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Local ecological knowledge of coffee agroforestry farmers on earthworms and their relation to soil quality in East Java (Indonesia)

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Abstract. *Mardiani MO, Kusumawati IA, Purnamasari E, Prayogo C, van Noordwijk V, Hairiah K. 2022. Local ecological knowledge of coffee agroforestry farmers on earthworms and their relation to soil quality in East Java (Indonesia). Biodiversitas 23: 3344-3354.* Farmers manage their land-based on their understanding of biotic and abiotic factors, including soils, and how these factors affect crop growth and productivity. Their local ecological knowledge (LEK) is built upon intergenerational transfer and can use concepts that don't directly match those of current science-based ecological knowledge. We explored farmer LEK related to soil organic matter management and earthworms in coffee-based agroforestry systems on volcanic slopes in East Java (Indonesia) by in-depth interviews with key informants and by surveying the concurrence of respondents, stratified by gender and age, with resulting statements. The term used in the local language for earthworms ('*cacing tanah'*) included a range of species. According to 22% (n=48) of farmers, small earthworms (probably *Pontoscolex corethrurus*) are harmful to coffee trees because they eat the roots. Also, 54% (n=48) of farmers thought earthworms that eat soil cause a decrease in soil volume. However, according to the farmers, large earthworms (reddish-brown) can fertilize the soil by leaving their casts on the soil surface. Such worms are often found in coffee agroforestry systems. Farmers have little explicit knowledge of the activities of earthworms and their relation with litter as a source of food. Farmer knowledge of ecosystem services provided by earthworms can enrich current scientific literature and trigger a two-way dialogue.

Keywords: Coffee-based agroforestry, litter quality, local ecological knowledge, modern ecological knowledge, soil quality

Abbreviations: LEK: Local Ecological Knowledge; MEK: Modern Ecological Knowledge

INTRODUCTION

In agricultural practices, farmers as the main decision-makers in land management are aware of changes in the quality and environmental conditions of their land. In the context of soil, beyond its inherent properties, soil fertility is highly dependent on the land management practiced by farmers, such as fertilizer usage (Nur et al. 2019). Farmer traditional knowledge is considered 'holistic and adaptive by nature, gathered over generations, accumulated incrementally, tested by trial-and-error and transmitted to future generations orally or by shared practical experiences' (Ohmagari and Berkes 1997; Singh et al. 2021). In many literatures, such a thing is called local ecological knowledge (LEK). In Kenya for example, farmers traditionally recognize soil fertility from soil color, texture, and moisture (Wawire et al. 2021). While physical and visual properties provide an initial insight regarding soil quality, sometimes it overlooks soil fertility at finer scales which is also influenced by soil biota.

Soil quality in modern ecological knowledge (MEK) is understood as the capacity of the soil to function in an ecosystem that maintains biological productivity and environmental health, and that sustains the plant and animal life that depend on it (Bünemann et al. 2018). Soil biota as studied in MEK is a major constituent of ecosystems, whether natural or managed by humans. Large species in soil are also an important aspect of soil biodiversity as well as being influential on soil properties (Bardgett and van der Putten 2014). 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 its interaction with decomposing microorganisms (Sofo et al. 2020).

One of soil biota which affects soil fertility is the earthworm. Of a total of around 7.000 species, only about 150 earthworm species are widely distributed around the world with the invasive *Pontoscolex corethrurus* being the most studied morphospecies (Taheri et al. 2018). Earthworms involve in many soil processes and are used as an indicator of soil quality and fertility, as their presence is easily noted. As 'ecosystem engineers', earthworms activities (e.g., organic matter burial, burrow creation, cast deposition) create favorable habitats and modified conditions of resource availability for many other soil inhabitants, from microorganism to plant roots (Liu et al. 2019). Earthworms can increase soil fertility by decaying organic matter and microorganisms into the lower layers. A meta analysis by van Groenigen et al. (2014) found that earthworms may increase aboveground biomass by on average 23% and increase crop yields by 25%. Van Groenigen et al. (2019) also revealed that earthworm casts contain on average 40-48% more total P, total N and organic C than bulk soil, while available N and P are even more increased (241% and 84%, respectively).

The way of soil biota and their roles are studied in MEK may differ from the categories and interpretations used in LEK. Matching the two knowledge systems (LEK and MEK) may reveal complementarity where different types of empirical evidence are involved. It can also indicate apparent contradictions that start with a mismatch of the taxonomic categories used. For example, various soil biota interacts with litter quality in maintaining a protective litter layer on the soil throughout the year (Sari et al. 2022). In simple and multistrata coffee agroforestry systems in Indonesia these can include epigeic, endogeic, and anecic earthworms that differ in the soil layers where they are active (Hairiah et al. 2006; Putri 2018), and thus in their functions as litter decomposer, and as a maker of horizontal and vertical soil pores. However, it is not clear how many distinctions between earthworm types or functional groups farmers recognize as part of their LEK.

In an LEK study among coffee farmers in the volcanic landscape in Ngantang, Malang District, East Java, Indonesia, Ato'ilah (2017) reported that farmers define fertile soil as being loose (low bulk density), black in color, and with the presence of earthworms. However, not all farmers attributed the beneficial effects and roles of earthworms in increasing soil fertility. Although not every worm living in the soil and described as '*cacing*' in Bahasa Indonesia is an 'earthworm' in the scientific classification, the local taxonomy may be less precise. A study by Rahma (2019) in the UB Forest area, Karangploso, Malang District, East Java found that 20% (n=27) of coffee farmers believed that earthworms are harmful because they eat the coffee plant's root. In the follow-up questions, the farmers referred to them as worms living in the soil that are small, reddish-white, and 'thin' or 'wire-like'. Farmers controlled such worms with detergent or agricultural lime diluted with water. These measures may disrupt soil fertility and lead to the extinction of other, beneficial soil macrofauna.

As part of experiments on organic matter management and the beneficial roles of earthworms in maintaining soil quality, there is a need to build farmer's concerns and their LEK to be reconciled with MEK. Thus, the possibility of taxonomic confusion over what is included as '*cacing*' can be explored and clarified. Developed upon the two aforementioned studies, this study aimed to investigate two research questions to connect LEK and MEK on the role, benefits and drawbacks of earthworms in the context of coffee agroforestry: (i) How are earthworms and related taxa represented in soil-based local ecological knowledge of coffee agroforestry farmers?; (ii) How can an apparent gap between farmers' local ecological knowledge (LEK) and modern ecological knowledge (MEK) regarding the role of earthworms in soil fertility be understood?.

MATERIALS AND METHODS

Study area

The study was conducted at two locations. The first location was at the foot of Mount Kelud, Ngantang Sub-district, Malang District, East Java, Indonesia (112º16'42.4 E and 07º45'35,6" S), while; the second location was at the foot of Mount Arjuno, Karangploso Sub-district, Malang District, East Java, Indonesia (122º35'066"-122º37'53" E and 755'14"-752'27" S) (Figure 1). The elevation of the Ngantang area ranges from 500-700 m a.s.l. (above sea level), while the Karangploso area ranges from 700-1100 m a.s.l. Ngantang has an average temperature of 23-32ºC with annual rainfall ranging from 2900-4400 mm, a humidity of 70% (BMKG of Malang District, 2019), and has hilly topography. Karangploso has an average temperature of 21-27ºC with an annual rainfall of around 2107 mm/year and average humidity of 58% (BMKG of Malang District, 2019).

In both study areas, coffee farming is based on agroforestry practices. Farmers in Ngantang combined coffee plants with an upper canopy of fruit trees, including the locally favored durian (*Durio zibethinus*) tree (Saputra et al. 2022). In contrast, farmers in Karangploso grew coffee as an understory in existing timber plantations of pine (*Pinus merkusii*) or mahogany (*Swietenia mahagoni*) within an area of state forest company Perum Perhutani (Rowe et al. 2022). Earlier agroforestry characterization studies in the two study areas showed a clear difference in tree basal area, stem density and tree diversity (Table 1), although both meet the definitions of '*simple agroforestry systems'* (Hairiah et al. 2019). According to de Foresta and Michon (1997) agroforestry systems are divided into two systems; complex and simple agroforestry. A complex agroforestry system consists of > 5 types of tree combination, while simple agroforestry consists of ≤ 5 tree species (Hairiah 2021).

Data collection

The research was carried out in two stages: (i) Interviews with coffee farmers to determine farmers' knowledge regarding organic matter management, benefits (or drawbacks) and roles of earthworms in soil fertility, their habitat and activities in the soil; (ii) Analysis of correspondence, complementarity and gaps between LEK and MEK regarding the role and benefits (or drawbacks) of earthworms for soil fertility management.

Data collection was carried out using in-depth interviews with 48 respondents from two villages in Ngantang (Tulungrejo Village and Sumberagung Village) and from two representative villages in Karangploso (Sumbersari Village and Buntoro Village). Purposive sampling was used to choose farmers who met the criteria of (i) farmers who manage coffee agroforestry in Ngantang and Karangploso (Perhutani area) consisting of adult male or female farmers (aged older than 20 years), (ii) coffee agroforestry owners with an area of larger than 0.5 ha, (iii) engaging in coffee agroforestry for at least 10 years. As part of the LEK analysis soil organisms that local informants referred to were collected in the field and brought to the laboratory for rearing and identification.

Figure 1. Simple agroforestry systems in (A) Ngantang; fruit tree-based coffee agroforestry (*Toona, Durio zibethinus, Gliricidia sepium, Persea americana*) and (B) Karangploso; pine-based coffee agroforestry

Table 1. Characterization of coffee agroforestry systems in Ngantang (Purnamasari, 2019) and Karangploso (Prayogo et al. 2021)

Location	BA (m^2 ha^{-1})	Tree population (ha^{-1})	Tree species
Ngantang	11.4	1399	5
Karangploso	33.8	2075	2

Data analysis

Data from interviews were processed using Microsoft Excel and analyzed descriptively. They were presented in the form of narrative text/graphics and compared to the outcomes of technical data processing. Discrepancy between the interview data of local ecological knowledge and modern ecological knowledge focused on the taxonomic identity of the worms was analyzed.

RESULTS AND DISCUSSION

Demographic and socioeconomic profile of respondents

The total respondents were 48 farmers of which 33 were male and 15 female (Figure 2); among the 24 respondents in Karangploso 46% was female while in Ngantang was only 17%. Age distribution and schooling were independent of gender (when tested with Chi-square tests) across both locations.

The majority of farmer respondents relied solely on agriculture for income. Most male farmers reported that they are in charge of land management decisions such as land preparation, planting and planning coffee agroforestry production, while female farmers report that they are in charge of maintenance of the coffee agroforestry (pruning and harvesting). The area of coffee managed per respondent varied from 0.5-2 ha; the average was 0.90 ha in Ngantang and 0.80 ha per respondent in Karangploso.

Three main sources of soil-based knowledge were identified in the interviews: family-based knowledge transfer, own experience and farmer groups. Several farmers mentioned multiple sources. Family as a source of knowledge was mentioned by 67% of farmers in Ngantang, but only 29% in Karangploso, own experience was indicated by 33% of farmers in Ngantang and 92% in Karangploso, farmer groups were indicated by 29% and 4% of farmers in Ngantang and Karangploso, respectively. Age and gender differentiation of these percentages were limited, but farmer groups were only mentioned by male farmers in Ngantang.

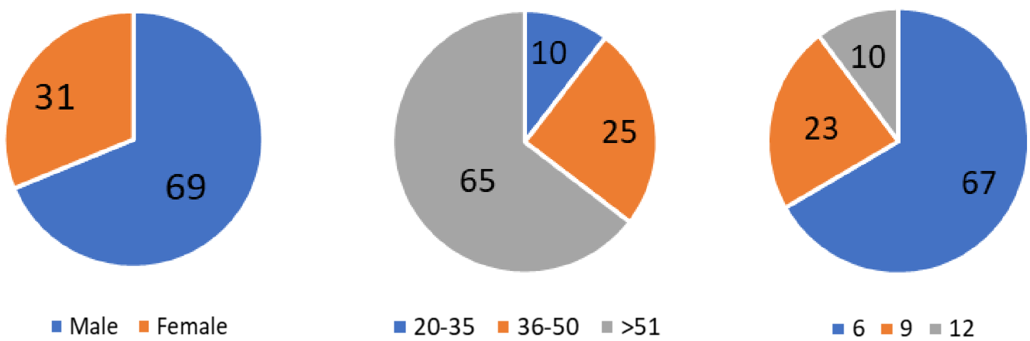

Figure 2. Distribution of farmer respondents by gender, age and years of schooling across the two study sites

Indicators of soil fertility according to farmers

In general, coffee farmers did not understand the Bahasa Indonesia equivalent of the term 'soil quality' but they knew the term 'fertile soil' ('*tanah subur'*). According to the results of interviews with 48 coffee farmers, 88% of respondents characterized fertile soil-based soil color, with secondary indicators based on soil texture (friability; 27%) and plant growth (25%). The presence of surface litter (13%) and earthworms (19%) were reported by less than 20% of respondents. Only 1 farmer specifically included the presence of earthworm cast at the soil surface as a soil fertility indicator. The gender-based differentiation of these indicators was limited (Figure 2), but farmers below 50 year of age were more likely to mention surface litter as indicator, and less likely to include soil texture, plant growth or earthworms. Farmers in Ngantang were three times more likely than those in Karangploso to mention soil texture and earthworms, with less differentiation in the other indicators.

The vast majority (88%) of the farmers stated that black soil which farmers usually call *'lemah ireng'* is fertile soil compared to other types of soil; less fertile soil is called *'lemah abang'* or literally translated as *red soil* (Figure 4). Farmers described that the color of fertile/black soil was obtained from humus that comes from the litter on the soil surface. Because infertile soil has a small amount of humus, the color of the soil is pale/red. In addition to soil color, farmers also mentioned soil friability as an indicator of soil fertility. Farmers called fertile soil "*gembrong*" (friable), which is easy to cultivate for having the structures of "*amoh/mempur/mempyar"* (crumb) when gripped. From the observations, the soil hue range extends from 10 YR 5/6 to 10 YR 2/1 (grayish dark brown to black) in the agroforestry system.

Soil organisms

All farmers mentioned that there are many types of soil organisms. Farmers said that in the soil there are many soil organisms that affect soil fertility. Soil organisms mentioned by farmers include '*cacing tanah*' or earthworms, '*cacing kawat*' or 'thread'worms, '*semut*' or ants, '*rayap*' or termites, *'ulat tanah*' or black cutworm, '*gayas*'/'*uret*'/'*embug*' or *Lepidiota stigma*, '*luwing*'/'*kluwing*' or millipide, '*klabang*' or centipedes, '*keong*' or snails, '*siput telanjang*' or slag. '*jangkrik*' or crickets, and '*orong-orong'* or mole cricket (Figure 5).

On average, farmers mentioned 4.38 groups of soil organisms (Figure 6), while only 6% of farmers stated that soil organisms have no function ('*tidak pengaruh'*). Earthworms were the only group mentioned by all farmers, 13% of farmers also mentioned 'small' or 'thread' worms ('*cacing kawat'*). In follow-up questions 38% of farmers in Karangploso (and none in Ngantang) said that 'small worms' are a pest (as they eat coffee roots).

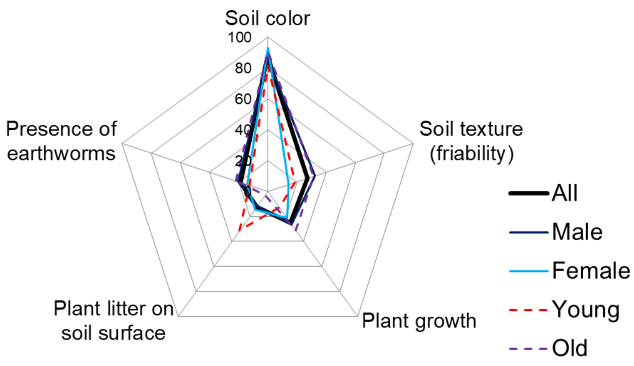

Figure 3. Indicators of soil quality according to farmer's LEK

A **B**

Figure 4. Farmers' knowledge about the color of fertile soil (A) '*lemah ireng'* and infertile soil '*lemah abang'* (B)

Figure 5. Soil organisms mentioned by farmers: A. '*cacing*' or earthworms (Photo credit/PC: M.O, Mardiani); B. '*Cacing kawat*' or 'thread' worms (PC: MO, Mardiani); C. '*rayap*' or termites (PC: K.Hairiah); D. '*semut rang-rang*' or ants (PC: https://bukanarjuna.com/budidaya-semut-rangrang/); E. '*Ulat tanah*' or black cutworm (PC: https://agrokomplekskita.com/hama-ulat-tanah-agrotis-ipsilon-pada-padi/); F. '*Gayas/uret*' or Lepidiota stigma (PC:http://www.infonet-biovision.org); G)'*luwing*'/'*kluwing*'or millipede (PC:https://www.researchgate.net/figure/A-brown-giant-millipede-of-the-family-Harpagophoridae-This-millipede-measured_fig4_266614573; H. '*klabang*' or centipede (https://m.medcom.id/properti/tips-properti/ob3eaZyK-musim-hujan-tiba-begini-cara-usir-kelabang-dari-rumah; I. '*keong*' or snail (PC: M. van Noordwijk); J. '*Siput telanjang*' or slag (https://id.quora.com/Bagaimana-cara-mencegah-siput-tanpa-cangkang-masuk-ke-dalam-rumah); K. '*Jangkrik*' or cricket (PC: Shutterstock/ahnhuynh); L. Mole cricket ('orong-orong) (https://id.wikipedia.org/wiki/Anjing_tanah)

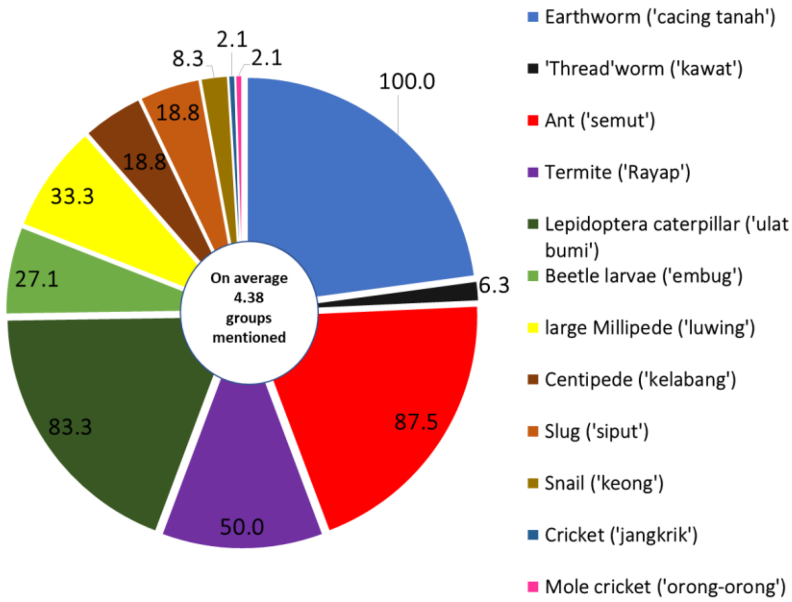

Figure 6. Broad groups of soil organisms mentioned by farmers

Earthworm activity and role

The role of earthworms in soil fertility

The interview result revealed that 72% of coffee farmers stated that earthworms could fertilize the soil, but 22% of coffee farmers said that earthworms are benefited depend on their size (large earthworms could fertilize the soil, but small earthworms are dangerous because they eat the roots of the coffee plant). On the other side, 6% of coffee farmers stated that earthworms had no effect on soil fertility (Figure 7).

The interview result revealed that there were four categories of earthworms found in their coffee agroforestry areas. According to farmers, there were two types of earthworms, namely big earthworms and small earthworms. Big earthworms are classified into two types: the brown earthworm (Figure 8A) and the reddish-brown earthworm (Figure 8B). Big earthworms were found in the soil at a depth of more than 10 cm. While small earthworms are classified into two types: black earthworms (Figure 8C), which are found on the surface of the soil, and reddish-white earthworms (Figure 8D) clustered in the soil. According to 22% of Karangploso farmers, these small worms eat coffee plant roots. Small, thin, and clustered 'wire' worms were considered harmful by farmers (Figure 8D). Rearing the latter type of organisms in the laboratory, showed that they are juveniles of *Pontoscolex corethrurus*. Earthworms that fertilize according to farmers are shown in Figures 8A (*Lumbricus* sp), 8B (*Amynthas* sp), and 8C (juveniles of *Pheretima* sp) after identification in the laboratory.

Aside from earthworms, farmers said there were other harmful soil biotas that could make the soil infertile, namely '*embug'* or '*gayas*' caterpillars (probably: *Leucopholis rorida*).

Earthworm activity

Most farmers (72%) stated that earthworm activity could positively affect soil fertility, including the movement of earthworms in the soil to make tunnels for water to enter (33%), bringing litter from the soil surface into the soil (2%), and dispose of feces on the soil surface (37%). On the other hand, there were farmers (22%) who said that earthworms are harmful because the activity of worms in the soil can reduce soil fertility (negative effects) such as eating coffee plant roots (12%), worm activity in the soil causes soil compaction (2%), earthworms eat the soil causing the soil to decrease (8%). A small portion (6%) of farmers claimed that earthworm activity in the soil had no impact on soil fertility. Male farmers aged >52 years were more aware of the role of earthworms on soil fertility, 3% of male farmers (M-3) said that earthworms have a positive impact on soil fertility. Farmers' knowledge about the role of earthworms varied depending on age and gender (Table 2).

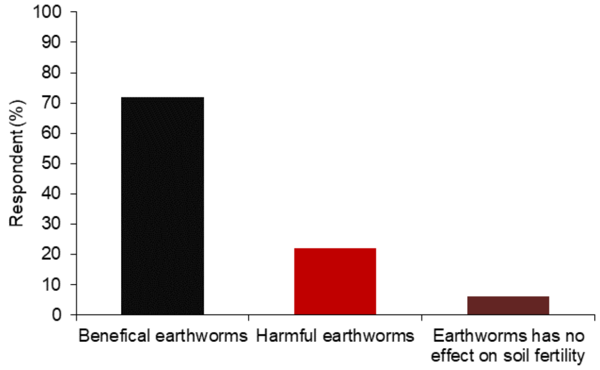

Figure 7. Farmer's Local Ecological Knowledge (LEK) on the role of earthworms on soil fertility

Figure 8. Types of earthworms according to their benefits for soil fertility based on farmers' local ecological knowledge (LEK): Earthworms are beneficial (A, B, C), and earthworms are harmful because they eat coffee plant roots (D)

Tree leaf litter and earthworm habitat

Earthworm feed

As many as 54% of farmers said that earthworms eat soil, while 29% of farmers stated that earthworms feed on litter on the soil's surface, and only 2% of farmers said that earthworms feed on cow dung. The remaining 15% of farmers did not know what earthworms eat (Figure 9). Farmers' local ecological knowledge related to the soil as food for earthworms is the knowledge that has been passed down from generation to generation. Besides, farmers observed that earthworm cast resembles soil so they assumed that soil is food for earthworms.

The litter that earthworms like

The 19% of farmers who believed that earthworms eat litter specified leaf litter sources that earthworms enjoyed consuming as: coffee litter (2%), pine (2%), mahogany (2%), dead roots (2%), gliricidia (4 %), and leucaena (7%) (Figure 10). The majority of farmers are unaware of which litter earthworms prefer (81%). Farmers claimed that litter on the soil's surface would rot and turn into humus, causing the soil to become dark and loose.

Litter decomposition

One of the primary energy sources for earthworms is tree leaf litter that accumulates on the soil surface, which later decomposes into soil organic matter and then provides various benefits to the soil ecosystem. Half of all farmers (55%) said that coffee leaf litter would rot faster than other shade tree leaf litter. If the shade tree is the leucaena tree, it will decay faster than other litter (according to 19% of respondents) (Figure 11). However, about 5% of farmers said that the most rapid decaying litter is litter of '*wedusan*' or Billy Goat Weed (*Ageratum conyzoides*), '*dadap*' or Variegated Coral Tree (*Erythrina variegata*) (4.8%), albasia (*Albizia chinensis* or *Falcataria moluccana*) (4.8%), and durian (*Durio zibethinus*) (4.8%). Only 2% of farmers believed that the decomposition rate of coffee leaf litter is the same as that of pine tree litter.

Earthworm habitat and life cycle

A favorable environment has a significant impact on earthworm activity. According to 98% of farmers earthworms prefer moist soil, while the rest said earthworms prefer open and dry places. Almost all of the respondent farmers knew that earthworms lay eggs in the soil, and 58% of farmers knew the shape, and the existence of earthworm eggs (cocoons), which are round, white-like pearls and reddish, and the cocoon was found at a depth of 10 cm from the soil surface.

Discussion

Local ecological knowledge (LEK) of coffee farmers in Ngantang and Karangploso

Ngantang and Karangploso are two of the coffee-producing areas in the Malang District. The two areas have similarities in term of the intercropped lands with the coffee tree are wood-producing trees belonging to Perum Perhutani, a state-owned forestry company. The differences in policies, land management, and vegetation cause differences in the farmers' local ecological knowledge. Farmers of coffee agroforestry in Ngantang and Karangploso have common and different knowledge about the benefits and roles of earthworms (Table 3).

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

All the indicators of fertile soil according to the farmer's LEK can be matched with global soil quality indicators used in MEK (Table 4).

A gap analysis was carried out to see the gap between coffee agroforestry farmers' local ecological knowledge (LEK) and modern ecological knowledge (MEK) regarding organic matter management and the role of worms on soil fertility. The result of the gap analysis is presented in Table 5.

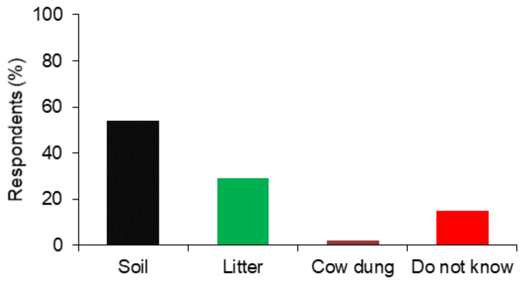

Figure 9. Earthworm food based on farmer's local ecological knowledge

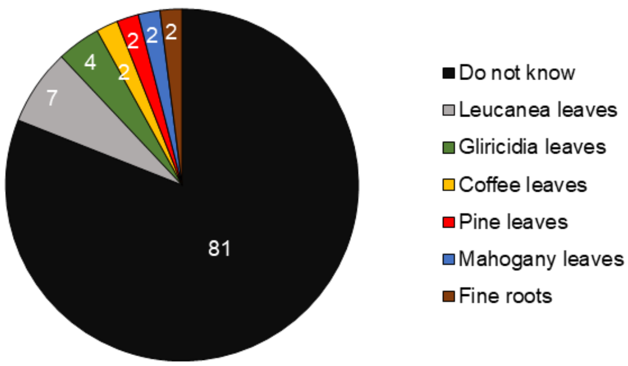

Figure 10. Farmers' local ecological knowledge (%) on litter that is preferred by earthworms

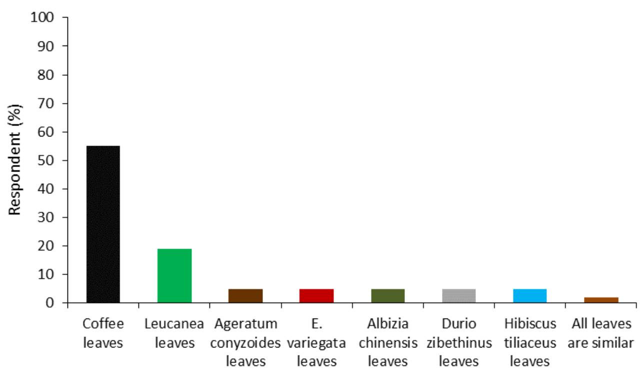

Figure 11. Decomposition rate of litter according to farmers' local ecological knowledge (%) where n=48

Table 2. Farmers' local ecological knowledge (LEK) on the role and benefits of earthworms on soil fertility by gender and age (percentages of overall respondents)

The role of earthworms on soil fertility according to LEK	Gender/age class						Total (100%)	
	M-1 6.3%	F-1 4.2%	M-2 14.5%	F-2 10.4%	M-3 47.9%	F-3 16.7%	Male (n = 33)	Female (n= 15)
	(%)							
Positive effect								
Earthworms create burrows in the soil	4	0	7	4	13	4	24	9
Earthworms cast on the soil's surface	0	4	2	2	21	8	23	14
Bringing litter from the soils surface into the deeper soil	0	0	2	0	0	0	2	0
Negative effect								
Earthworms eat coffee plant roots	2	0	4	2	2	2	8	4
Earthworm activity makes soil compaction	0	0	0	0	2	0	2	0
Worms eat the soil so the soils amount is reduced	0	0	0	0	8	0	8	0
No effect on soil fertility	0	0	0	2	2	2	2	4

Note: Gender, M: Male, F: Female, age Groups 1: 20-35 years old, 2: 36-51 years old, 3: ≥ 52 years old

Table 3. Farmers' LEK regarding the role and benefits of earthworms in Ngantang and Karangploso

Subject	LEK in Ngantang	LEK in Karangploso
Benefits	Earthworms are beneficial for soil fertility regardless their size (small and big earthworms)	Earthworms are beneficial according to their size. Big worms fertilize the soil, while small worms are harmful for coffee plant because they eat its roots.
Activities	Earthworms create burrows in the soil, and deposit its feces (cast) on the surface of the soil	Farmers do not know about the activity of worms in the soil
Feed	Soil, litter and cow dung are food sources for earthworms	Soil is a source of food for earthworms
Types of Feed	Leucaena leaves are the litter that earthworms like	Farmers do not know the litter that earthworms like
Cocoon	Farmers are aware of the existence of earthworm eggs (cocoon)	Farmers are aware of the existence of earthworm eggs (cocoon)
Benefit of earthworms cast	Cast is useful for fertilizing the soil	Casti is useful for fertilizing the soil

Table 4. Soil quality indicators based on LEK (our case study) and MEK (global studies) in coffee agroforestry areas

LEK "fertile soil"	MEK "soil quality"
Soil color (dark black)	Soil color (Munsell Soil Color Charts), 10 YR 5/6-10 YR 2/1 (grayish dark brown to black)
Plant growth (dark green leaves)	Plant growth (Wawire et al. 2021)
Soil friability (*gembrong, amoh, mempur, mempyar*)	Bulk density of < 1.2 g cm^{-3} (Kooch et al. 2021)
Earthworms are found	Soil fauna play important roles in agroecosystems, as crucial actors of the four aggregated and interrelated function that determine soil health (Marsden et al. 2019), The soil 'ecosystem engineer' macrofauna (earthworms, ants, termites) play a major role in soil structure maintenance (Jouquet et al. 2006)
Humus; litter ('*resek*') is found	C-Organic (2-6%) (Marinho et al. 2017)
Earthworm casts present	Soil pH (6.6-7.5) (Nguemezi et al. 2020)

Coffee land management activities carried out by both male and female farmers elsewhere in the tropics (Zúñiga et al. 2013) revealed that the age factor affects farmers' local ecological knowledge about the soil. Generally, older farmers have more knowledge than younger farmers because of their expertise in coffee production under diverse conditions. Farmers have acquired local ecological knowledge from generation to generation and from experiences and experiments (Singh et al. 2021). Tree species richness in agroforestry plots in Vietnam was found to be much higher for coffee compared to non-coffee plots, including those with annual crops and tree plantations (Nguyen et al. 2020), with most farmers aware of the benefits of trees for soil improvement, shelter (from wind and frost), and the provision of shade and mulch. Farmers managing coffee production systems in Rwanda (Dumont et al. 2019) had detailed knowledge about soil and water conservation processes associated with trees, but they were also concerned about perceived competition for light, water and nutrients with coffee trees.

Table 5. Gaps between local ecological knowledge (LEK) and modern ecological knowledge (MEK) on soil quality

Aspect	LEK	MEK
Soil color	Black soil is fertile	Dark soil is rich in C-Organic, dark soil is rich contains a lot of C-Organic and contain soil microbes i.e. macro and microorganisms. Soil biology means the soil microbes present in the soil like bacteria, fungi, nematodes, earthworms etc (Swami et al. 2017).
Benefits of earthworms	Small earthworms found on the surface of the soil are harmful because they eat the roots of coffee plants.	Small earthworms (5-15 mm) are microdrili (Brown, 1999). Epigeic species who live on the surface soil whose feed on a litter layer and are unable to move down into the soil (Al-Maliki et al. 2021)
Earthworm activity	Earthworm activity can increase soil fertility by leaving burrows and cast on the soil's surface of	Earthworm burrows can promote soil macroporosity and infiltration (Hairiah et al. 2006), by mixing fresh residuein aggregates and improved stability of soil aggregates, earthworms have a major effect on soil structure (Guo et al. 2020)
Earthworm feed	Earthworms eat the soil causing the amount of soil to decrease	Earthworms tend to be able to consume different organic materials (litter) and this affects their behavior (Guo et al, 2020), depending on the type of plant and quality of the litter.
Earthworm's Favorite Feed	Leucaena leaves are the litter preferred by earthworms.	Earthworm feed varies depending on the type of earthworm; manure, litter with lower C/N, compost. Zhang et al. (2013) incubated a soil with the Metaphire guillelelmi anecic earthworm and found that microbial biomass C,N, P had decreased after suggesting that microorganisms were a secondary food resource for earthworms.
Cast	Earthworm cast is useful for fertilizing the soil.	Casting-earthworm is very important for raising soil fertility and biological characterictics of the soil (Boonchamni et al. 2020). Annual castings of worms approx. 40 t ha^{-1} year-^{1} contribures approximately 0.4 cm of top soil per year (Blouin et al. 2018). Earthworms casts have higher increases in C-enrichment and microbes than the surrounding soil and are the keystone of soil sustainability (Co1 et al. 2007; Al-Maliki et al. 2021)

Many of the farmers we interviewed recognized the diversity in the broad 'earthworm' category, and they attribute different properties and functions to different species. This finding agrees with other studies. Budijastuti (2019) documented five species of earthworms in banana habitats in four locations in East Java: *Metaphire javanica, M. postuma, M. californica, Amynthas robustus* and *Pheretina racemosa.* Earthworms around bananas are preferred as bait for fishing, feed for ornamental fish and as traditional medicine (to cure typhus disease).

Earthworms make burrows in the soil that allow water to enter the soil. Earthworms will also dispose of their cast on the soil surface, and it could increase soil fertility. Earthworms from the group of ecosystem engineers leave many burrows in the soil as 'biopore', which increases soil porosity and soil infiltration. Mardiani (*in prep*.) reports that in the planar cage experiment, *P. corethrurus* was able to produce pores of 0.8-2.7 cm/day per individual, and earthworm activity increased by a factor of two in fertile soil. Earthworm activity in Inceptisols leaves burrow length/total macro pores up to 618.5 cm for five weeks of observation. The movement of earthworms in looking for food in all directions leaves burrows called 'biopore', pores formed by living organisms (Helliwell et al. 2014). These burrows made by endogeic earthworms moderately increase water infiltration, earthworm behavior where burrowing is assumed to be mainly governed by soil water content, temperature and soil bulk density (Capowiez et al. 2021). Macro pores are large soil holes, earthworm burrows, and root canals, which pass through the soil profile (Helliwell et al. 2014). Macro pores are essential, these pores influence soil biodiversity (i.e., soil microorganism) by facilitating space for their survival (Ramesh et al. 2019). Endogeic earthworms may contribute to the decomposition of organic matter because their species obtain their food from moist organic matter or fine roots. Sometimes, earthworms eat dead organic matter / litter after being decomposed by microorganisms and forms a midden or cast (Dwiastuti 2012). Endogeic earthworms or 'topsoil dwellers', are geophagous earthworms that feed on mostly moistened soil organic matter and dead roots. Earthworms eat soil as they move through the soil while making burrows and mixing it with organic matter, then excreting it in the form of cast (Schelfhout 2017).

Palungkun (2006) stated that earthworms prefer litter with high water content and avoid litter with a strong odor, such as acacia, lime leaves, basil, and pine needles. Yatso (2015) reported that previous studies showed a strong correlation between litter quality (%N, lignin (L), polyphenols (P), C/N ratio) with the selection of litter by earthworms. According to a study on earthworm feed preferences, coffee leaves has a low chemical content, namely (L+P)/N 12.6%, lignin 26.9%, polyphenols 13.8%, N 3.2%, and C/N ratio 14.3. The addition of coffee litter can increase the weight of earthworms (initial average 0.5-0.63 g/individual), increase the number of cocoons, and have a low mortality rate.

The humidity level is very influential on the activity of earthworms because part of their body consists of water ranging from 75 to 90%. Rajkhowa et al. (2015) described that earthworms' ideal soil moisture level is 15-50%. Nouri-Aiin and Görres (2019) stated that cocoons were mostly observed at a depth of 10-23 cm depth. Their research stated that earthworms could produce cocoons throughout the year, with an estimated production of 0.6 cocoons per day.

Cerdán et al. (2012) reported that farmers in smallholder plantations stated that the abundance of earthworms as an indicator of fertile soil, but could not explain the role of earthworms on soil fertility. In our study, 24% of the interviewed farmers said that earthworms are harmful because they eat the coffee plant root, cause soil density, eat the soil and cause the amount of soil to decrease. Most farmers claim that earthworms eat the soil. This result follows research conducted by Bichalo et al. (2016) that farmers in natural forest areas stated that *"Worms eat the land, come up to the surface and release it in the form of manure"*. Farmers did not entirely comprehend the role of earthworms in soil fertilization. Some farmers stated that earthworms caused the soil to become dense and decreased. A similar effect has elsewhere been attributed specifically to *Pontoscolex corethrurus* as an invasive earthworm linked to agricultural expansion (Ortíz-Ceballos et al. 2019). Although the name *P. corethrurus* might in fact relate to a morphospecies with multiple taxonomic identities, there is no consensus on its preferred food source (Taheri et al. 2018) with a 100% litter reported to be lethal, and a preference rhizosphere carbon sources indicated. 'Eating roots', as part of our farmer's report, however, has not been confirmed with scientific rigor.

In decomposition studies, litterbag method remains the most generally used technique for determining litter decomposition (Moore et al. 2017; Sun et al. 2017). Litter mass loss and rate were calculated by fitting mass loss to a single exponential model of decay (Robertson and Paul, 2000; Yolanda 2007). The litter decomposition rate can be seen by the half-life (t_{50}), which is the loss rate of litter that is half of the initial weight that occurs during the decomposition period at the soil surface. Hairiah et al. (2019) reported that coffee leaf litter is a fast-decomposed litter with a half-life time (t_{50}) = 33 weeks, while mahogany and pine tree litter is slow weathering with a half-life time (t_{50}) > 55 weeks. Thus, farmers in Ngantang and Karangploso claimed that the weathering rate of coffee plant litter is faster than litter from its shade trees (pine or mahogany), which is supported by study and scientific knowledge.

Farmers, particularly the older ones, already had a lot of knowledge about "what" is in their land (organic matter, earthworms, markers, and the environment). However, their understanding of the issues of "why" and everything related to soil processes seems to be lacking and need assistance. They lacked an understanding of why the rate of litter decomposition varies in agroforestry and why the earthworm density in agroforestry fields varies, which makes the soil friability vary as well. This understanding is needed to assist farmers in making decisions to improve their in-situ land management without relying a lot on external inputs; thus, this kind of integrated research is very much needed in the current climate change era to achieve sustainable development of agricultural production.

In conclusion, we found that farmers knowledge of the positive ecosystem services and risks of crop damage provided by earthworms depended on the respondents and the landscape in which they farm. Part of the knowledge was based on oral transfer within families, another part was based on the observations farmers made themselves. Where apparently contradicting statements emerged, reporting positive or negative effects of worms, it helped to follow up and established the taxonomic identities local names referred to. In such a process of dialogue, local ecological knowledge can enrich current scientific literature. It also indicates the communication challenges that providers of 'external knowledge' have to face when sharing ideas about sustainable soil management with farming communities.

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