Investigation of Nitrogen and Mineral Content in Soil Struck by Lightning in Kendari City

Rosliana Eso[1], Sayahdin Alfat[2], Arman Arman[3], Hasbullah Syaf[4], Syamsu Alam[4], Syamsul Razak[1], M. Tufaila[4], Tahir Tahir[3], and Sitti Kasmiati[5]

[1]Department of Geophysics Engineering, Halu Oleo University
[2]Department of Physics Education, Halu Oleo University
[3]Department of Mathematics, Halu Oleo University
[4]Department of Soil Science, Halu Oleo University
[5]Department of Geography Education, Halu Oleo University
rosliana.eso@uho.ac.id

Abstract. This research aims to understand the influence of lightning strikes on the nitrogen content in the soil around trees exposed to lightning. The study uses the Kjeldahl method to analyze the nitrogen content in soil samples collected from areas with high-intensity and low-intensity lightning strikes. The results indicate that the highest nitrogen content was found in the topsoil of areas exposed to high-intensity lightning, with a value of 0.3111%, which is significantly higher than the nitrogen content in areas exposed to low-intensity lightning, which had a value of 0.127%. Additionally, the nitrogen content of the topsoil is much higher than that of the subsoil. In areas with high-intensity lightning exposure, the highest nitrogen content was observed at a distance of 5 meters to the south, at 0.257%. In contrast, in areas with low-intensity lightning exposure, the highest nitrogen content was also observed at a distance of 5 meters to the south, at 0.187%. The nitrogen concentration varies with distance from the point of impact, following a consistent pattern, the nitrogen content decreases as the distance from the center of the lightning strike increases.

Keywords: Lightning Strikes, Low-Intensity Lightning, High-Intensity Lightning, and Nitrogen Content.

1 Introduction

Indonesia has a tropical climate with two distinct seasons and high annual rainfall. Given these climatic conditions, numerous clouds, including cumulonimbus (Cb) clouds, develop in the region. These clouds produce lightning, leading to an average of 200 days of thunder per year, making Indonesia particularly prone to lightning strikes [1]. Lightning is generally caused by atmospheric dynamics, which are significantly influenced by weather and climate factors at global, regional, and local levels. Bad weather conditions such as heavy rains and strong winds are closely associated with thunderstorms originating from cumulonimbus clouds, which have a strong convection

S. Alfat et al. (eds.), *Proceedings of the 3rd International Conference on Mathematics and Science Education (ICMSE 2024)*, Advances in Social Science, Education and Humanities Research 922,
https://doi.org/10.2991/978-2-38476-402-0_12

system on a regional scale that intensifies with solar heating [2]. According to the world lightning map, Indonesia falls into the category of areas with high lightning intensity [3].

Lightning is an electrical discharge that occurs either within a cloud or between a cloud and the ground [4]. It originates inside the cloud as electric charge channels [5]. A discharge directed at a specific object is called a lightning strike, which can occur in highly developed and densely populated areas, increasing their vulnerability to lightning strikes [6]. The average lightning current is 30,000 amps, with a maximum current of up to 300,000 amps. The voltage of lightning is extremely high, ranging from 100 million to 1 billion volts. The power of a moderate thunderstorm can reach 10 million watts, equivalent to the output power of a small nuclear power plant. When a charged thunderstorm approaches a protrusion on the ground, an intense discharge can occur [7].

Among the four types of lightning—cloud-to-ground (CG), intra-cloud (IC), cloud-to-cloud (CC), and cloud-to-air (CA) lightning [8]—CG lightning is the most dangerous and destructive type because it involves a single discharge with the energy of millions of volts [9, 10]. CG lightning can have two types of charges: positive CG (CG+) and negative CG (CG-) [11, 12]. Positive CG lightning (CG+) occurs due to the induction of a negative electric field on the surface, with concentrated positive electricity at the top of the cloud. Negative CG lightning (CG-) occurs due to the induction of a positive electric field on the earth's surface by the negatively charged center of the cloud [13, 14]. The effects of lightning exposure are varied; besides having a negative impact on living things and the surrounding environment, lightning can also benefit soil fertility. The soil provides plants with the nutrients they need for growth [15], with nitrogen being the most essential macronutrient [16]. Nitrogen in the soil comes from two primary sources: the atmosphere in the form of N2 and the activities of life in the soil [17]. Nitrogen, in its simplest form, is a gas and the main component of atmospheric air (78%) [18]. Unfortunately, free nitrogen is inert, requiring high energy to break its bonds, a process that can be facilitated by lightning [19].

Lightning has enough energy to ionize water vapor into H+ and OH- ions, which, together with oxygen, can react with N2 to form nitric acid. This acid, combined with rain, is deposited into the ground, enriching the soil with nitrogen. Nitrogen is essential for plant growth and development, with total nitrogen content generally ranging from 2000–4000 kg/ha in the top 0–20 cm layer of soil [20]. Mineral nitrogen, which includes ammonium, nitrite, and nitrate [21], does not accumulate in the soil but is subject to losses through evaporation into the atmosphere (as ammonia, nitrogen oxides, and molecular nitrogen) and leaching into water sources (mainly nitrate) [22, 23]. Although there has been considerable research explaining nitrogen fixation by lightning, there is still little information on how nitrogen is distributed as a result of lightning strikes. This preliminary study aims to further evaluate the nitrogen content of the soil in areas exposed to varying intensities of lightning (high and low intensity) in Kendari City, Southeast Sulawesi, Indonesia.

2 Method

Based on data from the Southeast Sulawesi Climatology Station, the rainy season in Kendari in 2022 spanned from January to September, with a total of 14,449 lightning strikes recorded for the year, averaging 1,204 strikes per month. The highest number of strikes occurred in January, and the lowest in August [32]. Soil sampling in May 2022 was conducted at specific locations exposed to varying intensities of lightning. The high-intensity lightning area was located on Sambuli Village, Abeli District (coordinates: 4°00'24.9012"E 122°37'44.6016"BT). The low-intensity area was in Punggolaka Village, Puuwatu District (coordinates: 3°57'34.5"S 122°29'39.5"E), marked with green round circles in map on Figure 1. Soil samples were collected directly from the field and analyzed for nitrogen content using the Kjeldahl method. Soil color was determined using the Munsell Soil Color Chart (MSCC), and soil texture was measured using a hydrometer. The soil structure was assessed qualitatively.

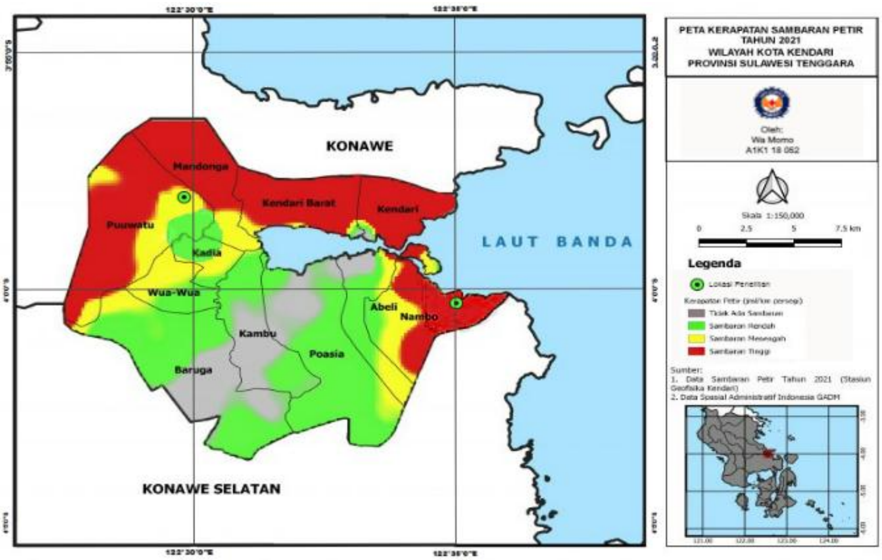


Fig. 1. Map of Kendari City Lightning Strikes

The sampling location was determined by measuring diagonally from the tree that was struck by lightning, following the cardinal directions: north, east, south, and west. Samples were taken at distances of 5 meters and 50 meters from the standing tree, as illustrated in Figure 2. This approach ensures a comprehensive assessment of nitrogen distribution in the vicinity of the tree affected by lightning.

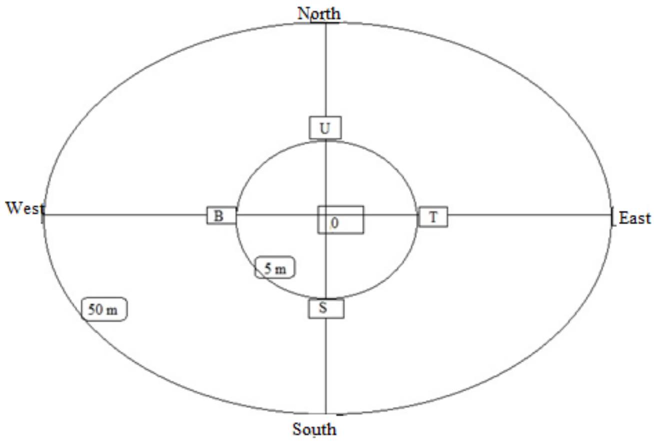


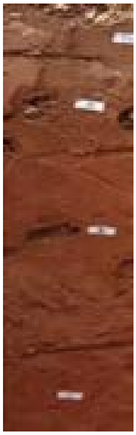
Fig. 2. Soil sampling diagonal

3 Results

Under the tree that was struck by lightning, we dug a soil profile to a depth of 2 meters, and dividing it into four layers based on the horizons formed. The soil samples from each layer were analyzed for their physical properties and nitrogen content. Profile 1 is for low lightning exposure intensity and Profile 2 for high lightning exposure intensity. The physical properties of the soil under trees struck by high and low intensity lightning are presented in Table 1.

Table 1. Analysis of Nitrogen Content , pH, Moisture, and Soil Physical Properties soil exposed by lightning

Lightning Exposure	Subsoil	pH	Nitrogen (%)	Soil Physical Properties			
				Structure	Texture	Color	Soil Profile
High Intensity	Horizon O	6.4	0.3111	Granular	Sandy loam	Dark Brown (7,5 YR 3/3)	
	Horizon A	6.8	0.1269	Granular	Silt loam	Pale Brown (10 YR 7/4)	
	Horizon B	6.8	0.1406	Sub angular	Loam	Yellowish-brown (10 YR 5/6)	
	Horizon C	7.3	0.0918	Sub angular	Loam	Pale Brown (10 YR 7/2)	

Low Intensity	Horizon O	6.3	0.1272	Sub angular	Silt loam	Brown (7,5 YR 5/3)	
	Horizon A	6.8	0.1559	Sub angular	Silt loam	Very pale brown (10 YR 7/4)	
	Horizon B	6.7	0.0986	Sub angular	Loam	Yellowish-brown (10 YR 5/6)	
	Horizon C	6.9	0.0425	Sub angular	Loam	Yellowish-brown (10 YR 5/8)	

Meanwhile, the distribution pattern of nitrogen content in trees exposed to high-intensity and low intensity lightning using the vertical sampling process can be seen in Figure 3 below. The left side of the figure shows a graph representing the vertical distribution of nitrogen content (%) through the soil profile, while the right side displays the actual soil profile with identified horizons (O, A, B, and C). The nitrogen content of the soil profile exposed to high-intensity lightning is known to be more significant than that at low intensity. Additionally, the nitrogen content of topsoil is much higher than subsoil. This applies to both soil profiles. This is because organic matter, where nitrogen is stored, tends to accumulate near the surface through processes like decomposition of plant material and organic waste. The deeper into the soil layer, the less nitrogen content becomes. This is because nitrogen is a relatively mobile element in soil and can be leached away by water moving through the soil layers or taken up by plant roots closer to the surface.

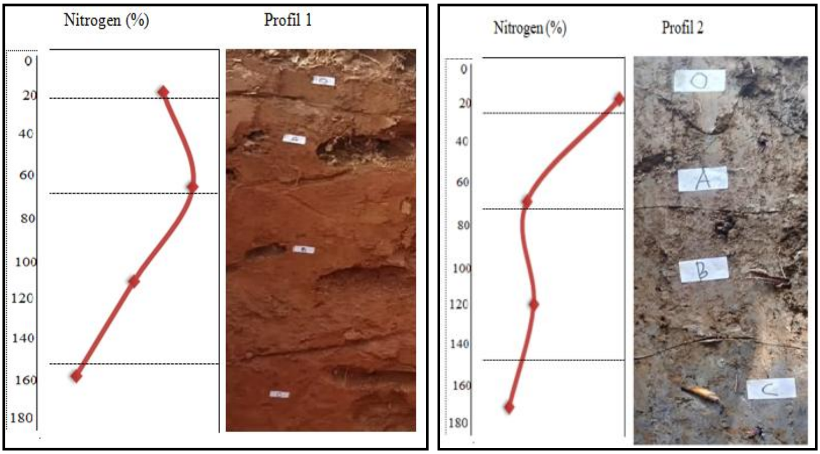


Fig. 3. Vertical Distribution Pattern of Soil Nitrogen Content in Soil Profile

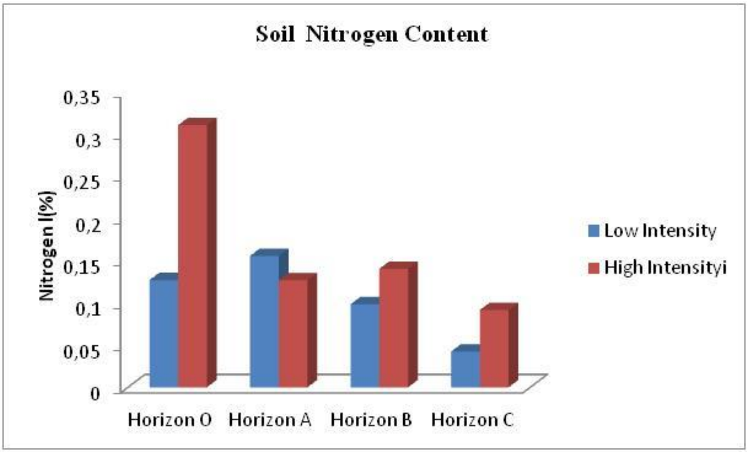


Fig. 4. The distribution of nitrogen content in the samples

To understand the distribution of nitrogen fixation by lightning in areas exposed to low-intensity and high-intensity lightning, we collected topsoil samples around trees struck by lightning. Sampling was done diagonally from the trees in the north, east, south, and west directions, at distances of 5 meters and 50 meters from the tree base. The distribution of nitrogen content in these samples is illustrated in Figure 4. The nitrogen content around trees struck by lightning in areas exposed to high-intensity lightning appears greater than at low intensity for all sampling directions. However, the value of nitrogen content is not the same in each direction at the same distance from the tree stand. For this reason, we illustrate it in the following diagram in Figure 5.

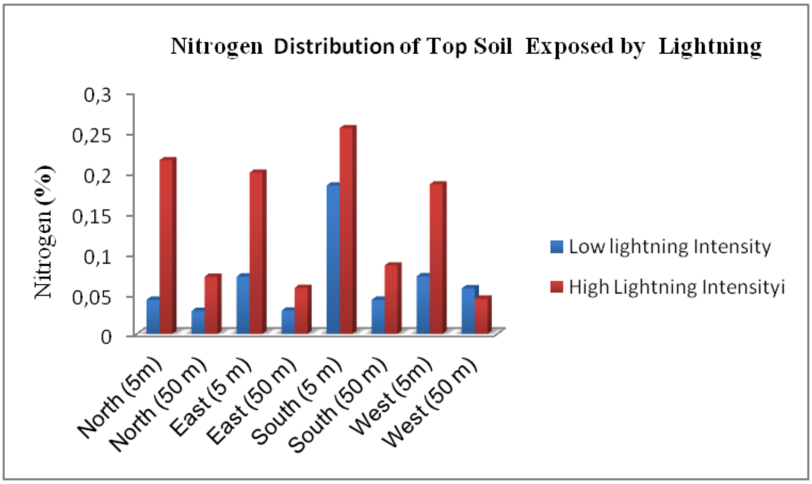


Fig. 5. Nitrogen Distribution Pattern of Topsoil around Trees Struck by Lightning

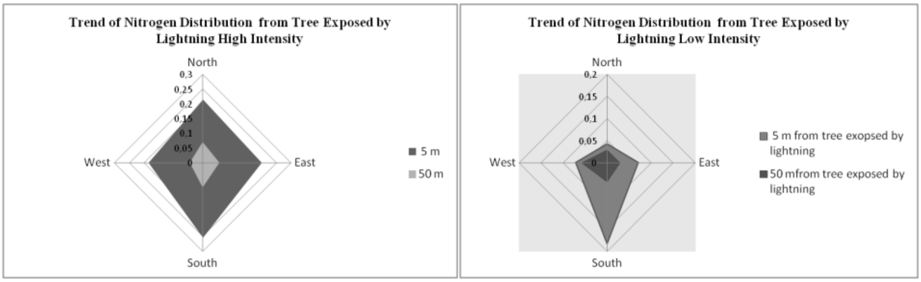


Fig. 6. Trend of Nitrogen Distribution in a Tree Exposed High-Intensity Lightning

The graph above illustrates the trend of nitrogen distribution in a tree exposed to high-intensity lightning. The x-axis represents the distance from the point of lightning impact on the tree, while the y-axis indicates the concentration of nitrogen in %. From the graph, it's evident that nitrogen concentration varies with distance from the point of impact. Closer to the impact site, there is a notable peak in nitrogen concentration, suggesting that the lightning event significantly affects nitrogen distribution in this region. As the distance from the impact increases, the nitrogen concentration gradually decreases, showing a dispersion pattern. This trend indicates that high-intensity lightning may cause localized increases in nitrogen concentration, likely due to the electrical activity altering the nitrogen uptake or redistribution within the tree. The data points highlight the immediate impact of lightning on the tree's nutrient profile, with a gradual normalization of nitrogen levels as one moves further away from the impact zone. This pattern is crucial for understanding how lightning influences tree physiology and nutrient dynamics.

The graph above illustrates the trend of nitrogen distribution in a tree exposed to low-intensity lightning. The x-axis represents the distance from the point of lightning impact on the tree, while the y-axis indicates the concentration of nitrogen in parts per million (ppm). From the graph, it's evident that nitrogen concentration varies with distance from the point of impact. Closer to the impact site, there is a notable peak in nitrogen concentration in the South direction, suggesting that lightning affected nitrogen distribution differently in this region. As the distance from the impact increases, the nitrogen concentration gradually decreases, indicating that low-intensity lightning may cause localized increases in nitrogen concentration.

4 Discussion

In general, the nitrogen content decreases with soil depth, meaning that the deeper the soil, the lower the nitrogen content. This is because the most abundant source of organic matter is above the surface, where it includes litter and plant roots. Even though the soil consists of several layers, the top layer (topsoil) is very important because it contains the highest organic matter compared to the bottom layers. The soil pH at trees exposed to high-intensity lightning ranges from 6.5 to 7.3, while those exposed to low intensity range from 6.3 to 6.9. These values vary greatly depending on the type of vegetation, the soil parent material, and rainfall. The availability of nitrogen in the soil shows the highest nitrogen content is located at a distance of 5 m to the south in areas with high-intensity lightning exposure, where a nitrogen content of 0.2547% is obtained. In contrast, areas with low-intensity lightning exposure have a nitrogen content of 0.1838%. For tree stands, the highest nitrogen content in the topsoil is 0.3111% for locations exposed to high-intensity lightning, while it is 0.05% for locations exposed to low-intensity lightning. The effect of lightning exposure cannot be said to have a significant impact, as the nitrogen content of soil exposed to lightning did not show a substantial increase. This may be due to several factors, including high surface runoff and erosion at the sampling location, evaporation, and absorption by plants. Some nitrogen gets absorbed by plants, some returns as plant residues, some is lost through leaching, and some returns to the atmosphere.

The nitrogen content analysis shows that locations close to the center point of high lightning exposure have higher nitrogen content compared to locations farther from the center of lightning exposure. It is suspected that the high nitrogen content is due to lightning strikes. Organic matter, in the form of soil nitrogen, tends to be concentrated in the topsoil because most of the soil organic carbon supply comes from litter at the soil surface. At depths of 30-100 cm, the amount of surface litter supply decreases with increasing soil depth, leading to lower soil organic carbon content. The decrease in soil fertility is often the result of nutrient loss from the top layer during erosion. There are also differences in soil color between layers due to varying organic matter and mineral content. Generally, the higher the organic matter content, the darker the soil color. Based on observations of the physical condition of the land, the soil texture includes clay, silty loam, and sandy loam. If the soil contains too much clay, it can store large amounts of water, but water does not easily seep into the soil, causing surface runoff and erosion. Conversely, if the soil is sandy, water will easily seep in but cannot be stored for long, as it infiltrates into the lower layers. The nitrogen content in soil is generally low, has dynamic properties, and is easily lost due to evaporation and erosion. These processes can cause fertile soil to become infertile as minerals are eroded. Additionally, soil with a coarse texture has a high rate of water absorption, leading to inefficient water use and nutrient loss.

5 Conclusion

The nitrogen content of the soil exposed to high-intensity lightning in the Sambuli sub-district showed that the highest nitrogen content was in the topsoil, with a value of 0.3111% and an average content of 0.1485%. Meanwhile, the nitrogen content of the soil exposed to low-intensity lightning in the Punggolaka sub-district, Kendari City, was 0.127%. The highest nitrogen content results were observed at a distance of 5 meters to the south, with values of 0.257% for high-intensity lightning and 0.187% for low-intensity lightning. Although the nitrogen content values are not the same in all directions from the tree stand, they follow the same pattern: the farther from the center of the strike, the lower the soil nitrogen content.

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