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The Effect of Land Clearing Techniques on the Chemical and Biological Character of Soil in Sugarcane Fields

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Abstract

Land clearing after harvest in sugarcane cultivation is often done by burning. However, burning influences the ecosystem, such as the chemical and biological characteristics of soil. This research aims to analyze the impact of different methods of clearing sugarcane fields on the chemical and biological conditions of the soil. This research used a non-factorial, completely randomized design (CRD) with two treatments: land clearing with burning and without burning. Each treatment was carried out on an area of 50 m^2 with two blocks as repetitions. For chemical and biological analysis, soil samples were taken from pitfall traps and soil monoliths (1 m x 1 m x 30 cm). Two treatments showed significant differences in the total N and available P, and burning reduced 21% the number of organisms significantly. There were significant differences between the two treatments regarding the macrofauna diversity index, species evenness value, and dominance index. Post-harvest burning significantly reduces total N and available P and negatively impacts biological indicators such as organism numbers, diversity, evenness, and dominance index. This decrease in organic matter causes a reduction in the populations of organisms, thus disrupting soil health. Therefore, this study recommends that sugarcane residues be returned to the land as a source of organic matter to maintain soil health, biodiversity, and optimal productivity.

Keywords: organic matter dynamics; post-harvest burning; soil biological indicators; soil microbial activity; sugarcane field

INTRODUCTION

Sugarcane (*Saccharum officinarum* L.) is one of the vital plantation commodities in Indonesia. Regarding nutritional value, the benefits of consuming sugarcane juice can enhance health, as it may strengthen the stomach, kidneys, heart, eyes, brain, and sexual organs and can even treat hepatitis (Thagunna and Kaur, 2022). In addition to its health benefits, sugarcane is a plant used as a raw material for the sugar industry in Indonesia, making it essential for the economy (Masto et al., 2008). Sugarcane stalks contain 10% sucrose, which depends on sugarcane variety, plant condition, maintenance method, and the sugarcane's maturity level. Cultivating sugarcane is one of the determining factors in achieving the target results in both productivity and sugarcane yield.

Changes in soil conditions due to human activity can affect the productivity of growing plants (Andrews et al., 2004). Indicators of a soil condition's quality can be classified as inherent qualities determined by soil-forming factors such as climate, parent material, time, topography, and dynamic qualities that describe soil conditions

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due to land use or management (Wienhold et al., 2004). Just like fire or burning conditions in land areas in Indonesia often occur for various reasons, this event has a significant impact. Forest fires often occur due to clearing new land or rejuvenating industrial plants in forest areas. Forest fires that arise in peatlands cause the Fe content to increase and affect other soil chemical characteristics (Aryanti et al., 2023).

In a sugarcane cultivation activity, sugarcane plants will be cut down or harvested at an age of between 8 and 12 months. The activity after harvesting is clearing the land or harvesting the residue. Many farmers use the method of clearing sugarcane land after harvesting or cutting by burning. Farmers consider land clearing by burning to be the answer to the difficulty of labor and labor costs because it is considered the cheapest and easiest (Kumar et al., 2020). In previous research, burning activity has some effect. Post-harvest burning on sugarcane fields in Brazil can reduce soil organic matter, total N, and soil P (Souza et al., 2012). The content of organic matter and K decreases, and organisms' lives are lost due to forest burning (Rizal et al., 2023). However, higher levels of soil organic matter and micro- and macronutrients interacting with soil pH and texture were confirmed to affect microbial ecology (Bigott et al., 2019). Burning sugarcane residues after harvesting can negatively impact the stability of the ecosystem (Subiyakto et al., 2020). Burning plant residues affects air quality, such as the release of various pollutants that worsen human health and soil and ecosystem quality (Zhang et al., 2019).

There have been many studies on the impact of burning land, but not many studies on the impact of burning as a method of clearing sugarcane land after harvesting (cutting), especially in sandy land. This study aims to analyze the changes or impacts of sugarcane land-clearing methods on soil chemical and biological conditions.

MATERIALS AND METHOD

Study site and research design

This research was conducted on harvested sugarcane land in Wedomartani Village, Ngemplak Sub-district, Sleman, Yogyakarta, Indonesia (coordinate location 110°25'0.61" E, 7°44'24.86" S), which has an Am climate type, from July 2023 to January 2024, using a non-factorial completely randomized design (CRD). The soils are classified as Entisol. There were two treatments: land clearing with burning and without burning. Each treatment was carried out on an area of 50 m^2 with two blocks as repetitions and repeated twice. The research location map can be seen in Figure 1, and the visual comparison of land clearing methods in Figure 2.

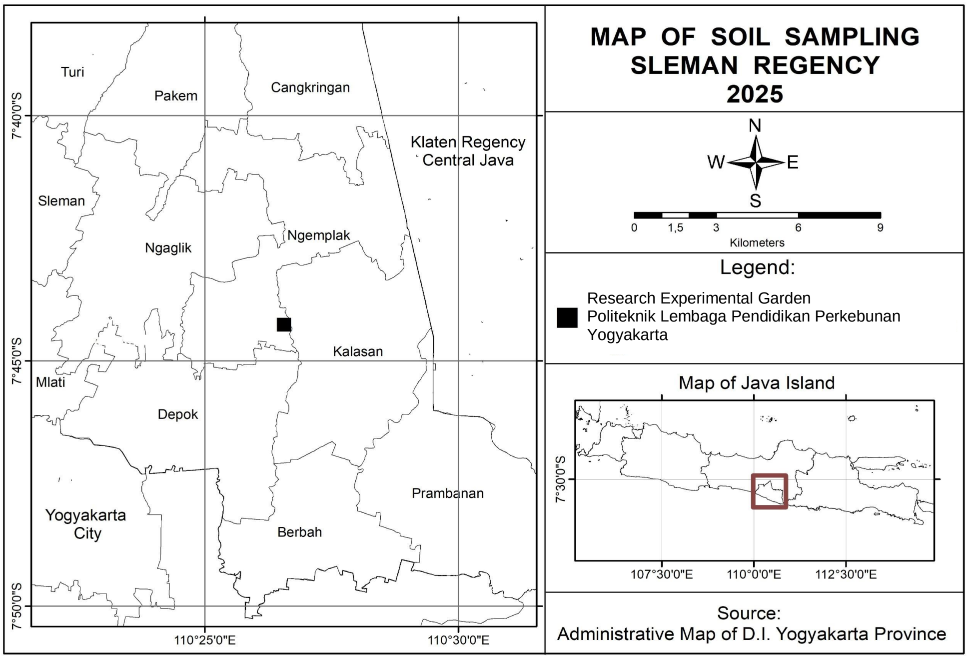

Figure 1. Map of soil sampling

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a.


b.

Figure 2. Land with no burning (a) and burning treatment (b)

Soil sampling

Sampling was carried out using the transect method by taking samples in an area that was determined in a straight line with a distance between the points that had been defined and used in a relatively large observation area and had a relatively homogeneous agroecosystem. Soil sampling was also conducted at each observation point and then composited for analysis. In this study, the distance set between soil macrofauna sampling points was 1 m with a transect line length of 10 m. Soil macrofauna sampling was carried out in two ways, namely, taking macrofauna in a 1 m x 1 m plot with a depth of 30 cm (Vasconcellos et al., 2013), which was dug using a hoe, then the soil was taken using a shovel and put into a bucket. The macrofauna in the soil was collected and then stored in a specimen bottle containing 70% alcohol.

Analysis method

Soil samples were taken from a 0 to 30 cm depth from 5 soil mini pits and then composited for chemical analysis. Soil characteristics are analyzed, including pH H_2O with a ratio of 1:2.5 (soil:water), organic-C (Walkley and Black method), organic matter, total N, and available P (Olsen or Bray extract method depending on soil pH) and available K (extraction with NH_4Cl, followed by reading with a flame photometer). The data obtained for macrofauna abundance were then used to calculate the value of the species diversity index, species evenness index, and dominance index.

Macrofauna diversity index

The diversity value combines species richness and species evenness—the Shannon-Wiener species diversity index (Equation 1) (Magurran, 1988).

$$H' = -\sum Pi \ln Pi \qquad (1)$$

$$Pi = \frac{ni}{N}$$

Where H’ = Shannon-Wiener species diversity index; Pi = the proportion of the i-th species; ni = number of individuals of the i-th species; N = number of individuals of all species.

Pielou’s evenness index

Pielou’s evenness index shows the degree of evenness in the abundance of each species. Pielou’s evenness index is expressed as Equation 2.

$$E = \frac{H'}{\ln(S)} \qquad (2)$$

Where E = Pielou’s species evenness index; H’ = Shannon-Wiener species diversity index; S = number of species found; Ln = natural logarithm.

Dominance index (C)

According to Odum (1993), Simpson’s dominance index can be calculated using Equation 3.

$$C = \left(\frac{ni}{N}\right)^2 \qquad (3)$$

Where C = Simpson’s dominance index; ni = total number of individuals of the i-th species; N = total number of individuals in the total n.

Data analysis

Data analysis was performed statistically using Analysis of Variance (ANOVA) with a 95%

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confidence level. To see the significant effects of the treatment and their interactions on the variables, a post-hoc test (Duncan's Multiple Range Test/DMRT) was carried out at the 5% significance level. Correlation analysis (Pearson correlation) was used to see the relationship between the differences in the two treatments.

RESULTS AND DISCUSSION

Characteristics of soil chemical properties in different land clearing methods

Planting media plays a crucial role in determining the growth and yield of cultivated plants, while land clearing by burning negatively affects soil quality as a planting medium (dos Santos et al., 2020). Table 1 shows that clearing sugarcane land after harvest does not provide significant differences in soil pH, organic C, and soil organic matter in treatments with and without burning. Soil pH is one of the essential parameters for determining soil fertility status, and pH will affect other soil characteristics, affecting plant growth (Sanches et al., 2019). Soil pH in both treatments ranges from 6.45 to 6.55. Soil pH is naturally influenced by parent material and the level of soil development (Augusto et al., 2017). The research location has a sandy soil texture with a low level of soil development, causing the soil pH to be slightly acidic.

Organic matter has a role and influence on the soil's physical, chemical, and biological properties (Cherubin et al., 2018). The organic C value in the burning and non-burning treatments is not significantly different. Organic matter is a parameter that is very closely related to soil temperature. Burning causes an increase in soil temperature, and this causes the total soil organic matter content to decrease (dos Santos et al., 2020). There is no significant difference here because the land that was not burned during the study is usually burned during land clearing and was not burned only this year (the first year). This could cause the absence of a significant difference in the organic matter content of the soil.

Clearing sugarcane land after harvest by burning provides a lower and more significant total soil N value than without burning (Table 1). Nitrogen is bound by soil organic matter, so a decrease in soil organic matter will also cause the soil N content to decrease (Eleftheriadis et al., 2018). The available soil P value on land with burning was significantly higher than that of land without burning (Table 1). Forest burning causes an increase in the available P in the forest compared to unburned forests (Rizal et al., 2023). Potassium is an essential macronutrient for plant growth and development because it activates several enzymes in plant metabolism (Panggabean et al., 2017). The method of burning sugarcane fields after harvest did not affect the availability of soil K (Table 1). This shows that the available K in the soil is not affected by burning activities but other factors, such as changes in soil pH and water content (Li et al., 2021).

Soil biological characteristics in different land clearing methods

The treatment of burning sugarcane land after harvesting turned out to provide a lower number of individual organisms and was significantly different from the number of individual organisms on land without burning (Table 2). Soil organisms are soil fauna that play a role in the decomposition of organic matter and soil nutrient cycling and can also be an indicator of soil fertility biologically. More species of organisms in the soil indicate a high soil fertility level (Kusumastuti et al., 2022). The remaining litter and sugarcane stumps on the soil's surface are also burned in sugarcane fields that are burned during land clearing. This condition directly impacts the number of soil macrofauna, especially those living on the

Table 1. Effect of treatment on soil chemical characteristics

Treatment	pH H_2O	Organic C (%)	Organic materials (%)	Total N (%)	Avail-P (ppm)	Avail-K (ppm)
Burning	6.45[a] (Slightly acidic)	0.88[a] (Very low)	1.52[a] (Very low)	0.12[a]	12.68[b]	40.54[a]
No burning	6.55[a] (Slightly acidic)	1.37[a] (Low)	2.37[a] (Low)	0.16[b]	7.34[a]	42.02[a]

Notes: Means followed by the same lowercase letters in the same column are not significantly different according to DMRT 5%. Avail-P = Available P; Avail-K = Available K. Criteria according to the Soil Research Institute

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Table 2. Effect of treatment on soil biological characteristics

Treatment	Number of organisms	H’	E	C
Burning	92.5[a]	1.988[b]	0.6705[b]	0.1965[a]
No burning	440.5[b]	1.059[a]	0.3555[a]	0.6070[b]

Notes: Means followed by the same lowercase letters in the same column are not significantly different according to DMRT 5%. H’ = Macrofauna diversity index; E = Species evenness value; C = Dominance index

soil surface, as their habitat and food sources are reduced.

Soil biological characteristics can also be seen from several parameters, such as the macrofauna diversity index, species evenness value, and dominance index. Secondary forests such as acacia have a high diversity index (Handayani and Winara, 2020), and sugarcane fields using organic fertilizers have a high macrofauna diversity index (Afifatur, 2021). This provides information that different land uses and land management will affect the diversity of macrofauna on the land. Table 2 shows that land clearing methods with and without burning significantly provide different macrofauna diversity index values (Kusumastuti et al., 2022). At the research location, the treatment without burning was carried out in the research year only (usually cleaning by burning is also carried out) and also, the observation time was 2 weeks after harvest or cutting, so it still has the same species diversity category (moderate category).

In the calculation of the species evenness index, the higher the index value approaches 1, the more it indicates that the level of evenness of all species is almost the same and there are no particular species that dominate. In contrast, if the value approaches 0, it indicates that there is a dominant species in a community. Table 2 shows that land clearing methods with and without burning provide significantly different species evenness index values. The dominance index on land cleared by burning and without burning showed significantly different values (Table 2). The dominance index value on sugarcane land with burning was almost close to 0 (C = 0.1965), and this indicated that in sugarcane land with burning, the distribution of species was even so that there were no dominant species. This condition was different from the dominance index value on land without burning; the value was > 0.5, indicating that a species was dominant in the community on sugarcane land without burning. No macrofauna species are more dominant on burned land than on land without burning. This happens because fires cause major disturbances to the soil environment, making it difficult for macrofauna to survive or reproduce optimally. These disturbances include destroying macroorganism habitats, and high temperatures during fires can kill macrofauna, especially those living on the surface or topsoil (Wasis et al., 2018). Fires burn organic matter, such as dead leaves, roots, fungi, and microorganisms, which are the main food source for macrofauna (Puga et al., 2024). After the fire, the environment was so disturbed that no macrofauna species could develop well and dominate.

Figure 3 shows the number of individuals in each species in both treatments. The species of Anoplolepis ants or yellow ants (*Anoplolepis gracilipes*), included in the Formicidae family and the Hymenoptera order, is the species with the largest number of individuals on land without burning. *Anoplolepis gracilipes* originates from lowlands in tropical rainforests with high-humidity habitats (Chen, 2008). This species is called a scavenger predator because it preys on various fauna in litter and canopies. This type is found on the stems and leaves of trees and shrubs (Putra et al., 2019). The dominance of Anoplolepis ants in sugarcane fields without burning can occur because ants are macrofauna that live close to the soil surface under plant debris and litter. After all, many organisms are their food sources. At the same time, in burned sugarcane fields, the number of individuals is small due to burning litter, which has implications for the decline in the number of Anoplolepis ants on the land.

Black ants are the most abundant species on land that has been burned (Figure 3), although their numbers are lower than those of black ants on land without burning. Black ants, whose Latin name is *Dolichoderus* sp., are predators and foragers in an ecosystem (Prayoga et al., 2021). The presence of ants in an area can be a biological indicator in environmental assessments, such as fire conditions, deforestation, and the impact of land use (Wang et al., 2000). Ants act as predators, decompose organic matter, control pests, and even help pollination (Haneda and Yuniar, 2020).

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Table 3 shows that soil organic matter levels are significantly and strongly positively correlated (r = 0.960*) with the number of microorganisms in the soil. Increasing soil organic matter will increase the number of soil organisms and their activities (Kusumastuti et al., 2022). The number of soil organisms also appears to correlate very strongly with the pH value (r = 0.844) and total soil N (r = 0.885). Soil organisms also have living conditions to live, one of which is the pH of the soil media environment (Frac et al., 2018) and increasing organisms in the soil causes an increase in total N because one of the primary sources of soil N comes from organisms (Kurovsky et al., 2021).

The macrofauna diversity index has a very strong and positive correlation with the available P content of the soil (r = 0.895). The same thing is also seen in the correlation between the species evenness value and the available P of the soil, which is also very strongly correlated (r = 0.930). Phosphorus is an essential nutrient that supports the productivity and stability of soil ecosystems. Available P accelerates the decomposition of organic matter and the activity of microorganisms, which enrich the soil with food. This provides conditions that support various macrofauna species to coexist, increasing diversity and evenness values (Zhou et al., 2022). Fertile and balanced soil conditions (with sufficient P) reduce competitive pressures among macrofauna species because resources are not limited to one type of food or habitat. As a result, no one species is too dominant, and all species have a more balanced chance of survival, increasing evenness (Wu et al., 2023). The dominance index strongly correlates with the soil organic matter content and total soil N (Table 3). The presence of organisms in the soil significantly impacts soil fertility and health (Chekaev et al., 2022).

Post-harvest burning activities impact the planting medium's chemical and biological characteristics. This will be even worse if the entire sugarcane land area in Yogyakarta (6,318.11 ha) (Lolo et al., 2022) is cleared by burning. The decline in soil quality in Yogyakarta will be very rapid. Improvements in post-harvest management of sugarcane cultivation need to be carried out, one of which is by returning waste or sugarcane harvest residue to the land to become additional organic material and not damage the environment (Kumar et al., 2020). On land where this activity has been carried out for a long time, one of the improvement efforts is to add additional organic materials, such as vinasse, which is one of

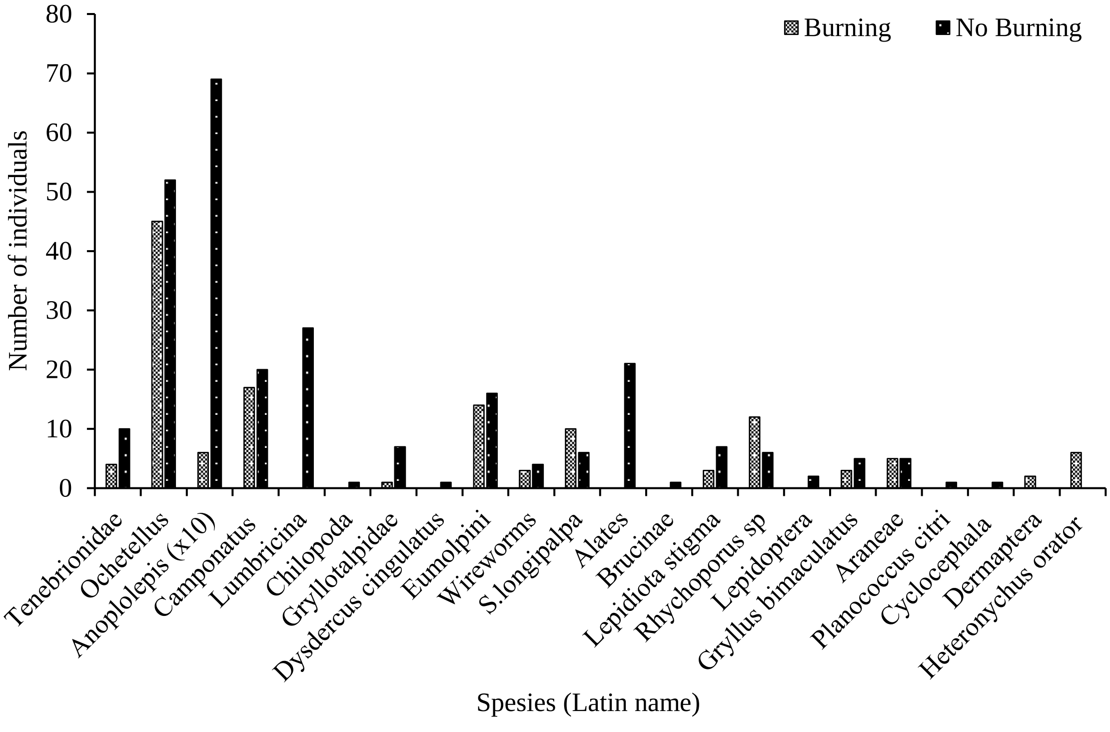

Figure 3. The number of individuals of each species in the two treatments

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Table 3. Correlation between parameters

Parameter	pH	OM	Total N	Available P	Available K
J	0.844	0.960*	0.885	-0.864	0.341
H’	-0.802	-0.931	-0.918	0.895	-0.304
E	-0.747	-0.898	-0.949	0.930	-0.224
C	0.792	0.925	0.925	-0.902	0.291

Notes: *Correlation is significant at α = 0.05; J = Number of macroorganisms; H’ = Macrofauna diversity index; E = Species evenness value; C = Dominance index; OM = Organic matter

the wastes from sugar factories. This vinasse will improve soil conditions and provide extra nutrients, so it is expected to improve soil conditions after burning (Dewi et al., 2022).

CONCLUSIONS

Post-harvest burning detrimentally affects both the chemical and biological properties of soil. In particular, burning significantly reduces total soil N and available P, negatively impacting biological indicators such as organism number, diversity, evenness, and dominance index, compared to the non-burning method. Microorganism populations are positively correlated with soil organic matter. To improve post-harvest management and reduce environmental damage, sugarcane residues should be returned to the field as organic matter to fertilize the soil. Further in-depth research on the impact of land management by burning is needed in a broader area and comparing different land uses to make the impacts more visible.

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