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Study on the potential of silica-available based on types of soil on the productivity of paddy field in West Java Province, Indonesia

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Abstract

The Si-available (Si_{ap}) content in the soil of paddy fields is decreasing, so it will affect decreasing the productivity of paddy fields. Soil type maps can be used to estimate the potential Si_{ap} content in paddy fields. The purpose of this study was to assess the productivity of the paddy field in West Java Province based on the Si_{ap} potential in each region using maps of soil types and paddy productivity data. This research was conducted in West Java Province. The research was carried out from February 2021 to March 2021. The research method used was the descriptive research method. This research is secondary data analysis so that no field test is carried out. The validation of the data from the analysis was based on the literature from the previous researchers. The parameters measured in this study were: the distribution of paddy fields, the percentage of soil types in each paddy field, the average productivity of paddy field on each type of soil, the distribution of paddy productivity levels, the potential for Si_{ap} to paddy productivity and map of the potential distribution of Si_{ap} in West Java Province. Secondary data obtained were then analyzed using spatial analysis and descriptive analysis. The results of the spatial analysis show that 77% of paddy fields in West Java have medium Si_{ap} potential, 17% low and 7% high. The results of the correlation analysis show that the productivity of paddy plants has a strong correlation (r = 0.99) to the Si_{ap} of paddy soil. The soil maps can be used to estimate the potential of Si_{ap} and the productivity of paddy plants. The Si application was recommended in paddy fields in the southern region of West Java Province.

Keywords: Land planning, paddy soil, productivity map, Si available.

Introduction

The National paddy filed productivity in 2019 based on data from the Central Bureau of Statistics (Badan Pusat Statistik, 2020) is 5.1 t/ha. The provinces of West Java, East Java and Central Java contributed to be the top three provinces with the highest paddy productivity in 2019, with average productivity of 5.8 t/ha. National paddy productivity and paddy productivity on the island of Java at the regional level of Southeast Asia, Indonesia, is still below the Vietnamese state's paddy crop's productivity, with the production of 5.88 t/ha (Foreign Agricultural Service, 2021). According to Adiningsih et al. (2000), the paddy fields productivity in Java is high, so increasing productivity is more challenging. The fertilization program recommended by the government still focuses on nitrogen (N), phosphorus (P) and potassium (K) fertilization (Husnain et al., 2020). Efforts to increase productivity on the island of Java, especially in West Java Province, need additional fertilization efforts and N, P and K. Silica (Si) is identified as a functional nutrient in paddy plants (Takahashi,

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1968). Some recent studies have strengthened the role of Si in paddy plants. Agostinho et al. (2017) and Pereira et al. (2004) stated that plants that were applied with Si fertilization had a high Si content in plant tissue and resulted in higher paddy productivity.

According to Wedepohl (1995), naturally, the Si content on the earth's surface is around 28% (Si-total), but the Si-available content is lower than the total Si content. According to Sumida (1992), Si available for paddy plants is a minimum of 300 mg SiO2/kg of soil. Paddy is a Si accumulator plant. Dobermann and Fairhurst (2000) stated that 480 kg of Si-available is removed from the soil of paddy field in a planting season. About 15% of Si-available paddy plants are removed out of the paddy fields. The process of transporting Si out of the fields in the form of husks and paddy straw. The Si content in paddy husks is about 10% of the biomass of the paddy plant. The management of paddy straw by burning can indirectly affect the available Si.

The burning of paddy straw in fields is a bad habit of most farmers in this country. The process of burning straw is considered more practical and makes it easier to cultivate the soil. The straw that is burned causes some nutrient loss of nutrients and they cannot be used by plants. The Si element in plant tissue will not be released into the air, but there is a change from Si-amorphous to Si-crystalline (Todkar et al., 2016). Several studies have shown that the use of paddy straw by fermentation as organic fertilizer can increase the paddy yields (Simarmata et al., 2016; Thammasom et al., 2016; Birnadi et al., 2019; Setiawati et al., 2020). The Si element available to paddy plants is in the amorphous form. Every time the harvest is continuously available, the Si reserves available in the long term will continue to decline. The continuously decreasing Si-available content causes the productivity of paddy plants to decrease. the effect of applying N, P and K fertilizers also decreases and the quality of the paddy produced decreases in protein and amino acid content (Liu et al., 2017; Nwajiaku et al., 2018).

The research conducted by Husnain et al. (2008) reported the Si availability of paddy soil varies in one area of the Citarum river basin. According to Dengiz (2020) soils in river basin areas show large variation even though over a short distance. The Si content is available in paddy soil, according to Liang et al. (2015), is influenced by basic material, soil type, land use, soil texture, soil pH, redox potential, organic matter content and environmental temperature. According to Savant et al. (1997), there is a relationship between soil types and available Si based on the USDA classification from the lowest available Si potential to the highest, namely Oxisols, Ultisols, Alfisols, Inceptisols, Vertisols and Mollisols. Identification of available Si potentials based on soil classification maps is an attempt to utilize soil type maps as a working map in land resource management planning (Grealish et al., 2015).

The scoring method or quantitative method is one of the methods in evaluating land resources. This method provides value to both qualitative data and quantitative data (Sitorus, 2010). The scoring is determined based on the results of the literature search. In the final assessment of this quantitative method, each parameter's score is added to obtain a total score. This total score is used to assess the potential status of Si in West Java Province. This study assessed the productivity of lowland paddy plants in each district/city based on the Si-available potential in each district/city. The research results are expected to provide recommendations for priority areas that require Si fertilization.

Material and Methods

Field description

The areas with the broadest paddy fields are Indramayu Regency, Karawang Regency and Subang Regency. The paddy field area in these three regions contributes 34% of the total paddy field area in West Java (Figure 1). Based on Indonesia's geomorphological map, the northern part of West Java is a depositional landform (alluvial plain). The central part is a volcanic landform and the southern part is a structural landform (Verstappen, 2014). The north coast region has rainfall less than 2000 mm per year based on morphoclimatic maps, including dry areas. However, the northern region of West Java Province is a lowland area through which rivers flow into the Java Sea. The availability of abundant water for irrigation water supports increased production throughout the year. The southern part of West Java and central West Java is included in the intermediate zone, where the average annual rainfall is above 2000 mm per year and below 3000 mm per year. A small proportion in the central region, especially in mountainous areas, has rainfall above 3000 mm per year (Perhumid).

Soil types in West Java paddy fields based on soil classification Dudal and Soepraptohardjo (1957) were dominated by Alluvial (35.28%) and Latosol (29.81%) types. The lowland paddy fields are dominated by Alluvial and Gleisol soils, while the paddy fields of latosol type are dry land that is tilled. The classification of soil types in paddy fields is determined by the classification of the soil from which it originates

(Hardjowigeno et al., 2004). Alluvial soil characteristics as young soil have varied textures, sticky consistency when wet and soil fertility is generally moderate to high. Moderate to high fertility variations are influenced by soil fertility on the upper slopes because alluvial soils are formed in river alluvial plains, coastal alluvial plains and basin areas (Sartohadi et al., 2014). The lower slope area is generally affected by soil deposition from the upper slope due to erosion. According to Hardjowigeno (2003), soil type Latosol has soil weathering characteristics, including advanced acid soil pH (4.5-5.5), low organic matter content and silica leaching.

This research was conducted from February 2021 till March 2021. The research location was in the administrative region of West Java Province at the geographic position (5˚50'- 7˚50' South Latitude and 104˚48'- 108˚ 48' East Longitude). The study area was illustrated in Figure 1. The materials and tools used in this research were:

Materials:

1. Data on paddy production and West Java Province's productivity in 2019 from the Central Bureau of Statistics (Badan Pusat Statistik, 2020).
2. Map of Indonesia's Earth (RBI) West Java Province from Geospatial Information Agency (2021).
3. Map of West Java Province soil types from the Regional Development Planning Agency of West Java Province.
4. Map of West Java province land cover from the Regional Development Planning Agency of West Java Province.

The equipment used is a laptop that contains the Arc Gis 10.1, SPSS 19, MS Office 2010 program.

Methods

This present study used the descriptive research method. The parameters observed in this study were: the distribution of paddy fields in West Java Province, the percentage of soil types in each paddy field, the average productivity of paddy plants on each type of soil, the distribution of paddy productivity levels, the potential for Si-available to paddy productivity and map of the potential distribution of Si-available in West Java Province. Secondary data obtained were then analyzed using spatial analysis, regression analysis and descriptive analysis presented in Table 4 and Figure 1 - 6. This research activiy is divided into several stages, namely secondary data collection, data input, data analysis and data presentation. The data collection process is carried out using digital exploration through the Central Statistics Agency, the Development Planning Agency, the Geospatial Information Agency through https://portal.ina-sdi.or.id/. The collected data is then processed using Arc GIS and MS Excel.

Data processing is in the following stages:

1. Overlay land use maps of paddy fields, administrative maps of West Java Province and maps of soil types. The overlay results map is then completed with paddy productivity data per district/city in the attribute table. The approach method used in filling paddy productivity data is the average productivity data from each district. The paddy field polygon data in the same administrative area have the same productivity value.
2. the next stage is the classification of paddy productivity levels in West Java into three classes: low, medium and high. The method of determining the interval for each class uses the following equation (Sudjana, 2005):
   - Interval = X max – X min
   - Number of classes = 3 (low, moderate and high)
   - Class length = $\frac{\text{Interval}}{\text{Number of classes}}$

Table 1. Paddy productivity category in West Java

Paddy Productivity (t/ha)	Class
X ≤ 5,4	Low
5,4 < X < 5,8	Moderate
X ≥ 5,8	High

3. Si's potential is determined by the scoring method, which is a method used to assign a value to each type of soil (Sitorus, 2010). The Si potential scoring refers to Liang et al. (2015) with modifications in scoring. The scoring is based on the USDA classification Histosol = 1, Oxisol = 2, Ultisol = 3, Alfisol = 4, Inceptisol = 5, Vertisol = 6 and Andisol = 7. Paddy productivity category in West Java.

Table 2. Si potential score based on soil type

Dudal and Soepraptohardjo (1957)	USDA*	Si-available Potential Score
Organosol	Histosols	1
Red Yellow Podsolik	Ultisols	3
Mediteran	Alfisols	4
Gleisol	Inceptisols	5
Litosol	Entisols	5
Alluvial	Entisols	5
Regosol	Entisols	5
Latosol	Inceptisols	5
Brown Podsolik	Inceptisols	5
Grumosol	Vertisols	6
Andosol	Andisols	7

Note: * The conversion of Dudal and Soepraptohardjo (1957) classification to USDA based on Subardja et al. (2014)

Data of the table for each soil type in the overlapping map are then scored according to soil types classification. The available Si potential was then classified into three categories, namely low, medium and high. Determination of the interval in each potential class Si - available using the equation from (Sudjana, 2005).

– Interval = X max – X min
– Number of classes = 3 (low, moderate and high)
– Class length $=\frac{\text{Interval}}{\text{Number of classes}}$

Table 3. Potency class Si-available

Si-available potential score	Class
$X \leq 4$	Low
$4 < X < 5$	Moderate
$X \geq 6$	High

4. Determination of paddy field area based on soil type and paddy field area based on available Si potential using spatial analysis. Spatial analysis is carried out by projecting maps from the World Geodetic System 1984 (WGS-84) coordinate system to The Universal Transverse Mercator (UTM) 48 S and 49 S. The UTM 48 S and 49 S projections are used because the administrative territory of West Java Province is located in two zones.

Results

The spatial analysis of paddy fields with the most significant area is concentrated in the Karawang, Subang and Indramayu regions. The deep green colour (Figure 1) in the northern part of West Java indicates vast paddy fields in that area. Meanwhile, in the southern part of West Java, there are fewer paddy fields.

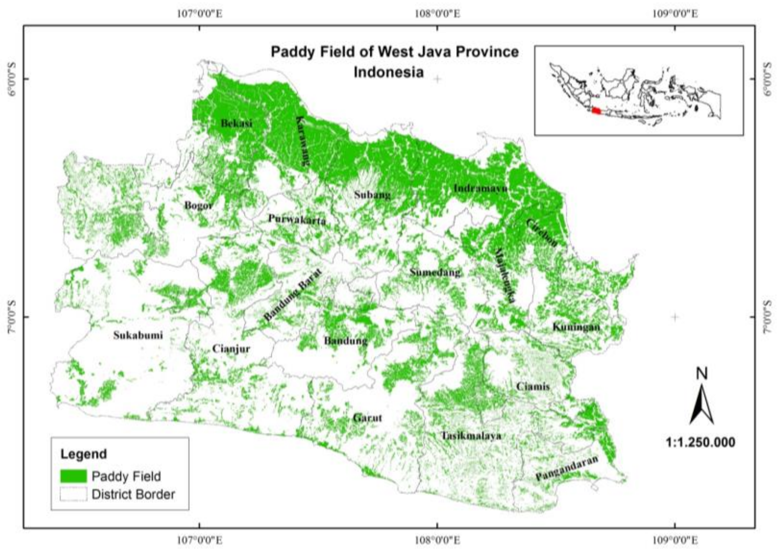

Figure 1. Output of spatial analysis paddy field West Java Province

Based on the soil type classification map Dudal and Soepraptohardjo (1957) from Regional Development Planning Agency (Bapeda) West Java Province shows that the paddy fields in West Java (Figure 2) with the most significant percentage are Alluvial soil types (35.28%).

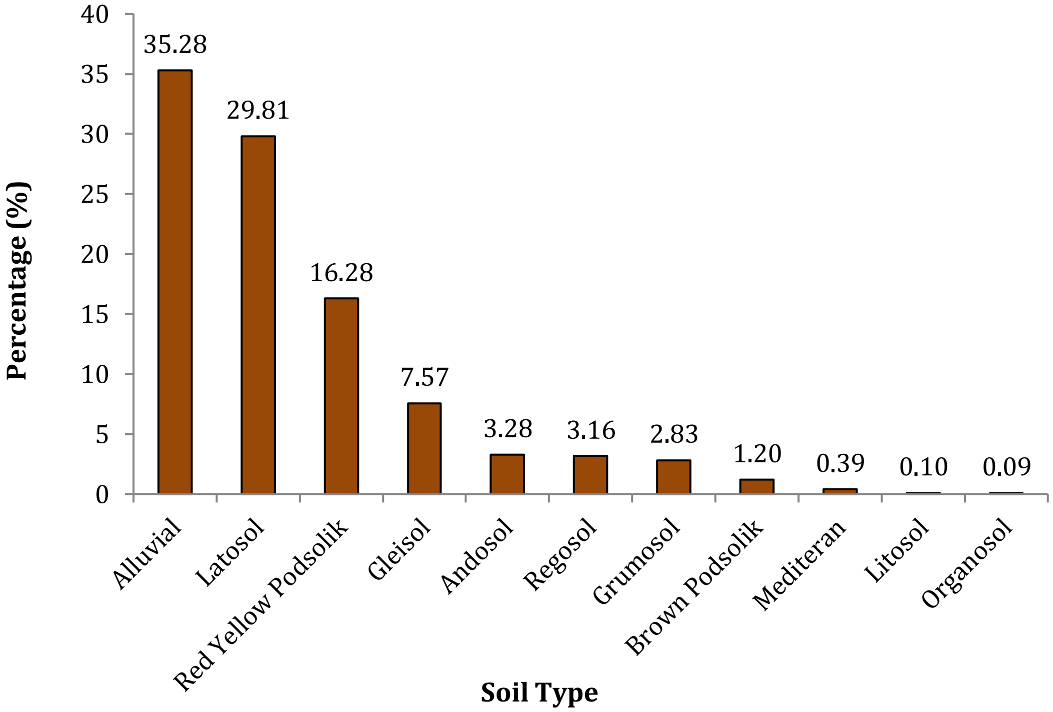

Figure 2. Percentage area of soil type West Java Province

The results of the analysis of paddy productivity data in 2019 from the Central Bureau of Statistics of West Java Province (Badan Pusat Statistik Provinsi Jawa Barat, 2020) and the soil type classification map based on Dudal and Soepraptohardjo (1957) from Bapeda West Java Province showed that Gleisol, Litosol andosol and Alluvial soil produced average paddy productivity of more than 5.8 t/ha (Figure 3).

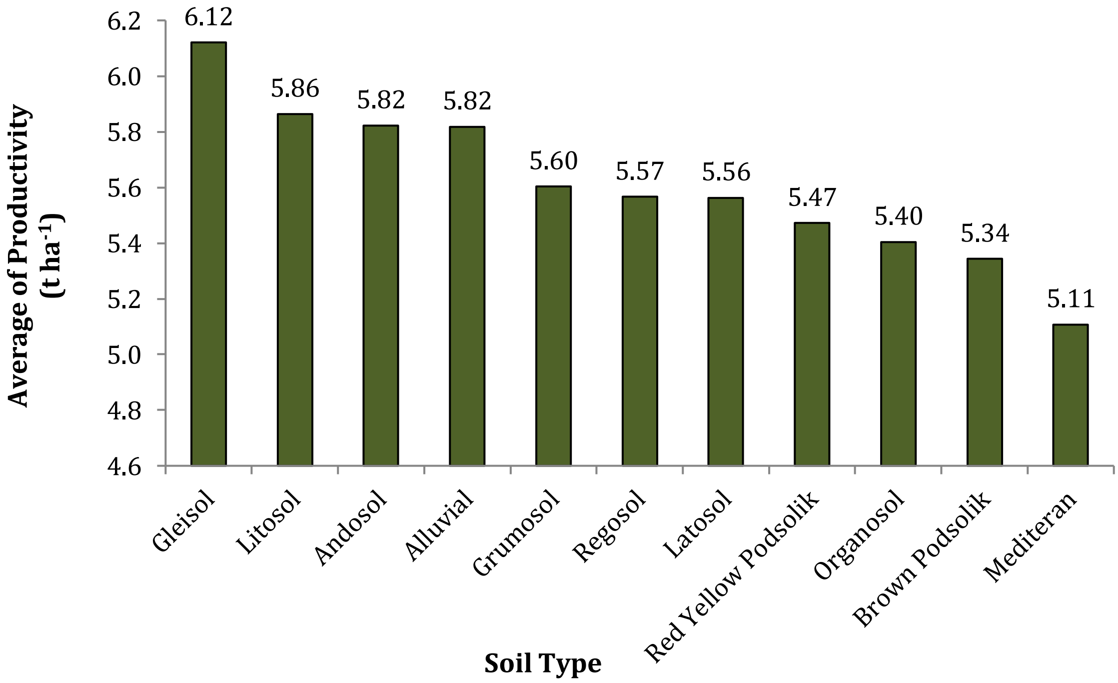

Figure 3. Graph of paddy productivity 2019 West Java Province based on soil type

The results of spatial analysis of paddy productivity levels in West Java Province (Figure 4 B) areas with a high average category of paddy productivity (> 5.9 t/ha) are primarily located in the northern part of West Java. The percentage of paddy fields in West Java with high productivity category is 44.78%, medium productivity is 35.65% and low productivity is 19.56%.

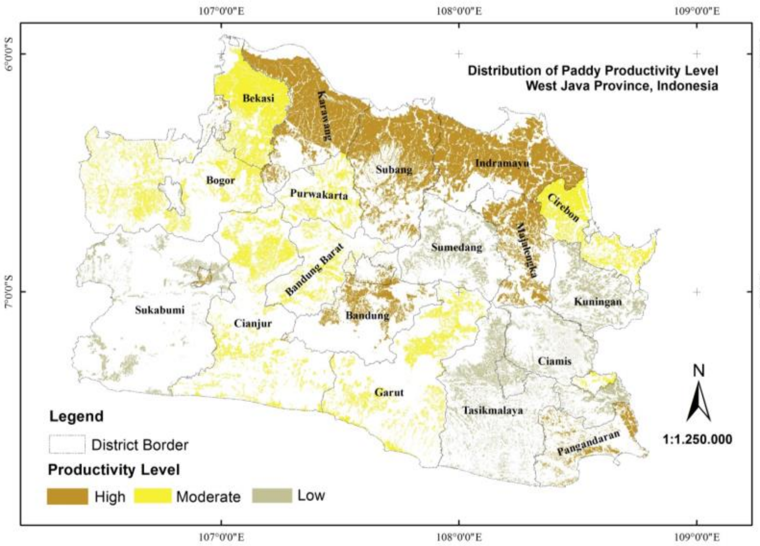

Figure 2. Output of spatial analysis (A) Soil type distribution of paddy field (B) Distribution of paddy productivity level

The results of the regression analysis of paddy productivity on the Si-available level (Figure 5) obtained a correlation coefficient of 0.99, which indicates a very high correlation (Sugiyono, 2012). The correlation coefficient value is positive, indicating that the increase in Si content will affect the increase in paddy productivity.

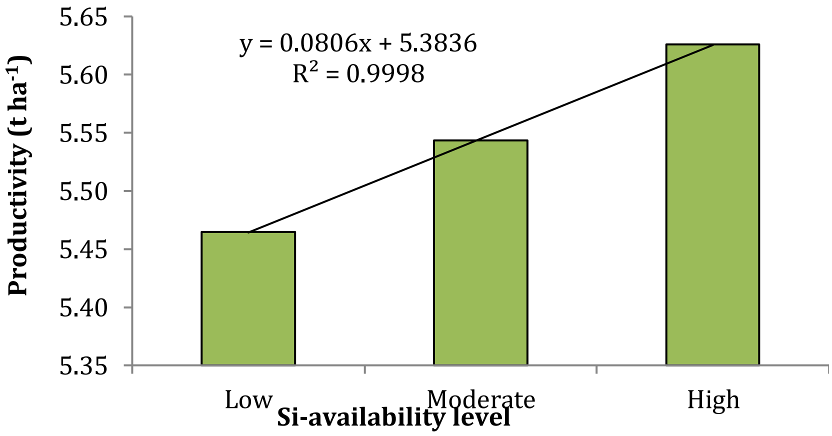

Figure 3. Graph of potential Si-availability level to paddy productivity

The spatial analysis results of the distribution of paddy productivity levels and Si-available levels (Figure 6) show that the productivity of medium and high paddy plants are in areas that have moderate and a high potential for Si-available. Meanwhile, areas that have low productivity are in areas that have low Si-available potential.

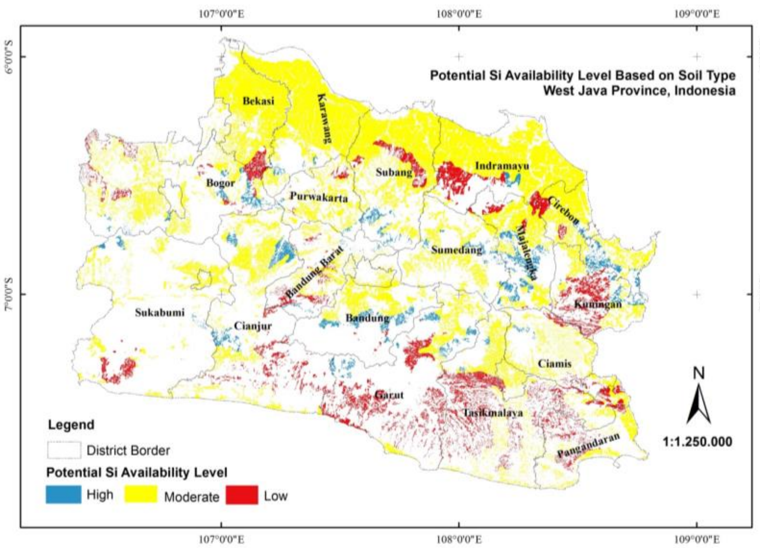

Figure 4. Distribution of Si-availability level based on soil type

The cross-tabulation of paddy field area based on productivity level and available Si level (Table 4) shows that low paddy productivity came from low to high Si-available paddy fields was 18.58%. The percentage of land with low productivity in paddy fields with high Si potential is 0.99%. Paddy productivity is being planted in paddy fields with a low to moderate Si-available potential of 32.62%. Medium paddy productivity in paddy fields with high Si-available potential is 3.03%. Paddy productivity is high in paddy fields with a low to medium Si-available potential of 42.04%. Paddy productivity is high in paddy fields with a Si-available potential of 2.75%.

Table 4. Cross-tabulation of the percentage of paddy field area based on the level of productivity and the level of Si-available

Paddy productivity level	Paddy field area (%)		
	Si-available potential level		
	Low	Moderate	High
Low	5.97	12.61	0.99
Moderate	6.83	25.79	3.03
High	3.82	38.22	2.75

Discussion

Forty-two percents of paddy fields in West Java Province are in the northern part, while the rest are scattered in the central and southern parts of West Java. The spatial analysis of soil types with productivity data (Figure 3 and 4) shows that the Gleisol soil type has the highest average productivity of 6.12 t/ha. The lowest is the Mediterranean type of 5.11 t/ha. Although Gleisol land has the highest productivity, it covers only 7.6% of the total paddy field area in West Java. The soil of Gleisols is constantly saturated with water and has a greyish colour. Soil types with the most significant percentage, namely Alluvial, Latosol and Red Yellow podsolic, have average paddy productivity of 5.82 t/ ha, 5.56 t/ha and 5.47 t/ha, respectively. The difference in productivity reduction from Alluvial soil type to Latosol soil type is 0.29 t/ha. The existence of paddy productivity differences in each type of soil provides information that paddy field management needs to adjust to the characteristics of the type of soil it originates. The Ministry has made the method of providing site-specific fertilizers of Agriculture of the Republic of Indonesia into a national program (Husnain et al., 2020). Soil type does not directly affect productivity, but different soil types have different characteristics, including soil fertility.

The regression analysis results (Figure 5) show a linear increase in paddy productivity with an increase in the potential of Si-available. According to Lavinsky et al. (2016) and Ning et al. (2016), fulfilling the Si needs of paddy plants in the reproductive phase will increase the number of seeds and weight of seeds. Meeting the need for available Si helps increase nutrient uptake of paddy plants N, P and K so that the efficiency of nutrient use and biomass formation also increases (Rao et al., 2019). The Si element in paddy plants and increasing nutrient uptake also helps plants minimize stress due to salinity, especially in paddy fields adjacent to coastal areas (Coskun et al., 2016).

The spatial analysis results (Figure 6) show that paddy fields with moderate and high paddy productivities are primarily located in northern West Java. Meanwhile, the southern part of West Java has a low level of productivity. The cross-tabulation of paddy field area based on the level of paddy productivity and the available Si potential level (Table 4) showed several anomalous conditions, including the percentage of land with high available Si potential, only 2.75%, which resulted in a high level of paddy productivity. Meanwhile, there is 3.82% of the land at the low Si-available potential, which produces high paddy productivity. The area of paddy fields with the potential level of Si-available in the medium category produces medium and high productivities levels of 64.01% of the total paddy field area in West Java. Alluvial and Latosol soil types with the most significant percentage affected the high land percentage with moderate Si-available potential.

Conclusion

The study shows that the productivity of paddy plants has a strong correlation (r=0.99) to the Si-available of the paddy soil. The soil map can be used to estimate the potential of Siap and the productivity of paddy plants. Further research is needed to determine the dose of Si fertilization based on the Si-available potential of paddy soil.

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