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The Impact of Termite Activity on Soil Fertility: A Case Study in Pine Stands in the Alas Bromo Education Forest Area

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Abstract

Termites function as soil engineers and play a crucial role in the decomposition of organic matter. This study was conducted in the Alas Bromo Educational Forest under pine stands of various age classes. The objective of the research was to investigate the influence of termite activity on soil fertility, as indicated by the levels of soil organic matter (SOM), soil organic carbon (SOC), and soil pH. The method employed involved baiting pinewood stakes placed in polyvinyl chloride pipes (PVC) to assess termite activity, which was evaluated based on the level of damage to the stakes and classified into damage classes. The stakes used were made of pine wood, similar to the species of the overlying stands. This study identified four termite genera in the Alas Bromo area: *Macrotermes*, *Microtermes*, *Odontotermes*, and *Schedorhinotermes*. The findings revealed significant differences in SOM and SOC across the stake damage classes within each stand. In general, the highest values were observed in soils with the highest levels of termite activity, as reflected in damage class 4. However, soil pH values did not show significant differences across the varying levels of termite activity. These findings highlight that termites, as soil engineers, play a vital role in enhancing soil fertility and hold promising potential for application in the pursuit of sustainable agriculture.

Keywords: decomposition; ecosystem engineers; Isoptera; soil organic carbon; soil organic matter

INTRODUCTION

Termites are commonly perceived as agricultural pests due to their ability to cause structural and crop damage (Constantino, 2021). A study by Indrayani (2022) identified seven termite species in a rubber plantation in the Kubu Raya Regency, responsible for approximately 13.97% of observed damage to rubber trees. Moreover, termites can adversely affect a range of tropical crops, leading to significant economic losses (Rouland-Lefèvre, 2010). Although termites are often regarded as destructive organisms, they play a vital role as decomposers in tropical ecosystems (Issoufou et al., 2019).

Termites are widely recognized as ecosystem engineers and play a pivotal role in maintaining soil functions and delivering essential ecosystem services (Jouquet et al., 2014). Termite activity can significantly influence soil microbial communities and impact nutrient cycling by decomposing wood residues or other organic material sources (Traoré et al., 2015). For instance, a study by Schaefer et al. (2016)

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in the Carajás grasslands of the Amazon, Brazil, demonstrated that soil organic matter (SOM) concentrations significantly increased due to termite activity. Symbiotic microorganisms such as bacteria and protozoa live in termites' gut or digestive tract, enabling them to efficiently decompose organic materials such as dead wood, plant residues, or leaf litter. These microorganisms break down complex compounds like cellulose and lignin into simpler substances. Therefore, termites play a significant role in the carbon cycle (Brune, 2014). The ecological value of termites has also led to their practical use in sustainable agriculture; in South Africa, smallholder farmers utilize termite mound soil as a natural fertilizer to improve soil fertility (Chisanga et al., 2020).

Environmental factors, including stand type, contribute to termite population diversity. A study in Malawi showed that stand conditions directly affect termite distribution across a landscape (Nyirenda et al., 2019). The Alas Bromo Educational Forest features various stand types with different age classes. Pine is one of the dominant stand types (Nufus et al., 2020). Pine is commonly used as termite bait in research activities due to its palatability (Ariana et al., 2022), making it highly preferred by termites (Waller et al., 1990).

Termite research has predominantly focused on mound investigations, while comprehensive studies utilizing the pipe-embedded wooden stake bait method remain notably absent. This method accurately assesses termite activity by systematically classifying stake damage severity at each observation point, directly demonstrating termites' role in soil modification. The study was conducted in the Alas Bromo Educational Forest, specifically targeting pine stands, which constitute favorable termite habitat (Waller et al., 1990). This investigation aims to identify termite species at the study site and quantitatively evaluate termite activity concerning key soil fertility.

The results of this study are especially relevant to the United Nations Sustainable Development Goals (SDGs) through the enhancement of soil fertility by leveraging the functional role of termites, which could serve as a solution to improve agricultural productivity. This research also contributes to soil ecology and sustainable forest management, promoting ecosystem services and organisms such as termites to maintain soil health.

MATERIALS AND METHOD

Study site

The study was conducted under pine stands of various age classes (Table 1) in the Alas Bromo Educational Forest area, Karanganyar, Central Java, Indonesia. Soil fertility analysis was conducted in the Soil Chemistry and Fertility Laboratory, Faculty of Agriculture, Universitas Sebelas Maret. The research period lasted from July to December 2024. This study used a descriptive-exploratory method with a purposive sampling approach, focusing on stands with high potential for termite activity.

Research method design

Termite activity was assessed using the wooden stake bait method, where stakes were placed inside PVC pipes to monitor termite feeding intensity. Bait installation was conducted at each stand, with a bait plot area of 25 m × 25 m. Each plot consisted of 4 subplots spaced 10 m apart. Each subplot contained 16 bait stations inserted into pipes, with 2.5 m spacing between stations. The PVC pipes used in this study measured 25 cm in length, while the wood bait dimensions were 3 cm × 3 cm in cross-section with a length of 20 cm. The baits were placed in each stand for 2 weeks, after which the condition of the stakes was observed to assess the damage class level (Table 2). There were five damage classes for the stakes (0 to 4). The damage class of the stakes was used to reflect the level of termite activity at each point, meaning that the higher the damage class, the greater the termite activity (Rachmadiyanto et al., 2023).

Sampling and parameter observation

This study collected termite-activity soil samples from the vicinity of monitoring stakes. Sampling was conducted using five distinct stake damage classes (reflecting varying termite activity levels), with six replicate samples collected per damage class from each stand type. This sampling design resulted in a total of 120 soil samples for analysis. Laboratory analysis determined the organic matter content, organic carbon, and soil pH for each stake damage class in each stand. The termites collected from each observation stake were preliminarily identified at the genera level through rapid field assessment

Table 1. Baiting location for termite stakes

Location	Stand	Location coordinates
1	Pine 2016	110°59’45,21102” E; -7°34’59.57779” S
2	Pine 2001	111°0’26.57018” E; -7°35’30.17373” S
3	Pine 1973	110°59’47.25446” E; -7°35’5.56025” S
4	Pine 1994	111°0’36.38214” E; -7°35’33.71897” S

Table 2. Classes and criteria of damage to wooden stakes used to assess termite activity

Damage class of stakes (Termite bait)	Damage level	Damage criteria for stakes
0	Undamaged	There is no indication of termite infestation or presence on the observed stakes
1	Minor damage	Few traces of an attack on the bait were found, but no termites
2	Moderately damaged	There is damage to the stake due to termite attacks and deeper attack holes
3	Damaged	There was damage to the wooden stake, which was quite severe, and the attack was deep
4	Severely damaged	Very severe damage to wooden stakes (deep and thorough damage) or the state of the stakes has disappeared. In this class, termite infestation activity is usually no longer active

Sources: Rachmadiyanto et al. (2023)

using morphological characteristics. All specimens were preserved in alcohol-filled vials for subsequent laboratory examination under microscopy.

Statistical analysis

Analysis was performed using one-way ANOVA to assess the effect of termite activity levels on soil chemical conditions, as represented by the stake damage class. A post-hoc test was then conducted to compare soil conditions based on stake damage classes (representing different activity levels) using Duncan’s Multiple Range Test (DMRT) at a 95% confidence level. The analysis of parameter relationships was conducted using Pearson’s correlation test.

RESULTS AND DISCUSSION

Termite genera in Alas Bromo

Termites, belonging to the order Isoptera, are social insects characterized by distinct castes and morphologies (Krishna and Weesner, 1969). There is a specific division of tasks for each caste, whereas, in termite colonies, their activities are highly integrated and well organized. There are three castes in a termite colony, each having a role (Toly et al., 2024). The worker termites are responsible for all the necessary work in the nest, including maintaining, repairing the colony, and collecting food (Eggleton, 2010). Termites of the soldier caste have different head characteristics compared to others, where the heads are bigger and sturdier because their job is to defend the colony. There are also reproductive castes, namely the king and queen of termites (Khan and Ahmad, 2018). The reproductive or queen termite is responsible for producing and laying eggs (Eggleton, 2010).

Determination of termites in the field is done by looking for soldier caste termites in a colony found. According to Wu et al. (2018), Miura and Maekawa (2020), and Radford et al. (2022), the soldier character is often used for species identification because this caste has distinctive and significant morphological characteristics in a termite colony, such as having significant and strong jaws. There are four genera found in Alas Bromo (Figure 1).

The four species of genera were found in every stand, and the most common was *Microtermes.* The *Macrotermes* has the physical characteristics of a large head (head size is larger than the body) (Ahmad, 1958). These genera are found in Indonesia, Thailand, South Africa, Peninsular Malaysia, and the Arabian Peninsula (Bakhtiari et al., 2010). *Microtermes* is a type of termite with a body size larger than the head. The food of this genera can be plant roots, leaf layers, and dead

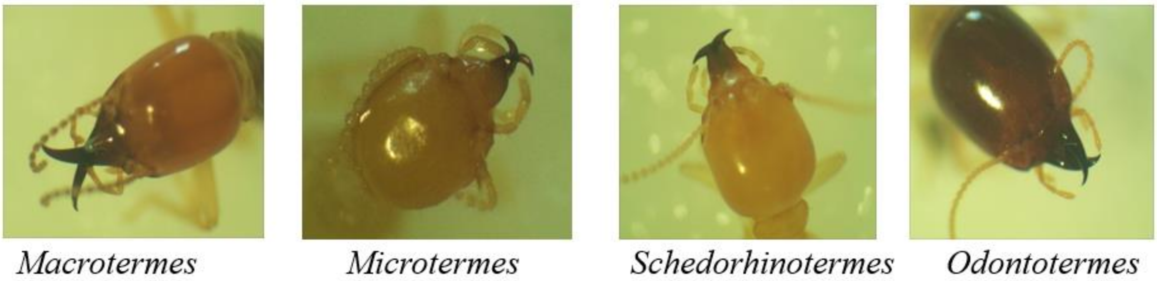

Figure 1. Genera of the Alas Bromo termite

wood. These termites build large underground tunnel networks. Nature performs its role in decomposing organic matter. Termites of the genera *Macrotermes* and *Microtermes* symbiotize with the fungus *Termitomyces* (van de Peppel and Aanen, 2020; Egan et al., 2021). The *Schedorhinotermes* genera have a proportional body shape. According to Donovan et al. (2000b), this termite is a group of dead wood eaters, so these genera are often found in logs (Faszly et al., 2005). The *Odontotermes* nest in the soil, especially near organic matter containing cellulose, such as wood and litter (Sulantika and Diba, 2019). The *Odontotermes* termites often eat dead or decaying wood and bark.

SOM by damage class of stake baits reflecting termite activity levels

As ecosystem engineers, termites enhance organic matter decomposition and soil nutrient cycling by modifying soil hydrological properties and structure (Myer and Forschler, 2019). Based on Figure 2, the level of termite activity indicated by the damage class of the pegs has a significant effect on SOM content in all stand ages. The ANOVA results confirmed that the differences in organic matter content among damage classes were statistically significant: Pine 1994 ($p < 0.001$), Pine 2016 ($p < 0.001$), Pine 1973 ($p < 0.001$), and Pine 2001 ($p < 0.001$). In each stand, the highest value is produced in the damage class of peg 4, which is the highest level of termite activity, Pine 2016 (3.18%), Pine 2001 (2.73%), Pine 1973 (2.85%), and Pine 1994 (4.09%), for the lowest value is produced in the damage class of peg 0 which reflects the low or no termite activity at that point.

The 1994 pine stand showed the highest values, possibly due to the dominance of understory vegetation in that area, as supported by Nierop (2001) and Oktariani et al. (2023), who

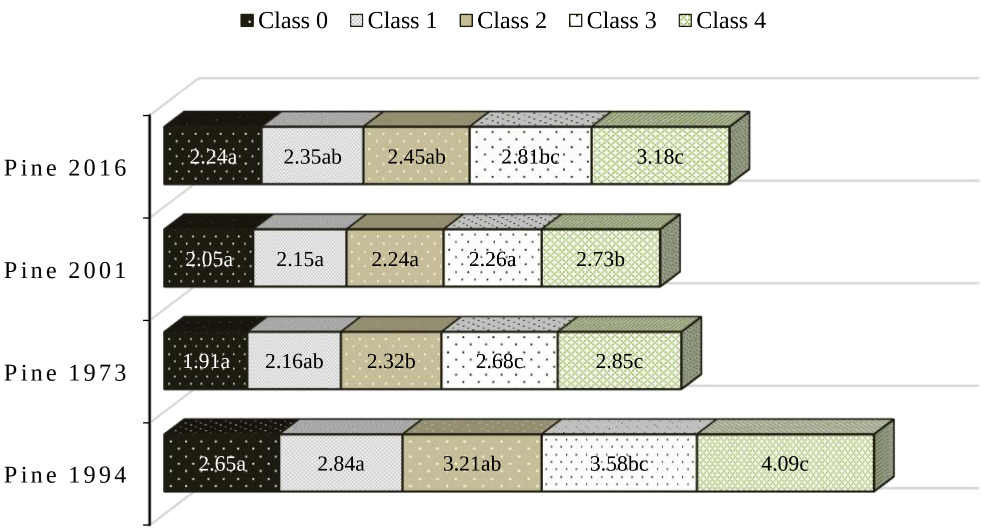

Figure 2. SOM content (%) among damage classes of stakes in each stand

Note: The numbers followed by different letters indicate significantly different results in the DMRT test (α = 0.05) demonstrated that understory plants contribute significantly to organic matter input in soils. The results show that higher damage class or termite activity contributes to the increase of SOM. Through intestinal transit, termites facilitate humification by degrading and converting organic matter and increase the stability of SOM (Khan et al., 2018), so the presence and activity of termites can have a positive impact on improving the fertility of the soil (Febriani et al., 2025).

SOC by damage class of stake baits reflecting termite activity levels

Termites significantly improve soil properties, including organic carbon (Sarcinelli et al., 2013). Based on the analysis, there is a significant difference in SOC content between damage classes. Based on Figure 3, the level of termite activity indicated by the damage class of the pegs has a significant effect on SOC content in all stand ages. The ANOVA results confirmed that the differences in organic matter content among damage classes were statistically significant: Pine 1994 ($p < 0.001$), Pine 2016 ($p < 0.001$), Pine 1973 ($p < 0.001$), and Pine 2001 ($p < 0.001$). In each stand, the highest mean value was recorded in damage class 4 (the highest level of termite activity), with organic matter content reaching Pine 2016 (1.84%), Pine 2001 (1.58%), Pine 1973 (1.65%), and Pine 1994 (2.37%). Conversely, the lowest organic matter content was found in damage class 0, where termite activity was absent or very low. These findings indicate a positive relationship between termite activity and SOC accumulation. This is consistent with Clarke et al. (2023), who reported that termite-driven bioturbation and frass deposition play a crucial role in enhancing SOC levels, not only in surface soils but also in deeper subsoil layers (> 1 m), which spatially correlate with biogenic structures such as tunnels and nest chambers. Such activity promotes biogeochemical processes that accelerate the translocation and stabilization of organic matter within the soil profile.

Furthermore, termites function as ecosystem engineers by facilitating carbon transfer from organic materials, such as woody debris, into the soil matrix (Myer et al., 2021). Their study revealed that approximately 42% of the carbon in wood is released as CO_2, 40% is returned to the environment as organic residues (frass and construction materials), and 18% is retained in termite biomass, illustrating a systematic flow of carbon from wood into soil ecosystems. Additionally, Jones (1990) and Issoufou et al. (2019) highlighted the ecological role of termites in accelerating the decomposition of organic matter and enhancing soil fertility, further underscoring their importance in terrestrial biogeochemical cycling.

Figure 3. SOC content (%) among stake damage classes in each stand

Note: The numbers followed by different letters indicate significantly different results in the DMRT test ($\alpha = 0.05$)

Soil pH by damage class of stake baits reflecting termite activity levels

Based on Figure 4, the level of termite activity indicated by the pegs' damage class does not significantly affect soil pH content in all stand ages. The ANOVA results confirmed that the differences in soil pH among damage classes were statistically not significant: Pine 1994 ($p > 0.005$), Pine 2016 ($p > 0.005$), Pine 1973 ($p > 0.005$), and Pine 2001 ($p > 0.005$). The pH values recorded in the 2016 pine stand ranged from 6.57 to 6.77, in the 2001 pine stand from 6.04 to 6.34, in the 1973 pine stand from 6.29 to 6.54, and the 1994 pine stand from 6.23 to 6.64. These values are consistent with findings from Ariyanto et al. (2021), who reported soil pH in the Alas Bromo area ranging from 6.35 to 6.81. Across all stands, soil pH values for each damage class fall within a slightly acidic to neutral range. According to Gunawan et al. (2019), soil with a pH above 5.5 provides favorable conditions for soil microbial development. A high microbial population supports faster and more efficient leaf litter decomposition, accelerating nutrient availability in the soil.

Relationship between termite activity and soil fertility

The relationship between termite activity and soil parameters was analyzed using Pearson correlation. Based on Table 3, the results show that termite activity, represented by the degree of bait damage, is significantly and positively correlated with SOM ($r = 0.583^{**}$) and SOC ($r = 0.521^{**}$). This positive relationship indicates that higher termite activity is associated with increased SOM and SOC contents. Ecologically, termites act as ecosystem engineers, as their activities influence various soil processes and properties, including the acceleration of organic matter decomposition (Jouquet et al., 2006). According to Bera et al. (2020), the enhancement of soil carbon and organic matter content by termite activity occurs through several mechanisms, including the accelerated breakdown of organic material, the accumulation of carbon-rich excreta such as frass and saliva into the soil, and the upward transport of fine mineral particles from the subsoil to the surface. These particles are used in mound construction, resulting in structures that are physically and chemically capable of storing and stabilizing organic matter more effectively.

There is a symbiotic relationship in the termite digestive system with bacteria and protozoa that facilitate the breakdown of lignocellulose from wood into simpler, nutrient-rich compounds (Donovan et al., 2000a; Kaschuk et al., 2006; Filipiak and Weiner, 2017; Lejoly et al., 2019). Therefore, termite activity contributes significantly to the improvement and dynamics of soil ecosystems. Environmental conditions also influence termite activity levels. Termites live

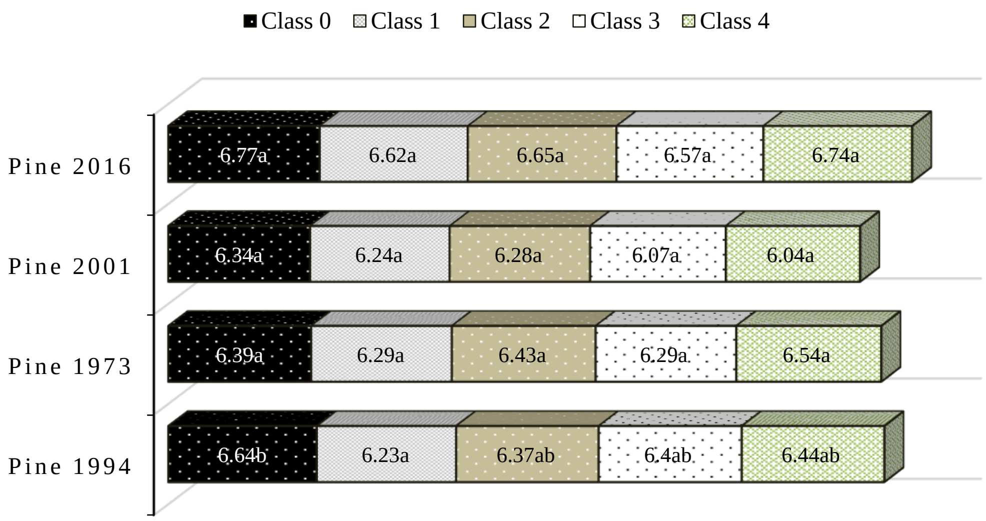

Figure 4. Soil pH values between peg damage classes in each stand

Note: The numbers followed by different letters indicate significantly different results in the DMRT test ($\alpha = 0.05$)

Table 3. Correlation test results between termite activity level, SOC, SOM, and soil pH

Correlations	
Parameters	Termite activity
SOM	0.583**
SOC	0.521**
pH	-0.083

Notes: * = Significant (p = 0.05 to 0.01), ** = Very significant (p = < 0.01), SOM = Soil organic matter, SOC = Soil organic carbon

well in relatively high topography and slightly acidic soil pH, both characteristics of forest ecosystems. These conditions create an ideal habitat for termites, further supporting their ecological role as soil engineers (Thant et al., 2023).

CONCLUSIONS

Four types of termite genera are found in the Alas Bromo Educational Forest. As soil ecosystem engineers, termites are associated with improved soil fertility, notably through enhanced SOM and SOC content. The level of termite activity, indicated by the damage classes of wooden stake baits, may contribute to increased soil fertility. Higher termite activity tends to correlate with greater SOM and SOC content; however, in this study, termite activity did not significantly affect soil pH. The findings also indicate that the damage classes of bait stakes, which reflect termite activity levels, positively correlate with SOM and SOC content. This supports the role of termites as ecosystem engineers due to their ability to accelerate the decomposition process. Future research may directly assess the effects of termite-processed soil amendments in experimental plots to evaluate their potential as alternative nutrient sources for sustainable agriculture. Such applications could enhance soil quality, improve crop productivity and resilience, and ultimately contribute to food security and overall ecosystem health.

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