BIODIVERSITAS
Volume 23, Number 7, July 2022
Pages: 3793-3807

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d230756

The physical, chemical, and biological characteristics of microhabitats inside oil palm trunk axils in North Sumatra, Indonesia

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Manuscript received: 13 April 2022. Revision accepted: 29 June 2022.

Abstract. *Pradiko I, Farrasati R, Rahutomo S, Sapalina F, Pane RDP, Hidayat F, Ginting EN. 2022. The physical, chemical, and biological characteristics of microhabitats inside oil palm trunk axils in North Sumatra, Indonesia. Biodiversitas 23: 3793-3807.* Above-ground ecosystems (AGE) components in oil palm plantations consist of epiphytic plants and fauna in microhabitat within the axil of pruned fronds. This research aimed to identify the characteristics of microhabitat, including microclimate profile, physical and chemical properties of the material deposit, epiphyte abundance, and microbe population. The study sites were located in the eastern and western regions of North Sumatra. Furthermore, vertical observations were taken on oil palm trunks at the height of 20, 100, 150, 200, and 300 cm. The study indicated that the microclimate, nutrients content, physical properties of the material deposit, and bacterial populations in the trunk axils of oil palm in the eastern differed from the western region. There was no obvious pattern in the microclimate profile for individual oil palms. However, there was a change in N, C-organic, and C/N ratios with the increasing height of microhabitat sites. In terms of abundance, *Nephrolepis bisserata* and *Vittaria ensiformis* epiphytes were more dominant in the upper and bottom trunk, respectively. The microhabitat at the bottom trunk had a denser bacterial population, negatively correlated with N, C-organic, C/N ratio, Mg, and pH.

Keywords: Leaf pockets, material deposit, microhabitat, oil palm, understory vegetation

INTRODUCTION

Oil palm plantation expansion and intensification significantly modify surface and underground ecosystems become Indonesian's main commodities (Ashton-Butt et al. 2018; Arifiyanto et al. 2017). Ecosystem changes are frequently linked to a decline in soil biota population, biodiversity, soil carbon, and increased greenhouse gas emissions (Barnes et al. 2014; Van Straaten et al. 2015). The soil biota was singled out due to their critical role in the ecosystem, including organic matter decomposition, nutrient mineralization, soil structure formation, and plant growth support (Bardgett and Van Der Putten 2014). Meanwhile, biodiversity depletion is mainly caused by a reduction in the structural complexity and variability of vegetation, microclimate variations, and changes in the physical and chemical properties of the underlying soil (Luke et al. 2020). In the early stages of oil palm planting, high biodiversity in the above-ground ecosystem (AGE) may compensate for the declining population (Potapov et al. 2020).

AGE components include epiphytic plants, macrofauna, and microbes in the pruned frond or trunk axils (leaf pockets). The unique configuration of the leaf pocket causes a small basin to accumulate litter from oil palm reproductive organs and the decayed epiphytic plants (Potapov et al. 2020). Decomposed organic contents trapped in the leaf pocket are known as material deposits (Mildaryani et al. 2019), canopy (Allen et al. 2018), or suspended soils (Eskov et al. 2021). The axils can also intercept rain, providing a water source for epiphytic plants (Tarigan et al. 2018; Luke et al. 2019). The material deposit and the microclimate environment in the trunk's axils form a microhabitat for maintaining the existence of flora and fauna.

Material deposit is a medium for most epiphytic plants to grow on oil palm trunks. Vascular epiphytes are commonly attached to the oil palm stem (Suzanti et al. 2016), where microfauna, mesofauna, macrofauna, and different types of amoeba, are also observed (Potapov et al. 2020). Each material deposits microbiome will differ from terrestrial soils (Eskov et al. 2021). Material deposits have unique microbial biodiversity (Zytynska et al. 2011) than tropical terrestrial soils (Lindo and Winchester 2007). The presence of flora and fauna in the microhabitat contributes to AGE biodiversity in oil palm plantations (Ganser et al. 2017). Moreover, material deposits can supply many ecosystem services related to nutrient cycles (Potapov et al. 2020).

The microhabitat characteristics in the leaf pockets are still largely unexplored. Information on these topics is required to understand and maintain the AGE sustainability of oil palm plantations. This research aimed to determine the physical and chemical properties of the material deposit, as well as the microclimate within the trunk's axils. The types of epiphytes were also studied with the total number of microbes. Additionally, detailed observations of the microhabitat characteristics were conducted at various height levels in several locations, including the eastern and western parts of North Sumatra, Indonesia, with varying climatic conditions.

MATERIALS AND METHODS

Study area

The research was conducted at five oil palm plantations owned by the Indonesian Oil Palm Research Institutes (IOPRI) from October 2020 to April 2021 (Figure 1). The sites were at Bukit Sentang (BS, ±5 m a.s.l) and Pulau Maria (PA, ±23 m a.s.l) for the eastern region of North Sumatera, then, Padang Mandarsah (PM, ±195 m a.s.l), Simirik (SM, ±583 m a.s.l), and Pargarutan (PG, ±555 m a.s.l) to represent the western part. The eastern region is at low elevation, while the western part is mid to high elevation. Climate data for the last 11 years was obtained from The Prediction of Worldwide Energy Resource (POWER) dataset from the National Aeronautics and Space Administration (NASA 2021). The secondary data was calibrated with the nearest climate station. Climate conditions in the sites are presented in Figure 2. The eastern region tends to have higher air temperature, humidity, and lower solar radiation than the western region. Furthermore, the eastern region's annual rainfall is lower than that of the western region (Figure 2A-2F).

Procedures

Microclimate measurement

A block of oil palm of the same age was randomly selected at each study site. The ages observed were 15, 17, and 24 years at BS, 15 years at PA, 15 and 16 years at PM, 15 years at SM, and 19 years at PG. Furthermore, ten palms in the middle of the block were randomly selected to observe material deposits, epiphyte, and bacterial populations. In particular, one out of ten was used for the microclimate observation, and five portable digital thermohydrometers were installed inside trunks' axils at 20, 100, 150, 200, and 300 cm above the soil surface. Air temperature (T) and relative humidity (RH) were observed for two days at 06:00, 12:00, 18:00, and 24:00. Vapor pressure deficit (VPD) was estimated from T and RH using the method provided by Murray (1967).

The results of two days microclimate measurements were used as the basis for estimating microclimate conditions from climate data. The climate data used is hourly data for the site between January 2010 and March 2021 obtained from NASA (2021). The coefficient of determination (R^2) of the microclimate estimation model from the climate data in this study is mostly above 60%. The R2 value of the micro-temperature estimation model ranges from 64.63% to 98.10%. Meanwhile, the R^2 value of the micro-RH estimation model ranged from 30.80% to 89.60%. The microclimate data is presented in Figure 4.

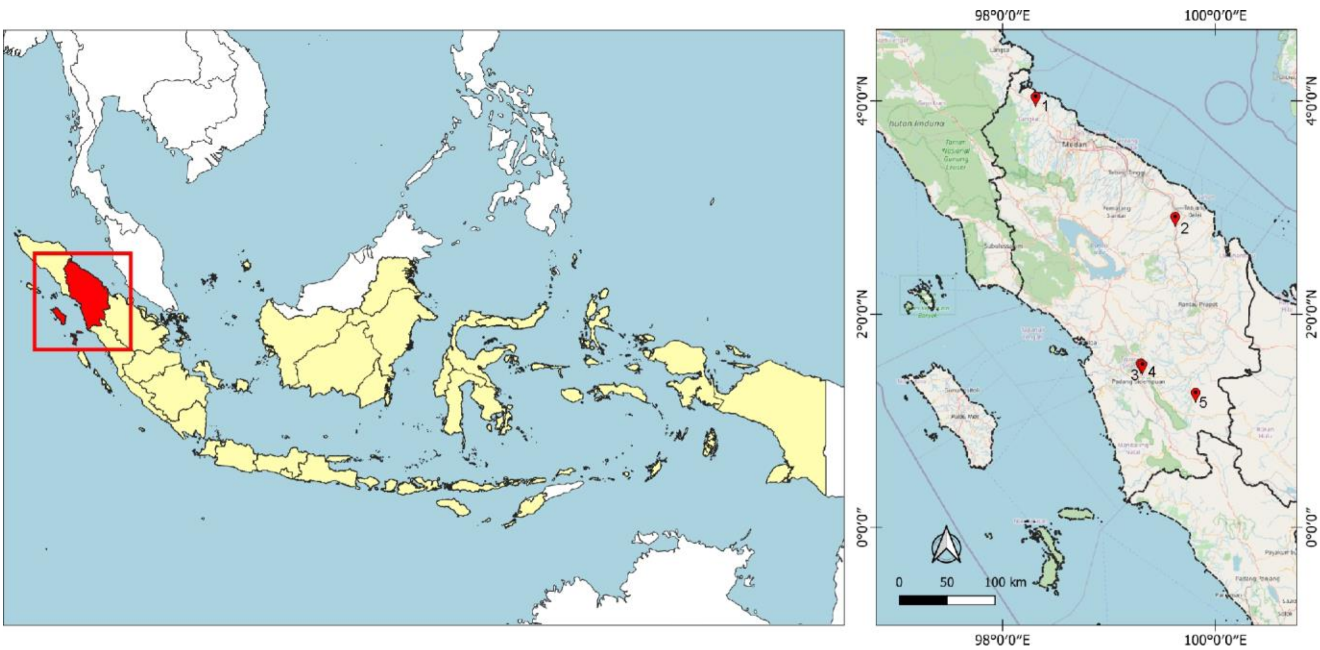

Figure 1. The oil palm plantations where the study sites are located in North Sumatra: 1. Bukit Sentang (BS); 2. Pulau Maria (PA); 3. Simirik (SM); 4. Pargarutan (PG); and 5. Padang Mandarsah (PM)

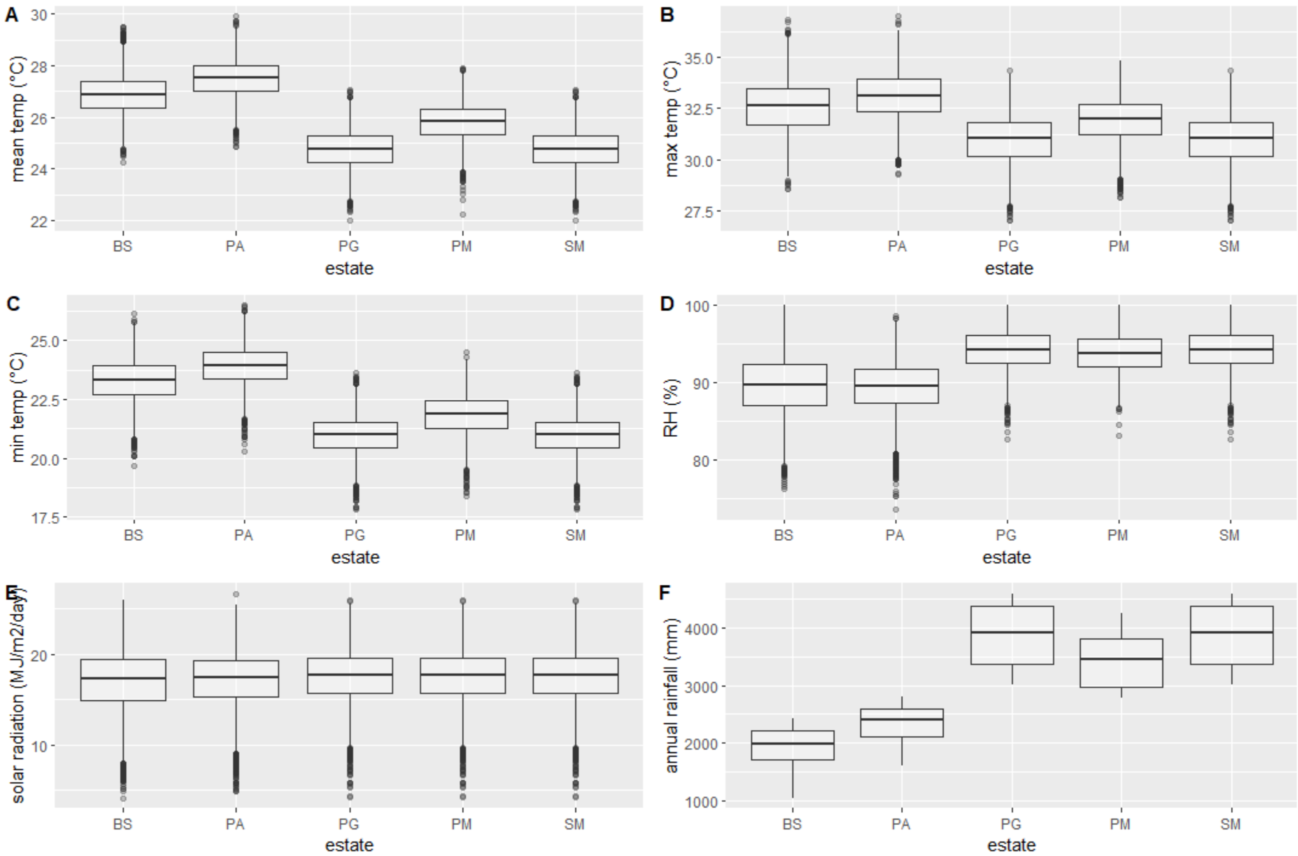

Figure 2. Mean, maximum, and minimum air temperature (A to C), relative humidity (D), solar radiation (E), and annual rainfall (F) in the five estates (BS: Bukit Sentang, PM: Padang Mandarsah, PA: Pulau Maria, SM: Simirik, and PG: Pargarutan)

Physical and chemical analysis of material deposits

The samples of material deposits were composited from the ten selected palms. The samples were collected from the axils at 100, 200, and 300 cm above the soil surface. They were then delivered to the IOPRI lab for bacterial populations with physical and chemical properties analysis. The chemical properties cover water content, pH, the content of N, P, K, Ca, Mg, C-organic, cation exchange capacity (CEC), and C/N ratio. The N-content was analyzed with the Kjeldahl method, P_2O_5 and K_2O with 25% 1N HCl, exchangeable bases (Ca, Mg, K), and cation exchange capacity (CEC) with 1N NH_4OAc pH 7, as well as soil organic carbon (SOC) by the Walkley and Black method. The gravimetric method was employed to compute water content, and a pH meter was used to measure pH. Meanwhile, the bacterial population in the material deposits were calculated using the plate count method (Nannipieri et al. 2017; Damodaran et al. 2013).

Epiphytes abundance

The abundance was identified by observing the fresh epiphytes attached to oil palm trunks at a height of 20-300 cm above the soil surface. The samples were collected and stored in a plastic bag before being delivered to the IOPRI lab. Furthermore, they were cleaned, sprayed with 70% alcohol, and placed on newspaper sheets in the lab. The pieces were clamped, pressed, and stored in a dry place for 1-2 weeks. The samples were then transferred to A3 paper and labeled with their respective classifications. The epiphytes were identified by comparing the specimens with literature studies and data banks from the Global Biodiversity Information Facility/GBIF (GBIF 2021). Additionally, all epiphyte-infested palms in the sample were documented. The abundance was classified into low (<20%), rare (21-40%), abundant (41-70%), and very abundant (>70%) (Sofiyanti 2013).

Bacteria populations

The bacterial populations were also calculated from the material deposit at the height of 100, 200, and 300 cm from composites of ten sample palms. The calculation was carried out using the plate count method (Nannipieri et al. 2017; Damodaran et al. 2013). Figure 3 illustrates sampling sites to collect material deposits and observe microclimate with epiphytes on the oil palm trunk.

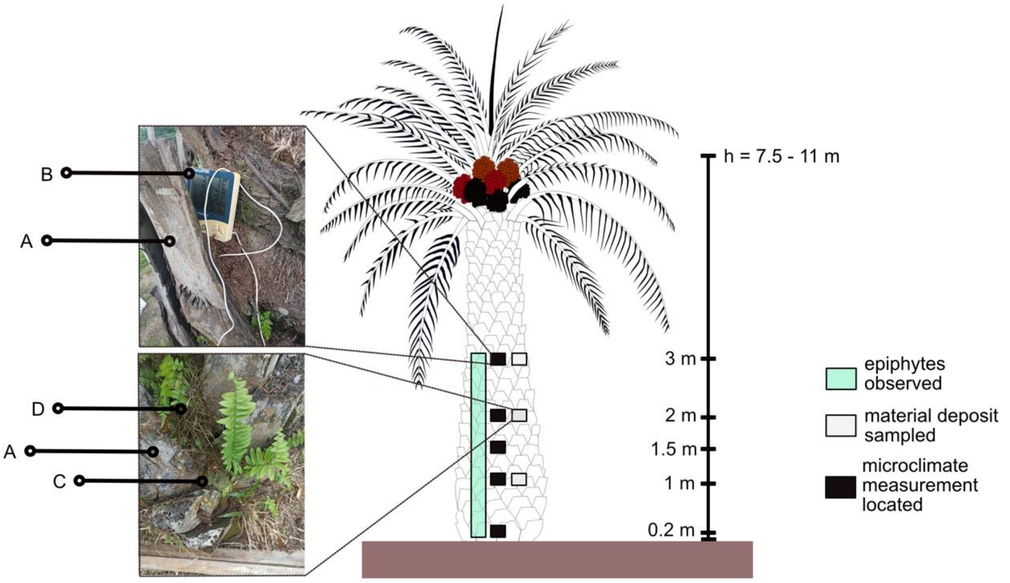

Figure 3. Sampling sites for collecting material deposits, observing microclimate, and collecting the epiphyte plants on the oil palm trunk. A. axils of pruned fronds attached to the trunk, B. sensor for micro-air temperature and relative humidity, C. material deposit, and D. epiphytes and others

Data analysis

R-software v. 4.0.4 and R-studio v. 1.4.1106 were used for data presentation, calculation, and significance tests. Descriptive statistics were used to determine the daily pattern of microclimate in the sites. The statistical t-test (α = 5%) was generated by comparing microclimate data in the eastern (BS and PA) and western regions (PG, SM, and PM) due to climatic patterns and age compositions. The t-test was also used to compare physical properties, chemical properties, and bacterial populations between the two regions. ANOVA / analysis of variance (α = 5%) compared the physical and chemical properties, as well as the population of bacteria in the material deposit. This was conducted at three heights of 100, 200, and 300 cm, and Tukey HSD was used for the post-hoc test. In contrast, Spearman correlation analysis was used to determine the correlation between microclimate variables, physical properties, chemical properties, and the bacterial population.

RESULTS AND DISCUSSION

Climate profile

The climatic conditions in eastern and western North Sumatra were significantly different (Figure 4). As previously explained, the difference in climatic conditions between the two regions is caused by differences in altitude. The previous information about the temperature difference in the east and west of North Sumatra is lacking. However, research conducted by Montgomery (2006) shows that air temperature decreases when the altitude increases. Furthermore, the average annual rainfall in PM, PG, and SM is higher than in BS and PA. A similar condition was also stated by Prasetyo et al. (2018). The rainfall pattern in the locations is presented in Figure 4G. It can be seen that the rainfall pattern for both locations is equatorial, although the western region has a higher average monthly rainfall. Lower rainfall predominantly occurs in February-April. This condition is per Pradiko et al. (2016).

Microclimate profile inside trunk's axils

The average air temperature inside the leaf pocket or trunk's axils is lower than the mean air temperature of each estate. The average diurnal pattern of microclimate temperature was lower in the west rather than the eastern region (Figures 5A and 5B). The low temperature lasted from midnight until before sunrise (06:00 am). The maximum value of micro temperature inside the trunk's axils is reached after midday at 01:00 pm. Not much literature discussed the micro temperature in the trunk's axils. The diurnal pattern is relatively similar to the microclimate pattern of oil palm's understory. Thus, microclimate conditions inside the leaf pocket are associated with the oil palm's understory. The results differed slightly from the previous study by Donfack et al. (2021), which stated that the micro-temperature under oil palm stands reached its maximum at 03:00 pm. Another study by Hardwick et al. (2015) showed that the maximum temperature understory of oil palm peaked at midday. Hardwick et al. (2015) also stated that the minimum temperature under the canopy of oil palm plantations occurred at 06:00 am.

There was no consistent air temperature pattern in the trunk's axils or leaf pockets at various heights, and the average fluctuation in the axils was ±4.40ºC. The highest (±4.67ºC) and lowest (±4.14ºC) were observed at 100 cm and 300 cm above the soil surface, respectively (Figure 5). Furthermore, the fluctuation in the leaf pockets in the eastern was ±3.85ºC, lower than in the western region

(±4.76ºC). The fluctuations were consistent with previous research by Luskin and Potts (2011), where the air temperature dynamic in oil palm plantations was ±4ºC. The diurnal pattern of relative humidity in leaf pockets was opposite to air temperature (Figure 5D and 5E), with the highest at night and the lowest during the day. The RH was relatively similar in all study sites from night to morning in the leaf pocket. The average fluctuation in RH between day and night was 15.42%. In addition, the average RH fluctuation at BS and PA was 15.22%, lower than the 15.55% at PM, PG, and SM.

The leaf pocket's average air temperature in the eastern was significantly higher than in the western part (Figure 5C). The average RH in the leaf pockets in the eastern regions was significantly lower than in the west (Figure 5F). This condition was consistent with the climatic profile depicted in Figure 2. The eastern part of North Sumatera has higher air temperatures and lower RH than the western region. It demonstrated that climatic effects could influence microclimate conditions in an oil palm plantation. This finding is consistent with previous reports (Richardson et al. 2013), where atmospheric conditions affect vegetation in the surrounding environment. Zellweger et al. (2020) stated that microclimate affects organisms more than macroclimate. Furthermore, it was also mentioned that the plant canopy, which acts as temperature buffering, can also reduce the impact of climate change.

The vapor pressure deficit in the microhabitat was nearly 0 kPa at night until 06:00 am, then peaked at midday (Figure 5G and 5H). The fluctuation of VPD was similar to the findings of Luskin and Potts (2011). In particular, the average in the west of North Sumatra was lower than in the eastern region (Fig. 4I). VPD reflects the rate of transpiration of the plant (Broz et al. 2021). Higher VPD indicated a higher capacity of the atmosphere to absorb water from the environment. As an implication, leaf pockets in the eastern region might have a higher rate of water losses than in the western region. However, it should be understood that higher VPD is not the only factor that causes more water loss. In the case of the plants-atmosphere continuum, water loss through evapotranspiration is strongly influenced by environmental conditions and physiological regulations in related plants (Massmann et al. 2019).

Physical and chemical properties of material deposits

The analysis results for the samples of material deposit, including N, P, K, Ca, Mg, C-organic, C/N, and water content, are shown in Figure 7. According to the t-test, N, K, C-organic, and water content differed significantly between the two regions. Material deposits from North Sumatera's eastern region had higher K and water content but lower N and C-org than those from the west. The range of N content in the material deposits was 0.83-3.00%, which was consistent with a previous study by Mildaryani et al. (2019).

The content of other nutrients such as P, K, Ca, and Mg was comparable to a previous study by Mildaryani et al. (2019). Furthermore, the pH was less than 4.9 (Figure 7G), in line with the study by Potapov et al. (2020), and the water content ranged from 9.73%-69.43% (Figure 7H). The wide range of the water content was associated with rainfall before sample collection, especially in the eastern region. The total C-organic content ranged from 13.58% to 53.84 % (Figure 7F), and the average from the western region was 49.95 %, significantly higher than samples from the eastern region, which was 31.76%. This finding was slightly higher than the results reported by Potapov et al. (2020) and Mildaryani et al. (2019) at 39.16% and 17.12-24.85%.

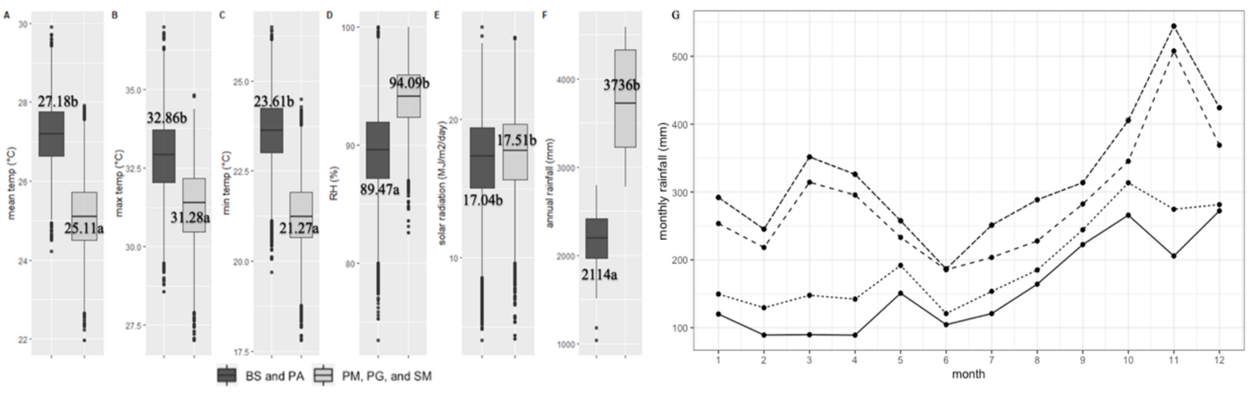

Figure 4. Comparison of the mean temperature (A), maximum temperature (B), minimum temperature (C), relative humidity (D), solar radiation (E), and annual rainfall (F) between the eastern and western regions of North Sumatra. The average monthly rainfall at the study site is depicted in Figure G. The numbers in the boxplot represent the mean values. Numbers followed by different letters have significantly different mean values based on the t-test (α =5%)

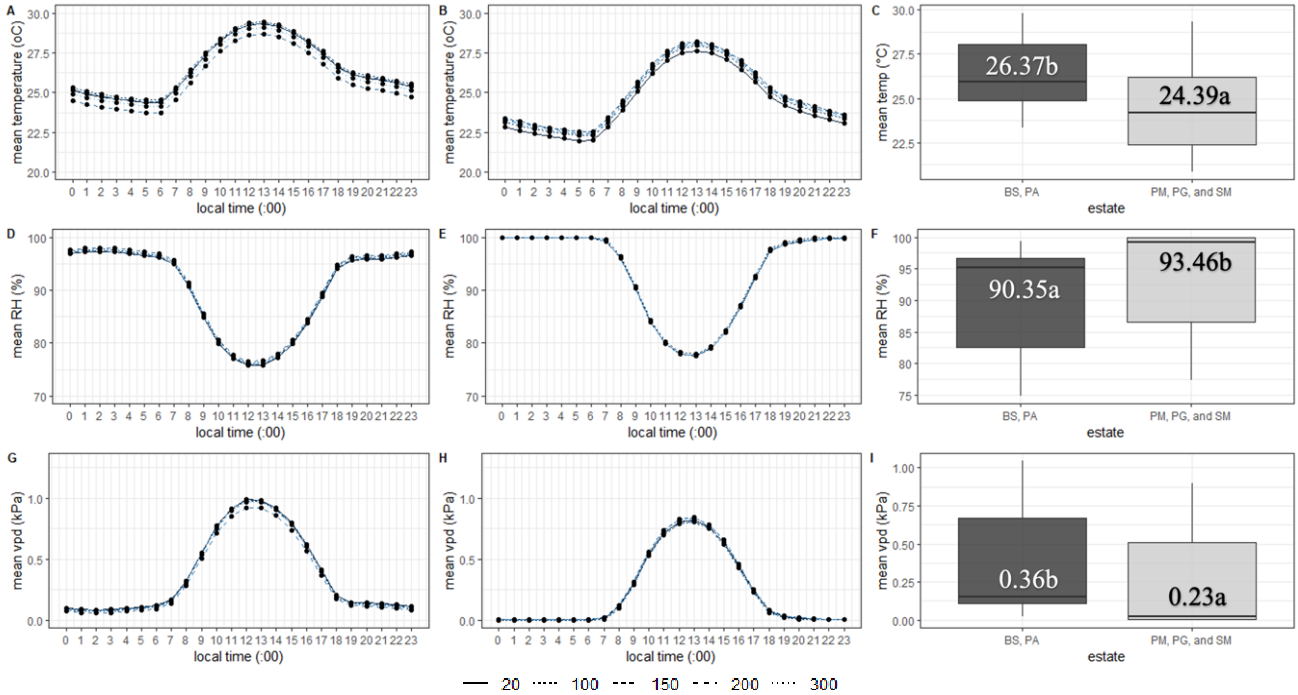

Figure 5. The diurnal air temperature inside the axils of oil palm trunks at various heights in North Sumatra's eastern (A) and western region (B), relative humidity in eastern (D) and western region (E), and vapor pressure deficit in eastern (G) and western region (H). Graphs C, F, and I are the t-test results for mean temperature, relative humidity, and VPD in the eastern and western regions. The numbers in the boxplot represent the mean values. Numbers followed by different letters have significantly different mean values based on the t-test (α =5%)

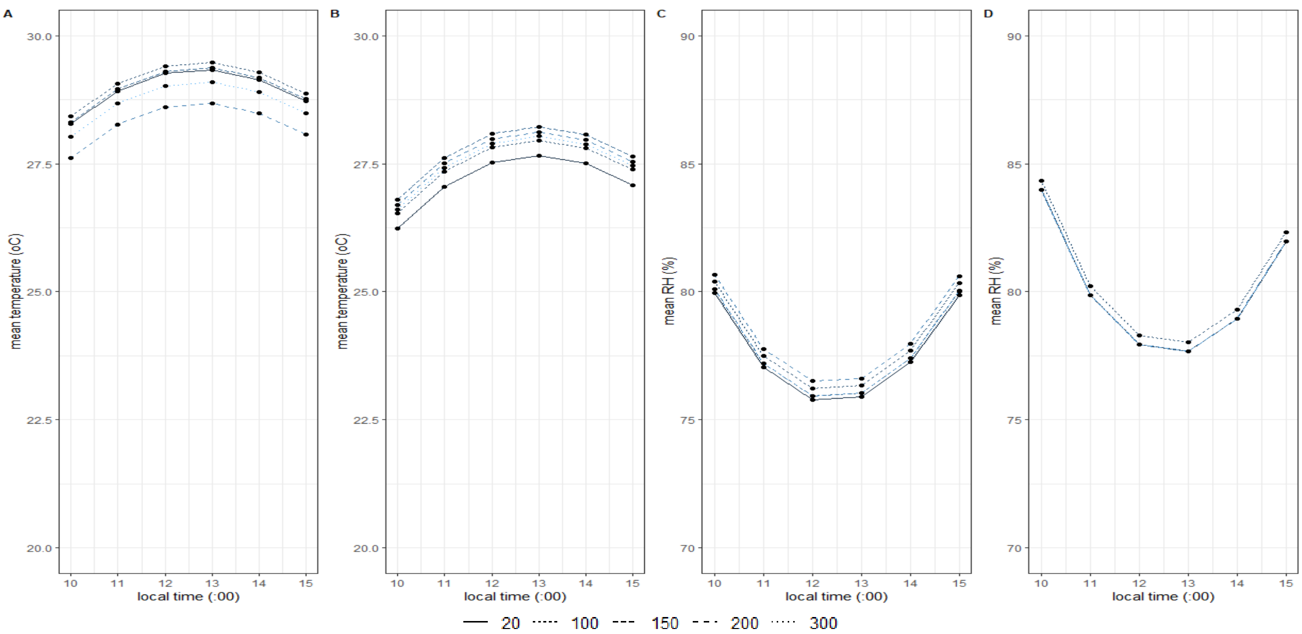

Figure 6. Subset data for 10:00-15:00 local time of the mean temperature in the eastern (A) and western region (B); mean relative humidity of eastern (C) and western region (D)

The C/N ratio of the material deposit ranged from 14.3 to 21.6 (Figure 7I and 8I), with no significant difference between samples. The C/N ratio describes the degree of organic matter decomposition and mineralization (Jílková et al. 2020; Talgre et al. 2017; Ostrowska and Porbska 2015; USDA 2011). Several factors influence the rate of organic matter decomposition, such as microclimate, constituent materials (particularly N and C-organic nutrient levels), lignin content, microbial respiration, microbial decomposer population, time, mineralization, and nutrient immobilization processes (Talgre et al. 2017; Brödlin et al. 2019; Jlková et al. 2020). Even though organic matters are composed of different fractions and mineralization rates, the C/N ratio is controlled by the fluctuation of N content with a higher percentage of C than N (Ostrowska and Porbska 2015; Brust 2019). Organic substrates with a C/N ratio of 1-15 experience a faster mineralization process and N release, allowing the N to be available to the plants. A C/N ratio greater than 35 can result in microbial immobilization and a slower decomposition rate. Therefore, it should be maintained between 20 and 30 to balance the immobilization and mineralization processes (Watson et al. 2002; Brust 2019; USDA 2011).

The vertical profile of the physical and chemical properties of material deposits is presented in Figure 8. The t-test for chemical and physical properties of material deposits at various leaf pocket heights showed no significant difference. However, there is a tendency for the levels of N, C-organic, C/N ratio, and water content in material deposits to increase with the higher the leaf pocket position. This condition is thought to be related to the rate of decomposition. Temperature, water availability, and hydrological processes drive the decomposition rate (Chen et al. 2021). Soils in the tropics generally have lower organic matter than soils in temperate regions because of the high decomposition rate due to higher temperature and moisture (Thongjoo et al. 2005).

The higher water content in the upper leaf pocket can be affected by the length of the remaining pruned fronds and the angle of the axils. The length and angle of remaining pruned fronds difference the rate and sum of rain interception. Allen et al. (2018) also found higher water content in the material deposit closest to the upper stem (stem apex). The upper axils of the oil palm fronds will be filled with intercepted rainwater first before the water flows to the lower axils due to the spiral arrangement of the fronds. Figure 8H shows that the upper leaf pocket tends to be more humid than the lower.

Epiphytes abundance

Table 1 shows epiphytes abundance in the axils of pruned fronds, and the pictures of some are included in Figure 9. The species include pteridophytes and non-pteridophytes. According to previous research by Harmida et al. (2018) and Sofiyanti et al. (2013), the most dominant pteridophytes species identified are *Goniophlebium verrucosum and Nephrolepis bisserata*. These species can grow well on the soil surface, indicating they are not true epiphytes. The results confirmed the findings of Suzanti et al. (2016), which found that true epiphytes were uncommon in an oil palm plantation.

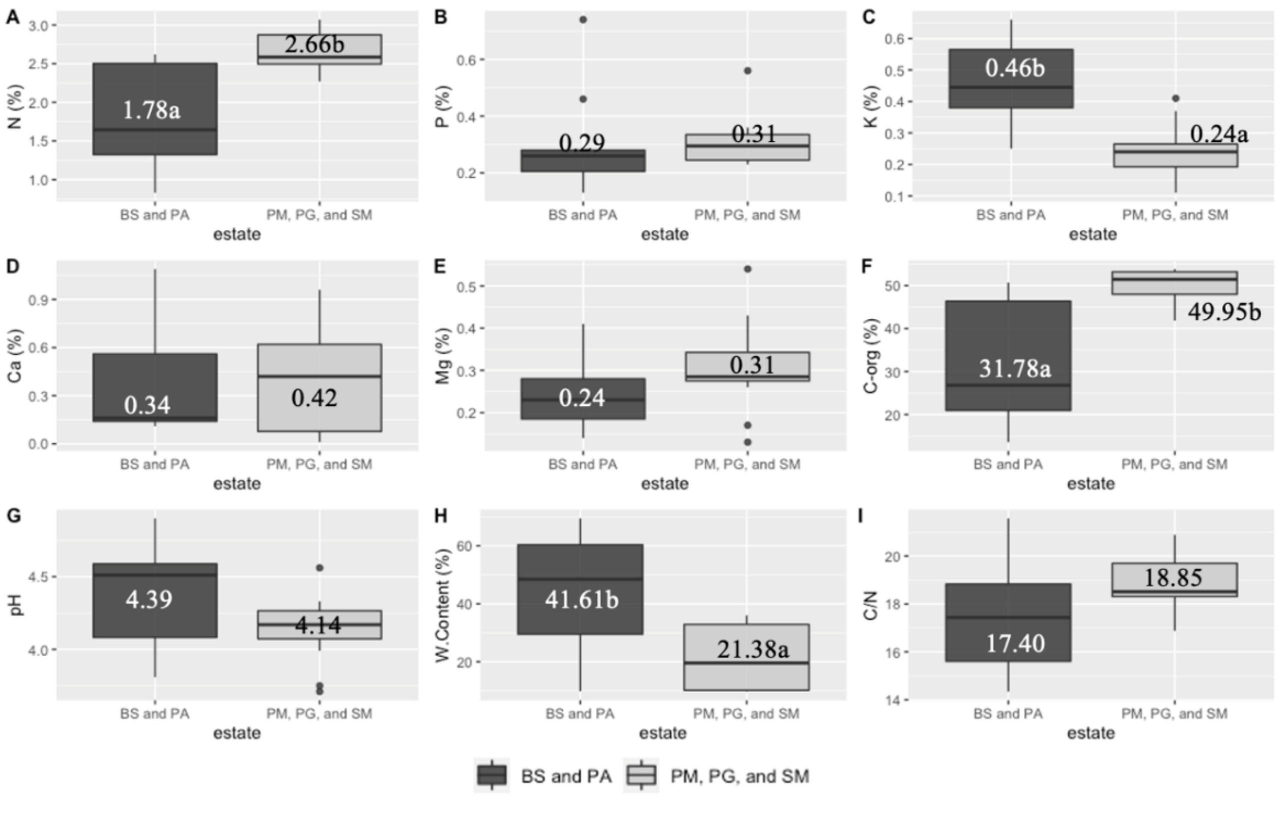

Figure 7. The t-test for nitrogen (A), phosphorus (B), potassium (C), calcium (D), magnesium (E), C-organic (F), pH (G), water content (H), and C/N ratio (I) between samples of material deposit from North Sumatra's eastern (BS, PA) and western (PM, PG, and SM) regions. The numbers in the boxplot represent the mean values. Numbers followed by different letters have significantly different mean values based on the t-test (α=5%)

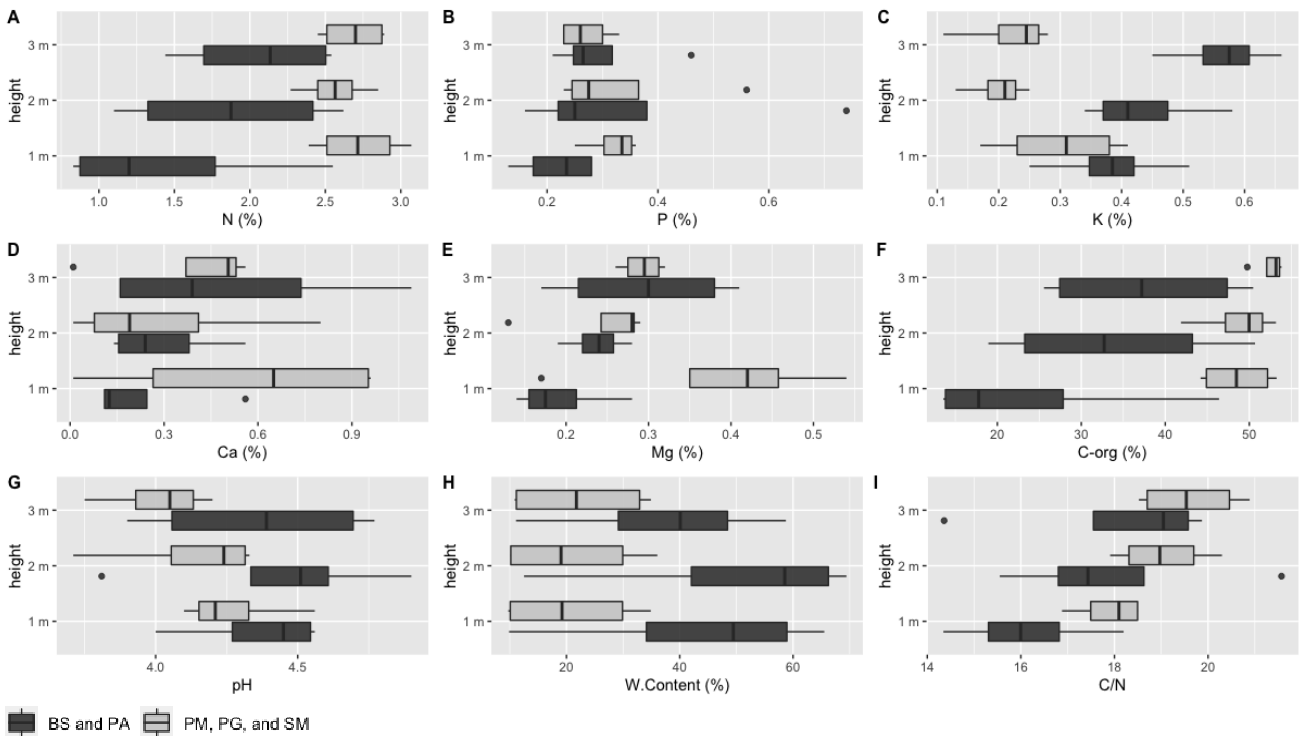

Figure 8. The comparison of Nitrogen (A), Phosphorus (B), Potassium (C), Calcium (D), Magnesium (E), C-organic (F), pH (G), water content (H), and C/N ratio (I) per height between western (PM, PG, and SM) and eastern regions (BS and PA) of North Sumatra. Boxplots with different letters have significantly different mean values based on the t-test (α=5%)

The species of pteridophytes in the eastern region were more diverse than those in the west, as seen in Table 2. Table 1 showed that BS (eastern) had twice as many pteridophytes species as SM (western). According to Saharizan et al. (2021), the diversity and abundance of ferns in an oil palm plantation are dependent on the environment, the age of the host, and the agronomic practices applied. In addition, elevation significantly impacts fern distribution (Othman et al. 2015), with Saharizan et al. (2021) showing that terrestrial pteridophytes are more frequent in oil palm plantations at lower elevations. It supported the findings of this study, where pteridophyte species were substantially less numerous in SM (583 m a.s.l.) than in BS (5 m a.s.l).

The correlation between epiphytes abundance and microclimate inside the leaf pocket is listed in Figure 10. It showed that the two dominant epiphytes, Gv and Nb, negatively correlated with VPD. Meanwhile, others epiphyte abundance of all sites is positively correlated with VPD. It means that epiphyte abundance is higher in eastern regions with higher micro-VPD. However, it should be noted that the mean micro-VPD at the study site was < 1.0 kPa. Therefore, a different correlation could be observed when the micro-VPD > 1.0 kPa.

The dominant fern in the upper part of the oil palm trunk (> 200 cm) was *Nephrolepis bisserata*, but other species were identified in the middle and lower part (Figure 11) in line with the study of Saharizan et al. (2021). Epiphytic ferns can grow by utilizing nutrients from the slowly decomposing organic material in the leaf pockets (Richardson and Walker 2010), fixing nitrogen directly from the atmosphere, and intercepted water (Hietz et al. 1999). However, epiphytic ferns are very reliant on the characteristics of their hosts, particularly in terms of water, nutrients, and light (Zhang et al. 2010). They are frequently found in the more fertile parts of the host plant (Richardson and Walker 2010; Lwanga et al. 1998).

Bacteria populations

The total bacteria population in the leaf pocket of oil palm plantations is presented in Figure 12. Although statistically insignificant, there is a tendency for the bacterial population in the eastern (BS and PA) region to be higher than in the western part (PM, SM, and PG). There was also no significant difference between the total bacterial population in the leaf pocket at the height of 100 cm, 200 cm, and 300 cm. However, it tends to be more at the height of 100 cm than 200 cm and 300 cm. The results of this study are relatively similar to Potapov et al. (2020), where there was no significant difference in the microfauna population in the axils of oil palm trunks at 0, 90, and 180 cm heights.

The correlation between environmental conditions and bacterial populations is presented in Figure 13. Ecological conditions that negatively correlate with bacterial populations were N, C-organic, C/N ratio, Mg, and pH. The bacterial population in the eastern part strongly shows a negative correlation with the C/N ratio. Furthermore, Ca and C-organic have a moderate negative correlation with the bacterial population. In the western region, the population of bacteria has a strong negative correlation with C-organic, water content, and air temperature. In contrast, N has a moderate negative correlation with the bacterial population.

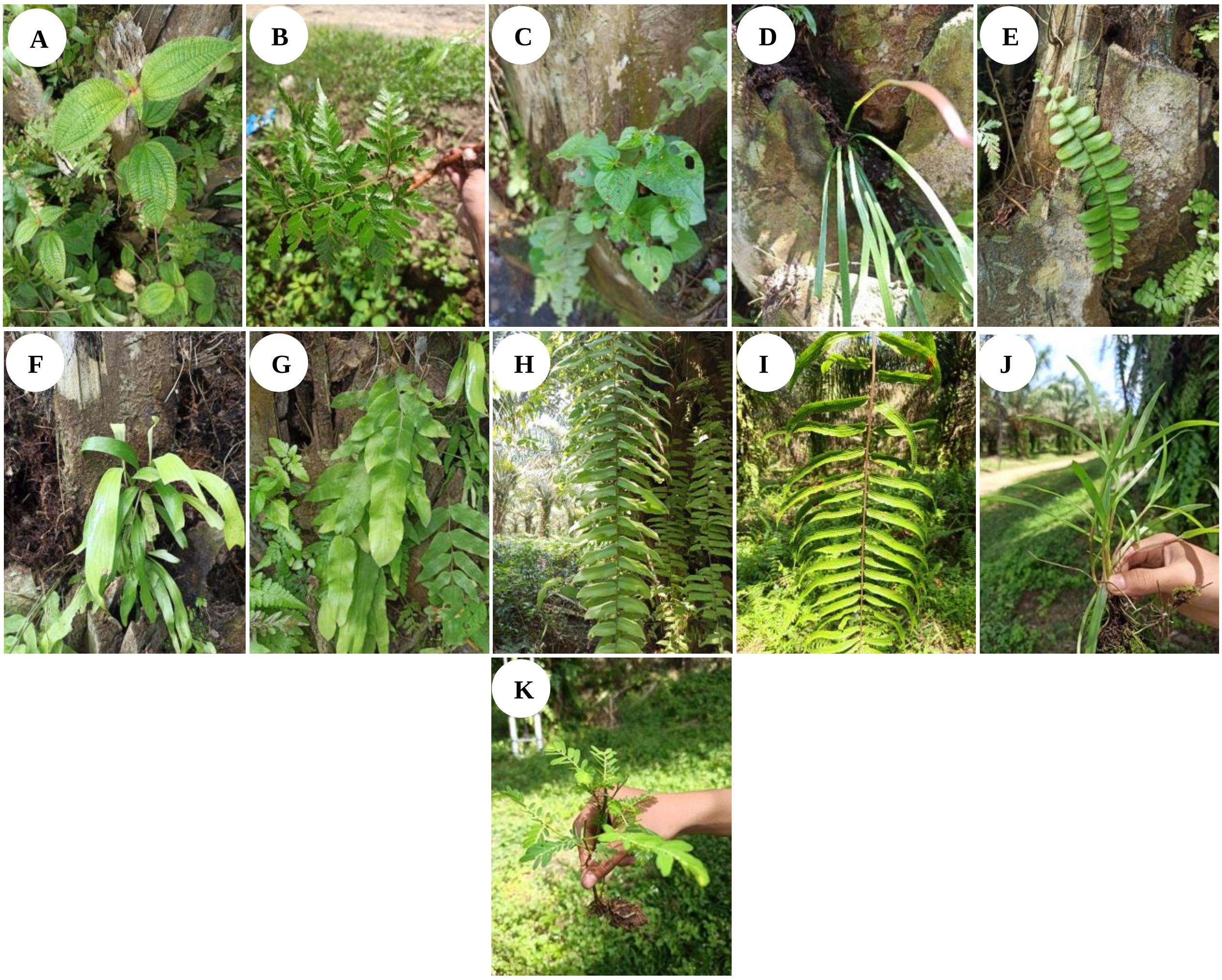

Figure 9. *Clidemia hirta* (A), *Davallia divaricate* (B), *Peperomia pellucida* (C), *Vittaria ensiformis* (D), *Nephrolepis cordifolia* (E), *Vittaria elongata* (F), *Goniophlebium verrucosum* (G), *Nephrolepis bisserata* (H), *Nephrolepis brownii* (I), *Stenotaphrum secundatum* (J), *Phyllanthus amarus* (K)

Discussion

The climate conditions of the study sites are related to that of microhabitats. Observed plantations in the eastern region have higher air temperature, VPD, and lower RH than those in the western part. The physical and chemical properties of the material deposit also show a different trend between the plantations in the two regions. The nutrient content of N, P, Ca, Mg, C-organic, and the C/N ratio in the west tended to be higher. Meanwhile, the pH level, K nutrient, and water content showed the opposite trend. The profiles of air temperature, RH, and VPD in the microhabitat at a height range of 20-300 cm are relatively similar. Moreover, only the N, C-organic, and C/N ratio nutrients had a clear pattern of changes as the height of the microhabitat location increased.

Table 1. Plant species and their abundance in the axils of oil palm at the study sites

Plant species	Eastern region		Western region		
	BS	PA	PM	PG	SM
Pteridophyte group					
Davallia divaricata	**	***	***	*	**
Goniophlebium verrucosum	****	****	****	****	****
Nephrolepis bisserata	****	****	****	****	****
Nephrolepis brownie	*				
Nephrolepis cordifolia	****		*	*	
Vittaria elongate		**	***	*	
Vittaria ensiformis	***	*	***	*	
Non pteridophyte group					
Clidemia hirta	*	**	*	****	***
Peperomia pellucida	*	*		*	
Phyllanthus amarus	*				
Stenotaphrum secundatum	*				

Note: *very rare (<20%); **rare (21-40%); ***abundant (41-70%); ****very abundant (>70%). Abbreviated letters are the codes for the study sites, where BS: Bukit Sentang, PA: Pulau Maria, PM: Padang Mandarsyah, PG: Pargarutan, and SM: Semirik

Table 2. Detailed epiphytes abundance in the axils sampled palm at the study sites

No. of tree	*Ch*	*Dd*	*Eg*	*Gv*	*Nb*	*Nbr*	*Nc*	*Pp*	*Ppe*	*Pa*	*Ve*	*Ven*
Bukit Sentang												
1	-	-	1	1	1	-	1	-	-	-	-	-
2	-	-	1	1	1	1	1	-	-	-	-	1
3	-	-	1	1	1	-	1	-	-	-	-	1
4	-	-	1	1	1	1	1	-	-	-	-	1
5	1	-	1	1	1	-	-	-	-	-	-	-
6	-	-	1	1	1	-	1	-	-	-	-	1
7	-	1	1	-	1	-	1	-	-	-	-	-
8	-	-	1	1	1	-	1	-	-	-	-	-
9	-	-	1	-	1	-	1	-	-	-	-	1
10	-	-	1	1	1	1	1	-	-	-	-	-
11	-	1	1	1	1	-	1	-	-	-	-	1
12	-	1	-	1	1	-	1	-	-	-	-	-
13	-	1	-	1	1	-	1	-	1	-	-	1
14	-	1	1	-	1	-	1	-	-	-	-	-
15	-	1	1	1	-	-	-	-	-	-	-	1
16	1	1	-	1	1	-	1	1	-	1	-	1
17	-	1	1	-	-	-	-	-	-	-	-	-
18	-	1	1	-	1	-	1	-	-	-	-	-
19	1	-	-	-	1	-	1	1	-	1	-	1
20	1	-	1	-	1	-	1	-	-	-	-	1
21	-	-	-	1	1	-	1	-	1	-	-	-
22	-	-	-	1	1	-	1	-	-	-	-	-
23	-	-	-	1	1	-	1	-	-	-	-	-
24	1	-	-	1	1	-	1	-	1	-	-	-
25	-	1	1	1	1	-	1	-	-	-	-	1
26	-	-	-	1	1	-	1	-	-	-	-	-
27	-	-	-	1	1	-	1	-	-	-	-	-
28	-	-	-	1	1	-	1	-	-	-	-	1
29	-	-	1	1	1	-	1	-	-	-	-	-
30	-	-	1	1	1	-	1	-	-	-	-	1
Total	5	10	19	23	28	3	27	2	3	2	0	14
Abund. (%)	16.67	33.33	63.33	76.67	93.33	10.00	90.00	6.67	10.00	6.67	0.00	46.67
Pulo Maria												
1	-	-	-	1	1	-	-	-	-	-	1	-
2	1	1	-	1	1	-	-	-	-	-	-	-
3	-	1	-	1	-	-	-	-	-	-	-	-
4	-	-	-	1	1	-	-	-	-	-	-	-
5	-	1	-	1	1	-	-	-	1	-	1	-
6	1	1	-	1	1	-	-	-	-	-	1	1
7	-	-	-	1	1	-	-	-	-	-	-	-
8	-	-	-	1	1	-	-	-	-	-	-	-
9	1	1	-	1	1	-	-	-	1	-	-	1
10	-	1	-	1	1	-	-	-	-	-	1	-
Total	3	6	0	10	9	0	0	0	2	0	4	2
Abund. (%)	30.00	60.00	0.00	100.00	90.00	0.00	0.00	0.00	20.00	0.00	40.00	20.00
Pargarutan												
1	1	-	-	1	-	-	-	-	-	-	-	1
2	1	-	-	1	1	-	-	-	-	-	1	-
3	1	-	-	1	1	-	-	-	-	-	-	-
4	1	-	-	1	1	-	-	-	-	-	-	-
5	1	1	-	1	1	-	1	-	-	-	-	-
6	-	-	-	1	1	-	-	-	-	-	-	-
7	1	-	-	1	1	-	-	-	1	-	-	-
8	1	-	-	1	1	-	-	-	-	-	-	-
9	1	-	-	1	1	-	-	-	-	-	-	-
10	-	-	-	1	1	-	-	-	-	-	-	-
Total	8	1	0	10	9	0	1	0	1	0	1	1
Abund. (%)	80.00	10.00	0.00	100.00	90.00	0.00	10.00	0.00	10.00	0.00	10.00	10.00
Simirik												
1	1	1	-	1	1	-	-	-	-	-	-	-
2	1	-	-	1	1	-	-	-	-	-	-	-
3	-	-	-	1	1	-	-	-	-	-	-	-
4	1	-	-	1	1	-	-	-	-	-	-	-
5	1	-	-	1	1	-	-	-	-	-	-	-
6	-	1	-	1	1	-	-	-	-	-	-	-
7	1	1	-	1	1	-	-	-	-	-	-	-
8	-	-	-	1	1	-	-	-	-	-	-	-
9	-	1	-	1	1	-	-	-	-	-	-	-
10	1	-	-	1	1	-	-	-	-	-	-	-
Total	6	4	0	10	10	0	0	0	0	0	0	0
Abund. (%)	60.00	40.00	0.00	100.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Padang Mandarsah												
1	-	1	-	1	1	-	-	-	-	-	-	-
2	-	1	-	1	1	-	-	-	-	-	1	-
3	-	1	-	1	1	-	-	-	-	-	-	-
4	-	-	-	1	1	-	-	-	-	-	1	-
5	-	1	-	1	1	-	-	-	-	-	1	-
6	-	-	-	1	1	-	-	-	-	-	-	-
7	-	1	-	1	1	-	-	-	-	-	1	-
8	-	1	-	1	1	-	-	-	-	-	1	1
9	-	-	-	1	1	-	-	-	-	-	-	1
10	-	1	-	1	1	-	-	-	-	-	-	1
11	-	-	-	1	1	-	-	-	-	-	1	1
12	-	1	-	1	1	-	-	-	-	-	-	-
13	-	-	-	1	1	-	-	-	-	-	1	-
14	-	1	-	1	1	-	-	-	-	-	1	1
15	-	-	-	1	1	-	-	-	-	-	1	1
16	-	-	-	1	1	-	-	-	-	-	-	-
17	-	-	-	1	1	-	-	-	-	-	-	1
18	1	-	-	1	1	-	-	-	-	-	-	1
19	-	-	-	1	1	-	-	-	-	-	1	1
20	-	1	-	1	1	-	1	-	-	-	1	1
Total	1	10	0	20	20	0	1	0	0	0	11	10
Abund. (%)	5.00	50.00	0.00	100.00	100.00	0.00	5.00	0.00	0.00	0.00	55.00	50.00

Note: Ch: *Clidemia hirta*; Dd: *Davallia divaricata*; Eg: *Elaeis guineensis*; Gv: *Goniophlebium verrucosum*; Nb: *Nephrolepis bisserata*; Nbr: *Nephrolepis brownii*; Nc: *Nephrolepis cordifolia*; Pp: *Pennisetum purpureum*; Ppe: *Peperomia pellucida*; Pa: *Phyllanthus amarus*; Ve: *Vittaria elongata*; Ven: *Vittaria ensiformis*

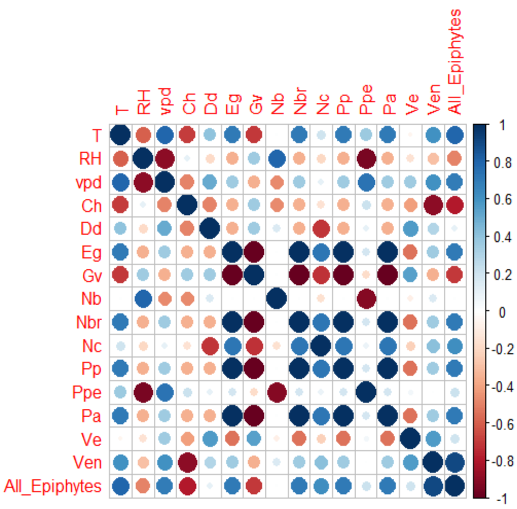

Figure 10. Correlation of epiphytes abundance with microclimate in microhabitat inside leaf pocket

Figure 11. The pattern of epiphytes distribution on the oil palm trunk. *Nephrolepis bisserata* is dominant in the upper stem (>200 cm), while others, especially *Vittaria ensiformis,* are dominant in the bottom stem

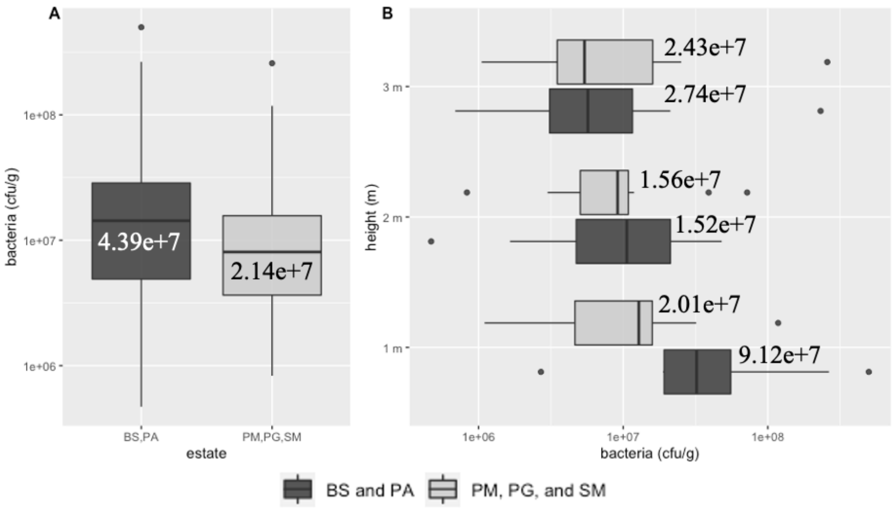

Figure 12. (A) Bacteria population in the material deposit of eastern region (BS and PA) and western region (PM, PG, and SM) of North Sumatra. (B) Bacteria population at several height levels. The results of the t-test on data with a significance level of 5 showed that there was a difference in the mean number of bacteria in material deposits between the eastern and western regions of North Sumatra. The results of the ANOVA test at the 5 level of significance did not show a significant difference between the total bacteria in material deposits from various heights

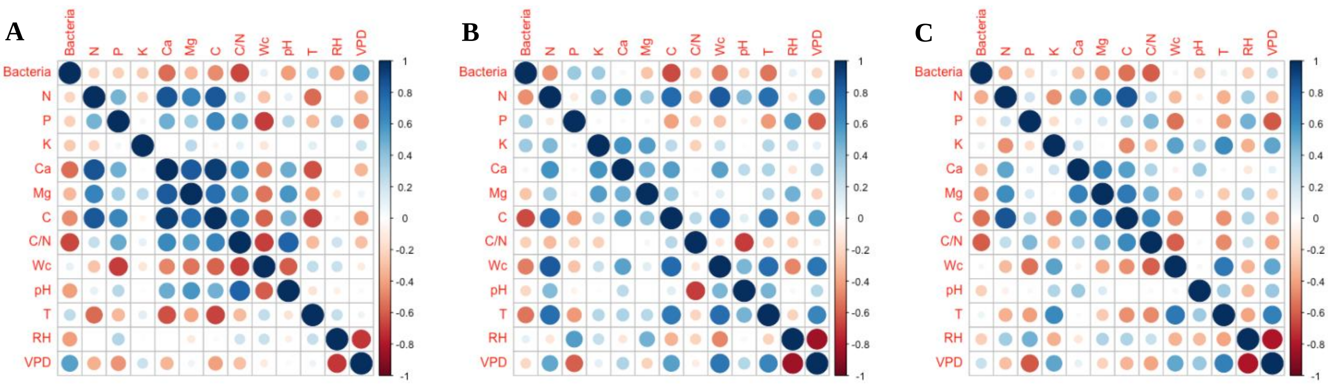

Figure 13. Correlation of bacteria population with physical and chemical properties of material deposit and microclimate in microhabitat inside leaf pocket. The correlation index of oil palm plantations in the eastern region (A), the western region (B), and a combination of all data on plantations in eastern and western North Sumatra (C). The correlation index is calculated based on the Spearman correlation

This study confirmed that the N content was higher than soil, as reported by Potapov et al. (2020), where it was 20 times that of the mineral soil. The decomposition of epiphyte plants in the oil palm trunk was a source of N in the material deposit. Several types have high N content; for example, *Nephrolepis biserrata* has increased soil N by 41 (Ariyanti et al. 2015). Cardelús and Mack (2010) reported that the range of foliar N content for the epiphyte group of ferns at an altitude of 30-2600 m a.s.l. was 1.05-1.34. However, the nutrient content at different altitudes will vary depending on epiphyte type and population, as well as air temperature and RH (Salazar et al. 2015; Salazar et al. 2021). The decomposition of other organic materials accumulated in the leaf pocket can contribute as a source of N in the material deposit (Powlson et al. 2015).

The C-organic content was considerably higher than the average soil C-organic content in several oil palm plantations in North Sumatra, which was less than 0.18 (Farrasati et al. 2019). For the material deposit, the content was 40 times that of the mineral soils (Potapov et al. 2020) due to the abundance of organic matter input, the continuous decomposition process of epiphytes, and litters accumulated in the leaf pockets. Ariyanti et al. (2015) found that *Nephrolepis biserrata* had a foliar C-organic content of 27.9, contributing to the high C-organic content in the material deposit.

The C/N ratio increased with the leaf pocket's height. Based on the microclimate profile and water content in the leaf pocket, it is suspected that there are different decomposition rates between the upper and lower leaf pocket's material deposits. However, one thing is clear the organic materials in the lower leaf pocket had accumulated more litter and decomposed for a more extended time than in the upper position. Therefore, the nutrient and C-organic levels in the lower leaf pocket were lower than in the upper. Dried leaves, reproductive organs, fruits, dust, epiphyte, living microbial biomass, and a small portion of the soil are the most common organic materials found in the leaf pockets (Allen et al. 2018; Mildaryani et al. 2019; Sofiyanti et al. 2013; Eskov et al. 2021). Different C/N ratios and organic material types at different leaf pocket heights may influence epiphyte plants and fauna (Potapov et al. 2020). In addition, material deposits with a lower C/N ratio that fall to the soil surface may improve soil properties.

Regarding epiphytes abundance, *Nephrolepis bisserata* tends to be dominant in the upper stem, while *Vittaria ensiformis* grows on the bottom stem. Furthermore, *Nephrolepis bisserata* was the dominant species, where the material deposit had a higher C/N ratio and a more humid environment (Figure 11). Unlike other fern species, it is more tolerant of less fertile growing mediums, as previously described by Saharizan et al. (2021) and Satriawan et al. (2021).

In agronomic practices, epiphytic ferns can be tolerated as long as they do not interfere with oil palm maintenance and harvesting. Nurdiansyah et al. (2016) suggested that maintaining plant diversity and fostering weedy strips could be effective for the biological control of pests and disease. Meanwhile, vascular epiphytes may help support insect biodiversity (Suzanti et al. 2016). It also increases understory vegetation, mitigates the adverse effects of forest resources, and prevents the loss of diversity (Ashton-Butt et al. 2018; Nájera and Simonetti 2010).

The variety and population of bacteria are related to nutrients, especially the C/N ratio (Högberg et al. 2007; Koorem et al. 2014). The total population was higher in the eastern region with a lower C/N ratio. Meanwhile, there is also a tendency for the highest bacteria population in leaf pockets at the height of 100 cm, with the lowest C/N ratio. Research has shown that soil microorganisms have a low C/N ratio of about 8 (Howell 2005). Other studies stated that the most balanced ratio for microbial growth is 24:1. Microbes with C/N ratio higher than 24:1 should seek additional N to remove excess carbon to experience growth inhibition. In addition, those living at lower C/N ratios will produce a temporary surplus of N for plant growth to decompose other residues with a ratio greater than 24:1 (Brust 2019; USDA 2011). The high and low C/N ratios will be very suitable for fungal and bacterial growths (de Vries et al. 2006; Gao et al. 2007; Leite et al. 2017). According to De Vries et al. (2006), the C/N ratio in fungi is higher than in bacteria (10:4), and a high ratio can stimulate the growth of fungi. Meanwhile, bacteria have a lower C/N ratio and require higher N to fulfill their nitrogen needs.

For the Mg content correlation with the bacteria population, the results differ from other studies, where the addition of Mg fertilizer or Mg content in the growth medium can stimulate the proliferation of soil microorganisms (Wyszkowska and Wyszkowski 2002). Few studies discuss the direct correlation between Mg and bacterial populations. Therefore, the correlation between Mg, especially the decomposition process of Mg, with the bacterial population should be further studied.

The pH levels also affect the bacteria population in the material deposit, and it was negatively correlated with pH. It means that locations with lower pH tend to have a larger total population of bacteria. This is not consistent with the research results of Zhalnina et al. (2014), where pH is positively correlated with microbial abundance. Zhalnina et al. (2014) reported that pH is the primary control in bacterial metabolism, and pH is also closely related to microbial communities in many biogeochemical conditions (Thompson et al. 2017). It alters the metabolism of bacteria either directly or indirectly by affecting the environment (Jin and Kirk 2018). However, another study discovered a higher diversity in forests with lower pH (Roesch et al. 2007). Acidophilic bacteria live at pH < 5 (Jin and Kirk 2018), and they predominate the population. Further study is needed to understand the pH correlation with bacteria's diversity and abundance population.

The correlation between water content and the total bacteria population should also be determined. The total bacteria population is higher in the eastern region, with higher water content in material deposits (Figure 7H). However, water content was negatively correlated with the total bacteria population in the western part (Figure 13B). The result contradicts the previous study that explained moisture content is the most crucial soil parameter underlying microbial community structure (Banerjee et al. 2015; Zhang et al. 2012). The increased amount of water can accelerate the growth of microorganisms (Panggabean et al. 2016).

The correlation between P, K, and Ca nutrients with the total bacteria population was inconsistent and had a weak correlation. Further studies are needed to ensure the correlation between these nutrients and bacteria. A weak correlation between P and the bacteria shows that P content does not significantly affect the population. Wang et al. (2018) stated that phosphorus's addition has no significant effect on the soil bacteria community.

Microclimate factors (T and RH) and VPD in the microhabitats have a weak negative and positive correlation with the bacteria population. Because the literature on material deposits is minimal, the findings of this study are compared to the microclimate research on soil conditions and bacteria. Consensus regarding the effect of temperature on bacterial activity is still lacking because respiration has an apparent sensitivity influenced by several indirect factors depending on soil type (Nottingham et al. 2015). Several studies have been conducted to determine the correlation between air temperature and microbial diversity and activity. An increase in soil temperature leads to bacterial abundance change. Proteobacteria, Acidobacteria, and Planctomycetes decreased, while Actinobacteria and Chloroflexi increased with an increase in soil temperature (Mun and Ling 2020). Another study conducted in tropical forests showed that an increase of 2°C in the mean annual temperature could increase microbial activity by up to 28 (Nottingham et al. 2019). For comparison, research in the Antarctic maritime shows a positive correlation between air temperature and soil bacteria diversity (Dennis et al. 2019). On the other hand, an increase in temperature can also decrease water content by up to 22, as well as bacterial and fungal abundance by over 50 in boreal ecosystems (Allison and Treseder 2008).

The increment in RH causes changes in soil bulk density and rhizosphere bacterial community structures. However, the effect of increasing RH in different soil bacteria can vary widely (Truu et al. 2017). Further studies are needed to determine the exact effect on the bacteria population. Moreover, VPD has a weak positive correlation with the bacteria population; hence, there is not much explanation regarding the effect of VPD on microbial activity. The findings of this study differ from the general conditions in plants. In plants, transpiration strongly correlates with VPD (Pradiko et al. 2022). The increase in transpiration occurs in the morning with an increase in VPD but then decreases before the VPD reaches its peak (Meijide et al. 2017; Waite et al. 2019).

Based on the explanation above, there is a complex relationship between the parameters, and changes in one variable affect others. Therefore, the AGE of oil palm plantations should be maintained. Furthermore, biodiversity is threatened under oil palm stands when the AGE ecosystem is not maintained (Potapov et al. 2020).

ACKNOWLEDGMENTS

The funding for this research was allocated from research activity plan 2 (RK 2) for the fiscal year of 2020/2021. The authors are thankful to IOPRI management for its support in this research. The authors are also grateful to the soil science and agronomy research department technicians who have worked hard in collecting data in the field and the laboratory.

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