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Assessing the available silica of paddy soil on different landforms

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Abstract

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Fertilization of paddy plants with nitrogen (N), phosphorus (P), and potassium (K) fertilizers that has been ongoing so far has not reached the expected yield potential. The limited availability of Si in paddy soil affects paddy crop productivity and nutrient uptake of N, P, and K. This research aimed to study the effect of landform position on available Si of paddy soil and the relationship of soil chemical properties to available Si. The research method used was a survey research method using a purposive sampling technique based on a unit map of paddy soil. On the lower volcanic slope, five samples of soil and irrigation water were taken. In the lacustrine basin landform, five soil and water samples were taken. Soil and water samples were then analyzed for available Si content in soil and water, soil and water pH, cation exchange capacity (CEC), electrical conductivity (EC), C-organic, carbonate content ($CaCO_3$), redox potential. The results of the laboratory analysis were then one-way variance analysis at 5% significance level and correlation-regression analysis. The results showed that the position of the landform did not affect the available Si content. The following variables, namely soil pH (r=0.75), CEC (r = 0.71), soil EC (r = 0.75), water pH (r = 0.90), and water EC (r = 0.75) had a moderate to strong relationship with the available Si of paddy soil. Water's pH and EC value are the potential to be used as easy and practical indicators in estimating the available Si of paddy soil.

Keywords: electrical conductivity; lacustrine basin; practical indicators; volcanic slope

Introduction

Silicon (Si) is one of nutrients needed by paddy plants. Paddy plants are Si accumulator plants, so that the availability of Si in the soil needs to be considered to support the growth and productivity of paddy plants (Savant et al., 1997). Efforts to increase paddy productivity can be through fertilization and pest-disease control. Fertilization of lowland paddy commonly done in Indonesia is nitrogen (N), phosphorus (P) and potassium (K) application given either in the form of single fertilizers (urea, superphosphate, potassium chloride) or compound fertilizers (NPK). Si fertilization is still rarely done by farmers, even though Si is the fourth largest element needed by paddy plants (Gong et al., 2012). The fulfillment of Si for the paddy plant increase the tolerance of paddy plants to biotic and abiotic stresses (Crooks & Prentice, 2017). Biotic stresses that affect growth include insect, fungal and bacterial attacks. Abiotic stresses on paddy plants include water availability, sunlight intensity, salinity and nutrient deficiency.

The decrease of Si in paddy fields occurs because after harvest only a small part of the biomass of paddy plants is returned to the soil. After harvesting, paddy farmers generally burn the straw while the rice husks are rarely returned to the fields (Husnain et al., 2008). The source of organic Si are

Straw and rice husks. According to Dobermann & Fairhurst (2000) Si content in straw is 5% to 6% and grain is 10%. If straw and rice husks are not returned to the soil every harvest, the potential for Si loss is 15%. The availability of Si in the long term will decrease if the return of paddy plant biomass and the addition of Si in the form of fertilization is not carried out. According to Darmawan et al. (2006) the available Si content of paddy fields on the Island of Java (top soil 0-20 cm) in a 33 year period (1970-2003) decreased by 18.6%. The Si content on the surface of the earth's crust is about 28.8% but the availability of Si in paddy soils varies (Abe et al., 2016; Quigley et al., 2017). According to Liang et al. (2015) Si availability is influenced by soil type, parent material, land use, soil pH, texture, redox potential, organic matter, temperature and ions in the soil.

The city of Bandung is morphologically located in a basin surrounded by volcanic mountains, paddy fields develop from lake sedimentary rocks, have a lacustrine basin landform, middle volcanic slopes and lower volcanic slopes (Indonesian Agency for Agricultural Research and Development, 2017; Dam et al., 1996; Geological Research and Development Center, 2003). Measurement of Si content in paddy fields in Bandung City is needed as a reference for determining Si fertilization and studying Si available at different landform positions.

Materials and Methods

This research had carried out from August-October 2021 in the city of Bandung, West Java, Indonesia (longitude: 107° 36′ and Latitude: 6° 55′). The research method used was a survey method. The determination of the survey location was based on the map of the paddy field unit obtained from the results of overlapping maps of soil types, paddy fields use and geological maps (Qurrohman et al., 2022). The results of the overlapping maps were then used to determine the sample points at each landform position (lower volcanic slopes and lacustrine basins). The position of this landform was chosen based on toposequence considerations.

The sampling method of paddy soil on each land map unit was carried out purposively. The total number of soil samples taken was 10, namely five location on the lower volcanic slope landform and five in the lacustrine basin (Table 1). The paddy soil samples were then analyzed for available Si (acetate buffer method) (Imaizumi & Yoshida, 1958), soil pH (pH H_2O method), redox potential, electrical conductivity (EC) and cation exchange capacity (CEC) (NH_4Oac 1M Extract method, pH 7) (International Institute of Tropical Agriculture, 1978) at the Indonesia Soil Research Institute. The data from the laboratory were then analyzed using one-way variance analysis (ANOVA) to test whether there were a difference in Si content in paddy soil on lower volcanic slope and lacustrine basin. Correlation analysis was conducted to determine the relationship between available Si and soil pH, redox potential, EC and CEC (Figure 1).

Result and Discussion

Soil characteristics and parent material of the study area

The soil located at lower volcanic slopes includes Udepts or Cambisols (FAO/WRB soil taxonomy) and the lacustrine basin includes Aquepts (USDA soil taxonomy) or Gleysols (FAO/WRB soil taxonomy) based on the soil map from Indonesian Agency for Agricultural Research and Development (2017). Differences in sub-orders in the study area are influenced by topography. The soil on the lower volcanic slopes was on average at an altitude of ± 825 m above sea level (asl) while the lacustrine basin landform is at ± 685 m above sea level.

Table 1. Soil taxonomy, parent material and research location coordinates

No.	Landform	Soil sub group	Parent matterial	Relief	Code	Elevation, m	Longitude (Decimal degree)	Latitude (Decimal degree)
1	Lower volcanic slope	Typic Dystrudepts (Cambisols)	Tuf andesit-basalt	Steep	UJB I	873	107.712	-6.89309
2					UJB II	854	107.712	-6.89445
3					UJB III	809	107.711	-6.89686
4					CBR I	792	107.718	-6.91290
5					CBR II	798	107.719	-6.91144
6	Lacustrine Basin	Typic Endoaquepts (Gleysols)	Clay and sand deposits	Plains	RNC I	683	107.712	-6.95273
7					RNC II	684	107.710	-6.96300
8					CNC I	683	107.701	-6.94460
9					CNC II	683	107.705	-6.94420
10					PNY I	692	107.707	-6.93439

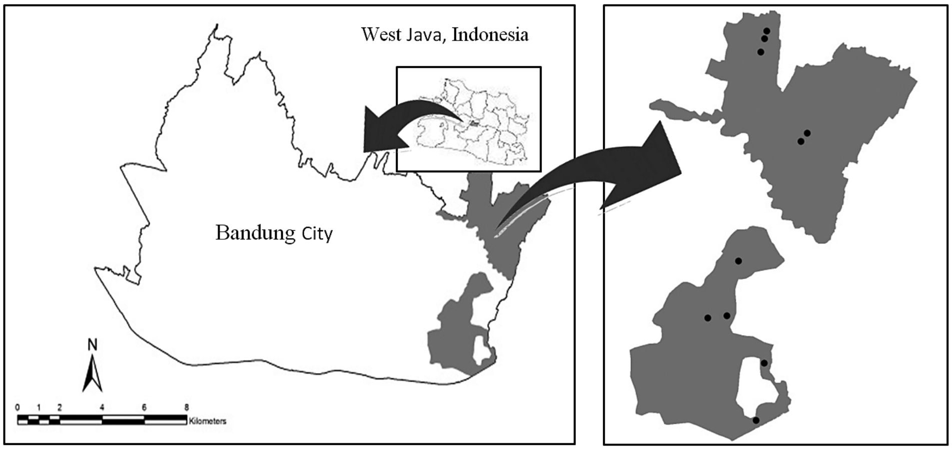

Fig. 1. Research locations and sampling points

At the higher landform (Figure 2a, b, c), the soil conditions will alternately undergo a reduction and oxidation process depending on the availability of water and rainfall. The lowland area (Figure 2d, e, f) was inundated for longer (reduction) than the higher area. Visually, the soil at the lower volcanic slope had brighter color than soil from basin lacustrine (black and gray).

The process of soil formation comes from different parent materials (Table 1). The parent material comes from igneous rocks on the lower volcanic slopes, while the basin comes from sedimentary rocks. The two types of rock formed in the study area originate from volcanic activity.

Effect of landform position on chemical properties of soil and irrigation water

The one-way ANOVA results (Table 2) α = 5% revealed that landform position only affected soil pH, oxidation-reduction potential (redox), cation exchange capacity (CEC),

Fig. 2. Actual conditions on lower volcanic slopes (a), (b), (c) and lacustrine basins (c), (d), (e). (a) UJB I location code, (b) UJB II location code, (c) UJB III location code, (d) PNY I location code, (e) CNC I location code, (d) RNC II location code

Table 2. Chemical properties of soil and irrigation water at different landform positions

No.	Chemical properties	Unit	Postition Landform	
			Lower volcanic slope	Basin Lakustrin
			Soil	
1	Si-available^{ns}	ppm	376.80 ± 70.10	543.20 ± 45.31
2	pH (H_2O)*	–	5.92 ± 0.06	6.90 ± 0.12
3	Electrical Conductivity^{ns}	mS/cm	0.08 ± 0.01	0.2 ± 0.04
4	Redox Potential*	mV	447 ± 3.39	425.40 ± 4.63
5	Cation Exchange Capacity (CEC)*	mmol^{+}/kg	166.3 ± 6.0	282.4 ± 18.7
6	Carbon-organic^{ns}	%	2.22 ± 0.1	2.77 ± 0.24
7	$CaCO_3$*	%	0	1.27 ± 0.21
			Irrigation water	
8	Si ^{ns}	mg/L	24.31 ± 3.72	23.37 ± 2.69
9	pH^{ns}	–	7.06 ± 0.14	7.32 ± 0.06
10	Electrical Conductivity*	mS/cm	0.22 ± 0.03	0.71 ± 0.05

Notes: * Significant (P < 0.025); ns: non significant

$CaCO_3$ content and electrical conductivity (EC) of irrigation water. The position of the landform did not affect the available Si content, EC of paddy soil, C-organic and Si of irrigation water. The analysis results showed that the average available Si content was 376.80 ± 70.10 mg/kg on volcanic slopes and 543.20 ± 45.31 mg/kg on lacustrine basin landforms. The rock and soil parent materials originating from volcanic activity caused the available Si content of paddy soil in both landforms to be relatively homogeneous. Park et al. (2019) revealed that the available Si content of soil originating from volcanic activity has higher available Si.

The relationship of available Si to soil pH, EC, redox potential, CEC and C-organic

Based on polynomial regression analysis (Figure 3) was found that the available Si of paddy soil had a strong relationship to pH-(H_2O), electrical conductivity (EC) of irrigation water, cation exchange capacity (CEC), soil pH and EC. The relationship of available Si to the C-organic content of the soil was moderate. The available Si of paddy fields had a weak relationship with the Si of irrigation water and the redox potential of the soil.

Based on Figure 3a, an increase in soil pH from 6-8 can increased the available Si. The availability of Si in alkaline soils was higher than in acidic soils (Sandhya & Prakash, 2019). According to Do Carmo et al. (2016), pH was a regulator that regulates the availability of ions in the soil. The results of Mahendran et al. (2021) showed a strong relationship between available Si and soil pH.

The relationship between available Si and electrical conductivity (EC) (Figure 3b) of soil including to strong (r = 0.75), the increase in soil EC, increases available Si. Electrical conductivity was an indicator of the content of dissolved ions in the soil (Do Carmo et al., 2016).

The relationship of available Si to oxidation-reduction potential was categorized as low. An increase in the reduction-oxidation potential (redox) value means the paddy field is inundated for longer. Conversely, the paddy soil with a lower redox potential indicates that the paddy field was inundated for a shorter time. Figure 3c shows the higher available Si content at the lowest redox value. The research results of Siregar et al. (2016) revealed that the available Si content is higher in fields that are flooded alternately compared to fields that are flooded continuously. The results of this study confirmed that the regulation of paddy soil drainage at each phase of rice plant growth provides an opportunity for rice plants to meet the needs of Si (Haque et al., 2017).

The relationship of available Si to soil CEC was categorized to moderate (r = 0.71), increase in soil CEC (Figure 3d) followed by an increase in available Si in paddy soil. Paddy soil that had a high CEC will have higher available Si content. The element Si can be utilized by plants in the form of H_4SiO_4 (anion $Si(OH)_3O^-$ dan $Si(OH)_2O_2^{2-}$) (Liang et al., 2015). According to Hazelton & Murphy (2016), CEC acts as a buffer against changes in soil pH to increase available Si indirectly.

Soil C-organic content to available Si had a moderate relationship (r = 0.61), Figure 3e shows an increase in C-organic with increasing available Si content (López-Pérez et al., 2018). Present study indicated that the addition of organic matter was needed to increase the available Si derived from the biogenic Si decomposition process. Giving rice straw organic matter to paddy fields was an easy way for Si fertilization (Birnadi et al., 2019).

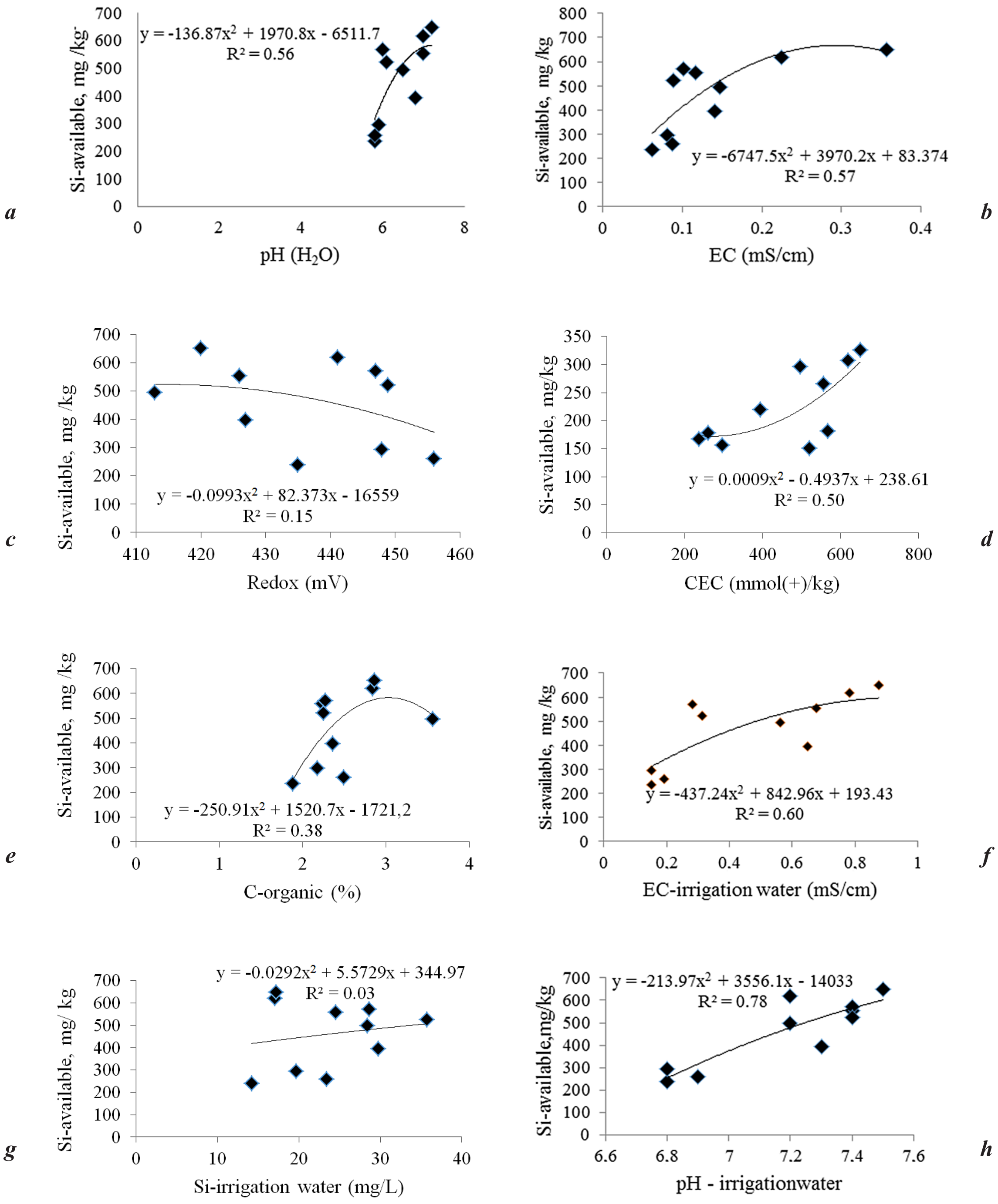

Fig. 3. Regression equation of 2nd order available Si polynomial (a) soil pH (H_2O); (b) Electrical conductivity; (c) Redox potential; (d) Cation exchange capacity; (e) C-organic; (f) the electrical conductivity of irrigation water; (g) Si irrigation water and (h) irrigation water pH

The relationship of available Si in paddy soil to Si-water, pH-water and EC-water

The relationship between irrigation water's electrical conductivity (EC) and available Si was categorized strong (r = 0.75). The increase in the value of EC gradually increased the available Si content of paddy soil. These results indicated the potential to be used EC of water as an indicator of available Si. The EC value were potential to be used as an indicator of available Si was specific in applications for areas not adjacent to the coast region. The relationship between the Si content of irrigation water and available Si in paddy soil was weak (0.28). The available Si content of paddy soil was influenced by its natural Si content. According to Husnain et al. (2008), soil derived from volcanic rock parent material has a high available Si content. The Si-water was influenced by the condition of the rock or soil through which the water flows. The content of available Si in irrigation water (17-35.73 mg/L) helped meet the Si requirement of paddy plants. If the height of the irrigation water puddle (0.05 m) and the land area is 10,000 m^2 (1 ha), then in each inundation period, an additional available Si 9–18 kg/ha.

The relationship between available Si and irrigation water pH was strong (r = 0.90). Si solubility increased at water pH higher than 7. An increase in pH could increase the availability of Si, but of course, the increase in pH needed to be adjusted to not interfere with the absorption of macro and micronutrients.

Conclusions and Suggestion

The position of the landform did not affect on the available Si of paddy soil. The available Si content of paddy soil was influenced by the pH of irrigation water, soil pH, soil electrical conductivity (EC), and Cation Exchange Capacity (CEC).

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