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The Relationship Between Soil Physics Characteristics with Nilam Production at Pasie Raja Sub-District South Aceh Regency

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ABSTRACT

Patchouli (*Pogostemon cablin*) cultivated in Pasie Raja District, South Aceh Regency, is widely recognized for its high-quality essential oil and distinctive aroma. However, despite favourable climatic conditions, patchouli production in this region declined substantially in 2023, reaching only 130 tons, which is considerably lower than the national average. This decline is presumed to be partly associated with soil fertility constraints, particularly soil physical properties. This study aimed to analyse the relationship between selected soil physical characteristics and patchouli productivity in Pasie Raja District. The research was conducted at six patchouli cultivation sites, with soil physical analyses performed at the Materials Testing Laboratory of Politeknik Aceh Selatan. Statistical analysis was carried out using Microsoft Excel to examine the relationships between soil porosity, bulk density, effective soil depth, and patchouli yield. The results indicated that bulk density showed a positive correlation with patchouli productivity, explaining 23.23% of yield variation. Soil porosity also exhibited a positive correlation, accounting for 16.68% of yield variation, while effective soil depth had the strongest association, explaining 36.3% of the variation in patchouli yield. These findings suggest that soil physical characteristics play an important role in patchouli production and may serve as a scientific basis for improving soil management practices to enhance patchouli productivity.

I. Introduction

Soil physical properties are one of the main considerations in determining land suitability for agriculture. These properties significantly affect the availability of water, air, and soil, which in turn determine root penetration in the soil and indirectly influence the availability of plant nutrients. These properties also impact the potential of the soil to produce at its maximum capacity [1]. Patchouli (Potogostemon cabin Benth) is one of the important essential oil producing plants, contributing more than 50% of Indonesia's total foreign exchange of essential oil exports. Almost all patchouli plantations in Indonesia are smallholder crops involving 32,870 farming families. Indonesia is the largest supplier of patchouli oil in the world market with a contribution of 70%. Aceh, especially the southern part, is known as a center for patchouli production with high quality essential oils, even considered the best in the world and has several superior varieties. Based on statistical data from the.

South Aceh district (2023), the patchouli harvest area reached 454 Ha with a total production of 88 tons or an average production of 193 tons in 2022, but patchouli production experienced a sharp decline in 2023, which only produced an average of 130 tons of patchouli [2]. The average production is still far below the national average production, it is suspected that soil fertility is one of the causes of the decline in patchouli plant productivity.

II. Theoritical Background

Based on the problems explained previously, one indicator of soil fertility is largely determined by the physical properties of the soil. The physical properties of soil that influence plant productivity are bulk density, soil porosity, and soil temperature. Efforts to improve the physical properties of the soil will indirectly improve the chemical and biological properties of the soil, thus improving the physical properties of the soil.

Previous research revealed that soil physical properties are related to patchouli plant production. The physical properties that influence patchouli plant production include bulk density, soil porosity, and soil temperature.

1.1 Bulk Density

Soil bulk density, also known as bulk density, is the ratio of the dry weight of soil to the volume of soil, including the pores. It is an indicator of soil density. Research conducted by Ardian shows that soil bulk density influences plant productivity because it is related to the organic matter in the soil. The more organic matter in the soil, the more ideal the bulk density and the greater its impact on plant growth.

Soil bulk density significantly influences soil physical properties, such as porosity, strength, bearing capacity, and drainage water retention. Bulk density was measured using undisturbed soil samples. In this study, the soil was placed in an oven at 105°C for 24 hours. It was then calculated using the formula:

$$\text{Bulk density} = \text{BKO (B-B1)/Soil Volume (g/}cm3\text{)}$$

Where:

BKO	: Oven-dry soil weight
B	: Soil weight + Sample ring
B1	: Sample ring weight
Soil volume	: $\pi r2$t

1.2 Soil Porosity

Soil porosity is the empty space in the soil filled with water and air. Soil porosity is calculated as the ratio of the volume of empty space to the total soil volume. [3] Soil porosity is correlated with patchouli productivity; as soil porosity increases, patchouli productivity also increases. This is influenced by a texture dominated by dust and a relatively low to high bulk density. The level of soil porosity depends on the bulk density; the higher the bulk density, the lower the porosity value. [4] Porosity is measured using the total pore space method, which uses a ratio between soil density (bulk weight) and particle density.

$$\text{Porosity} = (1 - \text{bulk weight / particle density}) \times 100\%$$

1.3 Soil Temperature

Soil temperature is an important property that directly affects plant growth and also moisture, structure, activity, microbial and enzymatic properties, plant residues and the availability of plant nutrients [5]. In this study, plant temperature was measured using a soil thermometer.

III. Results and Discussion

The study was conducted in several villages within Pasie Raja District, South Aceh Regency, Indonesia. Laboratory analyses of soil samples were performed at the Materials Testing Laboratory, Politeknik Aceh Selatan. The research was carried out from July to October 2025.The materials used in this study included a working map and a soil sampling location map of Pasie Raja District at a scale of 1:50,000. Equipment used for soil physical observations and analyses consisted of ring samplers, soil augers, hammers, hoes, knives, plastic bags, a compass, a digital camera, measuring tapes, plastic ropes, weighing scales, and standard laboratory instruments required for soil physical analyses.

1. Research Procedure

a. Soil sampling locations were determined based on the distribution of patchouli (Pogostemon cablin) cultivation areas in Pasie Raja District to ensure representative sampling.
b. Soil samples were collected using a composite sampling approach, in which several homogeneous subsamples were combined to represent each sampling point. At each observation site, two types of soil samples were collected: undisturbed and disturbed samples. Undisturbed soil samples were obtained using ring samplers at a depth of 0–30 cm to determine soil bulk density and porosity. Disturbed soil samples were collected using the composite method for further laboratory analysis. All samples were properly labelled and transported to the laboratory for analysis of soil physical properties.
c. Patchouli production data were collected through structured interviews with farmers cultivating patchouli within the sampling areas. This approach was employed to obtain field- based yield information corresponding to each sampling location.

2. Data Analysis

a. Soil physical data obtained from laboratory and field measurements were analyzed descriptively for each parameter, including bulk density, porosity, and effective soil depth.
b. Patchouli production potential was calculated using the following equation:

Annual patchouli harvest production was calculated using the following equation:

$$PsP = P \times F_p$$

where:

PsP: Annual patchouli harvest production (kg year^{-1})
P : Patchouli yield per harvest (kg harvest^{-1})
F_p: Harvesting frequency per year (times year^{-1})

Patchouli harvest productivity was calculated using the following equation:

$$P_sL = \frac{P_sP}{L}$$

where:

P_sL: Patchouli harvest productivity (kg ha^{-1} year^{-1})
P_sP : Annual patchouli harvest production (kg year^{-1})
L : Patchouli cultivation area (ha)

3. Regression Analysis

Soil data obtained from both laboratory and field measurements, along with patchouli production data, were subjected to descriptive statistical analysis, including minimum, maximum, mean, and standard deviation. Descriptive statistical analyses were performed using Microsoft Excel. Subsequently, regression analysis was conducted to examine the relationships between soil physical characteristics namely soil porosity, bulk density, and effective soil depth and patchouli production. Regression analysis was also employed to identify the soil physical characteristics that most strongly determine patchouli production in Pasie Raja District.

IV. Results and Discussion

a. Soil Physical Properties

1. Bulk Density and Soil Porosity

Table 1. Bulk density and soil porosity at different patchouli cultivation sites in Pasie Raja District.

Sampling Location (Village)	Bulk Density (g/cm^3)	Soil Porosity (%)	Soil Quality Class*
Ujung Batu	1.34	49.27	Less suitable
Ladang Teungoh	1.31	50.27	Suitable
Silolo	1.39	47.45	Less suitable
Payateuk	1.45	45.02	Less suitable
Lhok Sialang Cut	1.41	46.58	Less suitable
Lhok Sialang Rayeuk	1.32	50.05	Suitable

Based on Table 1, the highest soil bulk density values were observed in Paya Ateuk and Lhok Sialang Cut villages, at 1.45 g/cm³ and 1.41 g/cm³, respectively, while the lowest bulk density values were found in Ladang Teungoh and Lhok Sialang Rayeuk villages, at 1.31 g/cm³ and 1.32 g/cm³. According to [6], soil suitable for patchouli cultivation is loose or friable. One of the characteristics of friable soil is a low bulk density, ranging from 0.86 to 1.10 g/cm³ [7]. Therefore, from a physical perspective, soils with high bulk density are less favorable for patchouli growth as they can hinder root penetration and development [8]. This limitation can be addressed through soil management, such as loosening the soil around the plants. Proper soil management can reduce bulk density by improving soil aeration and enhancing soil structure.

The analysis of soil porosity across various patchouli cultivation sites in Pasie Raja Subdistrict showed the highest value in Ladang Teungoh village, at 50.27% (categorized as good), and the lowest value in Paya Ateuk village, at 45.02% (categorized as less favorable). Overall, the dominant soil porosity class was less favorable, indicating the need for efforts to improve soil porosity. According to [9], soil porosity can be increased by adding organic matter or applying minimum tillage. Excessive soil management, however, can damage soil structure. Furthermore, [10] stated that soil porosity is influenced by organic matter content; the higher the organic matter, the higher the soil porosity.

2. Soil depth

Table 2. Soil depth at various patchouli planting locations in Pasie Raja District

Sampel Location (Village)	Soil Depth (cm)	Criteria
Ujung Batu	112	Deep
Ladang Teungoh	95	Deep
Silolo	100	Deep
Payateuk	105	Deep
Lhok Sialang Cut	100	Deep
Lhok Sialang Rayeuk	110	Deep

Source: Field Observations at Patchouli Plantation Locations

Table 2 presents the soil depth at various patchouli cultivation sites, showing both varying and similar values. The deepest soil was recorded in Ujung Batu village at 115 cm, while the shallowest soil was observed in Ladang Teungoh village at 95 cm. Field observations in Pasie Raja Subdistrict indicated that soil depth ranged from 90 to 115 cm, which, according to [11], is classified as moderate to deep.

3. Patchouli Plant Production

Table 3. The productivity of patchouli plants.

Sampel Location (Village)	Lan Area (ha)	Total Production (kg/year)	Annual Crop Productivity (kg/ha)	Annual Crop Productivity (ton/ha)
Ujung Batu	0.9	792	880	0.88
Ladang Teungoh	0.8	660	825	0.82
Silolo	1	920	920	0.92
Payateuk	1	1.012	1.012	1.01
Lhok Sialang Cut	0.6	478	770	0.72
Lhok Sialang Rayeuk	0.9	660	733	0.73
Total	5.2	4.522	5.140	5.08
Average	0.87	758.7	856.7	0.85

Source: Primary data after processing, 2025

Table 3 shows that the patchouli cultivation sites in Pasie Raja Subdistrict varied in land area, with the smallest being 1 ha. Due to differences in land area and harvest frequency, the patchouli production each farmer (respondent) also varied, ranging from 733 to 1,012 kg/ha a year, with an average of 856.7 kg/ha, or approximately 0.85 tons/ha a year.

Relationship between soil physics and patchouli production

1. Bulk density

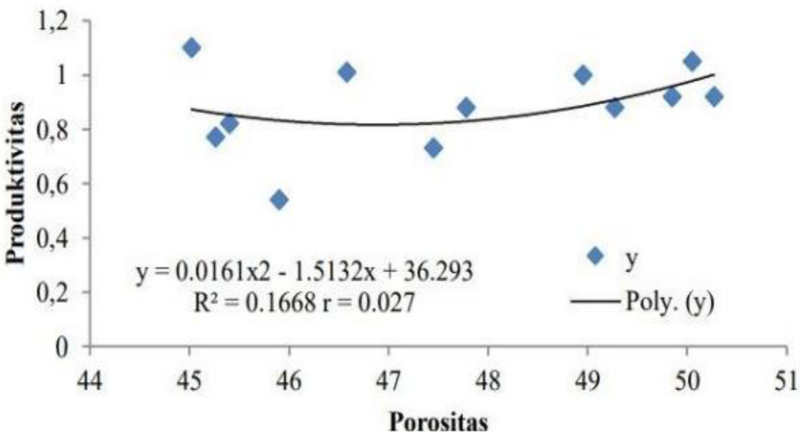

Fig 1. Relationship between bulk density and patchouli productivity

Figure 1 illustrates that the correlation coefficient (r = 0.035) and the coefficient of determination (R^2) indicate that patchouli productivity is influenced by soil bulk density by 23.23%. Bulk density affects plant productivity because it is closely associated with soil organic matter content. Higher organic matter leads to more optimal soil bulk density, thereby exerting a greater impact on plant growth. Previous studies have shown that bulk density significantly affects soil physical properties, including porosity, strength, bearing capacity, and the soil's water retention and drainage capabilities, which are critical factors for land utilization.

2. Soil Porosity

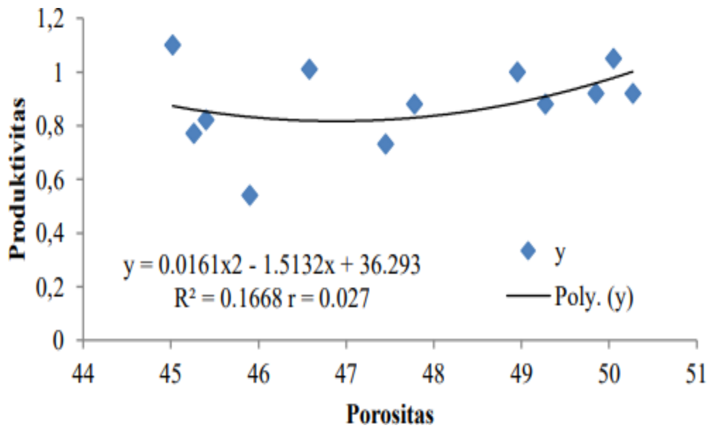

Figure 2. Relationship between soil porosity and patchouli productivity

Figure 2 presents the results of a third-order polynomial regression analysis, indicating a positive correlation between soil porosity and patchouli productivity. This suggests that an increase in soil porosity is associated with an increase in patchouli productivity. The regression results (R^2) indicate that soil porosity accounts for 16.68% of the variation in patchouli productivity. This relationship is influenced by the soil texture, which is dominated by silt, as well as the soil bulk volume ranging from low to high. Soil porosity is highly dependent on bulk density; the higher the bulk density, the lower the soil porosity.

3. Soil Depth.

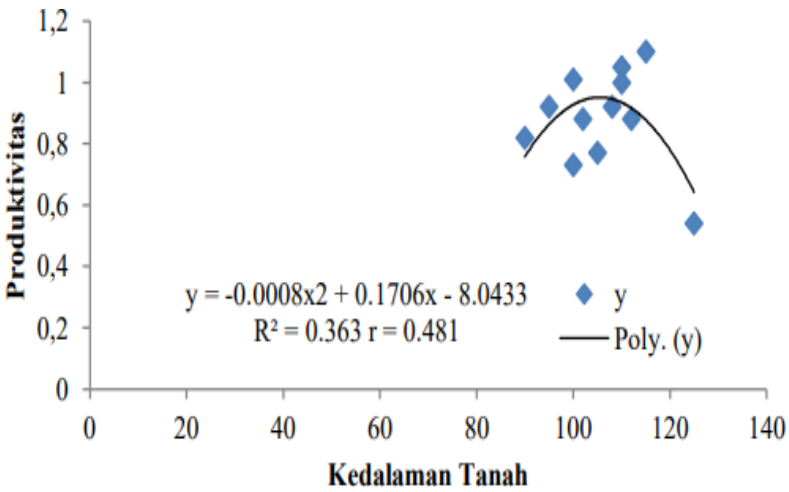

Figure 3. Relationship between soil depth and patchouli productivity

The results of the third-order polynomial regression analysis indicate a positive correlation ($r = 0.481$). The regression analysis (R^2) shows that effective soil depth accounts for only 36.3% of the variation in patchouli productivity. However, an increase in soil depth is accompanied by a decrease in patchouli productivity. This is because deeper soils tend to have lower organic matter content, resulting in reduced soil fertility. Previous studies have reported that, based on soil depth, the topsoil possesses higher bulk density and porosity than the subsoil, as air and water are stored in pore spaces, and plant roots as well as soil organisms require sufficient space for their activities.

V. Conclusion

Soil physical properties are closely related to patchouli productivity in Pasie Raja Subdistrict, South Aceh Regency. Among the properties studied, bulk density exhibited a positive correlation, accounting for 23.23% of the variation in productivity. Porosity also showed a positive influence, contributing 16.68%, while soil depth positively affected productivity by 36.3%. These results indicate that variations in soil physical characteristics significantly impact patchouli growth and yield.

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