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ANALYSIS OF HYDRAULIC CONDUCTIVITY OF TROPICAL PEAT SOIL ON SAND AND CLAY SUBSTRATUM IN PESISIR SELATAN, WEST SUMATRA

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ABSTRACT

The study of hydraulic conductivity is essential for the effective management of peat drainage systems, particularly in West Sumatra, Indonesia, where peatlands are layered with sand and clay substratum. These substrate variations are believed to influence soil conductivity, indirectly impacting plant growth. This study aimed to compare saturated hydraulic conductivity between peat soils with sand and clay substratum, analyze the characteristics of peat pores affecting conductivity, and establish relationships between soil parameters and peat drainage in both systems. Conducted in Pesisir Selatan, West Sumatra, the study involved 12 observation points for soil hydraulic conductivity. Results indicated that peat soil with a sand substratum exhibited an average hydraulic conductivity (HC) of 1.13×10^{-3} cm.s^{-1}, five times faster than peat with a clay substratum (2.21×10^{-4} cm.s^{-1}). Interestingly, soil HC values did not correlate with pore characteristics in the peat layer but were significantly associated with those in the substratum layer. Specifically, substratum layer HC positively correlated with Aeration Pores (AP) (r=0.680) and Drainage Pores (DP) (r=0.031), and negatively correlated with Available Water Pores (AWP) (r=-0.817, $p<0.047$, $r^2=0.667$). Notably, AWP in the sand substratum layer was lower (22.50%vol) than in the clay substratum layer (30.53%vol). Therefore, precise regulation of peat drainage in a sand substratum is crucial to mitigate the potential increase in water levels in peatlands

Keywords: Hydraulic Conductivity, Aeration Pores, Drainage Pores, Available Water Pores, Peat Soil.

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INTRODUCTION

In Indonesia, peatlands can develop on an above sand and clay substratum.[1,2] The nature of these substratum types can significantly influence the characteristics of the overlying peat layer. Previous studies have identified distinctions between peat formed above sandy and clayey substratum. For instance, examined the chemical attributes of peatlands in Kalimantan[3], while investigating the physical characteristics of peat and its correlation with palm oil production in Malaysian peatlands.[4] However, neither study delved into the soil hydraulic conductivity of peat with sand and clay substratum. It is hypothesized that varying types of peat substratum types may impact the hydraulic conductivity of the soil. Consequently, soil drainage management cannot be uniform, necessitating adjustments based on the substratum type. Therefore, this research aims to a) Examine the hydraulic conductivity between peat soils formed above sandy substratum and clayey substratum and b) Analyze the pore characteristics that influence the hydraulic conductivity of peat soils.

EXPERIMENTAL

Material and Methods

This research was conducted in peatlands private oil palm plantations in Pesisir Selatan Regency, West Sumatra. Soil analysis was performed in the Department of Soil Science and Land Resources laboratory,

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Faculty of Agriculture Andalas University, and Indonesian Soil Research Institute (ISRI). Measurements of saturated soil hydraulic conductivity were carried out using the Auger Hole method, which consists of a 2.5-inch PVC with a hole perforated with a diameter of 1 cm and a distance of 10 cm, a 2-inch PVC to remove water from a measured hole in the ground. The pump's design is illustrated in Fig.-1a.

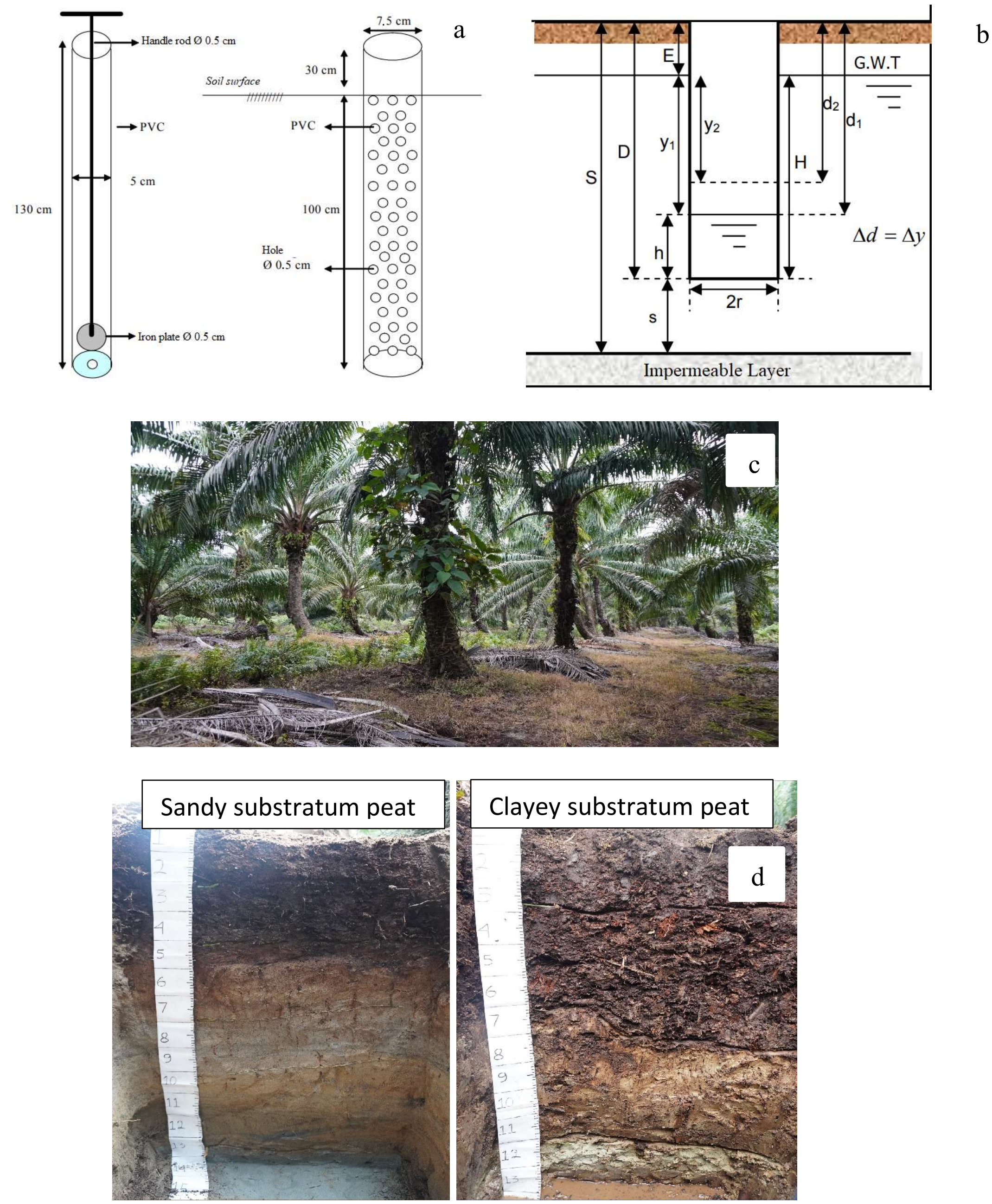

Fig.-1: (a) Sketch of the Pump of the Auger Hole Method for Measuring Soil HC, (b) HC Measurements in the Field with a Shallow Groundwater Table Above the Substratum Layer, (c) Installation of Auger Hole for Measurement of Soil HC on Oil Palm Plantation Peatlands, (d) Soil Profile of Sandy Substratum and Clayey Substratum Peat Soils

General Procedure

Hydraulic conductivity measurements were carried out directly in the field for five observations every two days. The measurement scheme can be seen in Fig.-1b, while the equations used to process the data refer to Boast and Kirkham and Boast and Langerbartel.[5,6] Two equations are used, i.e., Equation 1 for measuring (dry auger hole method) is used for soil that has a deep water surface (s>2H). In contrast, Equation 2 is used for measuring saturated HC with a limit of up to the substratum layer (S=O) and shallow groundwater level. Equation 1 is used for peat with a sandy substratum. Equation 2 is used for peat with a clay substratum, where K = hydraulic conductivity of the soil (cm/s), r = radius of the hole, H = distance from the bottom of the hole to the groundwater surface, y = difference in water depth in a hole with a groundwater level, Δy/ Δt = change in groundwater level in a specific time interval, Q = speed of water movement.

$$\text{Ksat} = \frac{Q\ [sin^{-1}\left(\frac{H}{r}\right)-\left(\frac{r^2}{H^2}+1\right)^{\frac{1}{2}}+\frac{r}{H}]}{2\pi H^2}\left(\frac{\Delta y}{\Delta t}\right) \quad (1)$$

$$\text{Ksat} = \left\{\frac{4.17r^2}{\left[y(H+10r)\left(2-\frac{y}{H}\right)\right]}\right\}\left(\frac{\Delta y}{\Delta t}\right) \quad (2)$$

RESULTS AND DISCUSSION

Soil Physical Properties of Sandy Substratum Peat and Clayey Peat Substratum

This research shows that peat with sand and clay substratum types has different characteristics (Table-1). The texture of the substratum layer is very contrasting between the peat soils. Differences in texture in the substratum layer affect various characteristics of the peat layer above it. The sand fraction is porous and dominated by macro pores, so it can easily pass through water.[7] The character of this fraction influences groundwater level fluctuations and various other physical properties of the soil.[8] Based on field observations, the ground water table (GWT) in peat with a sand substratum is much deeper (>90 cm) than in peat with a clay substratum (43 cm).[9] Thus, the peat layer with a sandy substratum would tend to be drier (oxidative) than peat with a clay substratum. The condition would affect peat decomposition rate and levels of peat maturity. Therefore, the sandy substratum peat becomes more mature (with lower fabric content) than clayey peat[10] (Table-1). The differences in maturity would cause differences in other characteristics such as ash content, organic matter, C-organic, Bulk Density (BD), and Total of Pore Space (TPS).[11] These findings contribute significantly to understanding how substrate types affect the physical properties of peat soils, groundwater level fluctuations, and peat maturity. In addition, they provide a basis for better soil management and mitigation of environmental impacts in peat areas.

Table-1: Soil Physical Properties of Sandy Substratum Peat and Clayey Substratum Peat of Tropical Peatlands in Pesisir Selatan, Sumatera Barat

Peat Type	Layer (cm)	Field Water Content (%)	BD (g/cm³)	PD (Particle Density) g/cm³	TPS (% v)	Ash (%)	Organic matter (%)	Organic Carbon (%)	Sand (%)	Silt (%)	Clay (%)	Texture class	Fabric Content (%)
Clay Substratum Peat	Peat surface 0-18	67.97	0.18	176	88.23	12.95	87.05	45.29	-	-	-	-	21.00
	Peat subsurface 18-51	81.45	0.14	1.94	92.10	6.72	93.28	48.54	-	-	-	-	32.00
	Substratum layer >51	67.30	0.56	2.31	75.90	79.50	20.50	10.67	12.57	43.50	43.93	Silty clay	-
Sand Substratum Peat	Peat surface 0-20	54.17	0.25	1.36	80.13	12.51	87.49	45.52	-	-	-	-	21.00
	Peat subsurface 20-40	69.60	0.17	1.70	89.80	19.67	80.34	41.80	-	-	-	-	25.00
	Substratum layer >40	43.45	0.98	2.50	60.95	91.70	8.30	4.32	79.85	2.50	17.65	Sandy loam	-

Water Retention Capacity of Peat Soil with Sand and Clay Substratum

Fig-3 shows the difference in water retention on peat soils with sandy and clayey substratum. The soil water content in AWP (available water pores) of sandy substratum peat soils is lower than clayey substratum peat soils in the surface, subsurface, and substratum layer. Soil water content in AWP describes the capability of the soil to retain and provide water available for plants. The higher the water content in the AWP, the greater the soil's ability to provide water for plants.[12] Figure-3 shows that the ability of peat soil with a sandy substratum is lower in retaining water available for plants than peat with a clay substratum. The

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predominant sand fraction in sandy substratum peat soils facilitates the easy passage of water into the soil due to the porous nature of the sand fraction. The soil substratum dominated by sand fraction has a higher DP (Drainage Pores).[9] The water in DP would quickly lose or descend into deeper soil layers due to gravitational forces, making it unavailable to plants, and the soil becomes dry. These findings suggest that peat substratum is crucial in determining water availability. The differences in water retention between sandy and clay substrates highlight the importance of substratum texture in peatland management strategies. These findings also shed light on how differences in substratum texture can affect groundwater dynamics and overall peat ecosystem health, offering important insights for future peatland conservation.

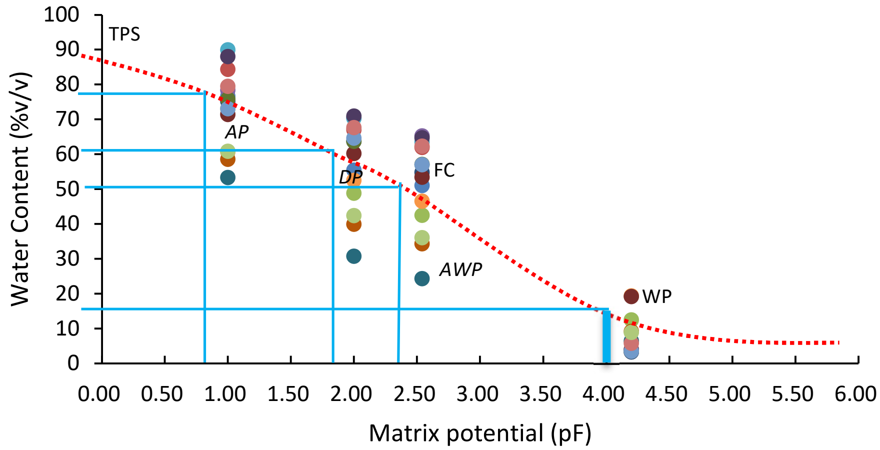

Fig.-2: The Relationship Matrix Potential (pF) and Water Content in Peat with Sand Substratum and Clay Substratum of Tropical Peat Soil (TPS = Total of Pore Space, FC = Field Capacity, WP = Wilting Point, AP = Aeration Pore, DP = Drainage Pore, AWP = Available Water Pore)

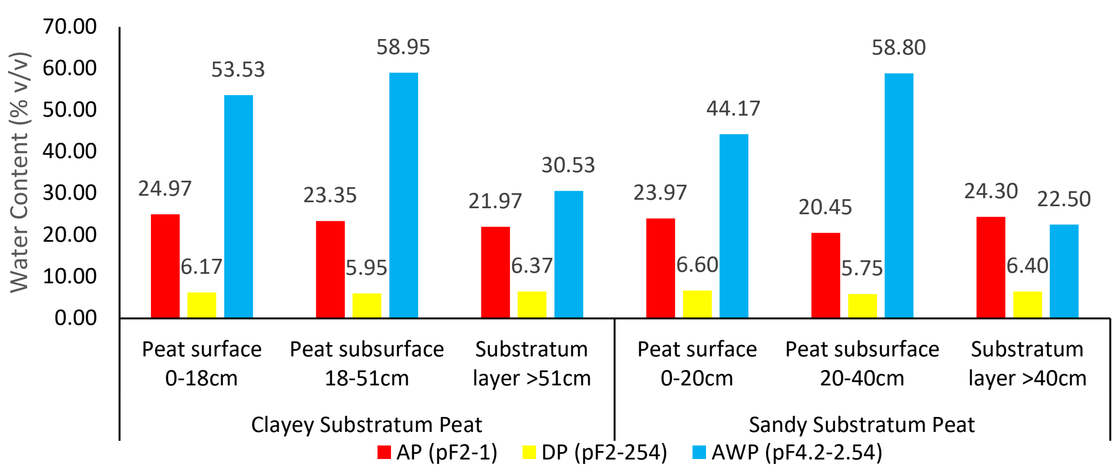

Fig.-3: Water Content of Aeration Pore, Drainage Pore, and Available Water Pores on Sandy Substratum Peat and Clayey Substratum Peat Soils

Hydraulic Conductivity of Peat with Sand and Clay Substratum Types and its Relationship with Soil Pore Characteristics

The Hydraulic Conductivity (HC) shows water movement in the soil. The difference in HC value indicates the potential for water fluctuation in the land. Figure-4 shows that the average value of HC in peat with a sand substratum (1.13x10-3 cm/s) is higher than in peat with a clay substratum (2.21 x 10-4 cm/s). A high HC value in peat with a sandy substratum indicates that water is quickly lost into deeper layers. Our results (Table-2) show that HC is highly correlated with pore characteristics in the substratum layer. The HC positively correlates with AP (r=0.680) and DP (r=0.031). The correlation indicates that the higher the AP and DP, the greater the HC value. De Boodt reported that the AP pore has a size >28.8 um and DP 8.6-28.8 um[7]. Due to gravity forces, water at this pore size would quickly shift into deeper soil layers. In this regard, the high HC value in peat with a sandy substratum is influenced by the high content of sand fraction in the substratum layer (which has lots of macro pores) and vice versa in peat with a clay substratum. These findings provide in-depth insights into the relationship between substratum texture, soil pore characteristics, and hydraulic conductivity in peatlands. The significant differences in HC between sandy and clayey substrates indicate the importance of considering substratum texture in peatland management strategies, especially regarding water management. This study also highlights potential risks associated with sandy peatlands, such as rapid water loss and potential soil drying, which can affect the health of peat ecosystems and the sustainability of agriculture on these lands.

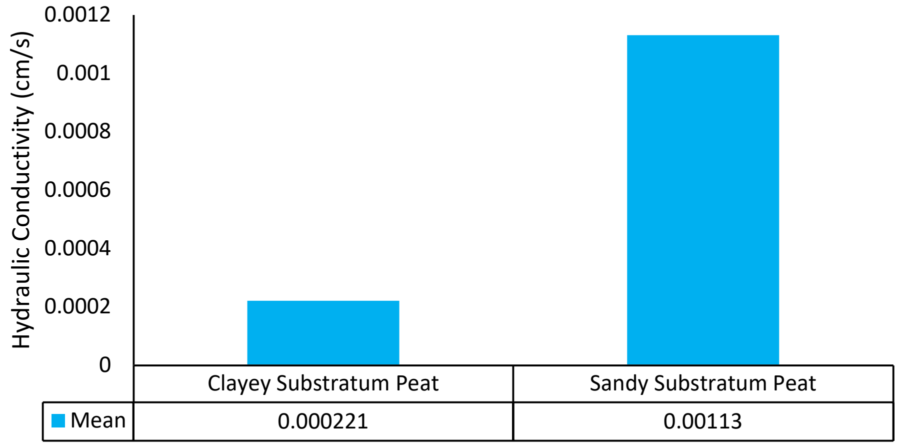

Fig.-4: Hydraulic Conductivity (HC) of Sandy Substratum Peat and Clayey Substratum on Tropical Peatlands in Pesisir Selatan, West Sumatra

Table-2: Pearson Correlation of Soil Hydraulic Conductivity and Aeration Pore, Drainage Pore, Available Water Pore in Substratum Layer

Soil Characteristics	Correlation	Aeration Pores	Drainage Pores	Available Water Pores	Hydraulic Conductivity
Aeration Pores	r	1	-0.300	-0.648	0.680
	Significance. (2-tailed)		0.564	0.164	0.138
Drainage Pores	r	-0.300	1	0.370	0.031
	Significance. (2-tailed)	0.564		0.470	0.953
Available Water Pores	r	-0.648	0.370	1	-0.817*
	Significance. (2-tailed)	0.164	0.470		0.047
Hydraulic Conductivity	r	0.680	0.031	-.817*	1
	Significance. (2-tailed)	0.138	0.953	0.047	

CONCLUSION

Based on the results of this research, peatlands with sandy substratum have higher HC values than peatlands with clayey substratum. The substratum type of peat soils influences the difference in HC as a determinant of soil pore characteristics, influencing groundwater movement (HC). Furthermore, the difference in HC of sandy and clayey substratum peat requires different drainage management.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS

All the authors contributed significantly to this manuscript, participated in reviewing/editing, and approved the final draft for publication. The research profile of the authors can be verified from their ORCID IDs, given below:

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