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EFFECTS OF SLOPE POSITION AND SAMPLING TIME ON SOIL FAUNA DIVERSITY INDICES UNDER COCONUT CULTIVATION PLANTED IN A LOW SLOPE GRADIENT AREA: A SHORT-TERM STUDY

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ABSTRACT

A short-term studies of soil fauna on the low slope gradient under coconut plantation is not well explored due to tedious and time taken for identification. This may ignore the baseline information to understand the relationships between the abiotic factors. Therefore, the objective of this study was to determine the effects of the slope position and sampling time on the diversity indices of soil fauna under coconut cultivation planted in the low slope gradient area. The study was conducted in December 2021 at the coconut farm, UiTM Perlis Branch, Malaysia using a Randomized Complete Block Design with four replications. This coconut farm lies on a low slope gradient ranging from 0^{o} to 6^{o}. In total, 96 pitfall traps were installed within the coconut area based on three slope positions (i.e., S1-bottom, S2-middle and S3-top). The soil fauna was collected three times (i.e., T1, T2 and T3) within a month of the study period. The soil fauna specimens were identified up to family level and five of the soil fauna indices (i.e, richness, abundance, Shannon-Wiener diversity index, Simpson's reciprocal index and evenness index) were calculated. As a result, 1,335 individuals from 10 orders and 15 families were identified in this study. The Formicidae (69.7%) and Scolopendridae (0.1%) groups had the most abundant and lowest number of individual soil fauna found in the coconut farm, respectively. Meanwhile, Termitidae (6.5%), Gryllidae (3.4%), Carabidae (2.8%), Acrididae and Paradioxosomaridae (1.6%) and Alydidae (1.5%) are the most average of individual soil fauna. Results showed that the abundance was significantly highest (41±8.4) at the top position (S3) compared to the other positions and this might be caused by the microclimate factor like moisture and temperature. Meanwhile, the sampling time of T3 shows a significantly highest of richness (7±1.2), the Shannon-Wiener diversity index (1.2±0.3), and Simpson's reciprocal index (2.5±0.6) and this might be caused by management practices like weed control. Overall, this coconut farm has moderate diversity with high variability of soil fauna during the study.

Keywords: Abundance, *Cocos nucifera*, evenness (Pielou) index, Shannon-Wiener index, Simpson's reciprocal index

ABSTRAK

Kajian jangka pendek mengenai fauna tanah pada kecerunan rendah di ladang kelapa masih tidak diterokai dengan baik kerana sukar dan mengambil masa untuk dikenal pasti. Ini mungkin mengabaikan maklumat asas untuk memahami hubungan antara faktor abiotik. Oleh itu, objektif kajian ini adalah untuk menentukan kesan kedudukan cerun dan masa persampelan terhadap indeks kepelbagaian fauna tanah di penanaman kelapa yang ditanam di kawasan kecerunan rendah. Kajian telah dijalankan pada Disember 2021 di ladang kelapa, UiTM Cawangan Perlis, Malaysia menggunakan Reka Bentuk Blok Lengkap Rawak dengan empat ulangan. Ladang kelapa ini terletak pada kecerunan yang rendah antara 0^{o} hingga 6^{o}. Secara keseluruhan, 96 perangkap lubang telah dipasang di kawasan kelapa berdasarkan tiga kedudukan cerun (iaitu, S1-bawah, S2-tengah dan S3-atas). Fauna tanah dikumpul sebanyak tiga kali (iaitu, T1, T2 dan T3) dalam sebulan tempoh kajian. Spesimen fauna tanah telah dikenal pasti sehingga peringkat famili dan lima daripada indeks fauna tanah (iaitu, kekayaan, kelimpahan, indeks kepelbagaian Shannon-Wiener, indeks timbal balik Simpson dan indeks keseragaman) telah dikira. Hasilnya, 1,335 individu daripada 10 order dan 15 famili telah dikenal pasti dalam kajian ini. Kumpulan Formicidae (69.7%) dan Scolopendridae (0.1%) masing-masing mempunyai bilangan fauna tanah individu yang paling banyak dan paling rendah ditemui di ladang kelapa. Manakala Termitidae (6.5%), Gryllidae (3.4%), Carabidae (2.8%), Acrididae dan Paradioxosomaridae (1.6%) dan Alydidae (1.5%) merupakan fauna tanah individu yang rata-rata. Hasil analisis statistik menunjukkan bahawa kelimpahan adalah yang ketara tertinggi (41±8.4) pada kedudukan teratas (S3) berbanding kedudukan lain dan ini mungkin disebabkan oleh faktor iklim mikro seperti kelembapan dan suhu. Sementara itu, masa pensampelan T3 menunjukkan kekayaan tertinggi yang ketara (7±1.2), indeks kepelbagaian Shannon-Wiener (1.2±0.3), dan indeks timbal balik Simpson (2.5±0.6) dan ini mungkin disebabkan oleh amalan pengurusan seperti rumpai kawalan. Secara keseluruhannya, ladang kelapa ini mempunyai kepelbagaian sederhana dengan kebolehubahan fauna tanah yang tinggi semasa kajian dijalankan.

Kata kunci: Kelimpahan, *Cocos nucifera*, indeks kesamarataan (Pielou), indeks Shannon-wiener, indeks timbal balik Simpson

INTRODUCTION

Soil fauna plays an important role in ecosystem function through the mediation of decomposition, nutrient cycling, and soil aeration. Their distribution in the ecosystem is governed mostly by environmental conditions that filter communities according to functional traits (Ellers et al. 2018) such as physiology (e.g. abiotic stress tolerance; Goberna et al. 2014), morphology (e.g. body size) or behavioural (e.g. feeding strategy, trophic level). Some soil fauna are variation to differences in soil because they forage, inhabit, and reproduce under specific soil conditions (Menta & Remelli 2020). They may dispersal and adapt due to the environmental conditions. Terrain slope gradient is one of the topography factors that affects the biological indices of soil fauna. The structure and diversity in the soil fauna communities may be significantly affected by the terrain slope gradient and may vary with time (He et al. 2012). This might be because the slope gradient has an influence on soil properties along the slope positions due to the surface runoff process. This condition may also cause soil moisture to vary. Consequently, this may influence the vegetation and surrounding environment (i.e., microclimate) along the terrain. Most of the studies have been conducted in flat and hilly areas that have a distinct slope gradient up to 25º (He et al. 2012). However, a few studies (Kamarudin et al. 2024) have been discussed on the soil fauna diversity in the low slope gradient area (slope = 0º–6º). This condition may limit the information of soil fauna in this area.

Coconut (*Cocos nucifera*) is one of the most important industrial crops in Southeast Asia. This crop has been cultivated on a flat and undulating area in the monoculture agrosystem with minimal care. The coconut plantation is relatively low in diversity and diversity index of soil fauna (Tang et al. 2006) compared to multicultural ecosystems like natural forests. This is partially because the coconut plantation has monoculture practice and high soil acidity due to agricultural management practices (Coleman & Wall 2015) and other environmental factors (Tang et al. 2006) like canopy closure (Martius et al. 2004). However, not many studies of soil fauna have discussed the effects of the low slope gradient in the coconut plantation, although some studies have been identified to have a focus on soil fauna in this cultivation area. This is because most of the coconut plantation has been cultivated on a flat area rather than undulating area. This condition may limit the understanding of biological indices of soil fauna in the coconut cultivation area as low slope gradient may alter soil condition. Understanding the soil fauna in the coconut plantation can provide valuable insight into soil health, stability and ecological function. This information is essential for effective land management, conservation and sustainable farming practices.

Commonly, the sampling interval for soil fauna in ecological studies can be weekly or monthly for short-term studies and annual or bi-annual for long-term studies, depending on the study purpose. However, only a few of them were discussed on soil fauna biodiversity in a short time. This is because the collection of soil fauna is tedious and takes time for identification. Thus, the collection of soil fauna at a certain period is more practical. However, this may ignore the important information that can be used to understand the interrelationships between the abiotic factors of their environment and the landscape. Moreover, the presence of soil fauna in the soil is one of the soil quality components that is important for the functioning of the agricultural ecosystem to sustain productivity. Thus, knowing the biological indices of soil fauna is one of the baselines for understanding and evaluating the environmental quality. Therefore, the objective of this study was to evaluate the effect of low slope gradient and sampling time on the biological diversity indices of soil fauna under coconut cultivation in a short-term study.

Materials and Methods

Study Site and Farming Practices

This study was conducted at the coconut farm (Figure 1) located in the Universiti Teknologi Mara (UiTM), Perlis Branch, Arau Campus, Malaysia (6°27’11.9” N, 100°16’50.7” E). The Matag coconut (*Cocos nucifera* cv. Matag) trees have been planted at 8.23 m × 8.23 m of planting distance in the triangular system. The coconut area is 10 acres (4.05 ha) with a total of 446 coconut trees. Currently, the trees were 16 years old (planted in 2005) when the study was done. The main types of soil in this coconut area are the Terap series (Typic Hapludults) and Jitra series (Rhodic Hapludults) in the north and south parts, respectively. Both soil series originated from pedimented materials, which are formed on pediplains developed from iron-rich shale parent materials. This coconut farm lies on a low slope gradient ranging from 0º to 6º.

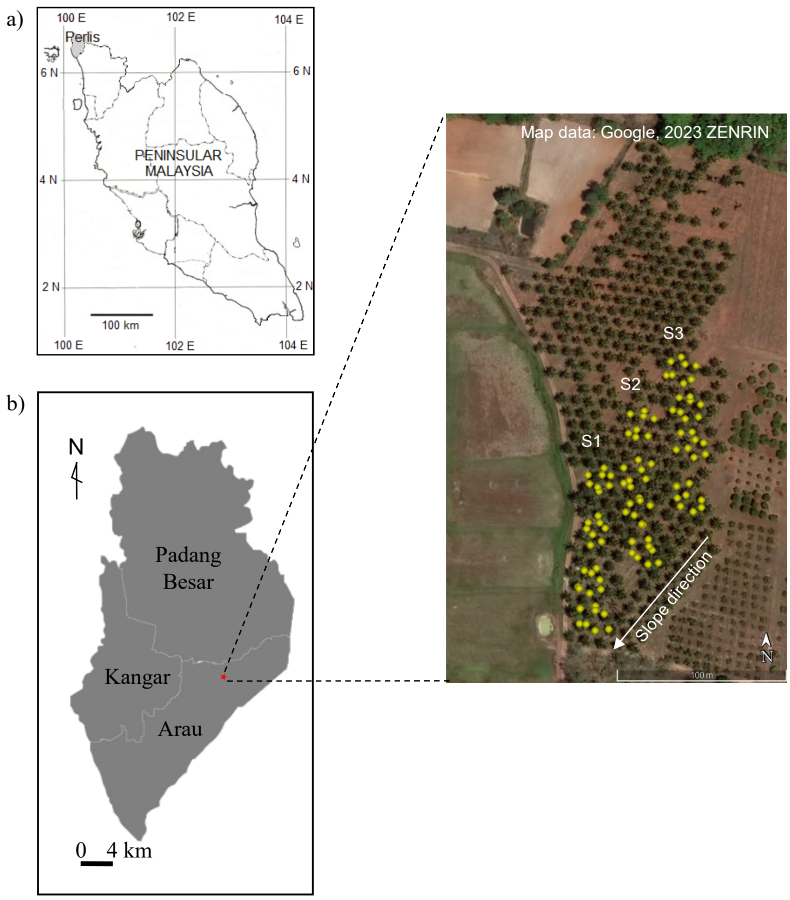

Figure 1. a) Location of Perlis, b) Location of study site. The distribution of pitfall traps within the coconut farm. Note: Slope position: S1 = bottom; S2 = middle, and S3 = top

This coconut tree received approximately 1.1 kg of urea per tree, given that the total fertilizer applied was 500 kg in 2021. This fertilizer was applied using a broadcast method. The undergrowth was controlled using both chemical and mechanical applications. The weeds growing between the trees were controlled using herbicides, i.e., glyphosate and metsulfuron methyl, which are sprayed once every three months. During the study, the herbicide was applied between the first and second samplings of soil fauna. Meanwhile, the weeds growing between the rows were manual weeding by using a mower attached to the tractor at a frequency of once every two months. The last slashing was done a week before the first sampling of soil fauna was carried out. The falling of coconut fronds was arranged between the trees once every three months.

Weather Conditions at Study Site

Generally, Perlis State has a tropical monsoon (Am) climate according to the Köppen-Geiger Classification System (Kottek et al. 2006), as this state is located in the northern part of Peninsular Malaysia, near the Malaysia-Thailand border. This state has had an average annual temperature of 27.4ºC and a mean annual precipitation of 1,893.7 mm over the past 30 years (1990–2021). The weather conditions during the field sampling are shown in Figure 2, where the total rainfall was 52 mm and the mean temperature was 26.9ºC (min = 24.1ºC; max = 31.4ºC) (MMD 2022).

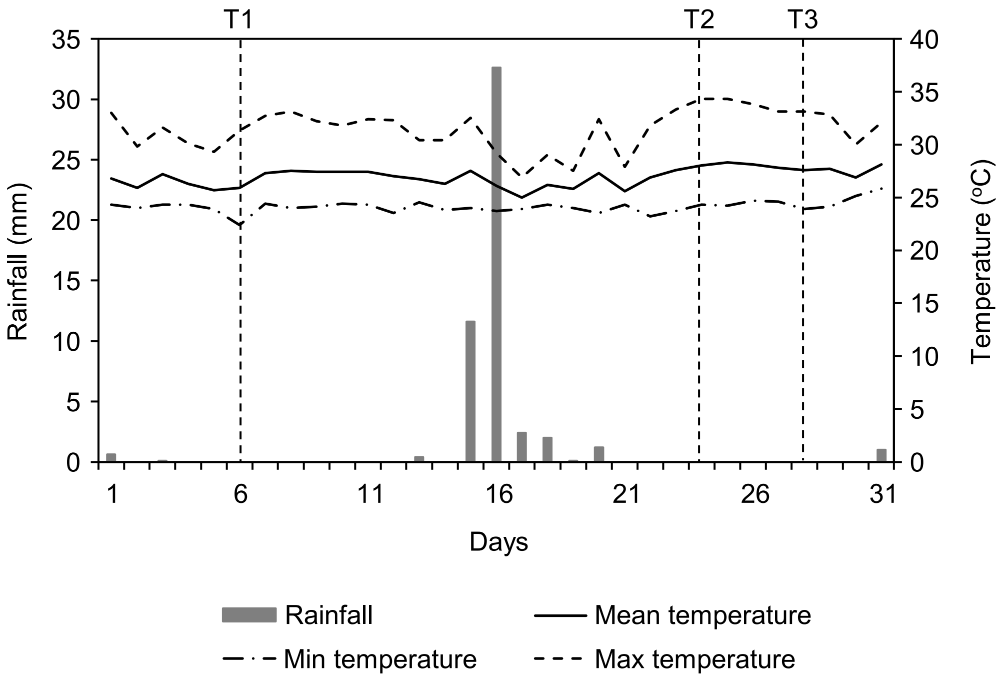

Figure 2. Weather status in December 2021. Note: T1 = first sampling (6th December), T2 = second sampling (24th December), and T3 = third sampling (28th December) in 2021

Soil Fauna Sampling

The experiment was designed based on a randomized complete block design. In this study, two factors were tested with four replications (i.e., blocks). The factors were slope position and sampling time. The area in the south part of the coconut farm was chosen to conduct this study because it has a clear and uniform slope pattern of 6º. The traps were installed based on three slope positions (i.e., S1 = bottom, S2 = middle, and S3 = top) along the terrain. This area was divided into 12 sub-plots, and each sub-plot was installed with 8 pitfall traps. In this study, the soil fauna that has been trapped in 96 traps was collected at each of three sampling times: T1 = first sampling (6th December), T2 = second sampling (24th December), and T3 = third sampling (28th December) in 2021. The sampling times were randomly chosen depending on the weather condition. Meanwhile, the interval days of samplings were chosen to evaluate how soil fauna might change in the short period of time.

The pitfall trap was installed by digging a hole similar to the size of the plastic cup (size = 9.5 cm × 12.0 cm). Then the cup was placed in the hole, and 100 ml of 75% ethanol was filled into the cup. The upper part of the plastic cup was kept at the same level as the ground surface. The trap was covered with a plastic plate (size = 12 cm × 10 cm) to protect it from rainfall by hanging a plastic plate using three wooden sticks. These traps were left in the farm for 24 hours. The pitfall traps have been widely used to sample litter- and surface-soil fauna (Fauzi et al. 2023; Kamarudin et al. 2024; Work et al. 2002). This method collects surface-active soil fauna that falls into the cups filled with preservative. The method yields comparative estimates when used with caution, although it is difficult to estimate the absolute population (Coleman & Wall 2015). The collection of soil fauna was preserved in 75% ethanol for identification.

Soil Fauna Identification
All the collections of soil fauna were screened and identified up to the family level, following the key to identification from Triplehorn and Johnson (2005). This identification process was done manually using the naked eyes.

Soil Fauna Indices
The richness was counted based on the total number of families presented in Equation 1.

$$\text{Richness} = \sum \text{the number of families present} \quad \text{[Equation 1]}$$

The abundance was generated based on the total number of individuals per family presented in Equation 2.

$$\text{Abundance} = \sum \text{the number of individuals per family} \quad \text{[Equation 2]}$$

The diversity index was calculated based on the Shannon-Wiener diversity index (H') presented in Equation 3.

$$H' = -\sum pi \log pi \quad \text{[Equation 3]}$$

The evenness (pielou) index (J) was calculated based on the Shannon-Wiener diversity index over the natural logarithm of richness, i.e., the total number of families in the sample (Equation 4).

$$J = H' / \ln(\text{richness}) \quad \text{[Equation 4]}$$

The Simpson's reciprocal index (sometimes called as dominance index) was also calculated based on Equation 5.

$$Ds = 1 / \sum pi^2 \quad \text{[Equation 5]}$$

where *pi* is the proportion of the total sample represented by family *i*. The proportion was calculated by dividing the number of individuals in family *i* by the total number of samples.

Statistical Analysis
The two-way analysis of variance (ANOVA) was computed using R version 4.0.2 (R Development Core Team 2022) to determine the differences between the tested factors. The mean comparison was calculated using Tukey's HSD.

RESULTS AND DISCUSSION

A total of 1,335 individuals of soil fauna were collected from this study site. From the sample collection, a total of 15 families of soil fauna (Figure 3) have been successfully identified in 10 taxonomic orders: Araneae, Blattodea, Chilopoda, Coleoptera, Hemiptera, Hymenoptera, Opisthopora, Orthoptera, Polydesmida, Scolopendromorpha, and Thysanoptera. These results were lower than the ones reported by Araujo et al. (2018) and Tang et al. (2006). Araujo et al. (2018) collected 34,982 specimens from 16 orders in a coconut farm in northeastern Brazil using the same pitfall trap method. The difference might be mainly caused by management practices due to the use of organic fertilizer (i.e., cow manure) and the soil type of Fluvic Neossol in the Araujo et al. (2018) study. Organic fertilizer has been known to be better at increasing soil organic matter and enhancing soil fauna (Zhou et al. 2022) than synthetic fertilizer. While the soil type of Fluvic Neossol generally known as alluvial soil has different soil characteristics than the soil type in this study which may affect the present of soil fauna (Burton et al. 2022). Although the soil properties were not analysed in this study, the Jitra series soil often has fine and medium subangular blocky structures, a high clay content with moderate nutrient contents, and low organic matter (DOA 2018) which makes it less fertile than alluvial soil.

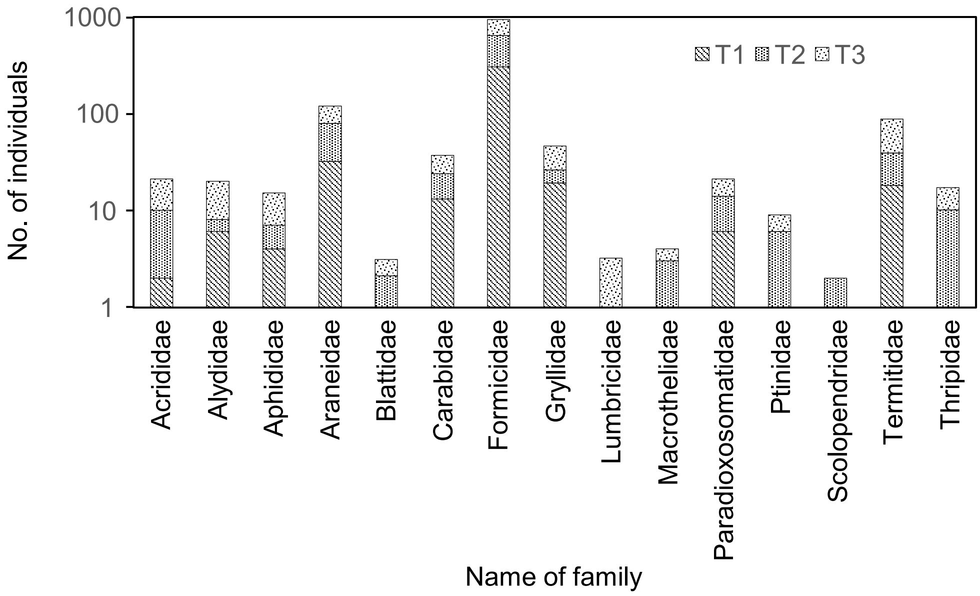

Figure 3. Total number of individual and families of soil fauna collected at the coconut farm. Note: T1 = first sampling (6th December), T2 = second sampling (24th December), and T3 = third sampling (28th December) in 2021

In this study, the Formicidae (n = 931) and Scolopendridae (n = 2) showed the most abundant and lowest number of individuals, respectively, among the collected specimens. The second highest number of individuals was Araneidae (n = 119), followed by Termitidae (n = 87), Gryllidae (n = 46), Carabidae (n = 37), Acrididae and Paradioxosomatidae (n = 21), and Alydidae (n = 20). Meanwhile, the Thripidae, Aphididae, Ptinidae, Macrothelidae, Blattidae and Lumbricidae contained less than 20 number of individuals. The abundance of Formicidae in the coconut farm has been reported by Araujo et al. (2018). The presence of the Formicidae group provides insight into the presence of other organisms, since many Formicidae members can maintain obligate interactions through trophic and symbiotic interactions with plants and other animals (Alonso & Agosti 2000). Although the population of Formicidae can be an excellent ecological indicator in the ground layer, they must be evaluated for relative proportions and diversity (Gerlach et al. 2013). This is because they are poor indicators of richness. The most common Formicidae species that can be found in the coconut cultivation is *Dolichoderus thoracicus* (Azhar & Musa 1988), *Nylanderia yerburyi*, *Oecophylla smaragdina* and *Pheidole* sp. (Dias & Peiris 2015). Large number of debris in coconut crowns serve as suitable nesting sites and natural habitats for *Dolichoderus thoracicus* (Azhar & Musa 1988).

The result of the slope position on soil fauna indices showed that only abundance shows a significant difference along the terrain slope (Table 1). Similar results on the effects of slope position on soil fauna diversity were reported by Jiang et al. (2021). They reported that relative abundance of microbial community was different in different slope positions. In this study, the number of soil fauna was highest at S3 (41±8.4) compared to S2 (37±6.5) and S1 (34±8.6). However, no significant difference was detected in the interaction between slope position and sampling time. In this study, Araneidae and Formicidae were the most common families found along the terrain slope. Meanwhile, among the collected families, Blattidae and Scolopendridae were the groups that have not been caught on S3. Regardless of their family, the number of individual soil fauna was found significantly higher at the top position. This significant might be due to its local climates (i.e., microclimates) especially moisture and temperature of soil surface. Basically, this low slope gradient area is facing to the west which indicates that this area received more solar radiation in the evening. Although this study did not measure microclimates, the influence of slope aspect on temperature has been reported elsewhere (Alice et al. 2015). In this study, Araneidae and Formicidae were the most common groups found along the terrain slope. It is well known that Formicidae are social insects that live together in colonies (Lee & Foster 1991) and can thus be found scattered on the study site. Araneidae and some species of Formicidae are predators. The presence of Araneidae in the agricultural area is a good sign, as this group consumes the pests. However, the presence of Formicidae in the agricultural area needs to be given attention as this group has a mutualistic relationship with Aphididae (Flatt & Weisser 2000), one of the common crop pests in agriculture. Blattidae is a soil-burrowing insect (Maekawa et al. 2003) while Scolopendridae is a generalist feeder that plays an important role as one of the top carnivorous invertebrates in soil ecosystems (Siriwut et al. 2016). Both Blattidae and Scolopendridae were found on S1 and S2, respectively.

Table 1. Analysis of variance (ANOVA) of soil fauna indices

Soil fauna indices	Slope (S)	Time (T)	S × T
Richness	0.696^{ns}	<0.001***	0.809^{ns}
Abundance	0.047*	0.171^{ns}	0.070^{ns}
Diversity index	0.873^{ns}	0.001**	0.735^{ns}
Avenness	0.758^{ns}	0.131^{ns}	0.546^{ns}
Reciprocal index	0.684^{ns}	0.004**	0.807^{ns}

*, **, *** indicates significant difference at $p < 0.05$, 0.01, 0.001 respectively while ns shows insignificant difference at $p \geq 0.05$

Meanwhile, richness, the Shannon-Wiener diversity index and Simpson's reciprocal index only show a significant difference during the sampling times (Figure 4). The number of families in T1 (n = 4±1.0) is low compared to T2 (n = 5±1.2) and T3 (n = 7±1.2). The

Formicidae, Termitidae, Araneidae, Gryllidae, Carabidae, Alydidae, and Acrididae were the most common families of soil fauna that were caught during T3. The Shannon-Wiener diversity index increased from the sampling times of T1 (0.8±0.2), T2 (0.9±0.2) and T3 (1.2±0.3). This indicates that both sampling times of T1 and T2 show low diversity (H’<1), while T3 shows moderate diversity (1<H’<3) (Fauzi et al. 2023) of soil fauna. The Simpson’s reciprocal index shows the significant values at T1 (1.8±0.3), T2 (1.9±0.4), and T3 (2.5±0.6). Basically, this index has the lowest value of 1, and the highest value is equal to the number of families. The evenness (pielou) index shows no significant difference along the terrain slope (S1 = 0.6±0.1, S2 = 0.6±0.1, and S3 = 0.6±0.1), sampling time (T1 = 0.6±0.1, T2 = 0.6±0.1, and T3 = 0.6±0.1) and their interaction. All the values indicate moderate evenness with high variability of soil fauna (0.4<J<0.6) (Fauzi et al. 2023).

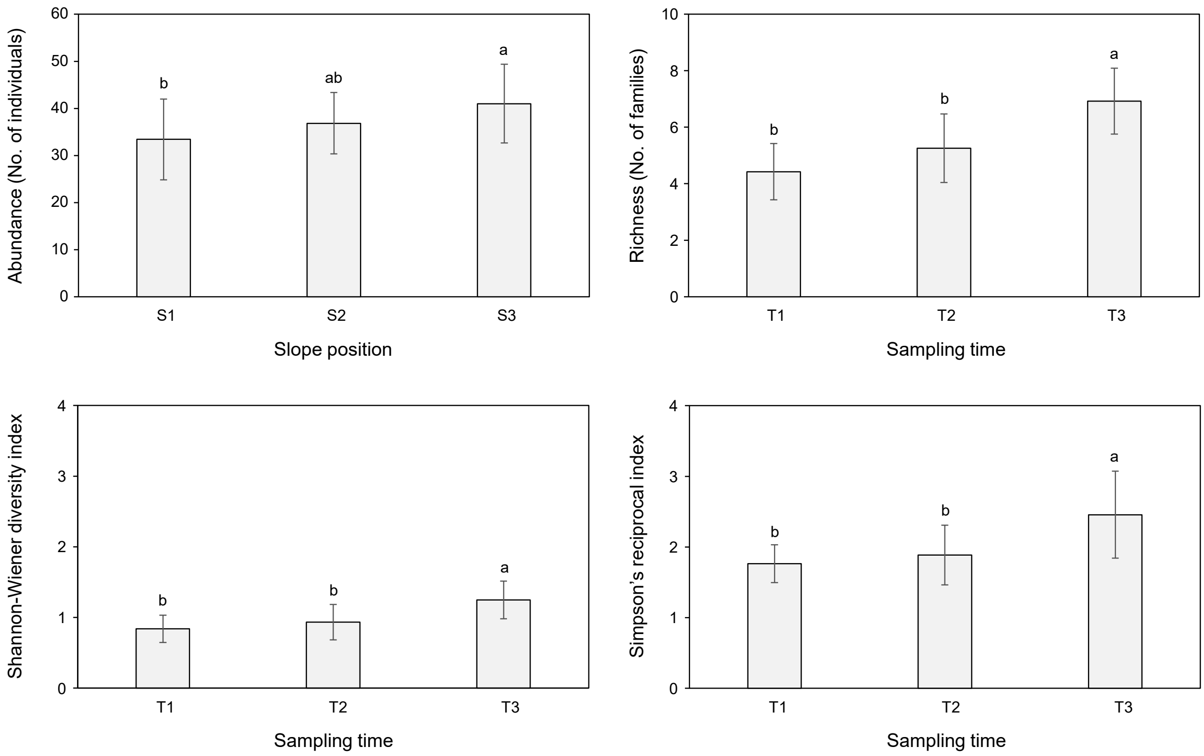

Figure 4. Comparison of slope position and sampling time on selected of soil fauna indices. Note: S1 = bottom, S2 = middle, and S3 = top; T1 = first sampling (6th December), T2 = second sampling (24th December), and T3 = third sampling (28th December) in 2021

The effects of sampling time on richness, the Shannon-Wiener diversity index, and Simpson’s reciprocal index are similar to the ones reported by He et al. (2012). Although the sample collection was done within a month, a significant difference can be observed between the time samplings. The difference between T1 and T2 might be due to the sampling being done on the third and fourth days after raining, while T3 was done on the eighth day after raining (Figure 2), thus resulting in a significant difference. Therefore, the sampling time after a rainy day needs to be considered, as there might be a difference after a week. Rainfall is one of the environmental parameters that was discovered to be among the most significant factors that negatively affecting soil fauna populations, which can reduce the diversity of soil fauna (Coyle et al. 2017) due to the sensitivity of water content (Liu 2012). Therefore, many soil fauna like Formicidae, Termitidae, Araneidae, Gryllidae, Carabidae, Alydidae, and Acrididae were collected during T3 compared to T1 and T2.

Besides that, other extrinsic environmental disturbances like management practices can also affect the diversity of soil fauna (Cole et al. 2008; Coyle et al. 2017). According to Wardle et al. (1995), the soil-associated macrofauna was usually linked to high weeds. In this study, the diversity indices (except abundance) show an increasing value from the first to third samplings. Although weed slashing and herbicide application were applied a week before and after first sampling, respectively, there were no significant difference between the weed slashing and herbicide application on soil fauna diversity in this area (Sulaimin 2022). Similarly, de Santo et al. (2019) found metsulfuron-methyl herbicides did not significantly affect the soil fauna, instead the soil management was the primary influencing factor. According to Lavelle et al. (2006), the biodiversity of soil fauna is highly sensitive to any disturbance since the soil environment is their habitat and the source of their food.

CONCLUSION

As a conclusion, 10 orders belonging to 15 families of soil fauna were recorded in this study, with the total number of soil fauna was 1,335 specimens. Among the identified groups, Formicidae is the common ground-dwelling arthropod that can be found in the coconut farm, and Scolopendridae is the limited soil fauna that can be found in this farm. Meanwhile, Termitidae, Gryllidae, Carabidae, Acrididae, Paradioxosomaridae and Alydidae are the most average of individual soil fauna. The abundance was significantly affected by the slope position, while richness, the Shannon-Wiener diversity index, and Simpson’s reciprocal index were significantly affected by sampling time. Both the slope position and sampling time did not affect the evenness index. Overall, this coconut farm has moderate diversity with high variability of soil fauna during the study. Further research should consider examining both soil physicochemical and microclimate at the study site.

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AUTHORS DECLARATIONS

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Conflict of Interest
The authors declare that they have no conflict of interest.

Ethics Declarations
No ethical issue required for this research.

Data Availability Statement
This manuscript has no associated data.

Authors' Contributions

KNK and MAMS conceived this research, designed experiments and performed experiments; KNK, MAMS, MIK and IMU participated in the data analysis and interpretation of the data; KNK, MIK and IMU wrote the paper and participated in the revisions of it. All authors read and approved the final manuscript.

REFERENCES

Alice, C., Marcell, K.P., William, J.K., Tim, A., Connal, D.E., Mary, W.G., Andreas, H., Thomas, N. & Ingolf, S.D. 2015. Temperature versus resource constraints: which factors determine bee diversity on Mount Kilimanjaro, Tanzania? *Global Ecology and Biogeography* 24(6): 642–652.

Alonso, L.E. & Agosti, D. 2000. Biodiversity studies, monitoring and ants: An overview. Agosti, D., Majer, J.D., Alonso, L.E. & Schultz, T.R. (eds.). *Ants – Standard Methods for Measuring and Monitoring Biodiversity*, pp. 1–24. Washington: Smithsonian Institute.

Araujo, J.L., Pastori, P.L., Gomes, V.F.F., Filho, P.F.M. & Nunes, L.A.P.L. 2018. Changes in the abundance and diversity of soil arthropods in the cultivation of fruit crops. *Revista Ciencia Agronomica* 49: 537–546.

Azhar, I. & Musa, M.J. 1988. Studies on the faunal and floral communities in the debris of the coconut crown. *Proceedings of the National Coconut Conference*, pp. 411–434. Kuala Lumpur: MARDI.

Burton, V.J., Contu, S., De Palma, A., Hill, S.L.L., Albrecht, H., Bone, J.S., Carpenter, D., Corstanje, R., De Smedt, P., Farrell, M., Ford, H.L., Hudson, L.N., Inward, K., Jones, D.T., Kosewska, A., Lo-Man-Hung, N.F., Magura, T., Mulder, C., Murvanidze, M., Newbold, T., Smith, J., Suarez, A.V., Suryometaram, S., Tothmeresz, B., Uehara-Prado, M., Vanbergen, A.J., Verheyen, K., Wuyts, K., Scharlemann, J.P.W., Eggleton, P. & Purvis, A. 2022. Land use and soil characteristics affect soil organisms differently from above-ground assemblages. *BMC Ecology and Evolution* 22: 135.

Cole, L., Buckland, S.M. & Bardgett, R.D. 2008. Influence of disturbance and nitrogen addition on plant and soil animal diversity in grassland. *Soil Biology and Biochemistry* 40: 505–514.

Coleman, D.C. & Wall, D.H. 2015. Soil fauna: occurrence, biodiversity, and roles in ecosystem function. In. Eldor, A.P. (ed.). *Soil Microbiology, Ecology, and Biochemistry,* 4th Edition. pp. 111–149. Oxford: Academic Press.

Coyle, D.R., Nagendra, U.J., Taylor, M.K., Campbell, J.H., Cunard, C.E., Joslin, A.H., Mundepi, A., Phillips, C.A. & Callaham, M.A. 2017. Soil fauna responses to natural disturbances, invasive species, and global climate change: current state of the science and a call to action. *Soil Biology and Biochemistry* 110: 116–133.

de Santo, F.B., Guerra, N., Vianna, M.S., Torress, J.P.M., Marchioro, C.A. & Niemeyer, J.C. 2019. Laboratory and field tests for risk assessment of metsulfuron-methyl-based herbicides for soil fauna. *Chemosphere* 222: 645–655.

Dias, R.K. & Peiris, H.A. 2015. Ground-dwelling ant assemblages (family: Formicidae) in six coconut (*Cocos nucifera* L.) plantations in Sri Lanka. *Journal of Insect Biodiversity* 3(14): 1–10.

DOA. 2018. *Common Soils of Peninsular Malaysia: Soil Profile Description and Analytical Data*. Putrajaya: Department of Agriculture.

Ellers, J., Berg, M.P., Dias, A.T.C., Fontana, S., Ooms, A. & Moretti, M. 2018. Diversity in form and function: Vertical distribution of soil fauna mediates multidimensional trait variation. *Journal of Animal Ecology* 87: 933–944.

Fauzi, A., Apriyanto, D., Zarkani, A., Santoso, S., Kamil, M.I. & Wibowo, H.E. 2023. Abundance and diversity of soil arthropods in the secondary forest and park at the University of Bengkulu. *Journal of Natural Resources and Environmental Management* 13(1): 168–174.

Flatt, T. & Weisser, W.W. 2000. The effects of mutualistic ants on aphid life history traits. *Ecology* 81(12): 3522–3529.

Gerlach, J., Samways, K.N. & Pryke, J. 2013. Terrestrial invertebrates as bioindicators: An overview of available taxonomic groups. *Journal of Insect Conservation* 17: 831–850.

Goberna, M., Navarro-Cano, J.A., Valiente-Banuet, A., Garcia, C. & Verdu, M. 2014. Abiotic stress tolerance and competation-related traits underlie phylogenetic clustering in soil bacterial communities. *Ecology Letters* 17:1191–1202.

He, X., Wu, P., Zhang, H. & Cui, L. 2012. Effects of slope gradient on the community structures and diversities of soil fauna. *Acta Ecologica Sinica* 32: 3701–3713.

Jiang, C., Feng, J., Zhu, S.F. & Shui, W. 2021. Characteristics of the soil microbial communities in different slope positions along an inverted stone slope in a degraded karst Tiankeng. *Biology* (*Basel*) 10(6): 474.

Kamarudin, K.N., Sulaimin, M.A.M., Kamil, M.I. & Umami, I.M. 2024. Spatial and temporal variability of soil fauna under coconut cultivation on lateritic soil. *Serangga* 29(1): 156–172.

Kottek, M., Grieser, J., Becj, C., Rudolf, B. & Rubel, F. 2006. World map of the Köppen-Geiger climate classification update. *Meteorologische Zeitschrift* 15(3): 259–263.

Lavelle, P., Decaens, T., Aubert, M., Barot, S., Blouin, M., Bureau, F., Margerie, P., Mora, P. & Rossi, J.P. 2006. Soil invertebrates and ecosystem services. *European Journal of Soil Biology* 42: S3–S15.

Lee, K.E. & Foster, R.C. 1991. Soil fauna and soil structure. *Australian Journal of Soil Research* 29: 745–775.

Liu, R.T. 2012. Relationships between soil fauna and rainfall change in desert steppe: A review. *Chinese Journal of Ecology* 31(3): 760–765. [Chinese with English abstract].

Maekawa, K., Lo, N., Rose, H.A. & Matsumoto, T. 2003. The evauation of soil-burrowing cockroaches (Blattaria: Blaberidae) from wood-burrowing ancestors following an invasion of the latter from Asia into Australia. *Proceeding of the Royal Society of London B* 270: 1301–1307.

Martius, C., Hofer, H., Garcia, M.V.B., Rombke, J., Forster, B. & Hanagarth, W. 2004. Microclimate in agroforestry systems in central Amazonia: does canopy closure matter to soil organism? *Agroforestry Systems* 60: 291–304.

Menta, C. & Remelli, S. 2020. Soil health and arthropods: from complex system to worthwhile investigation. *Insects* 11: 54.

MMD. 2022. *Weather data: Station Chuping, Perlis 1990–2021*. Putrajaya: Malaysian Meterology Department.

R Development Core Team. 2022. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna. http://www.R-project.org [5 December 2022].

Siriwut, W., Edgecombe, G.D., Sutcharit, C., Tongkerd, P. & Panha, S. 2016. A taxonomic review of the centipede genus *Scolopendra Linnaeus*, 1758 (Scolopendromorpha, Scolopendridae) in mainland Southeast Asia, with description of a new species from Laos. *ZooKeys* 590: 1–124.

Sulaimin, M.A.M. 2022. The effect of topography and undergrowth management towards soil fauna diversity in Matag Coconut Garden at Uitm Perlis. Final Year Project Report, Universiti Teknologi MARA.

Tang, B., Tang, M., Chen, C., Qui, P., Liu, Q., Wang, M. & Li, C. 2006. Characteristics of soil fauna community in the Dongjiao coconut plantation ecosystem in Hainan, China. *Acta Ecologica Sinica* 26: 26–32.

Triplehorn, C.A. & Johnson, N.F. 2005. *Borror and Delong's Introduction to the Study of Insects*. 7th Edition. USA: Thomson.

Wardle, D.A., Yeates, G.W., Watson, R.N. & Nicholson, K.S. 1995. The detritus food-web and the diversity of soil fauna as indicators of disturbance regimes in agro-ecosystems. *Plant and Soil* 170(1): 35–43.

Work, T.T., Buddle, C.M., Korinus, L.M. & Spence, J.R. 2002. Pitfall trap size and capture of three taxa of litter-dwelling arthropods: Implications for biodiversity studies. *Environmental Entomology* 31(3): 438–448.

Zhou, Z.K., Zhang, S.Y., Jiang, N., Xiu, W.M., Zhao, J.N. & Yang, D.L. 2022. Effects of organic fertilizer incorporation practices on crops yield, soil quality, and soil fauna feeding activity in the wheat-maize rotation system. *Frontiers in Environmental Science* 10: 1058071.