

ABUNDANCE AND DIVERSITY OF SOIL MACROFAUNA IN KATOKKON CHILI CULTIVATION FIELD IN NORTH TORAJA REGENCY

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ABSTRACT

Katokkon chili (Capsicum frutescens L.) is a leading local horticultural crop in Toraja, South Sulawesi, and holds significant economic and cultural value. However, declining soil health due to unsustainable cultivation practices has reduced productivity. Soil macrofauna are important indicators of soil health because of their roles in organic matter decomposition, nutrient cycling, and soil structure improvement. This study aimed to analyze the abundance and diversity of soil macrofauna as bioindicators of soil health in katokkon chili cultivation fields in Batupiak Hamlet, Kesu' District, North Toraja Regency. The method used was hand sorting for manual identification of macrofauna from soil samples, accompanied by measurement of soil physicochemical parameters, including temperature, pH, organic C (Walkley and Black method), and total N (Kjeldahl method). The results showed that the types of macrofauna found included Lumbricidae, Formicidae, Anisolabidae, Lycosidae, and centipedes, with a diversity index (H') of 1.103, classified as moderate, and an average population abundance of 466.67 individuals/m². Environmental parameters supported the presence of these macrofauna, with soil temperature 28–29°C, pH 5.3–6.78, organic C content 1.70–2.55%, and total N 0.12–0.29%, although soil moisture was relatively low. These findings indicate that katokkon chili fields in Batupiak exhibit fairly good soil biological activity and soil fertility potential, which should be maintained to support sustainable production. The results of this study contribute to the improvement of soil health indicators.

1. INTRODUCTION

Katokkon chili (*Capsicum frutescens* L.) is a known local chilli variety from Toraja, South Sulawesi, Indonesia (Daryono and Tammu, 2022). Its fruits are typically oval-shaped with tapered ends or occasionally square-tipped, resembling bell peppers (Maulana *et al.*, 2023). Katokkon chilli has a higher level of spiciness compared to other varieties, with Scoville Heat Units (SHU) (Scoville Heat Unit) scale of 30,000-50,000 (Amaliah, 2018). This uniqueness makes katokkon chili not only of high economic value but also plays an important role in the culinary culture of the Toraja people, especially as a main ingredient in various traditional dishes. In addition to its cultural value, katokkon chilli contributes to local food security in its native region (Daryono and Tammu, 2022). However, the successful cultivation of this plant is heavily reliant on the soil and environmental conditions prevalent in its growing area (Flowrenzhy and Harijati, 2017).

Katokkon chilli, which belongs to the large red chilli group, is a leading horticultural commodity widely cultivated by farmers in North Toraja and Toraja Regency (Daryono and Tammu, 2022). Toraja has environmental conditions suitable for the growth of katokkon chilli at elevations of approximately from 704 to 1,646 m above sea level. Katokkon chillies grown at an elevation of 1,200 m above sea level tend to bear fruit more quickly, have higher plant productivity, and have a spicier flavor compared to those grown at lower elevations, such as 600 m above sea level (Flowrenzhy & Harijati, 2017).

Market supply of Katokkon chillies is considerably lower than that of other chillies, leading to higher prices. They reached Rp. 70.000/kg in early 2025 (Tuerah, 2025), and can surpass Rp. 100.000/kg in peak seasons (Daryono and Tammu, 2022). Despite its promising economic potential, development faces significant challenges in this regard. Poor farming practices, heavy pesticide use, and climate shifts are degrading soil and disrupting local weather patterns (Putri *et al.*, 2024). As a result, large chilli production in North Toraja Regency decreased from 1,043.3 tonnes in 2019 (BPS, 2020) to 837.9 tonnes in 2021 (BPS, 2023), confirming that declining soil health directly reduces crop output. Strengthening soil health and adopting sustainable agricultural practices are key strategies to sustain katokkon productivity and regional agroecosystem balance.

The presence of soil macrofauna is a key indicator of soil health (Gumay *et al.*, 2023; Wibowo and Slamet, 2017). This group of organisms includes various creatures, such as earthworms, insects, and other large soil-dwelling animals. Macrofauna play a significant ecological role in supporting soil functions, such as the decomposition of organic matter, increasing nutrient availability, improving soil structure, and enhancing aeration and water infiltration (Wibowo and Slamet, 2017). In agricultural land, the abundant macrofauna generally reflects healthy and fertile soil, which directly contributes to plant growth and productivity (Hermansah *et al.*, 2023).

Katokkon chili plants require land with fertile and loose soil to support optimal growth. The optimal soil conditions for katokkon chili growth is a mixture of clay and sandy soil with a medium texture (Ramalho do Rêgo *et al.*, 2016). In this context, soil macrofauna, such as earthworms, insects, and other small organisms, play an important role in maintaining soil health. Macrofauna contribute to the decomposition of organic matter, accelerate nutrient cycling, and improve soil structure and aeration, ultimately boosting land productivity (Hermansah *et al.*, 2023; Ramalho do Rêgo *et al.*, 2016; Wasis *et al.*, 2024). Soils rich in macrofauna tend to have better structure (Demetrio *et al.*, 2022), higher water absorption capacity (Frouz *et al.*, 2006; Lal, 1988), and more readily available nutrients for plants (Pant *et al.*, 2017; Sofu *et al.*, 2020).

In this context, an analysis of the abundance and diversity of soil macrofauna in katokkon chili farmlands is an important aspect of understanding the impact of land management practices on the balance of the soil ecosystem (Chamorro-Martínez *et al.*, 2022; Rumahorbo *et al.*, 2020). Good soil management practices can increase the population of beneficial soil fauna (Mamabolo *et al.*, 2024).

Conversely, the excessive use of chemicals has been shown to reduce the number and diversity of soil macrofauna, ultimately decreasing soil quality and inhibiting plant productivity (Nare *et al.*, 2017).

However, scientific studies on the abundance and diversity of soil macrofauna in katokkon chili agricultural land are limited. Most existing research has focused on agronomic and cultivation aspects (Numba and Hazisah, 2024; Putri *et al.*, 2024), while ecological approaches, particularly those related to the role of soil biota, have not been extensively studied. Katokkon chili itself is cultivated in several subdistricts in North Toraja, one of which is Kesu Subdistrict (Daryono and Tammu, 2022). In this area, there is the Agriya Sari Farmers Group in Batupiak Hamlet, Ba'tan Village, which actively cultivates katokkon chilis. Considering the importance of soil macrofauna in maintaining land quality, as well as the lack of soil ecology data in this location, this descriptive observational study was conducted in katokkon chili farmland in Batupiak Hamlet. The study aimed to provide baseline information on the abundance and diversity of soil macrofauna as an initial assessment of soil biological condition in the area.

2. MATERIALS AND METHOD

2.1 Time and and Location of Research

This descriptive observational study was conducted from November 2024 to February 2025. Sample collection was done in Batupiak Hamlet, Ba'tan Village, Kesu' District, North Toraja Regency. The study was designed to characterize the abundance and diversity of soil macrofauna under existing field conditions without applying any experimental treatment. The study location map is shown in Figure 1. The chemical properties of the soil samples were analyzed at the Soil Chemistry and Fertility Laboratory, Department of Soil Science, Faculty of Agriculture, Hasanuddin University.

2.2 Tools and Materials

The tools used in the field for this research are: shovel, 25x25 cm monolith box, hoe, tray, knife, measuring tape, soil thermometer, sample bottles, labels, camera, GPS (global positioning system), plastic bags, tweezers, magnifying glass, gloves, 70% alcohol, and writing instruments. The materials used are disturbed soil samples from each sampling point, and a location map of Batupiak Village, Kesu' Subdistrict, North Toraja Regency.

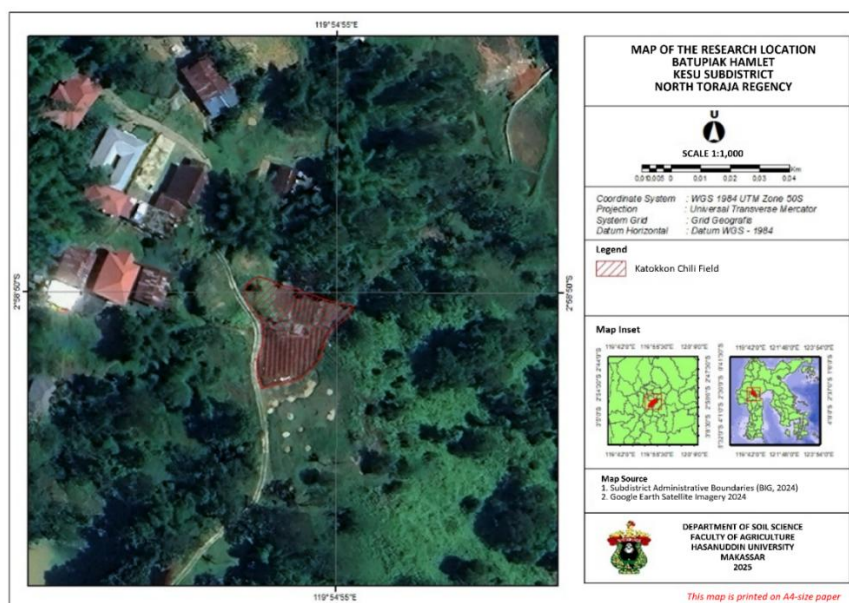


Figure 1. Map of sampling locations, the area shaded in red is the location of katokkon chili fields.

2.3 Methods

2.3.1 Soil Sample Collection

Soil samples were collected using the purposive sampling method (Ferdiansyah *et al.*, 2024). This approach was selected because the study aimed to characterize soil macrofauna in representative areas of katokkon chili farmland under relatively uniform management conditions. Sampling points selected based on criteria: (1) active cultivation of katokkon chili, (2) relatively homogenous land management practice, and (3) similar topographic conditions. Six sampling points were distributed across the study area to represent the existing field conditions. Each sampling point was replicated twice to increase the accuracy of the results, with a distance of 1 m between monoliths. Each soil sample was taken using the monolith method with a box sized 25 × 25 cm (Dyah Susanti and Halwany, 2017) to a depth 0–10 cm (Musyafa, 2005; Wibowo and Slamet, 2017). Litter on the surface and soil from the monolith were placed into separate plastic bags according to each monolith point (Wibowo and Slamet, 2017). The soil was then transferred to different trays based on the sampling point for further observation, collection, and identification of macrofauna specimens.

2.3.2 Soil Chemical Properties Analysis

Analysis of the soil's chemical properties was carried out to evaluate the environmental conditions affecting macrofauna presence. The parameters analyzed included soil pH (H₂O) using a pH meter, organic carbon content (% organic C) using the Walkley & Black method, and total nitrogen (% total N) using the Kjeldahl method. Soil temperature was measured directly in the field using a soil thermometer.

2.3.3 Collection and Identification of Macrofauna Specimens

The soil from each monolith was then processed for macrofauna collection using the hand collection method (Setiawati *et al.*, 2023). Each observed macrofauna was separated based on its category/group or taxon. Each macrofauna group was counted, and representative samples were carefully collected with tweezers and stored in vials as a collection for identification up to the family level.

2.3.4 Analysis of Soil Fauna Abundance

The soil macrofauna data obtained were then analyzed based on the total population abundance and relative abundance using the following equation (Kabar *et al.*, 2022).

$$PA = \frac{\text{The number of individuals of type A}}{\text{Number of volume units}} \quad (1)$$

$$RA = \frac{PA \text{ type A}}{\text{The total number of PA}} \times 100\% \quad (2)$$

Note: PA = Population abundance; RA = Relative abundance.

Furthermore, to determine the level of diversity and dominance in the soil fauna community, the Shannon-Wiener Index (H') and Simpson's Dominance Index (D) are used. The Shannon-Wiener diversity index is calculated using the following equation (Shannon and Weaver, 1964):

$$H' = - \sum (P_i) \ln (P_i) \quad (3)$$

Note: H' = Shannon-Wiener Diversity Index; P_i = n_i/N; N_i = ∑ individuals of species n; N = ∑ individuals of all species.

The Simpson Index is one of the most commonly used methods to measure biodiversity based on the number of individuals of each species in an area. This index calculates the level of dominance

or concentration of species within a community. The dominance concentration (D) describes the probability that two randomly selected individuals belong to the same species. The formula used is as follows (Simpson, 1949):

$$\text{Dominance Index} = \sum (P_i)^2 \quad (4)$$

Note: $P_i = n_i/N$; $n_i = \sum \text{individuals of species } i$; $N = \sum \text{Individuals of all species}$.

3. RESULT AND DISCUSSION

3.1 Analysis of Soil Chemical Properties In The Katokkon Chili Plantation Area

Soil conditions will affect crop growth. Crops require soil pH, temperature, and nutrients appropriate for their needs to achieve optimal growth. The results of the analysis of soil chemical parameters for soil in the katokkon chili plantation area in Dusun Batupiak can be seen in Table 1. Soil chemical analysis was conducted to determine the suitability of soil conditions in the katokkon chili plantation for its growth.

High or low pH levels affect plant growth. For chili cultivation, a suitable pH range is 6–7 (Bahar *et al.*, 2009; Fatchul Aziez *et al.*, 2021). However, some sources state that a pH of 5.5–6.8 is also appropriate for chili cultivation (Rivitra *et al.*, 2021). Soil pH directly affects nutrient solubility and plant uptake: under acidic conditions, macronutrients such as N, P, and K become less available due to fixation by Al and Fe, reducing their accessibility to roots (Syah *et al.*, 2025). In contrast, pH 6.0–7.0 is considered optimal for chilies, ensuring adequate solubility of both macro- and micronutrients. Based on the results of soil pH testing in the katokkon chili cultivation area in Dusun Batupiak, the pH ranged from 5.4 to 6.95, with an average pH value of 6.4, indicating that the soil pH range is still suitable for katokkon chili cultivation.

Temperature is a factor that influences the growth and development of chili plants. Katokkon chilis tend to be sensitive to temperature fluctuations. As tropical plants, chilis are better adapted to warm conditions than to cold. Temperatures below the optimum range can reduce metabolic activity and limit nutrient uptake by roots, whereas excessively high temperatures may increase transpiration rates, induce water stress, and negatively affect flower formation and fruit set (Bhattacharya, 2019; Lynch *et al.*, 2012). The ideal temperature range for chili growth is 21–30°C (Daryono and Tammu, 2022). Based on soil temperature measurements in the katokkon chili plantation area, the temperature ranged from 28–29°C, confirming that thermal conditions are within the ideal range for chili growth.

Organic matter is an essential soil component that enhances physical, biological, and chemical properties. It acts as a nutrient buffer and increases nutrient availability. The organic matter content in soil is directly proportional to the value of organic C (Nopsagiarti *et al.*, 2020). Organic C is the amount of carbon contained in the organic matter in the soil. The organic C content measured in the katokkon chili cultivation area ranged from 1.7% to 2.4%, classified as low to moderate, with an average of 2.12%, which is considered moderate. Ideally, soil for chili growth should contain at least 2% organic C in sandy soils and 1% in clay soils (Sumarni and Muharam, 2005). Thus, the organic C value in the katokkon chili plantation meets the minimum requirement, but adding more organic matter is needed to improve yields. Research shows that organic C can increase chili yields by around 24–75%, and the addition of 4% organic matter can provide optimal results for chili plants (Ranesa *et al.*, 2024).

In addition to organic matter, nutrients such as nitrogen are macronutrients required by chili plants. The results of the total N analysis (Table 1) also showed total N values in the low to moderate range, with an average of 0.23%, classified as moderate. This indicates that the soil in the katokkon chili plantation area still requires supplemental nitrogen nutrients. The amount of nitrogen nutrient

needed by katokkon chili plants is 3.5–5.5% (Daryono and Tammu, 2022).. An increase in available N in the soil has a positive impact on chili yields (Ranesa *et al.*, 2024). Although nitrogen is an important nutrient for chili plant growth, an excess can also negatively affect plants (Elhanafi *et al.*, 2019). Therefore, the nitrogen requirement in the katokkon chili plantation should be sufficient and balanced.

3.2 Analysis of soil fauna abundance

Observations at six sampling points in the Katokkon chili agricultural field revealed the presence of five soil macrofauna family groups: Lumbricidae, Anisolabidae, Lycosidae, Scolopendridae, and Formicidae (Figure 2). On average, four different family groups were found at each sampling point. However, at the fifth point, only two family groups were present. Based on the results of soil chemical property analysis, TS5 had higher soil pH, organic carbon, and total nitrogen levels than TS2, but TS2 had a more diverse family composition compared to TS5. This suggests that other microenvironmental conditions at that site may be less supportive of soil fauna diversity.

Based on Figure 2, it can be observed that the most dominant soil macrofauna across all observation points are the Lumbricidae family (marked in dark blue) and Formicidae (purple). The Lumbricidae found in the field are generally represented by earthworms, which are known as important soil organisms due to their role in maintaining soil structure and enhancing air and water circulation within the soil.

Table 1. Results of soil chemical analysis in the katokkon chili plantation area based on each sampling point

Code	pH	C-Organic (%)	N-Total (%)	Soil Temperature (°C)
TS 1	6,3	1,7	0,25	28
TS 2	5,4	1,7	0,12	29
TS 3	6,78	2,6	0,20	29
TS 4	6,55	2,1	0,29	29
TS 5	6,44	2,2	0,27	28
TS 6	6,95	2,4	0,23	29
Average	6,40	2,12	0,23	28,67

Note(s): TS = Sampling point.

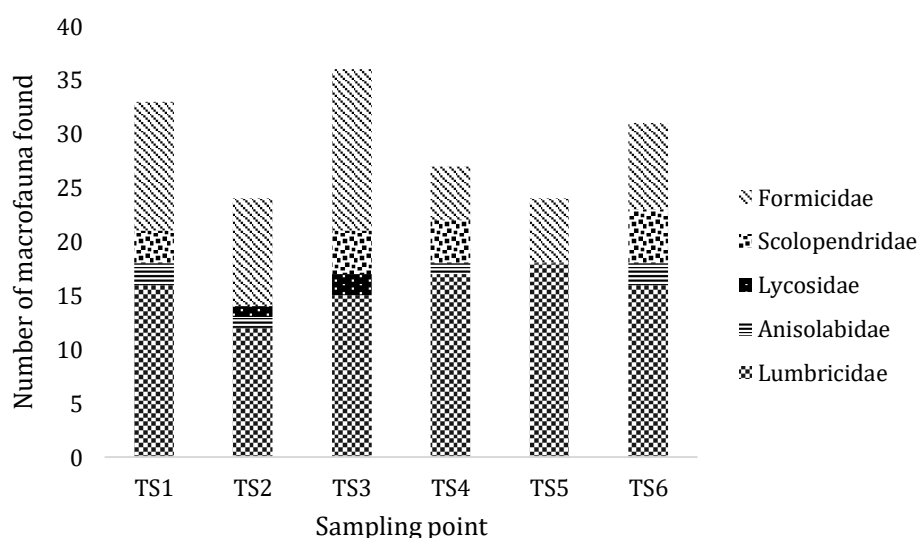


Figure 2. Stackbar diagram showing the number and types of macrofauna found at each sampling point

The results of population abundance calculations (Table 2) show that the Lumbricidae family reached 250.67 individuals/m², which means that in every square meter of the studied katokkon chili farmland, there are about 250-251 earthworms with a relative abundance of 53.71%, followed by the Formicidae family with a relative abundance of 32% and a population abundance of 149.33 individuals/m². Lumbricidae were most abundant at TS5 and least abundant at TS2. TS2 was the only site with a soil pH<6, falling into the 'moderatetely acidic' category, while the other sites had soil pH>6, classified as 'slightly acidic'. An increase in pH was associated with an increase in the number of Lumbricidae found, although this increase does not always occur—for example, TS6, with a pH of 6.9, has fewer Lumbricidae than TS5, which has a pH of 6.44. TS2 also has low organic carbon compared to TS3–TS6, which have moderate organic carbon. TS1 has the same organic carbon content as TS2, but its pH is higher than TS2's, so more earthworms (Lumbricidae) were found in TS1 than in TS2. According to Irmeler, (2010), there is a weak correlation between soil pH or soil organic matter content and the abundance of earthworms found. The Formicidae family found in the field was represented by ground ants. The dominance of these two families shows that the soil conditions in the katokkon chili farmland support the life of beneficial soil biota. Lumbricidae, represented by earthworms, play an important role in improving soil quality through their biological activity, such as accelerating the decomposition process of organic matter and increasing nutrient availability for plants (Kosman & Subowo, 2010). The presence of earthworms is also known as a bioindicator that is sensitive to changes in soil conditions, especially those resulting from soil management practices (Nurrohmah, 2022).

According to Purwani *et al.*, (2022), the higher the value of relative abundance and population abundance of fauna that are beneficial for agriculture, the more soil and crop management tends toward conservation and sustainability. Thus, the high earthworm population in this area can serve as a preliminary indication that the katokkon chili cultivation system applied by local farmers has the potential to support sustainable agriculture. In addition, ants (Family Formicidae) also act as soil engineers in the soil ecosystem and play a role in breaking down organic material. Ant activities, such as building nests and breaking down organic material, can increase the organic matter content, total nitrogen, phosphorus, as well as improve soil structure. This role directly contributes to increasing soil fertility, which ultimately supports plant growth (Zhou *et al.*, 2023).

Table 2. Abundance and relative abundance of soil macrofauna populations (individuals/m²) found in katokkon chili plantations up to a depth of 10 cm using the hand-sorting method

Ordo	Famili	Population abundance (individual/m ²)	Relative abundance (%)
Opisthopora	Lumbricidae	250.67	53,71
Dermaptera	Anisolabidae	16	3,42
Araneida	Lycosidae	8	1,71
Scolopendromorpha	Scolopendridae	42.67	9,14
Hymenoptera	Formicidae	149.33	32
Total		466.67	100

Table 3. Shannon-Wiener Diversity Index (H') and Simpson Dominance Index (D).

H'	Category	Interpretation	D	Category	Interpretation
1,103	Medium diversity	Indicate moderate diversity. The community was dominated by few species	0,401	Low dominance	Dominance value close to 0.5 indicates that the populations of each species are equilibrium. No species dominates the environment

Apart from Lumbricidae and Formicidae, three other macrofauna families were identified in the katokkon chili cultivation fields: Anisolabidae, Lycosidae, and Scolopendridae. These three families have relatively low abundance, each accounting for less than 10%, but they still play important roles in the soil ecosystem, especially as predators. The Anisolabidae family is known as predators of small insects and is frequently found in various types of agroecosystems. Their presence has been reported in taro (Ferdiansyah *et al.*, 2024) and oil palm cultivation systems (Setiawati *et al.*, 2023).

Lycosidae (spiders) are predators in the soil ecosystem that help control populations of small insects and pest organisms (Budiarti *et al.*, 2021; Kusuma Dewi *et al.*, 2019). According to Jocqué & Alderweireldt (2005) the Lycosidae family adapts well to environments with low vegetation, so they are commonly found in open areas and grasslands. Katokkon chili plantations have low-vegetation habitats, making them suitable for the Lycosidae family. However, in this study, Lycosidae actually showed the lowest abundance, which is likely influenced by competitive interactions with other predators or specific local microclimatic factors.

Meanwhile, the Scolopendridae (centipede) is recognized as a major predator in the soil macrofauna community (Bonato *et al.*, 2021). In addition to their role in the food chain, centipedes are also unique as bioaccumulators, being able to absorb heavy metals in their bodies. Because of this trait, centipedes are often used as bioindicators sensitive to changes in soil environmental quality, including heavy metal pollution (Mitić, 2023). Thus, although their abundance is low, these three families make important contributions to soil ecosystem stability and the potential for environmental recovery. Their presence indicates that katokkon chili agricultural land not only supports saprophytic and soil-burrowing macrofauna such as Lumbricidae and Formicidae, but also provides suitable habitat for soil predators that are important for biological control and as indicators of environmental health.

Based on the calculation results of the Shannon-Wiener Diversity Index (Table 3), the macrofauna diversity index value on katokkon chili fields is 1.103, which falls into the middle category (Abeyrathne *et al.*, 2024; Baliton *et al.*, 2020), indicating middle soil macrofauna diversity and biological dynamics. Previous studies by Qomariyah *et al.*, (2020) reported the soil macrofauna H' value in regular chili cultivation fields is 0.8, showing that the macrofauna H' value in katokkon chili fields is slightly higher than in regular chili fields.

In this study, the Simpson dominance index is close to 0.5, indicating that no fauna are overly dominant in the katokkon chili fields, with each fauna in a balanced state. This suggests that the soil management practices support ecological sustainability in agriculture.

4. CONCLUSIONS

This study shows that the Katokkon chili cultivation land in Batupiak, North Toraja, has a moderate level of soil macrofauna diversity and a total abundance of 466.67 individuals/m², indicating a functionally active and ecologically stable soil environment. The presence of major macrofauna groups such as Lumbricidae and Formicidae, supported by favorable physical and chemical soil conditions, reflects a soil ecosystem with good biological activity and promising fertility potential. These findings provide baseline ecological information on soil macrofauna communities in Katokkon chili farmland and highlight the importance of maintaining soil biodiversity to support sustainable land management and long-term agricultural productivity.

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6. REFERENCES

- Abeyrathne, B., Ranatunga, N., Chandrasiri, S., & Madola, I. (2024). Faunal diversity and the ecological aspects of a community-based fragmented lowland rainforest patch in Western Province, Sri Lanka. *Environment and Natural Resources Journal*, 22(2), 119–128. <https://doi.org/10.32526/enrj/22/20230220>
- Amaliah, N. (2018). Penentuan kadar capsaicin menggunakan metode kromatografi lapis tipis (KLT) pada cabe Katokkon. *Jurnal Sains Terapan*, 4(1), 49–56.
- Bahar, Y. H., Andayani, A., Agustini, Y. D., Tahir, M., Adam, I., Suwarno, E. H., Suryani, S., Sugiastuti, H., Hendaruddin, W., Ambyah, Mangunsidi, G., Budiman, A., Baswarsati, Arroyini, M. T., Komariah, L., Sumarni, T. R., Zulfiqar, U., Sutriyono, Sunyoto, A., Sukoco, Mudjijo, Saleh, M., Herman, & Ghufon. (2009). *Standar operasional prosedur (SOP) budidaya cabe rawit*. Departemen Pertanian, Direktorat Budidaya Tanaman Sayuran & Biofarmaka.
- Baliton, R. S., Landicho, L. D., Cabahug, R. E. D., Paelmo, R. F., Laruan, K. A., Rodriguez, R. S., Visco, R. G., & Castillo, A. K. A. (2020). Ecological services of agroforestry systems in selected upland farming communities in the Philippines. *Biodiversitas*, 21(2), 707–717. <https://doi.org/10.13057/biodiv/d210237>
- Bhattacharya, A. (2019). Effect of high-temperature stress on crop productivity. In *Effect of high temperature on crop productivity and metabolism of macro molecules* (pp. 1–114). Elsevier. <https://doi.org/10.1016/B978-0-12-817562-0.00001-X>
- Bonato, L., Peretti, E., Sandionigi, A., & Bortolin, F. (2021). The diet of major predators of forest soils: A first analysis on syntopic species of Chilopoda through DNA metabarcoding. *Soil Biology and Biochemistry*, 158, 108264. <https://doi.org/10.1016/j.soilbio.2021.108264>
- Badan Pusat Statistik. (2023). *Produksi tanaman sayuran menurut kabupaten/kota dan jenis tanaman di Provinsi Sulawesi Selatan, 2021*. <https://sulsel.bps.go.id/id/statistics-table/3/ZUhFd1JtZzJWVVpqWTJsV05XTllhVmhRSzFoNFFUMDkjMw==/production-of-vegetables-by-regency-municipality-and-kind-of-plant-in-sulawesi-selatan-province--2019.html?year=2021>
- Badan Pusat Statistik. (2020). *Produksi tanaman sayuran menurut kabupaten/kota dan jenis tanaman di Provinsi Sulawesi Selatan, 2019*. <https://sulsel.bps.go.id/id/statistics-table/3/ZUhFd1JtZzJWVVpqWTJsV05XTllhVmhRSzFoNFFUMDkjMw==/production-of-vegetables-by-regency-municipality-and-kind-of-plant-in-sulawesi-selatan-province--2019.html?year=2019>
- Budiarti, L., Kartahadimaja, J., Sari, M. F., Ahyuni, D., & Jurusan Budidaya Tanaman Pangan, D. (2021). Keanekaragaman arthropoda predator di agroekosistem sawah pada berbagai galur padi Politeknik Negeri Lampung. *AGROSCIPT*, 3(1), 31–47.
- Chamorro-Martínez, Y., Torregroza-Espinosa, A., Moreno-Pallares, M., Osorio, D., Paternina, A., & Echeverría-González, A. (2022). Soil macrofauna, mesofauna and microfauna and their relationship with soil quality in agricultural areas in northern Colombia: Ecological implications. *Revista Brasileira de Ciência do Solo*, 46. <https://doi.org/10.36783/18069657rbcs20210132>

- Daryono, B. S., & Tammu, R. M. (2022). *Karakteristik, potensi genetik, dan pemanfaatan cabai Katokkon asal Toraja, Indonesia*. Gadjah Mada University Press.
- Demetrio, W., Cavalieri-Polizeli, K. M. V., Guimarães, R. M. L., Ferreira, S. de A., Parron, L. M., & Brown, G. G. (2022). Macrofauna communities and their relationship with soil structural quality in different land use systems. *Soil Research*, 60(7), 648–660. <https://doi.org/10.1071/SR21157>
- Dyah Susanti, P., & Halwany, W. (2017). Dekomposisi serasah dan keanekaragaman makrofauna tanah pada hutan tanaman industri nyawai (*Ficus variegata* Blume). *Jurnal Ilmu Kelautan*, 10(2), 212–223.
- Elhanafi, L., Houhou, M., Rais, C., Mansouri, I., Elghadraoui, L., & Greche, H. (2019). Impact of excessive nitrogen fertilization on the biochemical quality, phenolic compounds, and antioxidant power of *Sesamum indicum* L. *Journal of Food Quality*, 2019(1), 1–6. <https://doi.org/10.1155/2019/9428092>
- Fatchul Aziez, A., Cahyono, O., Susilo Utami, D., Budiyono, A., Priyadi, S., & Ida Cahyani, N. (2021). Respon pertumbuhan dan hasil cabai rawit terhadap penggunaan pupuk fosfat cepat larut dan pupuk kandang. *Jurnal Ilmiah Agrineca*.
- Ferdiansyah, I. R., Hermita, N., Fatmawaty, A. A., & Saylendra, A. (2024). Peran serangga tanah dalam budidaya talas beneng di Karangtanjung. *JIA (Jurnal Ilmiah Agribisnis): Jurnal Agribisnis dan Ilmu Sosial Ekonomi Pertanian*, 9(2), 114–125. <https://doi.org/10.37149/jia.v9i2.1157>
- Flowrenzhy, D., & Harijati, N. (2017). Pertumbuhan dan produktivitas tanaman cabai Katokkon (*Capsicum chinense* Jacq.) di ketinggian 600 meter dan 1.200 meter di atas permukaan laut. *Jurnal Biotropika*, 5(2), 44–53.
- Frouz, J., Elhottová, D., Kuráž, V., & Šourková, M. (2006). Effects of soil macrofauna on other soil biota and soil formation in reclaimed and unreclaimed post mining sites: Results of a field microcosm experiment. *Applied Soil Ecology*, 33(3), 308–320. <https://doi.org/10.1016/j.apsoil.2005.11.001>
- Gumay, A. L. R., Sosilawati, L. E., & Baharuddin. (2023). Keanekaragaman makrofauna tanah di bawah naungan tanaman porang (*Amorphophallus muelleri* Blume) di hutan sekunder Senaru Lombok Utara. *Journal of Soil Quality and Management*, 2(1), 67–73.
- Hermansah, Marsandi, F., & Agustian. (2023). *Biodiversitas tanah tropika basah*. Andalas University Press.
- Irmiler, U. (2010). Changes in earthworm populations during conversion from conventional to organic farming. *Agriculture, Ecosystems & Environment*, 135(3), 194–198. <https://doi.org/10.1016/j.agee.2009.09.008>
- Jocqué, R., & Alderweireldt, M. (2005). Lycosidae: The grassland spiders. *Acta Zoologica Bulgarica, Supplementum*(1), 125–130. <https://www.researchgate.net/publication/265488275>
- Kabar, P., Anwar, E. K., Santosa, E., & Pratiwi, E. (2022). Analisis kelimpahan arthropoda: Collembola dan Acarina. In E. Husen, Surono, E. Pratiwi, & L. R. Widowati (Eds.), *Metode analisis biologi tanah* (pp. 387–394). Balai Penelitian Tanah.
- Kosman, E., & Subowo, G. (2010). Peranan cacing tanah dalam meningkatkan kesuburan dan aktivitas hayati tanah. *Jurnal Sumberdaya Lahan*, 4(2), 93–102.
- Kusuma Dewi, V., Sari, S., Hartati, S., Sunarto, T., & Rizkie, L. (2019). Kelimpahan dan keanekaragaman predator laba-laba pada ekosistem sawah padi hitam (*Oryza sativa* L.) berpupuk organik. *Jurnal Agrikultura*, 2019(3), 125–133.
- Lal, R. (1988). Effects of macrofauna on soil properties in tropical ecosystems. *Agriculture, Ecosystems & Environment*, 24(1–3), 101–116. [https://doi.org/10.1016/0167-8809\(88\)90059-X](https://doi.org/10.1016/0167-8809(88)90059-X)
- Lynch, J., Marschner, P., & Rengel, Z. (2012). Effect of internal and external factors on root growth and development. In *Marschner's mineral nutrition of higher plants* (pp. 331–346). Elsevier. <https://doi.org/10.1016/B978-0-12-384905-2.00013-3>

- Mamabolo, E., Gaigher, R., & Pryke, J. S. (2024). Conventional agricultural management negatively affects soil fauna abundance, soil physicochemical quality and multifunctionality. *Pedobiologia*, 104. <https://doi.org/10.1016/j.pedobi.2024.150961>
- Maulana, Z., Mentary, N., & Muhibuddin, A. (2023). Karakteristik keragaman morfologi cabai Katokkon (*Capsicum chinense* Jacq.). *Journal of Aquaculture and Environment*, 5(2), 84–88. <https://doi.org/10.35965/jae.v5i2.3458>
- Mitić, B. M. (2023). Centipedes (Chilopoda) as bioindicators of soil pollution. In *VIII International Congress "Engineering, Environment and Materials in Process Industry"* (pp. 317–324). <https://www.researchgate.net/publication/372680299>
- Musyafa. (2005). Peranan makrofauna tanah dalam proses dekomposisi serasah *Acacia mangium* Wild. *Biodiversitas*, 6(1), 63–65. <https://doi.org/10.13057/biodiv/d060113>
- Nare, R. W. A., Savadogo, P. W., Traore, M., Gountan, A., Nacro, H. B., & Sedogo, M. P. (2017). Soil macrofauna behaviour in the presence of pesticides and organic amendments. *Journal of Geoscience and Environment Protection*, 5(3), 202–212. <https://doi.org/10.4236/gep.2017.53014>
- Nopsagiarti, T., Okalia, D., & Marlina, G. (2020). Analisis C-organik, nitrogen dan C/N tanah pada lahan agrowisata Beken Jaya. *Jurnal Agrosains dan Teknologi*, 5(1), 11–18.
- Numba, S., & Hazisah, N. (2024). Pengembangan cabai Katokkon (*Capsicum annuum* L. var. *sinensis*) di luar habitat aslinya. *Jurnal Agrotek*, 8(2), 188–194.
- Nurrohman, N. N. (2022). *Keanekaragaman dan kepadatan cacing tanah sebagai bioindikator kualitas tanah pada lahan perkebunan apel konvensional dan semiorganik Desa Tulungrejo Kecamatan Bumiaji Kota Batu* [Skripsi, Universitas Islam Negeri Maulana Malik Ibrahim].
- Pant, M., Negi, G. C. S., & Kumar, P. (2017). Macrofauna contributes to organic matter decomposition and soil quality in Himalayan agroecosystems, India. *Applied Soil Ecology*, 120, 20–29. <https://doi.org/10.1016/j.apsoil.2017.07.019>
- Purwani, J., Sarmah, Aksani, D., & Santosa, E. (2022). Analisis kelimpahan dan keragaman makrofauna tanah. In E. Husen, Surono, E. Pratiwi, & L. R. Widowati (Eds.), *Metode analisis biologi tanah* (pp. 347–356). Balai Penelitian Tanah.
- Putri, K. S., Haerani, N., & Giono, B. R. W. (2024). Pertumbuhan cabai Katokkon (*Capsicum sinense* Jacq.) di dataran rendah pada aplikasi mulsa organik dan MOL bonggol pisang. *Jurnal Agrotan*, 10(2), 38–42.
- Qomariyah, N., Nugroho, A. S., & Hayat, M. S. (2020). Makrofauna tanah di lahan hortikultura Desa Losari Kecamatan Sumowono Kabupaten Semarang. *Quagga: Jurnal Pendidikan dan Biologi*, 13(1), 68–73. <https://doi.org/10.25134/quagga.v13i1.3613>
- Ramvalho do Rêgo, E., Monteiro do Rêgo, M., & Finger, F. L. (2016). *Production and breeding of chilli peppers (Capsicum spp.)* (1st ed.). Springer International Publishing. <https://doi.org/10.1007/978-3-319-06532-8>
- Ranesa, S. S., Tejawulan, R. S., & Padusung. (2024). Efek kandungan bahan organik terhadap pertumbuhan dan hasil tanaman cabai pada kondisi stres air. *Journal of Soil Quality and Management*, 1(1), 79–86.
- Rivitra, V., Thevan, K., & Norhafizah, M. Z. (2021). Growth of chilli plant (*Capsicum annuum* L.) treated with combined organic and inorganic fertilizer with *Saccharomyces cerevisiae*. In *Proceedings of the 3rd Asia Pacific Regional Conference on Food Security (ARCoFS 2021)* (pp. 1–7). <https://doi.org/10.1088/1755-1315/756/1/012050>
- Rumahorbo, D. P. R., Marheni, M., & Bakti, D. (2020). Macrofauna soil diversity in chili plants (*Capsicum annuum* L.) with the use of organic and inorganic mulch. In *Proceedings of the 3rd International Conference Community Research and Service Engagements (IC2RSE 2019)*. EAI. <https://doi.org/10.4108/eai.4-12-2019.2293815>

- Setiawati, R., Efendi, S., & Suhedra, D. (2023). Struktur komunitas Dermaptera predator pada tanaman kelapa sawit. *Jurnal Agroplasma*, 10(1), 329–336.
- Shannon, C. E., & Weaver, W. (1964). *The mathematical theory of communication*. The University of Illinois Press.
- Simpson, E. H. (1949). Measurement of diversity. *Nature*, 163, 688. <https://doi.org/10.1038/163688a0>
- Sofo, A., Mininni, A. N., & Ricciuti, P. (2020). Soil macrofauna: A key factor for increasing soil fertility and promoting sustainable soil use in fruit orchard agrosystems. *Agronomy*, 10(4), 1–20. <https://doi.org/10.3390/agronomy10040456>
- Sumarni, N., & Muharam, A. (2005). *Budidaya tanaman cabai merah* (Ed. ke-2). Balai Penelitian Tanaman Sayuran.
- Syah, R. F., Mawandha, H. G., Afroda, H., & Yonglie, W. (2025). Increasing the growth and production of chili plants (*Capsicum annum* var. *longum*) by administering various concentrations and doses of JAKABA biofertilizer. *Jurnal Agronomi Tanaman Tropika (Juatika)*, 7(2), 417–422. <https://doi.org/10.36378/juatika.v7i2.4272>
- Tuerah, F. S. (2025). Harga bahan pokok di Toraja Utara relatif stabil, cabai Katokkon tembus Rp70 ribu per kilo. *Tribunnews*. <https://toraja.tribunnews.com/2025/04/29/harga-bahan-pokok-di-toraja-utara-relatif-stabil-cabai-katokkon-tembus-rp-70-ribu-per-kilo>
- Wasis, B., Fatimah, G., & Winata, B. (2024). The abundance of soil mesofauna and macrofauna at different altitudes in Mount Gede Pangrango National Park. In *Proceedings of the 4th International Conference on Tropical Silviculture* (pp. 1–15). <https://doi.org/10.1088/1755-1315/1315/1/012028>
- Wibowo, C., & Slamet, A. S. (2017). Keanekaragaman makrofauna tanah pada berbagai tipe tegakan di areal bekas tambang silika di Holcim Educational Forest, Sukabumi, Jawa Barat. *Jurnal Silvikultur Tropika*, 8(1), 26–34.
- Zhou, W., Zhan, P., Zeng, M., Chen, T., Zhang, X., Yang, G., & Guo, Y. (2023). Effects of ant bioturbation and foraging activities on soil mechanical properties and stability. *Global Ecology and Conservation*, 46, e02575, 1–13. <https://doi.org/10.1016/j.gecco.2023.e02575>