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Soil Organic Matter and Its Correlation with Several Chemical Properties of Inceptisols in Rice Fields in Java

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Abstract The type of soil commonly used for wet rice cultivation on the island of Java is Inceptisols. The research aims to analyze the relationship between organic matter content and chemical properties of Inceptisols soil planted in rice fields at three locations in Java. Soil samples were taken from three different rice field locations, namely Jasinga 1, Jasinga 2, and Serpong. At the research location, three soil profiles were identified, and from each profile, disturbed soil samples were taken at soil depths of 0-20 cm, 20-40 cm, and 40-60 cm, resulting in a total of nine soil profiles and 27 disturbed soil samples. Soil chemical properties analyzed to support research include pH H_2O (1:2.5), organic carbon (C-organic), soil bases, total soil nitrogen, available phosphorus, and cation exchange capacity (CEC). The results of the research concluded that the chemical properties of paddy soil in three locations, including soil organic matter content, pH, total nitrogen, available phosphorus, CEC, and alkaline exchangeable-Ca, exchangeable-Mg, exchangeable-K, exchangeable-Na, were sufficient to meet the needs of rice plant nutrients. The very real negative correlation between organic matter content and soil pH and exchangeable-Na levels shows a direct relationship with paddy soil fertility. Optimizing rice production is recommended to add organic matter and improve paddy soil's pH value and chemical properties.

Keywords Inceptisols, Soil Fertility, Soil Productivity, Rice Fields

1. Introduction

Inceptisols is a young soil that has undergone moderate weathering with a low clay content (<8%) at a depth of 20-50 cm. This type of land is often found in tropical areas, covering approximately 4% of the total 207 million hectares. Inceptisols features a rather thick solum, ranging from 1 to 2 meters, with black or gray to dark brown coloration, a sand, dust, and clay texture, crumbly soil structure with a loose consistency, pH ranging from 5.0 to 7.0, and a relatively high organic matter content (10% to 31%). It exhibits moderate to high nutrient content and soil productivity. The texture of this whole solum is generally clayey, while the structure is crumbly and the consistency is loose. In general, the fertility and chemical properties of Inceptisols are relatively low [1]. The physical and chemical properties of Inceptisols soil include a specific gravity of 1,0 g/cm^3; calcium carbonate less than 40%, base saturation of less than 50% at a depth of 1.8 m, COLE (Coefficient of Linear Extensibility) between 0.07 and 0.09, porosity values ranging from 68% to 85%, and a considerable amount of available water at 0,1 ± 1 atm [2].

Swanda et al. [3] stated that Inceptisols is very susceptible to erosion and, therefore, highly prone to gully erosion development.

Inceptisols is classified as acid soil and is widely distributed in Indonesia, covering approximately 70.5 million hectares (37.5%), of which 5.2 million hectares (7.4%) are acidic and spread across Sumatra, Java, Kalimantan, Sulawesi, and Irian Jaya. Pinto et al. [4] stated that Inceptisols is currently extensively used as the primary focus for expanding agricultural land outside Java and has become a target for residential land development. Therefore, Inceptisols soil requires special attention considering its significant potential for development, though it faces substantial obstacles, especially regarding the chemical properties of the soil.

In various locations in Java, Indonesia, and other tropical regions, Inceptisols are commonly found. They have distinctive characteristics that reflect the formation process and the environment in which they develop. The varying soil chemical properties of Inceptisols in different Java locations play a crucial role in determining the success of agricultural production and the welfare of farmers. Therefore, an in-depth understanding of the soil chemical characteristics of Inceptisols in different Java locations is essential for effective soil management and increased agricultural productivity. Factors such as soil acidity level, organic matter content, cation exchange capacity, nutrient content, water retention ability, and mineral content significantly impact the soil's ability to support plant growth, maintain agricultural sustainability, and manage natural resources.

Rahayu et al. [5] stated that morphologically, paddy field soil causes the formation of horizons, color, and plow shape (Adg) in the rice field soil profile. Differences in soil physics include soil structure, density, and consistency. Paddy soil usually has a higher cation exchange capacity (K^+, Na^+, Ca^{2+}, and Mg^{2+}), C-Organic, and base saturation than dry land. In line with this, Azmi et al. [6] explained that Inceptisols in paddy fields can change the chemical properties of the soil, including basic cations (exchangeable-K, exchangeable-Ca, exchangeable-Mg, exchangeable-Na), CEC, and BS. The research results show that rice fields planted twice a year have better chemical properties than those planted once a year. This is evident from the exchangeable -K value of 0.71 $cmol^{(+)}kg^{-1}$ (high), CEC 21.73 $cmol^{(+)}kg^{-1}$ (medium), meeting better criteria. Agricultural practices carried out by farmers on Inceptisols soil were able to alter the chemical properties of the soil. According to Buragohain et al. [7], the use of biological fertilizer for 10 years in Inceptisols paddy fields has a positive effect on the chemical and biological characteristics of the soil, making it recommended for rice cultivation to provide nutrients and increase rice production.

Organic matter in soil can affect soil chemical properties, such as pH, cation exchange capacity (CEC), and nutrient availability. High organic matter content can increase the reducing power and pH of the soil, as well as increase the cation exchange capacity. Several studies have examined the correlation between organic matter and soil chemical properties. Providing organic matter in the form of organic and inorganic fertilizer on long-term agricultural land can improve soil fertility [8]. Additionally, Singh et al. [9] asserted that adding organic matter increases soil carbon and nitrogen content, resulting in increased soil fertility and plant productivity, which is environmentally friendly and cost-effective. Providing manure is the right strategy to increase crop yields because it can increase soil pH and soil fertility [10]. The impact of intensive land use in the long term will affect the low content of organic matter and soil fertility, thereby reducing spatial variability and dependence and homogenizing soil properties [11].

Based on the description above, it is important to conduct this research with the aim of analyzing the relationship between organic matter content and the chemical properties of Inceptisols soil in rice fields at three locations in Java. It is hoped that the results of this research can assist farmers, agricultural researchers, and policymakers in developing appropriate strategies to enhance agricultural productivity, preserve the environment, and promote agricultural sustainability in these three regions in Java.

2. Materials and Methods

The research was conducted from March to August 2021 in Bogor Regency, West Java, and South Tangerang Regency, Banten, specifically in 30-year-old rice fields. The soil samples taken were subsequently analyzed at the Soil Chemistry and Fertility Laboratory, Department of Soil Science and Land Resources, Faculty of Agriculture, Bogor Agricultural Institute (IPB). Profile observations and soil sampling were carried out at three locations, each having three soil profiles at depths of 0-20 cm, 20-40 cm, and 40-60 cm, resulting in a total of 9 soil profiles. The coordinate points for collecting rice field samples are as follows: 6°30'11.249"S – 106°25'4.395"E in Curug Village, Jasinga District, Bogor Regency, West Java, 6°30'3.164"S – 106°25'11.771"E in Curug Village, Jasinga District, Bogor Regency, West Java and 6°21'11"S – 106°39'38"E in Kademangan Village, Setu District, South Tangerang Regency, Banten. Soil sample analysis includes pH H_2O with a ratio of 1:2.5, N-total via the Kjeldhal method, P-available via the Bray I method, C-organic via the Walkley and Black method, and exchangeable base cations K, Ca, Mg, Na, and cation exchange capacity through extraction using 1 N NH_4OAc. Data analysis was carried out descriptively comparing the data obtained with soil property criteria and Pearson correlation using SPSS 22.

3. Result and Discussion

3.1. Organic Matter Content, pH, N-total, P-available, and Cation Exchange Capacity Soil in Java

Table 1 explains the results of soil analysis in Jasinga and Serpong, focusing on several soil profiles and their chemical properties, including organic matter content, pH, N-total, P-available, and CEC. The organic matter content in the observed 9 rice field soil profiles across the three research locations ranged from very low to medium. Table 1 illustrates that the organic matter content is high in all soil profiles in the upper layers and varies at different depths. In Indonesia, most rice fields have an organic matter content of less than 2%. The elevated content of soil organic matter on the surface aligns with the provision of organic material at the start of planting in the research location. The total carbon and nitrogen content were found to be higher in the top layer of soil than in the bottom layer [12].

The organic material content in paddy soil can be increased by adding organic fertilizer. Providing organic fertilizer at the beginning of planting in conjunction with inorganic fertilizer can enhance soil fertility [13, 14, 15]. Additionally, Wu et al. [16] added that carbon stability, such as in biochar, can be a key factor in determining the C sequestration effect, primarily depending on the physiochemical characteristics of organic matter and soil properties. However, there is limited knowledge about the stability of biochar C in paddy soils.

Table 1. Results of analysis of C-organic content, pH, N-total, P-available and cation exchange capacity of paddy soil in Java

Location	Profile	Depth (cm)	Organic matter (%)	pH	N-Total (%)	P-available (ppm)	CEC (me/100g)
Jasinga 1	Profile 1	0-20	2.06	5.80	0.15	1.78	51.00
		20-40	0.69	5.70	0.17	1.97	48.20
		40-60	0.86	4.70	0.07	2.15	49.40
	Profile 2	0-20	2.06	6.10	0.11	2.52	41.50
		20-40	0.34	6.20	0.06	2.70	47.80
		40-60	0.86	6.40	0.06	2.89	61.60
	Profile 3	0-20	2.06	5.40	0.11	3.07	41.10
		20-40	0.86	4.60	0.07	2.15	60.00
		40-60	1.03	4.40	0.10	1.60	54.90
Jasinga 2	Profile 1	0-20	1.41	5.25	0.13	2.33	45.43
		20-40	1.17	5.32	0.08	2.52	41.28
		40-60	1.10	5.88	0.08	2.70	65.18
	Profile 2	0-20	1.51	5.48	0.14	2.15	47.99
		20-40	0.96	5.54	0.13	2.70	49.77
		40-60	1.67	5.48	0.06	1.78	44.64
	Profile 3	0-20	1.24	5.48	0.10	2.33	48.98
		20-40	1.22	5.49	0.10	1.60	39.11
		40-60	1.07	5.89	0.13	2.15	39.90
Serpong	Profile 1	0-20	3.78	4.80	0.23	2.33	38.70
		20-40	3.27	4.70	0.18	19.12	31.60
		40-60	1.38	5.20	0.14	19.31	28.60
	Profile 2	0-20	2.06	5.10	0.07	2.52	20.70
		20-40	1.20	5.10	0.13	2.33	36.50
		40-60	2.92	5.10	0.11	2.15	26.30
	Profile 3	0-20	4.30	4.70	0.10	2.33	47.40
		20-40	1.03	4.70	0.10	2.52	41.50
		40-60	1.55	4.90	0.23	2.70	32.80

Soil pH values at all locations ranged from 4.40 to 6.40, indicating a range from very acid to slightly acid based on the criteria. Profile 2 at the Jasinga 1 location showed a higher pH value than other profiles and locations. The pH value significantly influences soil acidity and nutrient availability, impacting plant growth. The soil reaction in the Jasinga 1 and Jasinga 2 areas is generally moderately acidic, while in Serpong, it falls within the acidic criteria. When comparing the three locations, the Jasinga location is slightly better than Serpong. Soil alkalinity or acidity can affect nutrient availability to plants. Soil with a pH around 6.5-7.0 is more suitable for growing rice plants in these locations.

Research results from Minasny et al. [17] on land cultivated for 12 years in South Korea showed an increase in soil pH from 5.6 before 2000 to 5.9 after 2009, with an increase rate of around 0.3 pH units per decade. Based on the spatial prediction confidence interval, 35% of paddy fields (4180 km^2) are likely to experience an increase in pH (possibility > 66%), and 20% (2350 km^2) are likely to experience an increase in soil pH (possibility > 90%).

The pH value of the soil can be increased by using large amounts of plant residues in soil with a constant charge compared to soil with a variable charge [18]. Yunus [19] also adds that the rate of increase in soil pH is higher in more acidic soils. To further enhance the soil's ability to provide optimal nutrients, all research locations must be limed to increase the pH of each soil. The application of agricultural lime can increase soil pH, Ca, cation exchange capacity, and reduce Al-exchangeable.

The N-total in Inceptisol in rice fields ranges from 0.06% to 0.23%, falling within the very low to low criteria. Table 1 indicates that the nitrogen content in Jasinga 1 and Jasinga 2 ranges from very low to low, and for Serpong, across the three observation profiles, it ranges from 0.07% to 0.23%, categorizing as very low to medium. The low nitrogen content in paddy soil can be attributed to three factors. Patti et al. [20] stated that low N content is influenced by leaching with drainage water, evaporation, and absorption by plants. Some of the nitrogen is transported during harvest, some returns as plant residue, is lost to the atmosphere, and returns again, lost through leaching. Therefore, nitrogen is the most active factor in soil fertility and also the primary factor limiting crop yields in agricultural production. The ability to mineralize nitrogen in the soil is essential for maintaining agricultural productivity and environmental protection [21]. This nitrogen content can also influence the increase in CO_2 to boost yields; there must be enough nitrogen in the soil for absorption by rice [22].

According to Table 1, the phosphorus (P) content in Jasinga 1 and 2 rice fields is classified as very low, namely <10 ppm, while for Serpong rice fields in profile 1, in layer B2, the P content is classified as low, namely 19.12 ppm and 19.31 ppm. This difference arises because phosphorus levels in the soil are generally low and vary according to soil type. Young soil usually has higher levels than old soil. Inceptisols soil is classified as young soil, but the phosphorus level is still relatively low, even very low, which can be caused by two things: (1) phosphorus is one of the macronutrients needed by plants in large quantities, resulting in more phosphorus being lost as it is absorbed by plants; (2) the mobile nature of phosphorus in the soil solution makes it easily lost. Another factor contributing to low phosphorus levels in the soil is the low content of the parent material, as phosphorus is generally not abundant in soils in West Java and Banten, which have rock formations between acidic and intermediate.

Additionally, the neutralizing effect of using organic materials on paddy soil was able to inhibit Al hydrolysis by up to 57.4% and resulted in an increase in available P in the soil by 31.26% to 50.64%. The increased availability of P in soil is also caused by the high affinity of SiO_4^{4-} in absorbing P from soil minerals, and it is believed that SiO_4^{4-} can temporarily adsorb exchangeable base cations such as K^+, Ca^{2+}, Mg^{2+}, and Na^+ [23].

Cation exchange capacity (CEC) measures the ability of soil to hold and release cations (positive ions). The CEC values for all samples ranged from 20.70 to 65.18 me/100g. Soil with a higher CEC can provide better plant nutrition. The cation exchange capacity of soil depends on factors such as the type and amount of clay content, organic matter content, and soil pH. Therefore, the soil's CEC significantly determines its fertility level [24]. The cation exchange capacity of soil, which has many pH-dependent charges, can vary with changes in pH. Soil conditions that are acidic to slightly acidic cause a slight loss of cation exchange capacity and the ability to store cation nutrients in exchangeable form due to the development of positive charges. The nine rice field soil profiles in Table 1 were observed to have CEC values ranging from moderate to very high. This difference is caused by the organic matter content and soil pH value, which is not too acidic, allowing for high soil CEC. When soil pH becomes very acidic or very alkaline, CEC can decrease. The types of clay minerals also determine the soil's CEC; for example, soil with the clay mineral montmorillonite has a greater CEC than soil with the clay mineral kaolinite.

3.2. Base Cations and Bases can be Exchanged in Rice Fields in Java

Table 2 provides data on the chemical composition of soil in several locations and profiles for each location which include base saturation, and interchangeable bases (exchangeable-Ca, exchangeable-Mg, exchangeable-K, and exchangeable-Na).

Table 2. Results of analysis of base cations and exchangeable bases in rice field soil in Java

Location	Profile	Depth (cm)	BS (%)	Exch-Ca (me/100g)	Exch-Mg (me/100g)	Exch-K (me/100g)	Exch-Na (me/100g)
Jasinga 1	Profile 1	0-20	102.90	27.60	23.70	0.58	0.52
		20-40	101.10	24.30	23.40	0.51	0.50
		40-60	86.60	19.20	22.70	0.43	0.37
	Profile 2	0-20	109.20	21.90	22.80	0.40	0.29
		20-40	121.10	26.30	30.90	0.40	0.32
		40-60	97.00	26.60	32.40	0.45	0.33
	Profile 3	0-20	50.70	10.10	22.00	0.10	0.35
		20-40	42.80	9.90	14.80	0.51	0.56
		40-60	51.30	11.20	16.30	0.48	0.27
Jasinga 2	Profile 1	0-20	91.33	18.33	22.13	0.74	0.29
		20-40	89.46	14.80	21.09	0.71	0.33
		40-60	58.45	13.64	23.59	0.71	0.36
	Profile 2	0-20	86.41	18.51	22.23	0.43	0.30
		20-40	82.12	14.72	25.35	0.51	0.29
		40-60	81.59	7.82	27.90	0.45	0.25
	Profile 3	0-20	102.76	26.48	23.23	0.30	0.32
		20-40	98.98	18.69	19.17	0.53	0.32
		40-60	99.12	19.01	19.76	0.46	0.32
Serpong	Profile 1	0-20	36.60	11.30	2.60	0.05	0.18
		20-40	56.40	14.60	2.90	0.06	0.30
		40-60	73.10	17.40	3.10	0.08	0.37
	Profile 2	0-20	65.60	11,00	2.30	0.09	0.19
		20-40	21.20	6.00	1.60	0.06	0.11
		40-60	48.30	10.60	1.90	0.07	0.16
	Profile 3	0-20	17.70	6.30	1.80	0.05	0.20
		20-40	26.60	8.90	1.90	0.05	0.19
		40-60	49.60	13.30	2.60	0.07	0.30

Base saturation (BS) in Table 2 ranges from 17.70% to 121.10%, indicating a spectrum from very low to very high. The soil base saturation value represents the percentage of the total CEC influenced by base cations, namely Ca, Mg, Na, and K. The BS value is crucial for considering fertilization and predicting the availability of nutrients to plants. Base saturation is closely related to soil pH; soil with low pH generally has low base saturation, while soil with high pH has high base saturation. However, Table 2 shows that the base saturation of paddy soil in the three research locations ranges from very low to very high due to variations in the level of fertilization during the rice planting process. On soils where intensive fertilization is frequently applied, it will result in higher base saturation than on those that are not intensive.

The low base saturation in Inceptisols soil in rice fields in Jasinga and Serpong may be attributed to the climatic conditions in tropical areas, which can subsequently affect the growth of rice plants. The low base saturation in Inceptisols in rice cultivation in Jasinga and Serpong is thought to be caused by tropical climate conditions which in turn can affect the growth of rice plants. Low base saturation, cation exchange capacity, and soil organic matter are caused by high rainfall and hot temperatures, thereby accelerating the leaching of base cations such as potassium (K), calcium (Ca), magnesium (Mg), and sodium (Na) so that soil pH increasingly sour [25, 26, 27]. Added by Barchia et al., Gusmini et al., and Herman et al. [28, 29, 30] high rainfall has an impact on the high replacement of aluminum (Al), iron (Fe), and hydrogen (H) which can be exchanged in the soil.

Table 3. Pearson correlation of organic materials with selected soil chemical properties in Inceptisols Ricefield in Java

Location	pH	N-Total	P-available	CEC	BS	Exch-Ca	Exch-Mg	Exch-K	Exch-Na
Jasinga 1	0.111	0.467	-0.37	0.063	0.063	-0.125	-0.484	-0.325	-0.025
Jasinga 2	**-0.667***	-0.003	0.569	-0.302	0.628	0.022	0.378	-0.402	**-0.783***
Serpong	-0.124	0.55	0.214	-0.384	0.441	0.437	0.518	0.057	0.137

Notes *= Very real (p<0.01)
**= Real (nilai p<0.05)

3.3. Correlation of Organic Matter with Chemical Properties of Selected Soil Inceptisols Paddy Fields in Java

The results of the correlation between organic matter content and selected soil chemical properties in Inceptisols in paddy fields at three locations can be seen in Table 3. At Jasinga location 2, organic matter was negatively correlated with pH and exchangeable-Na. The very real negative correlation of organic matter with soil pH and exchangeable-Na shows that the lower the soil organic matter content, the lower the soil pH value, and soil exchangeable-Na levels. The results align with the soil organic matter content showing low pH values and exchangeable-Na levels at all research locations. This shows that the low organic matter content at all research locations that have been in rice fields for approximately 30 years affects the organic matter content and chemical properties of the soil. In a study conducted over 20 years in Qiyang County in Yunan, long-term inorganic fertilizer (NPK) reduced the annual average soil pH by 0.07, while organic fertilizer increased the soil pH by approximately 0.04 [31]. Consistent with research results Voltr et al. [32], it is stated that the application of inorganic fertilizer without being accompanied by organic fertilizer had a negative effect on soil nutrient content and soil texture. The correlation of organic matter with soil chemical properties in Inceptisols in paddy fields at all research locations is in line with the importance of maintaining soil fertility, especially in the simultaneous application of organic matter and inorganic fertilizer.

4. Conclusions

The Inceptisols produced in rice fields exhibits quite good chemical properties, as indicated by various observational parameters. The research location in Jasinga showed better chemical properties compared to the location in Serpong. It is hoped that optimizing the use of Inceptisols in rice fields can improve the management of rice fields, allowing them to maintain soil fertility and provide nutrients to support plant growth and production. The very real negative correlation between organic matter content and soil pH and exchangeable-Na levels shows a direct relationship with the fertility of paddy soil. The use of organic materials and proper land management can serve as an alternative for the successful utilization of Inceptisols soil in paddy fields.

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