

DYNAMICS OF ZINC (Zn) MICRONUTRIENT CONTENT IN THE SOIL OF RUBBER (Hevea brasiliensis) PLANTATIONS AT PT DARSUM ESTATE AND SMALLHOLDER PLANTATIONS, LANGKAT REGENCY

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ABSTRACT

This study aimed to determine the zinc (Zn) micronutrient content in rubber plantation soil (Hevea brasiliensis) at a depth of 0–20 cm, comparing a privately managed plantation and a smallholder plantation. The research was conducted at PT Darsum Plantation, Padang Tualang District, Langkat Regency, and at a smallholder rubber plantation, using a Non-Factorial Randomized Block Design with ten replications per location. Soil samples were destructed and analyzed using Atomic Absorption Spectrophotometry (AAS). The results showed that Zn content in the private plantation (K1) reached 82.63 mg/kg, while the smallholder plantation (K2) reached 18.10 mg/kg; analysis of variance indicated a highly significant difference between locations (F-count 689.57 > F-table 0.01). Both locations fell into the very high nutrient status category, indicating that Zn availability remains sufficient to support optimal rubber growth, although the higher value in K1 points to more intensive fertilization, organic matter management, and stimulant (ethephon) application.

Keywords: zinc (Zn); micronutrient; rubber plantation soil; Hevea brasiliensis; soil fertility

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INTRODUCTION

Rubber (*Hevea brasiliensis*) is a strategic plantation commodity for the Indonesian economy, with a national planted area reaching 3,694,716 ha and a production of 3,545,693 tons in 2020, of which 85.92% was managed by smallholder plantations, 7.82% by private large-scale plantations, and the remainder by state-owned plantations. As one of Indonesia's strategic agricultural commodities, *Hevea brasiliensis* plays a vital role in supporting national economic development. Nevertheless, the productivity of Indonesia's rubber plantations remains lower than that of several other major rubber-producing countries.

Currently, more than half of the rubber used worldwide is synthetic. However, several million tons of natural rubber continue to be produced annually, as it remains an indispensable raw material for various industries, particularly the automotive and defense sectors. Indonesia is recognized as one of the world's largest producers of natural rubber. As a globally significant agricultural commodity, natural rubber plays a crucial role in both the national and international economies. In Indonesia, the rubber industry has long been an important pillar of economic development, generating substantial export revenues and supporting the livelihoods of millions of people. Historically, Indonesia was once the world's leading producer of natural rubber, surpassing other producing countries, including the crop's native region in South America. (Fauzan, 2023).

Despite its significant contribution to non-oil and gas foreign exchange earnings, natural rubber soil nutrients are classified into macronutrients and micronutrients, both of which are essential for plant growth and development. Although required only in small quantities, micronutrients play indispensable roles in various physiological and biochemical processes within plants. However, certain trace elements, including lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As), mercury (Hg), iron (Fe), copper (Cu), cobalt (Co), and zinc (Zn), have the potential to contaminate soils when present at excessive concentrations.

These heavy metals are environmentally persistent because they are not readily degraded or removed from the soil. Among them, zinc (Zn) is one of the heavy metals that can accumulate in soil and become a source of environmental pollution when its concentration exceeds the permissible threshold (Kadim, 2023) Productivity still lags behind that of other major rubber-producing countries.

Soil fertility is a determining factor in rubber productivity, given that soil serves as the medium supplying nutrients yet remains vulnerable to degradation and contamination, particularly in the topsoil layer (0–30 cm), which is the most actively affected by land management activities (Gofar et al., 2021). Among the essential micronutrients, zinc (Zn) plays an important role in the formation of the growth hormone auxin (IAA), the activation of enzymes involved in protein and carbohydrate synthesis, and the conversion of carbohydrates into simple sugars (Widodo, 2019). However, at excessive concentrations, Zn also has the potential to become toxic and contaminate the soil (Kadim, 2023).

Differences in land management systems including fertilization intensity, organic matter addition, and the use of latex production stimulants such as ethephon are presumed to cause variation in micronutrient status among plantation management types; however, comparative data on Zn content between private and smallholder plantations in the Langkat Regency area remain limited. This study aims to: (1) assess the soil Zn content in private rubber plantations, (2) assess the soil Zn content in smallholder rubber plantations, and (3) compare the Zn content status between the two management types.

The rubber plant (*Hevea brasiliensis*) is a tropical tree species belonging to the family Euphorbiaceae and is recognized as one of the world's most important sources of natural rubber. It is a perennial tree that can reach a height of 15–25 m at maturity, with a straight cylindrical trunk measuring approximately 20–60 cm in diameter. The bark contains numerous laticifer vessels that produce latex, the primary raw material for the natural rubber industry. Taxonomically, the species is classified as follows: Kingdom Plantae; Division Spermatophyta; Class Dicotyledonae; Order Euphorbiales; Family Euphorbiaceae; Genus *Hevea*; and Species *Hevea brasiliensis* L. Morphologically, the rubber tree possesses a well-developed taproot system extending 2–3 m into the soil, supported by extensive lateral roots that enhance water and nutrient uptake while providing mechanical stability. The leaves are trifoliate, consisting of three elongated oval leaflets with pointed tips, dark green glossy upper surfaces, and lighter undersides. As a deciduous species, rubber trees shed their leaves during the dry season before producing reddish young foliage that gradually turns dark green. The plant is monoecious, bearing separate male and female flowers within the same inflorescence, with pollination primarily assisted by insects and wind. Its fruit is a three-locular

capsule containing one seed per locule, which dehisces explosively upon maturity to disperse the seeds. Besides producing latex, mature rubber trees are also valued for their high-quality timber after their productive life has ended (Roslim, 2022)

Rubber plants exhibit broad adaptability to tropical environments, making them one of the most widely cultivated plantation crops in Southeast Asia, particularly Indonesia. They thrive under average temperatures of approximately 28°C (within a range of 25–35°C), annual rainfall of 2,500–4,000 mm distributed over about 150 rainy days, and full sunlight, which is essential for vigorous vegetative growth and optimal latex production. Although rubber trees tolerate a wide range of soil types, they perform best in well-drained soils with a pH between 3.5 and 7.0, depending on soil characteristics, while poorly drained or waterlogged soils should be avoided. The ideal cultivation altitude ranges from sea level to approximately 200 m above sea level, conditions commonly found in western Indonesia, including Sumatra, Java, and Kalimantan.

Zinc (Zn) is an essential micronutrient required for numerous physiological processes, including enzyme activation, protein synthesis, and plant growth. Soil Zn concentrations generally range from 10–300 ppm, whereas plant tissue concentrations below 10 ppm indicate Zn deficiency, while concentrations exceeding 71–81 ppm are considered excessive. Continuous nutrient uptake by plants, coupled with unbalanced fertilization practices, often reduces Zn availability in the rhizosphere and may induce micronutrient deficiencies. Conversely, excessive Zn application decreases fertilizer use efficiency and may adversely affect soil quality. Soil itself constitutes a dynamic ecosystem composed of minerals, organic matter, water, air, and living organisms, all of which interact to regulate nutrient cycling and plant productivity. High-quality soils provide favorable physical, chemical, and biological conditions for water retention, nutrient exchange, root development, and microbial activity, thereby sustaining agricultural productivity and long-term environmental sustainability

RESEARCH METHODS

This study was conducted at a private rubber plantation owned by PT Darsum in Padang Tualang District, Langkat Regency, and at a nearby smallholder rubber plantation. Laboratory analyses were performed at the Socfindo Laboratory. The research was carried out beginning in December 2025. A non-factorial Randomized Block Design (RBD) was employed, consisting of two plantation management systems as treatments: private plantation (K1) and smallholder plantation (K2). Each treatment was replicated ten times. Soil samples were collected from the 0–20 cm soil layer using a soil auger at both the inter-row (gawangan) and tree basin (piringan) sampling points. Subsamples were collected at intervals of approximately 100 m and subsequently composited for laboratory analysis.

The determination of soil zinc (Zn) content was performed using the Atomic Absorption Spectrophotometry (AAS) method. Approximately 550 g of air-dried soil sample was placed in a furnace and ashed at 400°C for four hours. The resulting ash was dissolved in 10 mL of 65% HNO₃, diluted to a final volume of 50 mL with distilled water, and filtered through Whatman No. 42 filter paper. A blank solution was included throughout the analytical procedure to ensure measurement accuracy and quality control. The Zn concentration data obtained were statistically analyzed using analysis of variance (ANOVA) to determine significant differences between the two plantation management systems. The results were then summarized and presented in the form of tables and graphs prepared using Microsoft Excel.

The analysis of soil Zn content revealed differences between the two plantation management systems. The average Zn concentration in soils from the private plantation (K1) was 82.63 mg kg⁻¹, whereas soils from the smallholder plantation (K2) contained an average Zn concentration of 18.10 mg kg⁻¹. Based on the established soil nutrient status criteria, both locations were classified as having a very high Zn status. However, the Zn concentration in the private plantation was considerably higher than that observed in the smallholder plantation, indicating differences in soil nutrient accumulation that may be associated with plantation management practices, fertilization history, or other environmental factors. These findings are presented in Table 1 and Figure 1.

RESULTS AND DISCUSSION

Soil Zn Content

The results of the soil analysis showed that the Zn content in the private rubber plantation (K1) was 82.63 mg kg⁻¹, whereas the Zn content in the smallholder rubber plantation (K2) was 18.10 mg

kg⁻¹ (Table 1). Based on the soil nutrient status classification, both sites were categorized as having very high Zn levels. However, the Zn concentration in the private plantation was significantly higher than that in the smallholder plantation (Figure 1).

Table 1. Zn (Zinc) Micronutrient Content in Soil at a Depth of 0–20 cm in Rubber

Plantation Location	Soil Zn Content (mg kg)	Status
Plantation 1 (K1) – Private Plantation	82,63	Very High
Plantation 2 (K2) – Smallholder Plantation	18,10	Very High

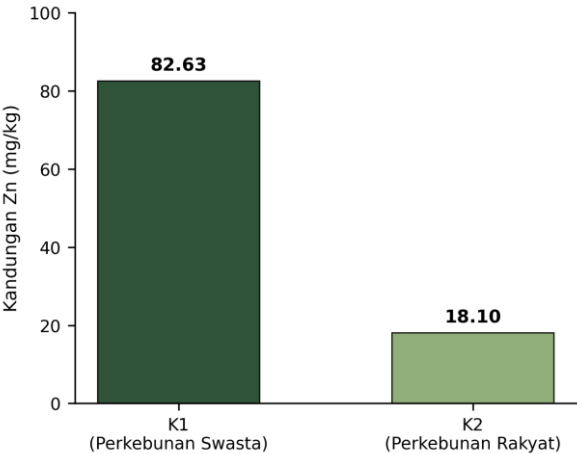


Figure 1. Bar Chart of Soil Zn Content at the Private Plantation (K1) and Smallholder Plantation (K2).

The results of the analysis of variance (Table 2) showed a highly significant effect of differences in management location on soil Zn content (F-calculated 689.57 > F-table 0.01), while the block factor had no significant effect. The coefficient of variation (CV) value of 10.91% indicated a good level of data precision.

Table 2. Analysis of Variance of Zn Micronutrient Content in Private Plantations and Smallholder Plantations (CV = 10.91%).

SK	db	JK	KT	F-hit	F 0,05	F 0,01
Block	9	318,57	35,40	1,17	3,18	5,35
Treatment	1	20825,00	20825,00	689,57**	1,16	10,56
Error	9	271,80	30,20	-	-	-

The significant difference between K1 and K2 is presumed to be related to the intensity of plantation management. Private plantations generally apply more regular fertilization and better organic matter management, as well as the application of latex production stimulants with ethephon as the active ingredient (Sinamo et al., 2015). Ethephon itself is not a source of micronutrients; however, the increase in plant physiological activity resulting from this stimulation also drives the demand for and utilization of nutrients, including Zn, thereby indirectly contributing to the higher nutrient status observed in K1.

In contrast, management practices in the smallholder plantation (K2), which tend to be more limited in terms of fertilization and organic matter addition, contributed to the lower Zn content, although it remained within the very high category. Other factors that also influence Zn availability include soil pH, texture, microorganism activity, nutrient loss due to leaching and erosion, as well as continuous plant uptake (Kaur, 2022).

Zn functions as an enzyme activator, supporting protein synthesis, auxin hormone formation, as well as the processes of photosynthesis and chlorophyll formation, such that its deficiency can inhibit plant growth and reduce plant productivity (Kaur, 2022). Nevertheless, excessive Zn content has the potential to cause toxicity, manifested as decreased photosynthetic activity, inhibited root

growth, and disrupted uptake of other nutrients. Therefore, the "very high" status observed at both locations should be interpreted as a condition that still supports optimal growth, but nonetheless requires monitoring to prevent it from developing into excessive accumulation.

CONCLUSIONS

The soil Zn micronutrient content in the private rubber plantation (K1) was 82.63 mg/kg and in the smallholder plantation (K2) was 18.10 mg/kg, with a statistically highly significant difference between the two locations. Both locations were classified into the very high nutrient status category, indicating that Zn availability remains sufficient to support optimal growth and development of rubber plants. The differences in values between locations are presumed to be influenced by fertilization intensity, organic matter management, and the application of latex production stimulants. Smallholder plantation managers are advised to improve soil fertility management through balanced fertilization and the addition of organic matter, accompanied by regular nutrient monitoring.

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