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Local Ecological Knowledge of Coffee Farmers on Earthworms and Pests as Soil Quality in Mount Tambora, Indonesia

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Abstract. The local ecological knowledge of coffee agroforestry farmers regarding earthworms serves as one of the soil fauna indicators of soil fertility and quality. This knowledge is inherited through generations from observations and experiences of coffee farmers, sometimes differing from modern ecological knowledge. This study aims to analyze the relationship between farmers Local Ecological Knowledge (LEK) in simple coffee agroforestry systems and their socio-demographic characteristics; to examine their understanding of the ecological roles of earthworms and *Lepidiota stigma*; and to identify and assess the gap between Local Ecological Knowledge (LEK) and Modern Ecological Knowledge (MEK). Local ecological knowledge was obtained through in-depth interviews with coffee agroforestry farmers concerning soil management, the role of earthworms, and pests in maintaining soil quality on the slopes of Mount Tambora (NTB). In-depth interviews were conducted with key respondents and coffee agroforestry farmers grouped by gender, age, and educational background using predetermined questions. Based on interviews with 50 coffee farmers, the percentages of soil quality indicators recognized by them ranked as follows: earthworms (80%), soil color (74%), plant growth (36%), humus or litter (10%), and soil structure (6%). Furthermore, 72% (n=50) of coffee farmers indicated that soil organisms significantly influence soil fertility. This study highlights the scientific value of Local Ecological Knowledge in sustainable soil management and encourages its integration with modern science through participatory research.

Keywords: coffee-based agroforestry; local ecological knowledge; modern ecological knowledge

INTRODUCTION

Local ecological knowledge refers to a collection of practices and views that develop through adaptation to the environment and are passed down from one generation to the next through cultural traditions. Local knowledge was related to forms of beliefs, understanding, or insights as well as customs or ethics that guided human behavior within an ecological community. Local/traditional wisdom was not only concerned with people's knowledge and understanding of relationships between humans but also encompassed knowledge, understanding, and customs about the relationship between humans and nature, as well as how relationships among the inhabitants of this ecological community should be built (Dadi, 2019). Traditional knowledge originates from the system of indigenous knowledge. Local/traditional/customary knowledge is defined as the intellectual behavior and beliefs of indigenous communities or local information about the relationships between living beings (including humans) and their environment. This knowledge is culturally developed through the experiences and knowledge of local communities across generations. Local ecological knowledge (LEK) refers to the knowledge, practices, and beliefs shared among local resource users regarding ecological interactions within ecosystems (Kupika et al., 2019). Agroforestry is a combination of perennial woody plants with components such as crop farming and livestock, which forms a diverse, layered, and multitemporal ecosystem on the same land unit. It plays an important role in integrating ecosystem conservation and human development in the fields of ecological agriculture and ecological restoration (Xiao & Xiong, 2022).

The gap between Local Ecological Knowledge (LEK) and Modern Ecological

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Knowledge (MEK) often results from differences in methods, language, and goals. This gap prevents optimal integration in sustainable agroforestry practices (Ramadani et al., 2022). According to Limpo et al., (2022) the integration of local ecological knowledge and modern ecological knowledge maximizes the benefits of agroforestry, prevents conflict and the loss of knowledge, and supports sustainable agroforestry. According to Adelifa et al., (2024), the practical impacts of the knowledge gap result from inefficient resource management, the development of irrelevant technologies, biodiversity loss, and weakened socio-ecological resilience.

The gap between local ecological knowledge (LEK) and modern ecological science poses a major challenge for the sustainable management of coffee agroforestry. LEK is often overlooked in formal planning, even though it is important for inclusive and context-sensitive decision-making. Strengthening the dialogue between local knowledge and modern science is essential to create resilient and sustainable agroforestry systems. The disconnect between local ecological knowledge (LEK) and modern ecological science significantly impacts coffee agroforestry. Excluding LEK from formal conservation efforts often leads to ecologically inappropriate interventions. Integrating LEK with scientific approaches is essential to improve conservation outcomes and sustainable coffee production (Williams et al., 2020).

According to the local ecological knowledge of farmers who manage coffee agroforestry, the earthworm is a notable indicator for measuring soil fertility and quality levels (Mardiani et al., 2022). Earthworms are the major macrofauna of soil and have been extensively applied to the restoration of contaminated soil due to their promising pollutant dissipation capacity (Chao et al., 2022).

Earthworms play an important role in regulating soil microbial biomass, and their activity not only accelerates plant residue decomposition on a global scale but also enhances microbial residue stabilization in soil aggregates (Liao et al., 2024). It is necessary to regulate the cycle of water, organic carbon, and other nutrients. Therefore, earthworm density and organic carbon levels are often used as indicators to assess soil health. The earthworm is a significant factor in soil physical properties, nutrient availability, and plant growth.

In addition to earthworms, soil uret (*Lepiodita stigma*) also affects soil quality. Uret attacks coffee plants by cutting and eating their roots, which causes the plant to wilt, turn yellow, and eventually die. Young urets consume softer roots, so the damage caused is not too severe. However, as the uret ages, its need for food increases along with its massive damage.

The development of pests could be influenced by different trees with varying canopy architecture and leaf characteristics, which resulted in differences in light quality and quantity, temperature, humidity, and rainfall under the canopy, thus altering the microclimate of the forest floor (Ayalew et al., 2022). This study aims to (1) Analyze the relationship of Local Ecological Knowledge (LEK) of coffee agroforestry farmers based on socio-demographic characteristics, (2) Analyze the Understanding of Coffee Agroforestry Farmers related to the Role of Earthworms and *Lepidiota Stigma*, (3) Analyzing the "*Gap*" between local ecological knowledge (LEK) and modern ecological knowledge (MEK).

METHODS

Type Research

This study used a descriptive qualitative approach, with data collection conducted through in-depth interviews. The study's main objective was to explore coffee farmers' understanding of the presence of earthworms and white grubs (urets) as indicators of soil quality, as well as their relationship with the farmers socio-demographic characteristics.

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Time and Place

This research was carried out from May to July 2023 on the slopes of Mount Tambora, Tambora Village, Pekat District, Dompu Regency, West Nusa Tenggara (NTB). Tambora Village is one of the villages that implements the coffee agroforestry system in several villages with a variety of shade trees including dadap trees (*Erythriba variegate* L.) and mahogany (*Swietenia mahagoni*). This research consists of several series, namely a survey of coffee agroforestry farmers followed by interviews (*in depth interviews*).

The research series consists of three stages, namely:

a. Stage 1. Interviews with coffee agroforestry farmers on Local Ecological Knowledge (LEK), focusing on socio-demographic characteristics and perceptions of the role of earthworms and *Lepidiota stigma* as indicators of soil quality.
b. Stage 2: Evaluation of Local Ecological Knowledge (LEK) of coffee agroforestry farmers based on the results of interviews with Modern Ecological Knowledge (MEK) so as to produce gaps related to the role of earthworms and *Lepidiota Stigma*.
c. Stage 3: Giving key questions including Identity, Land Specification, Agroforestry Management, the role of earthworms on soil fertility and the existence of *Lepidiota Stigma* as a pest for coffee plants on the slopes of Mount Tambora (NTB).

Sampling Methods

In-depth interviews were conducted with 50 coffee agroforestry farmers. The sampling technique used was purposive sampling, where respondents were intentionally selected based on specific criteria relevant to the study objectives. The selection criteria included coffee farmers of both male and female genders, respondents divided into three age groups (25-35 years); (36-50 years) and (> 50 years) (19–39 years and >39 years) and educational backgrounds ranging from elementary school (SD), junior high school (SMP), senior high school (SMA) to undergraduate level (Bachelor's degree). Besides the main respondents, three key informants were interviewed to enrich the contextual data. These key informants included representatives of local stakeholders, such as the Forest Management Unit (KPH), local village community leaders, and the Chairman of the Association of Farmer Groups (Gapoktan). Their insights provided valuable perspectives that complemented the information gathered from the primary respondents.

Data Analysis

The data obtained were analyzed using qualitative descriptive methods to capture the perceptions and experiences of farmers regarding the presence of earthworms and white grubs (urets) as indicators of soil quality. In addition to qualitative analysis, descriptive and inferential statistical analyses were conducted using RStudio. Descriptive statistics, such as frequencies and percentages, were calculated to summarize the data. Furthermore, Chi-square tests were performed to investigate the relationships between demographic variables gender, age and education the farmers' level of knowledge. This study used data triangulation to ensure validity and credibility by comparing interview results from various sources (farmers, stakeholders, community leaders, and the chairman of the farmer group association) as well as secondary information such as official documents and related reports.

RESULTS AND DISCUSSION

Socio-Demographic Profile of Coffee Agroforestry Farmers

Of the selected respondents, there were 50 farmers with 35 of them male (70%) and 15 female (30%). Based on the results of *the Chi-square* test, it was found that age and gender were not related to educational background. The age of farmers is divided into three groups: group 1 (25-35 years), group 2 (36-50 years) and group 3 (> 50

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years). The age range of coffee farmers ranges from 25 to 65 years old with 26% aged 25-35 years old, 72% aged 36-50 years old and 12% over 50 years old as presented in Figure 1.

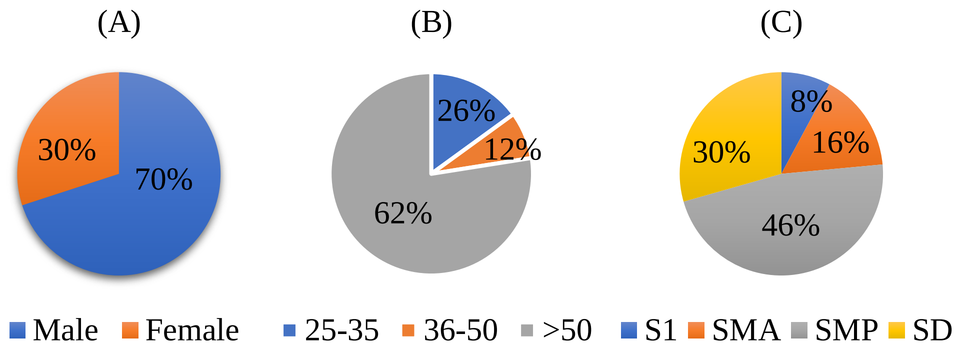

Figure 1. Socio-demographic profiles of farmers according to (a) gender, (b) age and (c) educational background in both research sites

Farmer education background, 15 elementary school students (30%), 23 junior high school students (46%), 8 high school students (16%), 4 S1 students (8%). Farmers in the research site are more dominant in relying on coffee land as their main livelihood. Based on the results of the interviews that have been conducted, male farmers are responsible as planners, implementers, and decision-makers in the management and harvesting of coffee agroforestry land. Meanwhile, women farmers are responsible for maintenance such as cleaning new growing shoots, harvesting and production.

The main source of farmers' knowledge about soil quality based on interviews is obtained from families, personal experiences and farmer groups. Some farmers get information inherited by previous generations (from generation to generation) through their families, 36% of 25 people in Pancasila Village and 56% of 25 people in Garuda Village. The majority of the local knowledge farmers practice comes from their experience in managing agricultural land, either from personal experience or inherited by their predecessors. Local knowledge has emerged as a dynamic resource based on contemporary observation and experimentation, rather than just a legacy from the past (Practices et al., 2021).

The local ecological knowledge of coffee agroforestry farmers in Pancasila Village and Garuda Village is enough to understand the role of worms as an indicator of fertile soil. Regarding the function of earthworms, coffee agroforestry farmers in Pancasila Village and Garuda Village said that earthworms are one of the soil macroorganisms that can loosen the soil and help the process of decomposing debris, so that according to coffee farmers there are no earthworms that are detrimental to coffee plants.

Coffee agroforestry farmers in both villages only know the activity of earthworms in the upper soil layer between 0-10 cm deep. Sometimes when farmers cultivate the soil, it is found that there are soil cavities formed by earthworm activity. Farmers mentioned that the source of earthworm food comes from weathered leaves and dead roots. Earthworms produce biomass in the form of worm droppings which is useful as a natural fertilizer to fertilize the soil.

Local ecological knowledge of coffee agroforestry farmers in Pancasila Village and Garuda Village related to the role of *Lepidiota Stigma* is still very lacking. Farmers said that uret is widely found in the soil close to the roots of coffee plants when tillage. The presence of uret in the soil is a pest that can harm coffee plants because it attacks the roots of coffee plants. The source of uret feed is

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young roots and coffee stems that have been weathered so that the presence of uret in coffee plants results in the death of coffee plant plants, which has an impact on decreasing crop production. According to coffee agroforestry farmers, the change of the rainy season to the dry season is a climatic condition preferred by *Lepidiota Stigma*.

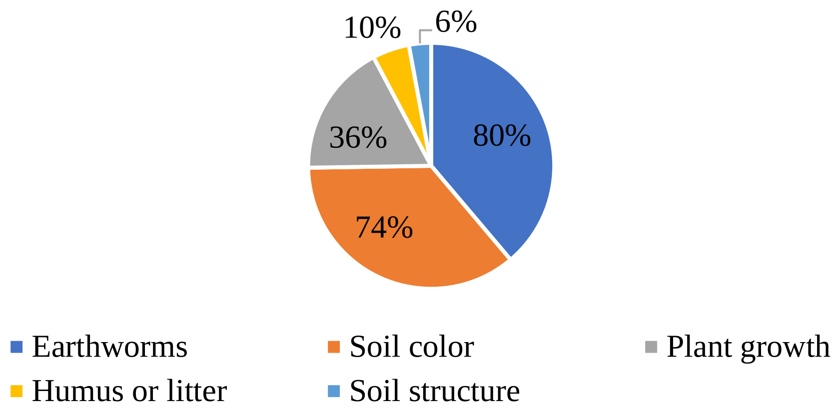

Figure 2. Understanding of coffee agroforestry farmers related to soil quality characteristics

Understanding of Coffee Agroforestry Farmers related to the Role of Earthworms and *Lepidiota Stigma*

Coffee farmers in Tambora Village (NTB) do not know the term "soil quality", but they have a good understanding of the concept of "fertile soil". The results of interviews with 50 coffee farmers revealed that there were 6 indicators that they considered as signs of fertile soil, namely: a) soil structure b) soil color c) plant growth d) the presence of litter and humus e) the presence of earthworms.

The results of interviews with 50 coffee farmers showed that the percentage of soil quality indicators most recognized by farmers as presented in the Figure 2 were earthworms (80%), soil color (74%), plant growth (36%), humus or litter (10%), soil structure (6%). In agroecosystems, a significant part of soil quality and fertility is due to the action of soil macrofauna, as colonizers, comminutors, and engineers within soils together with their interaction with decomposing microorganisms. In (Ribeiro, 2021), soil macroinvertebrates actively influenced pedological processes through structural and mineralogical transformations, as well as the improvement of soil hydraulic properties, such as aeration and drainage.

The percentage of soil quality indicators according to farmers from two regions of Tambora Village as presented in the Figure 3 according to two farmers in the Tambora Village area (80%), earthworms are the main indicators of soil quality percentage as stated by the coffee agroforestry farmers. Differences in knowledge can be seen from their social demographic such as gender and age of the coffee agroforestry farmers. The criteria for soil color, known to farmers (76%) of 50 respondents, stated that fertile soil can be seen from the brownish-black soil color. Plant growth is a benchmark for coffee agroforestry farmers in knowing soil quality. Coffee agroforestry farmers (36%) stated that soil quality can be seen from the rate of plant growth. Humus/litter is a supporter of soil quality that functions as a natural mulch that can protect and maintain soil moisture from sunlight. Coffee agroforestry farmers (24%) acknowledge the soil quality from the thickness of humus/litter. Soil structure composes the soil formation however, knowledge of soil structure criteria is rarely known by coffee agroforestry farmers. Of the 50 respondents, only (2%) coffee agroforestry

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farmers know that soil structure is the main indicator of soil quality.

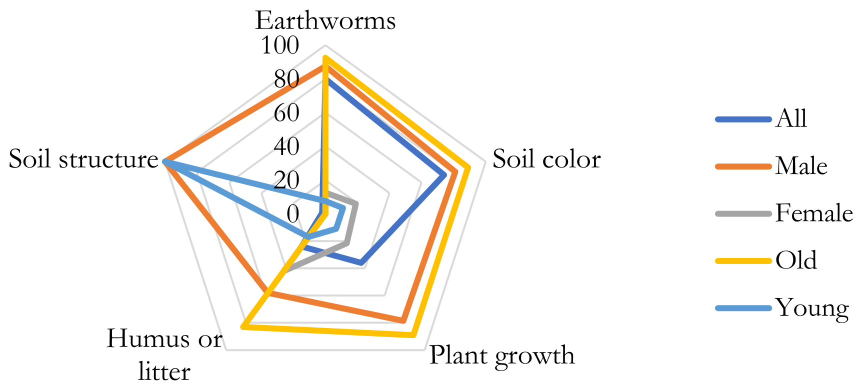

Figure 3. Percentage of coffee agroforestry farmers' understanding of soil quality based on socio-demographic profile

Table 1. Chi-Square Test of the relationship between demographics and farmers' knowledge of soil quality indicators

Statistical Test	**Value (χ^2)**	**df**	**Sig. (p)**	**Description**
Gender * Source of uret feed	8.058	2	0.018	Significant
Age * Benefits of worms	4.059	1	0.044	Significant
Age * Uret activity	8.444	3	0.038	Significant
Education * Soil fertility indicator	26.590	9	0.002	Significant
Education * Benefits of worms	10.675	3	0.014	Significant
Education * Worm activity	21.321	6	0.002	Significant
Education * Type of uret feed	27.196	6	0.000	Significant
Education * Benefits of uret	29.917	6	0.000	Significant
Education * Uret impact	22.238	9	0.008	Significant
Education * Uret activity	44.542	9	0.000	Highly significant

The Chi-Square test results presented in Table 1 indicate that education has the most decisive influence on local ecological knowledge (LEK) regarding earthworms and uret as indicators of soil quality. The association between education level and uret activity yields the highest Chi-Square value (χ^2 = 44.542; df = 9; p = 0.000), indicating a highly significant relationship. This result suggests that education level significantly affects farmers' LEK related to uret activity. Respondents with higher levels of education tend to demonstrate a better understanding and greater technical competence, as well as a more comprehensive appreciation of these soil organisms' ecological and economic roles. Education is the dominant determining variable influencing respondents' behavior and understanding of earthworms and urets. Therefore, educational approaches are critical in improving community participation in sustainable soil management practices.

Soil quality technical indicators usually include basic parameters such as bulk density, pH, effective rooting depth, water content, soil temperature, and total carbon. Local soil quality indicators were often more varied and included crop yields, soil color, soil texture and structure, as well as the number of plant species. Local ecological knowledge is defined as a "cumulative body of knowledge, practice and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment". For example, argued that involving indigenous peoples and local

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communities is essential to develop and implement more effective environmental governance system for ecosystems and biodiversity (Lam et al., 2020).

Coffee agroforestry land in Tambora Village (NTB), has a high diversity of soil organisms. According to the coffee farmers, several soil organisms affect the soil quality as presented in the Figure 4 namely: (1) Earthworms, (2) White grub, (3) Caterpillars, (4) Black slug, (5) White caterpillars, (6) Millipede, (7) Beetle, (8) Black ants, (9) Leaf caterpillar, (10) Crow caterpillars, (11) Centipedes, (12) White slug, (13) Ground bee, (14) Termites, (15) Mole cricket.

Figure 4. Soil organisms mentioned by coffee agroforestry farmers in Tambora Village (NTB) Personal documentation (2023)

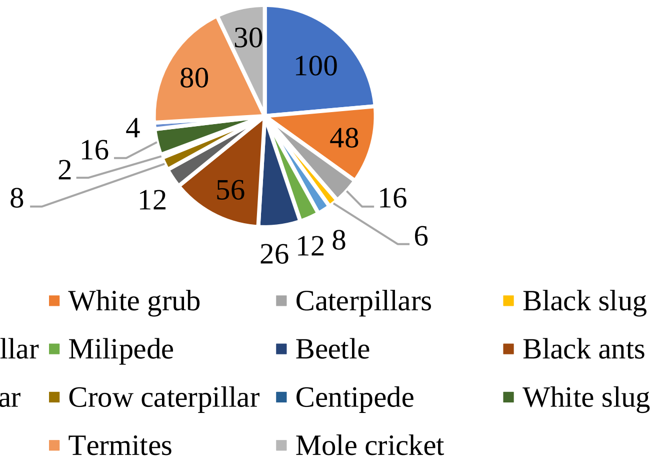

Figure 5. Groups of soil organisms mentioned by coffee agroforestry farmers in Tambora Village (NTB)

Based on the information as presented in Figure 5 regarding coffee farmers' knowledge about soil organism groups, 72% of farmers stated that soil fertility is influenced by the presence of soil organisms (earthworms), which play an important role in helping soil fertility. Earthworms are the most frequently mentioned soil organism with 40% of coffee farmers in Pancasila Village and 60% in Garuda Village revealing that earthworms significantly benefit soil fertility.

Factors that influenced the level of soil organism diversity included the availability of sufficient food, the presence of habitats

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influenced by the diversity of vegetation types, which in turn created a new life cycle for organisms that were tolerant to the climate and weather of the area. Soil macrofauna is also an essential key in decomposition and biodegradation processes that have died, soil organic changes, humification, nutrient cycles and physical properties of soil such as bulk density, porosity and groundwater availability (Prayogo et al., 2019). One of the roles of soil macroorganisms was to maintain soil fertility through the decomposition of organic matter, nutrient distribution, soil aeration improvement, and so on. The diversity and activity of earthworms, as one of the soil biota, are influenced by the physical, chemical, and biological properties of the soil. Their physical movement creates soil pores that facilitate the dynamics of nutrients and water within the soil (Diversity et al., 2021). Fertile soil had physical, chemical, and biological characteristics suitable for plant growth (Sumarniasih et al., 2023).

The "*gap*" between local ecological knowledge (LEK) and modern ecological knowledge (MEK)

The *"gap"* analysis aims to find the gap between the local ecological knowledge of coffee agroforestry farmers and modern ecological knowledge related to soil management to obtain quality soil as presented in Table 2.

Based on the results of the interviews, farmers between the ages of 36 and 50 years have more than 10 years of experience in coffee farming. The cultivation and management of coffee fields are generally carried out by male farmers, whereas female farmers are responsible for fertilization and harvesting. Socioeconomic factors, such as age, education level, experience, land area, number of dependents, and income level affect the extent to which farmers adopt agricultural technology. Farmers' productive age in the range of 15 to 64 years is considered the ideal age. In general, the older they get, the more knowledge farmers gain about soil management, although this is also influenced by the physical strength of farmers who decrease with age, so their productivity can decrease (Sugandi et al., 2020).

Education is also an important factor that reflects the level of community welfare because there is a positive correlation between education, productivity, and welfare. The level of education affects a person's ability to accept changes, information, and new innovations. Education significantly accelerates the process of change, supporting the acceptance of new things, which is considered important to create changes that bring positive and beneficial impacts (Hiola & Puspaningrum, 2019).

According to coffee farmers, the number of earthworm populations is influenced by the availability of food in the ecosystem derived from plant debris, organic residues of other organisms, and microclimate conditions around the area. (Liao et al., 2024) Earthworms play essential roles in the regulation of soil microbial biomass and its activities, and not only accelerate the decomposition of plant residues on a global scale, but also enhance the stabilization of microbial residues in soil aggregates. The results of the interviews show that 98% of coffee farmers stated that earthworms play a role in fertilizing the soil and plants. (Fowo, 2022) earthworms played a role in enriching the soil because their movement left pore spaces that facilitated the circulation of water and air.

The presence of earthworms is an indicator of soil quality that is easily recognized by farmers. (Kuria et al., 2018), farmers had deep and detailed knowledge about how the type, abundance, and behavior of earthworms (digging and mobility) helped them differentiate between fertile and infertile soils. The findings of farmers' new knowledge needed to be further explored to understand how the mobility of certain earthworms could be used as an indicator in soil quality monitoring systems.

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Table 2. Information on the "gap" of local ecological knowledge (LEK) of coffee agroforestry farmers and modern ecological knowledge (MEK) about soil quality

Aspects	LEK	MEK
Soil fertility markers	Dark soil color is a marker of soil fertility	In agroecosystems, soil quality often depended on vegetation that provided food for edaphic organisms and ground cover, especially where plant litter was found. Plant biomass also helped improve aggregation, water retention, and nutrient cycling, and the soil color tended to be black or brown (Medeiros et al., 2024).
Benefits of earthworms	Earthworms are useful for fertilizing soil and plants.	Epigeic species who live on the surface soil feed on a litter layer and are unable to move down into the soil (Al-Maliki et al., 2021).
Earthworm activity	The existence of worms in the soil is not known by coffee agroforestry farmers, they only know the activity of worms on the ground surface.	Earthworms played an important role in regulating soil microbial biomass and its activities. Earthworms not only accelerated the growth and activity of microbes through soil burrowing, but also improved air circulation and water flow in the soil, sped up the decomposition of organic carbon to increase resource availability for microbes, and reduced predation by suppressing the population of microbivores (Liao et al., 2024). Earthworms were widely recognized for consuming organic matter from the soil surface and distributing it as nutrient-rich casts throughout the soil layers. These casts contained abundant organic matter and essential macronutrients like phosphorus (P) and nitrogen (N). Additionally, their digging activities stimulated root growth around these nutrient-rich areas (Danish et al., 2024).
Types of earthworm feed	The source of feed for earthworms is leaves, twigs, roots that have rotted.	Earthworms were grouped into three categories: (1) anecics created deep vertical burrows, in which they dragged surface litter to feed on, (2) endogeics fed on organic matter within the soil and burrowed horizontally in the topsoil, (3) epigeics lived within the litter layers and fed on plant residues (Wöhl, 2024).
Benefits of cascing	Worm dung becomes a natural fertilizer that increases soil fertility.	Earthworm casts are known to contribute significantly to surface soil fertility in agroecosystems. casting-earthworms is very important for reading soil fertility characteristics of the soil (Boonchamni, 2019).
Effect of uret	Coffee agroforestry farmers know the impact of damage caused by uret attacks.	Uret was a strong plant pest because it consumed plant roots, causing the plants to wilt. The infected plant stems fell and eventually dried out (Shukla et al., 2020).
Urinary activity	Uret is often found in soil	The Lepidiota stigma pest lives in the soil near plant roots and is harmful because it feeds on them. The impact of a Lepidiota stigma pest infestation becomes visible when the season changes from rainy to dry. The pest feeds on various types of plant roots, including those of coffee plants (Wiratmoko et al., 2021).
Uret feed sources	Uret feeds on young roots of coffee plants	Lepidiota stigma pests damaged plants by feeding on their roots, which caused the plants to wilt and eventually die. If not handled effectively, these pests could significantly reduce plant productivity and result in substantial crop losses (Prasetyo et al., 2021).
The impact of uret	The impact of uret attacks is in the form of wilted leaves and dead trees.	Pests and diseases cause severe crop losses, threatening agricultural production and reducing the food security and incomes of farmers (Cerda et al., 2020).
Preferred climatic conditions of *Lepidiota Stigma*	The living conditions that the urit prefers at the time of the change of rain to the dry season.	The white grub pest preferred moist soil with stable soil temperature. The life cycle of most white grub species lasted about one year, with a larval period of six months (Amizhthini et al., 2024).

The local ecological knowledge (LEK) of coffee agroforestry farmers provides valuable insights for locally based environmental management; however, this knowledge has its limitations. LEK is often shaped by intergenerational gaps, anecdotal experiences, and limited access to scientific information, which can result in biases or inconsistencies.

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Moreover, local knowledge does not always adequately address emerging challenges such as climate change or biodiversity loss. A collaborative approach through knowledge co-production is necessary to bridge the gap between local ecological knowledge (LEK) and modern ecological science. Participatory research involving farmers, scientists, and extension agents helps validate and enrich LEK with scientific perspectives, while also ensuring that scientific interventions remain relevant to the local context.

CONCLUSION

Based on the research that has been conducted, it can be concluded that the relationship between Local Ecological Knowledge (LEK) and socio-demographic characteristics shows significant results. Age, gender and educational background factors affect coffee agroforestry farmers' level of Local Ecological Knowledge (LEK), where more educated and experienced farmers tend to understand sustainable agricultural practices better. The understanding of agroforestry farmers about earthworms and plant pest organisms, *Lepidiota stigma*, is quite good, where the existence of earthworms is recognized as a soil fertilizer, while the *Lepidiota stigma* is a pest that destroys plant roots. The evaluation of Local Ecological Knowledge (LEK) and Modern Ecological Knowledge (MEK) shows that there is a similarity in understanding related to earthworms and *Lepidiota stigma* as an indicator of soil quality so that local ecological knowledge can support a scientific approach to sustainable coffee agroforestry land management. The integration of local ecological knowledge of coffee agroforestry farmers into agroforestry policies constitutes an important step in promoting sustainable and adaptive agricultural practices. Policy support through formal recognition of local knowledge, development of extension programs, and protection of traditional knowledge rights are crucial to empowering farmers as central actors in conserving local environments.

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