum is higher in the weeded circle. The SOC content might influence this condition due to the addition of empty fruit bunches in the weeded area. This opinion is in line with several studies that reported that adding oil palm empty fruit bunches (EFB) could increase the SOC content (Farrasati *et al.*, 2019; Harahap *et al.*, 2020; Jacobs *et al.*, 2020). However, it is known that the addition of EFB is only found in oil palm intercropping fields with sorghum (Figure 2).

Another interesting finding is the SOC between MB and cassava showed a similar value which is 1.16% but not in sorghum. The SOC content in the weeded circle and windrow area was not much different but tended to

Figure 2: Oil palm with the addition of empty fruit bunches in weeded circle (a) and sorghum planted in windrow area (b) (Photo by: Edy Sigit Sutarta - IOPRI).

be lower in the weeded circle, except for sorghum because of the addition of oil palm empty fruit bunches. Reduction of organic carbon in agricultural land caused excessive use of inorganic fertilizers and pesticides, tillage and loss of biomass due to harvesting (Farrasati *et al.*, 2019). Syarovy *et al.* (2021) mentioned that the utilization of MB as a cover crop increased soil organic matter. SOC content in all soil ranged from 0.97-1.28% (Table 1). Plants can still grow, even though the obtained SOC is low. According to Santoso *et al.* (2010), the SOC content is classified as low. It is because the intercropping system was only applied for one year and the MB did not cover 100% of the observed area.

The soil pH range from 5.3 to 6.3 in this study was considered the optimum condition for soil bacteria and fungi growth. It is also suitable for oil palm growth, as stated by Pahan (2015) that the optimum soil pH for oil palm cultivation is around 5.0-5.5 and for the intercrops like sorghum, cassava and MB (Butchee *et al.*, 2012; Howeler, 2014). The pH range for bacteria growth is 5-9 with an optimum pH of 7 (Basu *et al.*, 2015) and pH between 1-9 for fungi, optimum pH of 4-6 (Saranraj and Stella, 2013). The soil pH in the weeded circle is higher than the windrow area. It is presumably related to the concentration of chemical fertilizers, especially rock phosphate, which is higher in the weeded circle than the windrow area. Rock phosphate can increase soil pH, as reported by Ginting *et al.* (2020). On the other hand, soil texture is relatively similar in all observed blocks and does not directly affect the microbial populations (Seaton *et al.*, 2020).

Furthermore, the soil bacteria and fungi population variation in different intercropping crops can be influenced by underground biological processes. Araujo *et al.* (2012) reported that microbial diversity in the soil could be affected by root exudates, availability of carbon material, and substrates such as amino acids, sugars and organic acids that are important for microbial energy needs. Wang *et al.* (2021) added that several plant species could produce secondary metabolites in their root systems, which encourage the interactions between roots and soil microbes and affect the structure and community of soil microbes.

Sorghum produces a secondary metabolite called sorgoleone. These exudates can stimulate certain microbe growth, form microbial communities in the rhizosphere and provide nutrients for microbes (Wang *et al.*, 2021). Research by Sarr *et al.* (2021) explained that sorgoleone production increased the association between sorghum with fungi and arbuscular mycorrhizae. Meanwhile, according to Frediansyah (2021), there has been no specific research about microbes in response to exudate production in cassava plants. Therefore, besides the availability of soil organic matter, the production of root exudates by sorghum provides a greater and preferable growing environment for soil bacteria and fungi than in cassava intercrops.

CONCLUSION

The intercropping system of sorghum and cassava during immature stage of oil palm in this study were shown to increase the soil bacterial population in windrow and weeded circle compared to the common cover crop *M. bracteata*. On the contrary, the fungi population in the intercropping (sorghum and cassava) and non-intercropping system is relatively similar. Therefore, it can be said that the intercropping system can be a promising nature-based solution to enhance soil health in oil palm plantation. Further research needs to be done to observe the soil quality improvement in long term intercropping system implementation. In addition, the urge to identify functional bacteria and fungi populations which will potentially enhance sustainability in crop production and soil health of the oil palm intercropping field is also required. This information can be used as a reference for selecting most preferable intercropping crops that are economically and ecologically beneficial.

REFERENCES

Araujo, A., Leite, L., De Iwata, B., De Lira, M., Xavier, G. and Do Figueiredo, M. (2012). Microbiological process in agroforestry systems. A review. *Agronomy for Sustainability Development* **32(1), 215-226.**

Balai Penelitian Tanah. (2009). Analisis Kimia Tanah, Tanaman, Air, dan Pupuk. Balai Penelitian Tanah, Bogor.

Basu, S., Bose, C., Ojha, N., Das, N., Das, J., Pal, M. and Khurana, S. (2015). Evolution of bacterial and fungal growth media. *Bioinformation* **11(4), 182-184.**

Benti, G., Degafa, G., Jafar, M. and Birhanu, H. (2020). Effect of cassava intercropping with legume crops followed by sorghum on growth, yield and yield parameters of cassava-based double cropping system. *Plant* **8(2), 37-42.**

Beretta, A. N., Silbermann, A. V., Paladino, L., Torres, D., Bassahun, D., Musselli, R. and García-Lamohte, A. (2014). Soil texture analyses using a hydrometer: Modification of the Bouyoucos method. *Ciencia e Investigacion Agraria* **41(2), 263-271.**

Malays. J. Microbiol. Vol 18(2) 2022, pp. 235-241
DOI: http://dx.doi.org/10.21161/mjm.211275

Butchee, K., Arnall, D. B., Sutradhar, A., Godsey, C., Zhang, H. and Penn, C. (2012). Determining critical soil pH for grain sorghum production. *International Journal of Agronomy* **2012, Article ID 130254.**

Chimonyo, V. G. P., Modi, A. T. and Mabhaudhi, T. (2015). Perspective on crop modelling in the management of intercropping systems. *Archives of Agronomy and Soil Science* **61(11), 1511-1529.**

Damodaran, T., Sah, V., Rai, R. B., Sharma, D. K., Mishra, V. K., Jha, S. K. and Kannan, R. (2013). Isolation of salt tolerant endophytic and rhizospheric bacteria by natural selection and screening for promising plant growth-promoting rhizobacteria (PGPR) and growth vigour in tomato under sodic environment. *African Journal of Microbiology Research* **7(44), 5082-5089.**

Dang, K., Gong, X., Zhao, G., Wang, H., Ivanistau, A. and Feng, B. (2020). Intercropping alters the soil microbial diversity and community to facilitate nitrogen assimilation: A potential mechanism for increasing proso millet grain yield. *Frontiers in Microbiology* **11, 601054.**

Duvvada, S. K. and Maitra, S. (2020). Sorghum-based intercropping system for agricultural sustainability. *Indian Journal of Natural Science* **10(60), 20306-20313.**

Effendi, Y., Pambudi, A., Sasaerila, Y. and Wijihastuti, R. S. (2019). Metagenomic analysis of diversity and composition of soil bacteria under intercropping system *Hevea brasiliensis* and *Canna indica*. *IOP Conference Series: Earth and Environmental Science* **391, 012023.**

Farrasati, R., Pradiko, I., Rahutomo, S., Sutarta, E. S., Santoso, H. and Hidayat, F. (2019). C-organik tanah di perkebunan kelapa sawit sumatera utara : Status dan hubungan dengan beberapa sifat kimia tanah. *Jurnal Tanah Dan Iklim* **43(2), 157-165.**

Fitriana, M. H. S., Koesmaryono, Y., Impron and Hidayat, T. (2019). Penggunaan mulsa reflektif pada sistem tumpangsari kedelai-kelapa sawit. *Agromet* **33(2), 71-83.**

Frediansyah, A. (2021). The microbiome of cassava (*Manihot esculanta*). *In*: Cassava: Biology, Production, and Use. Frediaansyah, A. (ed.). IntechOpen, London.**pp. 1-17.**

Ginting, E. N., Pradiko, I., Farrasati, R. and Rahutomo, S. (2020). Pengaruh rock phosphate dan dolomit terhadap distribusi perakaran tanaman kelapa sawit pada tanah ultisols. *Agrikultura* **31(1), 32-41.**

Goh, C. H., Loh, T. C., Foo, H. L. and Nobilly, F. (2020). Fecal microbial population and growth in broiler fed organic acids and palm fat-composed diet. *Tropical Animal Science Journal* **43(2), 151-157.**

Gong, X., Liu, C., Li, J., Luo, Y., Yang, Q., Zhang, W., Yang, P. and Feng, B. (2019). Responses of rhizosphere soil properties, enzyme activities and microbial diversity to intercropping patterns on the Loess Plateau of China. *Soil and Tillage Research* **195, 104355.**

Harahap, F. S., Walida, H., Rahmaniah, Rauf, A., Hasibuan, R. and Nasution, A. P. (2020). Pengaruh aplikasi tandan kosong kelapa sawit dan arang sekam padi terhadap beberapa sifat kimia tanah pada tomat. *Agrotechnology Research Journal* **4(1), 1-5.**

Howeler, R. (2014). Sustainable Soil and Crop Management of Cassava in Asia: A Reference Manual. International Center for Tropical Agriculture and The Nippon Foundation in Tokyo, Japan.

Jacobs, A., Poeplau, C., Weiser, C., Fahrion-Nitschke, A. and Don, A. (2020). Exports and inputs of organic carbon on agricultural soils in Germany. *Nutrient Cycling in Agroecosystems* **118, 249-271.**

Jiao, P., Li, Z., Yang, L., He, J., Chang, X., Xiao, H., Nie, X. and Tong, D. (2021). Bacteria are more sensitive than fungi to moisture in eroded soil by natural grass vegetation restoration on the Loess Plateau. *Science of the Total Environment* **756, 143899.**

Kannan, M. N., Sethi, S., Badoni, A., Chamoli, V. and Bahuguna, N. C. (2018). Isolation and characterization of bacterial isolates from agriculture field soil of Roorkee region. *Journal of Pharmacognosy and Phytochemistry* **5, 108-110.**

Koussihouèdé, H., Aholoukpè, H., Adjibodou, J., Hinkati, H., Dubos, B., Chapuis-Lardy, L., Barthès, B. G., Amadji, G. and Clermont-Dauphin, C. (2020). Comparative analysis of nutritional status and growth of immature oil palm in various intercropping systems in southern Benin. *Experimental Agriculture* **56(3), 371-386.**

Kusumawati, S. A., Yahya, S., Hariyadi, Mulatsih, S. and Istina, I. N. (2019). Analisis pendapatan usahatani tumpangsari pada peremajaan kebun kelapa sawit rakyat. *Buletin Palma* **20(1), 45-56.**

Li, N., Gao, D., Zhou, X., Chen, S., Li, C. and Wu, F. (2020). Intercropping with potato-onion enhanced the soil microbial diversity of tomato. *Microorganisms* **8(6), 834.**

Li, S. and Wu, F. (2018). Diversity and co-occurrence patterns of soil bacterial and fungal communities in seven intercropping systems. *Frontiers in Microbiology* **9, 1521.**

Lian, T., Mu, Y., Jin, J., Ma, Q., Cheng, Y., Cai, Z. and Nian, H. (2019). Impact of intercropping on the coupling between soil microbial community structure, activity, and nutrient-use efficiencies. *PeerJ* **7, e6412.**

Lisnawita, Safni, I., Lubis, K., Nurliana and Fadly, F. (2020). Abundance and diversity of bacteria associated with healthy and infected oil palm rhizosphere of *Ganoderma boninense* in Bahilang, North Sumatra. *IOP Conference Series: Earth and Environmental Science* **454, 012181.**

Pahan, I. (2015). Panduan Teknis Budidaya Kelapa Sawit untuk Praktisi Perkebunan. Penebar Swadaya, Jakarta.

Pandey, V., Gautam, P. and Singh, A. P. (2019). Study of microbial count in soil under different land use systems in a Mollisol. *International Journal of Current Microbiology and Applied Sciences* **8(1), 16-21.**

Purbaningtias, T. E., Qayyumah, N. B., Kurniawati, P., Wiyantoko, B. and Widati, A. A. (2018). Comparative analysis method of C-organic in fertilizers by gravimetry and spectrophotometry. *AIP Conference Proceedings* **2026(1), 020055.**

R Core Team. (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rashid, M. I., Mujawar, L. H., Shahzad, T., Almeelbi, T., Ismail, I. and Oves, M. (2016). Bacteria and fungi can contribute to nutrients bioavailability and aggregate formation in degraded soils. *Microbiological Research* **183(1), 26-41.**

Rasti, A., Pineda, M. and Razavi, M. (2020). Assessment of soil moisture content measurement methods: Conventional laboratory oven versus halogen moisture analyzer. *Journal of Soil and Water Science* **4(1), 151-160.**

Rochmah, H. F., Suwarto, S. and Muliasari, A. A. (2020). Optimasi lahan replanting kelapa sawit dengan sistem tumpangsari jagung (*Zea mays* L) dan kacang tanah (*Arachis hypogaea*). *Jurnal Simetrik* **10(1), 256-262.**

Santoso, H. Wiratmoko, D., Sutarta, E. S. and Sugiyono. (2010). Analisis kuantitatif dan spasial untuk menentukan indeks kesuburan tanah di kebun Dolok Ilir PT. Perkebunan Nusantara IV. *Jurnal Penelitian Kelapa Sawit* **18(1), 1-10.**

Saranraj, P. and Stella, D. (2013). Fungal amylase - A review. *International Journal of Microbiological Research* **4(2), 203-211.**

Saraswati, R., Husen, E. and Simanungkalit, R. D. M. (2007). Metode Analisis Biologi Tanah. Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian, Bogor.

Sarr, P. S., Nakamura, S., Ando, Y., Iwasaki, S. and Subbarao, G. V. (2021). Sorgoleone production enhances mycorrhizal association and reduces soil nitrification in sorghum. *Rhizosphere* **17, 100283.**

Schmitz, B. (2021). Visualizing soil microorganisms via the contact slide assay and microscopy. Environmental Microbiology. JoVE Science Education Database: https://www.jove.com/v/10053/visualizing-soil-microorganisms-via-contact-slide-assay

Seaton, F. M., George, P. B. L., Lebron, I., Jones, D. L., Creer, S. and Robinson, D. A. (2020). Soil textural heterogeneity impacts bacterial but not fungal diversity. *Soil Biology and Biochemistry* **144, 107766.**

Singh, A. P. and Mishra, S. (2013). Isolation and biochemical characterization of antibiotic producing microorganism from waste soil samples of certain industrial areas of India. *IOSR Journal of Pharmacy and Biological Sciences* **5(6), 80-89.**

Sornplang, P., Leelavatcharamas, V., Sukon, P. and Yowarach, S. (2011). Antibiotic resistance of lactic acid bacteria isolated from a fermented fish product, Pla-chom. *Research Journal of Microbiology* **6(12), 898-903.**

Sukhla, A., Panchal, H., Mishra, M., Patel, P. R., Srivastava, H. S., Patel, P. and Shukla, A. K. (2014). Soil moisture estimation using gravimetric technique and FDR probe technique : A comparative analysis. *American International Journal of Research in Formal, Applied and Natural Sciences* **8, 89-92.**

Sule, I. O. and Oyeyiola, G. P. (2012). Fungal population in the root region of cassava cultivar TMS 30572. *World Journal of Agricultural Sciences* **8(1), 73-79.**

Syarovy, M., Santoso, H. and Sembiring, D. S. (2021). Pertumbuhan tanaman kelapa sawit pada lahan dengan tanaman penutup tanah *Mucuna bracteata* yang tidak terawat dan alang-alang (Imperata cylindrica). *Warta PPKS* **26(1), 46-54.**

Tang, X., Luo, S., Huang, Z., Wu, H., Wang, J., Shi, G., He, L., Xiong, F., Jiang, J., Liu, J., Liao, G., Tang, R. and He, L. (2019). Changes in the physicochemical properties and microbial communities of rhizospheric soil after cassava/peanut intercropping. *BioRvix* doi: https://doi.org/10.1101/570937

Wang, P., Chai, Y. N., Roston, R., Dayan, F. E. and Schachtman, D. P. (2021). The *Sorghum bicolor* root exudate sorgoleone shapes bacterial communities and delays network formation. *mSystems* **6(2), e00749-20.**

Yan, N., Marschner, P., Cao, W., Zuo, C. and Qin, W. (2015). Influence of salinity and water content on soil microorganisms. *International Soil and Water Conservation Research* **3(4), 316-323.**

Zhang, X., Ning, T., Han, H., Sun, T., Li, G., Li, Z. and Lal, R. (2018). Effects of waxy maize relay intercropping and residue retention on rhizosphere microbial communities and vegetable yield in a continuous cropping system. *Pedosphere* **28(1), 84-93.**

 ISSN (print): 1823-8262, ISSN (online): 2231-7538