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# Relationships between Soil Properties and Rice Growth with Steel Slug Application in Indonesia

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**Abstract**

In the presence study representative rice producing sites in Lampung, Central Java and West Java Province was presented, the relationships between soil properties, rice growth and yield, and further evaluated the effect of Si application on rice growth and yield in different soil types were carried out using local steel slug, which was the most common material as the Si amendment. The soil samples were acidic to neutral with textural classes were clayey, loam and sandy clay loam. Mean nitrogen and available P content was below the value in tropical Asia. Silica availability has been decreasing in rice fields in Indonesia and Si deficiency in rice is now recognized as a possible limiting factor rice production. Steel slug, which has a high Si content and locally available, was selected as a potential source of Si in the present study. A greenhouse experiment was carried out to evaluate the effect of steel slug on rice growth in different soil types. Steel slug was applied at the rates of 0, 20, 50, 100, 200 and 300 kg Si/ha. Steel slug application increased plant height at 300 kg Si/ha. Grain yield of soils that contained low available Si was increased with steel slug application. In contrast, some soils with high available Si content did not respond to Si application and other soil properties affected rice growth.

**Keywords:** silica, Java, Lampung, grain yield

## 1. Introduction

Rice is the major staple food in Indonesia and the third in the world in regards to total rice production. The production of lowland rice is highly concentrated in Java, followed by Sumatera and Sulawesi. The average yield of rice grain is higher in Java (5 ton/ha) than in other regions (4 ton/ha). The share of harvested area and production of rice in Java from 1998 to 2002 has been nearly constant at around 51 percent. However, presently, Indonesia became the world's 7$^{th}$ largest rice importer over the past 5 years; on average requiring over 1.1 million tons of imports per year as a result of increasing population. Of the top ten global rice producing nations, only the Philippines and Indonesia also rank in the top ten of all rice importers (FAS-USDA, 2012; FAO, 2005).

Rice is cultivated more than 2 seasons per year in Indonesia. This intensive rice cultivation may degrade soil fertility and decline the yield. There have been several works on nutrient-balance studies majorly focusing on macronutrients such as nitrogen (N), phosphorus (P) and potassium (K). Arafah and Sirappa (2003) working on Inceptisol in South Sulawesi with low N, available P and exchangeable K content, found that N fertilizer was needed for increasing the growth and yield of rice. Nitrogen and K significantly influenced rice yields and biomass production in Jakenan-Central Java (Boling et al., 2004). According to Abdulrachman et al. (2006) from 21 cropping seasons (or 10.5 years of intensive cropping), they indicated that with balanced fertilization of N, P, and K grain yield averaged 5.5 ton/ha in the dry season and 6.5 ton/ha in the wet season. They also found that in West Java, farmers believed that the natural supply of K in the soil is sufficient for high rice yields and have never applied fertilizer K to their rice fields, but fertilizer K application increased the yield by 10 ton/ha across the 21 seasons. Sofyan et al. (2004) made a map of the nutrient status of N, P, K, Ca and Mg in rice field in Java and other islands for better fertilizer management in Indonesia. However, rice growth also depends on the other nutrients such as micronutrients and silica (Si). Repeated cropping and the constant application of chemical fertilizers have probably depleted micronutrients.

Silica is present in plants in amounts equivalent to those of such macronutrient element as calcium (Ca), magnesium (Mg) and P (Epstein, 1999). Rice plant obviously required Si to maintain healthy growth and high productivity. Although Si is recognized as the non-essential element for rice plant, rice plant uptakes Si ranging from 230 to 470 kg Si/ha, two times higher than N uptake (Savant et al., 1997). Silica increases rice resistance to leaf and neck blast, sheath blight, brown spot, leaf scald and stem rot (Datnoff & Rodrigues, 2005) and decreases the incidence of powdery mildew in several crops (Fauteux et al., 2005). Silica also alleviates many abiotic stresses including chemical stress (high salt, metal toxicity, nutrient imbalance) and lodging, drought, radiation, high temperature and freezing. An awareness of Si deficiency in soil is now recognized as being a limiting factor for crop production (Ma & Yamaji, 2006). Silica indirectly improves the P utilization efficiency of plant (Ma & Takahashi, 1990). The effect of silica on the growth of rice plant is most remarkable at the reproductive stage (Ma et al., 1989).

Available Si in rice fields in the whole of Java in Indonesian decreased by approximately 17-22% during the period 1970-2003 (Darmawan et al., 2006). With regard to mineral composition, many Indonesian soils contain low Si and high iron, aluminum and manganese (De Datta, 1981). The lower soil Si content was found to be severe in intensive rice field where enormous Si uptake is not followed by sufficient Si replenishment (Husnain et al., 2008). Soil is always at risk of Si depletion due to the large amounts of Si removal by plants. Husnain et al. (2009) found that dissolved silica in irrigation water, which is a main Si source to rice field, decreased through Si trap by diatoms in dams in the Citarum watershed. This phenomenon could be accelerated by N and P enrichment caused by chemical fertilizer usage in uplands and fish culture in the dams. This Si depletion in rice fields might be a reason for the recent fluctuation and stagnancy in rice productivity in Indonesia. Hence, there is need to study the actual effect of available Si in relation to this fluctuation in rice yield.

In the presence study, we selected representative rice producing sites in Lampung, Central and West Java Province and examined the relationships between soil properties, rice growth and yield, and further evaluated the effect of Si application on rice growth and yield in different soil types. We used local steel slug, which is the most common material as the Si amendment.

## 2. Materials and Methods

### *2.1 Site Selection for Soil Sampling*

Ten sites were selected to collect representative soil samples from main rice production areas as show in Table 1.

Table 1. Location and fertilizer doses of study sites

| Site No | Village | Regency | Province | Coordinates | | SP-36 | KCl | Urea | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Basal | Top dressing |
| | | | | | | -----------------------kg/ha------------------- | | | |
| Site 1 | Bolo Agung | Pati | Central Java | 06°51'34.0"S | 111°01'26.0"E | 75 | 50 | 150 | 150 |
| Site 2 | Dari | Sragen | Central Java | 07°43'81.8"S | 110°89'98.1"E | 50 | 100 | 150 | 150 |
| Site 3 | Rancaekek | Bandung | West Java | 06°54′53.08″S | 107°36′35.32″E | 50 | 50 | 150 | 150 |
| Site 4 | Bojong Kulon | Cirebon | West Java | 06°37'46.2"S | 108°22'05.2"E | 50 | 50 | 150 | 150 |
| Site 5 | Hegarmanah | Cianjur | West Java | 06°48'24.9"S | 107°11'09.6"E | 50 | 50 | 150 | 150 |
| Site 6 | Batukarut | Bandung | West Java | 07$^0$02'54.3"S | 107$^0$36'09.8"E | 50 | 100 | 150 | 150 |
| Site 7 | Majangsari | Garut | West Java | 07°03'14.3"S | 107°56'03"E | 100 | 50 | 150 | 150 |
| Site 8 | Sinar Galih | Garut | West Java | 07°15'8.1"S | 107°52' 21.4"E | 50 | 50 | 150 | 150 |
| Site 9 | Samarang | Garut | West Java | 07°12'50.4"S | 107°50'04"E | 75 | 250 | 150 | 150 |
| Site 10 | Taman Bogo | Taman Bogo | Lampung | 05$^0$00'20.7"S | 105°29'27.5"E | 50 | 100 | 125 | 125 |

Phosphorus and K fertilizer was applied regarding to extraction 2 g soil with 2 ml of P and K solution (concentrations of 0, 20, 40, 80 and 160 mg $P_2O_5$/kg and 0, 20, 40, 80 and 160 mg $K_2O$/kg). Thereafter incubated for several days until dry, 10 ml of 25% HCl was added to the soil, shaken for 5 hours and filtered. The P and K in supernatant were measured by using spectrophotometer UV-Vis (Hitachi U-2010) and atomic absorption spectrophometer (AAS Varian AA 55, Australia). Based on the result, we calculated the amount of SP 36 and KCl. Urea was applied based on recommendation from ISRI (Indonesian Soil Research Institute), where Lampung was lower of urea application than other location due to the production in that area was 5-6 ton/ha. While in Java Island, the production is > 6 ton/ha.

The rice production in Kayen (site 1) and Plupuh (site 2) in Central Java are 5.6 and 6.0 ton/ha, respectively (CBS Central Java, 2013). West Java is one of the central rice productions with a contribution of 17.6% to the national rice production (Iskandar, 2011). The rice production in Karang Tengah, Banjaran, Rancaekek, Susukan, Blubur Limbangan, Bayongbong and Samarang in 2013 ranged from 5.8 to 7.0 ton/ha (CBS West Java, 2009-2013). Rice productivity in Cianjur tended to fall from 5.43 ton/ha in 2003 to 5.25 ton/ha in 2007 (Ruli et al., 2010). Taman Bogo in Lampung is the site that has been degraded in soil quality which is characterized by relatively acidic soil (pH 4.17).

### *2.2 Soil and Si Fertilizer (Steel Slug) Analyses*

Soil samples were analyzed by standard methods (Indonesian Soil Research Institute, 2009). The soil samples were air-dried and crushed to pass through 2 mm sieve. The pipet method was used to evaluate the textural class of the soil (ISRI, 2009; Chintala et al., 2010). Total carbon (TC) content was assessed using Walkley-Black method (Black, 1965). Exchangeable Ca, Mg, K and Na were measured using 1 M $NH_4$ acetate at pH 7.0 and Ca, Mg, K, and Na in the extracts were analyzed by flame AAS (ISRI, 2009). The pH was measured in 1:5 soil:water ratio. Available P was measured using Bray 1 method. Total nitrogen (TN) content was obtained by Kjedahl method. The available Si in soils was determined using the acetate buffer method. Soil samples were extracted in 1 mol/L acetate buffer (pH 4.0) at ratio 1:10 incubated for 5 h at 40$^o$C with occasional shaking (Imaizumi & Yoshida, 1958). The concentration of Si in supernatant was determined by colorimetric analysis with Spectrophotometer UV-Vis.

As Si fertilizer, we used steel slug that was collected from Krakatau steel company in Banten Province, Indonesia. The material was analyzed by the same method with soil analysis for available Si (Imaizumi & Yoshida, 1958) and by $HNO_3$ digestion method with the determination by Inductive Coupled Plasma Spectroscopy (Shimadzu ICPE 9000, Kyoto Japan) for the other elements (Koyama & Sutoh, 1987). The chemical composition of steel slug was 1541 mg $SiO_2$/kg of avail. Si, 19.8% Ca, 0.04% K, 3.48% Mg, 0.11% Na, 28.16% Fe and 0.96% Mn.

### *2.3 Experimental Design*

A pot experiment was carried out under greenhouse conditions at the Indonesian Soil Research Institute in 2013. The experiment was set up in completely randomized design with three replicates. The soils used for experiment were collected from farmer's fields. They were collected from several points in the field using hoe at the depth of 0-15 cm (top soil). The soil was air dried and crushed with 2 mm sieve. Five kilogram of soils was weighed into each pot. The Puddling of soils was performed by saturating with water and stirred by hand to form slurry.

Husnain et al. (2013) reported that applying 160-200 kg/ha silica fertilizer produced higher yield in three sites farmer fields (Lampung, South Sulawesi and West Sumatera), with Si fertilizer application done at the rate of: 0, 20, 50, 100, 200 and 300 kg Si/ha. Steel slug, single fertilizer SP 36 and KCl were applied one day before transplanting. Urea was applied twice; 50% at 6 DAT (day after transplanting) and 50% at 35 DAT. Conventional continuous flooding system was used in this experiment. From transplanting up to 7 days after transplanting (DAT) water was added until 2 cm from soil surface. From 7 DAT to 15 days before harvest, the pot would be drain until harvest. Seeds of INPARI-15 variety were soaked in water for 24 hours before transferring into seedling pot filled with 3 kg soil as seedling growing media in the nursery.

### *2.4 Plant Growth Observation and Sampling*

After transplanting, the tiller number and plant height were recorded at 70 day after transplanting (DAT). Plant height was measured from ground level to the tip of the top most of the leaf. The tiller numbers were obtained by counting the number of tillers that grow from the main stem of rice plants. Rice plants were harvested at maturity, separated into straw and grain. Then washed thoroughly with distilled water. The dry weight of these tissues recorded after being oven-dried at 60-70 °C for 2 days.

### *2.5 Statistical Analysis*

The effects of the treatment, soil and the treatment-soil interaction on plant height, tiller number, grain and straw were analyzed using a two-way analysis of variance (ANOVA) at $p < 0.05$. One-way ANOVA was carried out to analyze the effects of the treatment and soil on straw and grain yield. Correlation analyses were conducted to identify significant relationships between the soil properties with tiller number, plant height, straw and grain yield. Effect of soil properties on the yield was analyzed by principle component analysis (PCA) and multiple regression analysis. All statistical analyses were done using the statistical package SPSS 22.

## 3. Results and Discussion

### *3.1 General Soils Properties*

Table 2 shows the soil properties, reference values of tropical Asia paddy fields (Kyuma, 2004) and deficiency criteria by International Rice Research Institute (Doberman & Fairhurst, 2000) of selected parameters.

Table 2. Selected properties of the soil

| Site No | | | | pH (1:5) | | | | | | Exchangeable | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sand | Silt | Clay | $H_2O$ | KCl | TC | TN | C/N | Available P (mg $P_2O_5$/kg) | K | Ca | Mg | Na | CEC | BS | Available Si (mg $SiO_2$/kg) |
| | ------------------%---------------- | | | | | ----------g/kg------- | | | | ------------------------------cmol$_c$/kg------------------------- | | | | | ---%--- | |
| Site 1 | 39.9 | 37.1 | 23.0 | 5.2 | 4.6 | 13.2 | 0.7 | 17.6 | 20.5 | 0.28 | 7.00 | 1.18 | 0.15 | 17.74 | 48.52 | 65 |
| Site 2 | 8.3 | 27.7 | 63.9 | 6.0 | 5.1 | 9.8 | 0.7 | 14.8 | 12.8 | 0.14 | 22.85 | 10.62 | 0.29 | 34.12 | 99.38 | 838 |
| Site 3 | 4.7 | 28.0 | 66.8 | 5.7 | 5.2 | 33.7 | 2.4 | 14.2 | 41.5 | 0.52 | 16.42 | 6.04 | 0.43 | 33.43 | 70.04 | 761 |
| Site 4 | 8.8 | 31.4 | 59.8 | 6.7 | 6.0 | 17.2 | 1.1 | 15.5 | 18.5 | 0.39 | 17.32 | 9.66 | 0.27 | 41.72 | 66.26 | 852 |
| Site 5 | 6.2 | 36.3 | 57.6 | 6.0 | 5.1 | 21.0 | 1.4 | 15.1 | 8.9 | 0.36 | 11.92 | 7.22 | 0.36 | 27.28 | 72.79 | 940 |
| Site 6 | 22.0 | 13.6 | 63.8 | 5.3 | 4.6 | 28.9 | 2.1 | 14.0 | 11.7 | 0.04 | 6.65 | 2.91 | 0.20 | 23.29 | 42.07 | 494 |
| Site 7 | 10.0 | 19.7 | 70.3 | 5.5 | 4.5 | 11.5 | 0.8 | 14.3 | 3.7 | 0.76 | 8.65 | 6.57 | 0.09 | 27.78 | 57.86 | 836 |
| Site 8 | 29.6 | 22.3 | 48.0 | 5.7 | 4.8 | 16.0 | 0.8 | 19.2 | 60.3 | 0.56 | 8.97 | 5.32 | 0.44 | 33.56 | 45.55 | 966 |
| Site 9 | 49.1 | 15.9 | 35.0 | 5.6 | 4.9 | 21.8 | 1.5 | 14.2 | 3.8 | 0.29 | 6.80 | 7.48 | 0.35 | 25.60 | 58.33 | 749 |
| Site 10 | 55.3 | 21.0 | 23.7 | 4.5 | 4.0 | 9.3 | 0.6 | 16.3 | 15.1 | 0.05 | 0.91 | 0.19 | 0.23 | 6.12 | 22.64 | 414 |
| Mean | 23.4 | 25.3 | 51.2 | 5.6 | 4.9 | 18.3 | 1.2 | 15.5 | 19.7 | 0.34 | 10.75 | 5.72 | 0.28 | 27.06 | 58.34 | 691 |
| CV | 81.3 | 32.1 | 34.9 | 10.3 | 10.9 | 44.8 | 52.0 | 11.0 | 91.0 | 68.1 | 60.0 | 59.7 | 41.3 | 36.7 | 35.6 | 41.0 |
| Tropical Asia (n=529)[a] | 23.3 | 30.5 | 41.2 | 5.6 | | | 1.7 | 11.5 | 30 | 0.4 | 9.3 | 5.6 | 1.5 | | | 237 |
| Deficiency criteria[b] | | | | | | | | | | < 0.2 | < 1 | < 1 | | | | < 86 |

*Note.* a: Kuyuma (2004); b: Doberman and Fairhurst (2000).

The soil textural classes were clayey, except for site 1 classified as loam and sites 9 and 10 classified as sandy clay loam. Soil samples were acidic to neutral (pH 4.5-6.7). Mean TC content was comparable with that in tropical Asia (20.7 g/kg). However, it showed high variation ranging from 9.3 to 33.7. According to Sofyan et al. (2004) most of rice soils in Indonesia have organic C less than 20 g/kg. Nitrogen content was also low compared with the average in tropical Asia. The average C/N ratio was 15.5, exceeded the mean value in tropical Asia. The exchangeable Ca was the dominant cation and exchangeable K exceeded the deficiency criteria of 0.2 cmol$_c$/kg in most sites, except sites 2, 6 and 10. The exchangeable Mg exceeded the deficiency criteria of 1 cmol$_c$/kg, except site 10 was lower than 1 cmol$_c$/kg. The averages were higher than those in tropical Asia at 5.6 cmol$_c$/kg.

The soil pH was 5.6 on average and ranged from 4.5 to 6.7. This acidic soil condition was due to high rainfall in most parts of Indonesia, which led to particularly high level of leaching of basic cation and form acidic complexes through the adsorption of clay and humus on the form $H^+$ and $Al^{3+}$, they making the soil acidic (Subagyo et al., 2000; Chintala et al., 2010, 2012). The available P content ranged from 3.7 to 60.3 mg $P_2O_5$/kg, with site differences possibly reflecting differences in the cumulative amount of phosphorus fertilizers applied in the paddy fields. Available Si ranged from 65 to 940 mg $SiO_2$/kg and exceeded the deficiency criterion of 86 mg $SiO_2$/kg, except site 10 (65 mg $SiO_2$/kg). The correlation analysis of 10 sites attribute, which represent soil properties is shown in Table 3.

Table 3. Correlations coefficient of among soil properties

| | pH-$H_2O$ | pH-KCl | Sand | Silt | Clay | C | N | Available P | Exchangeable | | | | CEC | BS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | K | Ca | Mg | Na | | |
| pH-KCl | 0.95*** | | | | | | | | | | | | | |
| Sand | -0.73** | -0.63** | | | | | | | | | | | | |
| Silt | 0.36 | 0.43 | -0.39 | | | | | | | | | | | |
| Clay | 0.61* | 0.47 | -0.91*** | -0.08 | | | | | | | | | | |
| C | 0.19 | 0.29 | -0.29 | -0.15 | 0.37 | | | | | | | | | |
| N | 0.17 | 0.26 | -0.32 | -0.21 | 0.43 | 0.98*** | | | | | | | | |
| Available P | 0.06 | 0.14 | -0.04 | 0.11 | 0.00 | 0.21 | 0.08 | | | | | | | |
| Exchangeable: | | | | | | | | | | | | | | |
| K | 0.36 | 0.26 | -0.42 | 0.11 | 0.39 | 0.04 | -0.02 | 0.31 | | | | | | |
| Ca | 0.80*** | 0.77*** | -0.78*** | 0.43 | 0.64** | 0.10 | 0.13 | 0.12 | 0.16 | | | | | |
| Mg | 0.89*** | 0.77*** | -0.65** | 0.14 | 0.63** | 0.03 | 0.06 | -0.11 | 0.31 | 0.83*** | | | | |
| Na | 0.35 | 0.40 | -0.12 | 0.08 | 0.09 | 0.45 | 0.38 | 0.62* | 0.10 | 0.32 | 0.33 | | | |
| CEC | 0.93*** | 0.87*** | -0.74** | 0.19 | 0.70** | 0.26 | 0.23 | 0.29 | 0.49 | 0.81*** | 0.85*** | 0.41 | | |
| BS | 0.75*** | 0.65** | -0.72** | 0.41 | 0.58* | 0.06 | 0.11 | -0.12 | 0.17 | 0.91*** | 0.86*** | 0.26 | 0.70** | |
| Available Si | 0.69** | 0.53* | -0.57* | -0.10 | 0.65** | 0.12 | 0.12 | 0.17 | 0.50 | 0.51 | 0.78*** | 0.55* | 0.71** | 0.52 |

*Note*. *, **,***: Correlation is significant at the 5, 1 or 0.1% level, respectively.

The pH-$H_2O$ was positively correlated with clay, exchangeable Ca, exchangeable Mg, CEC, base saturation (BS) and available Si. The pH-KCl showed positive correlation with exchangeable Ca, exchangeable Mg, CEC, BS and available Si. Sand was negatively correlated with clay, exchangeable Ca, exchangeable Mg, CEC, BS and available Si. There was positive correlation of clay with exchangeable Ca, exchangeable Mg, CEC, BS and available Si. The available P was positive correlation with exchangeable Na. High positively correlated of exchangeable Ca with exchangeable Mg, CEC and BS. The exchangeable Mg was positively correlated with CEC, BS and available Si. CEC showed positive correlation with BS and available Si. The exchangeable Na was positively correlated with available Si.

The available Si content of soil was possitively correlated with pH due to Si as an element whose amounts in available forms in the soil depend on soil pH. According to Szulc et al. (2015), the soil pH may have indirectly affected the increase in the availability of Si by limiting exchangeable Al. The possitive correlation of available Si and clay was also reported by Takahashi and Sato (2000).

The PCA grouped the estimated soil properties variables into four main components in which PC1 accounted for about 49.32% of the variation; PC2 for 15.64% and PC3 for 10.69% (Table 4).

Table 4. Factor loadings, eigenvalues and cumulative contribution ratio of total variance

| Variables | Component | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| pH-$H_2O$ | 0.94 | -0.14 | 0.03 |
| pH-KCl | 0.87 | -0.04 | 0.10 |
| Sand | -0.85 | 0.04 | 0.24 |
| Silt | 0.30 | -0.43 | 0.32 |
| Clay | 0.78 | 0.15 | -0.40 |
| C | 0.31 | 0.87 | -0.22 |
| N | 0.31 | 0.84 | -0.37 |
| Available P | 0.17 | 0.42 | 0.79 |
| Exchangeable: | | | |
| K | 0.43 | 0.00 | 0.30 |
| Ca | 0.89 | -0.23 | -0.02 |
| Mg | 0.89 | -0.25 | -0.09 |
| Na | 0.45 | 0.51 | 0.55 |
| CEC | 0.95 | 0.02 | 0.11 |
| BS | 0.83 | -0.31 | -0.15 |
| Available Si | 0.76 | 0.07 | 0.13 |
| Eigenvalue | 7.40 | 2.35 | 1.60 |
| Cumulative percent of variance | 49.32 | 64.96 | 75.64 |

*Note*. *, **,***: Correlation is significant at the 5, 1 or 0.1% level, respectively.

The variables, which contributed to PC1 were clay, pH, exchangeable Ca, exchangeable Mg, CEC, BS and available Si. While, sand texture contributed negatively to PC1. The rice soils in study sites were mainly characterized with this PC1 which explained about 50% of the variance. As an easy soil evaluation method in the fields, soil texture and pH could be practical indicators of the soil properties contributing to PC1. Variables which contributed to PC2 were TC and TN suggesting organic matter accumulation. PC3 was characterized by available P.

### *3.2 Relationships between Soil Properties and Rice Growth and Yield*

As in Table 5, tiller number was positively correlated with exchangeable Na content. Meanwhile, plant height, straw and grain yield were positively correlated with several parameters.

Table 5. Correlations matrix of plant growth parameters and soil properties

| | Tiller number | Plant height | Straw | Grain |
|---|---|---|---|---|
| Plant height | 0.19 | | | |
| Straw yield | 0.80*** | 0.65** | | |
| Grain yield | 0.61 * | 0.77*** | 0.81*** | |
| pH-$H_2O$ | 0.14 | 0.79*** | 0.51 | 0.76*** |
| pH-KCl | 0.35 | 0.69** | 0.59* | 0.79*** |
| Sand | 0.15 | -0.69** | -0.24 | -0.47 |
| Silt | 0.06 | 0.09 | 0.08 | 0.43 |
| Clay | -0.18 | 0.70** | 0.22 | 0.31 |
| TC | 0.51 | 0.53* | 0.51 | 0.47 |
| TN | 0.46 | 0.50 | 0.47 | 0.39 |
| Available P | 0.35 | 0.18 | 0.25 | 0.33 |
| Exchangeable: | | | | |
| K | 0.04 | 0.53* | 0.53* | 0.41 |
| Ca | 0.04 | 0.64** | 0.30 | 0.52* |
| Mg | 0.07 | 0.75*** | 0.48 | 0.60** |
| Na | 0.74** | 0.49 | 0.66** | 0.75*** |
| CEC | 0.12 | 0.85*** | 0.52* | 0.70** |
| BS | -0.04 | 0.68** | 0.30 | 0.51 |
| Available Si | 0.19 | 0.70** | 0.55* | 0.62** |

*Note*. *, **,***: Correlation is significant at the 5, 1 or 0.1% level, respectively.

Among the plant growth and yield parameters, we found that tiller number was significantly correlated with straw and grain yields. Plant height was significantly correlated with straw and grain yield. In other words, rice yield is supported by tiller number and plant height.

The correlation analysis in the preceding section revealed that some of the soil variables were highly interrelated. In order to simplify the relationship and to assess the major factors as the determinants of plant growth and yield, we also performed multiple regression analyses. Table 6 presents the stepwise regression analysis and the order of entry of variables into the model at the 5% significance level.

Table 6. Stepwise multiple regression equations

| Plant factor | Model | $R^2$ |
|---|---|---|
| Tiller number | Y = 27.256 × exchangeable Na + 9.881 | 0.54 |
| Plant height | Y = 0.611 × CEC + 83.628 | 0.73 |
| Straw | Y = 37.942 × exchangeable Na + 15.160 | 0.43 |
| Grain | Y = 7.888 × pH-KCl + 31.444 × exchangeable Na - 20.572 | 0.84 |

We could extract variable CEC as indicator to predict plant height. Exchangeable Na was the factor to predict tiller number and straw. Grain yield could be predicted by pH-KCl and exchangeable Na. As the soil pH correlated with the many of other parameters as shown in Table 3 and in the result of PCA (Table 4), it seems understandable that the soil pH could be an indicator of grain yield. It was very unique that exchangeable Na could be an indicator of plant growth (tiller number), straw and grain yield. However, we could not clarify why exchangeable Na showed such high correlation with the plant growth and the yield. Although it may be related with soil parameters other than those examined in the present study, we have not had concrete idea.

### *3.3 Effect of Si Application on Rice Growth and Yield*

We analyzed the effect of soil, treatment and soil-treatment interaction on rice growth and yield by using two-way ANOVA (Table 7).

Table 7. Results of two-way ANOVA for tiller number, plant height, straw and grain yield of rice exposed to variations in soil type and silica application. Shown are the degrees of freedom (df), F-statistic (F), and probability of type I error (P) with soil type and Si addition analyzed as fixed effects. NS = P > 0.05.

| Source | Tiller number | | | Plant height | | | Straw | | | Grain | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | df | *F* | P | df | *F* | P | df | *F* | P | df | *F* | P |
| Soil | 9 | 144.484 | .000 | 9 | 102.145 | .000 | 9 | 175.813 | .000 | 9 | 120.323 | .000 |
| Treatment | 5 | 2.153 | .064 | 5 | 4.809 | .001 | 5 | 4.339 | .001 | 5 | 8.229 | .000 |
| Soil × Treatment | 45 | .781 | .824 | 45 | 1.712 | .013 | 45 | 6.526 | .000 | 45 | 3.359 | .000 |

Soil type was significant, while treatment and interaction soil-treatment were not significant on tiller number. The soil types, Si treatment and interaction soil-treatment were significant at 5% level on the plant height, straw and grain yield. Application of Si increased straw of sites 1,7 and 10 around 68, 68 and 10%, respectively. The grain yield increased in sites 1, 6, 7 and 10 with percentage was 19, 42, 22 and 41, respectively.

### 3.3.1 Tiller Number

Regardless of treatment, there were no significant on tiller number (Table 7). These findings are in line to Ahmad et al. (2013), where productive tiller was lower in Si application than control. While, in opposition to results of Hosseini et al. (2011) who reported higher $SiO_2$ fertilization level (10 g $SiO_2$) resulted in the higher number of tiller and Yasari et al. (2012) who found tiller number was larger when 250 kg Si/ha was applied than without Si. The tiller number was not affected by Si application and probably due to soil properties. The tiller number was significant in soil type, as show in Figure 1 with the letter indicating significant difference.

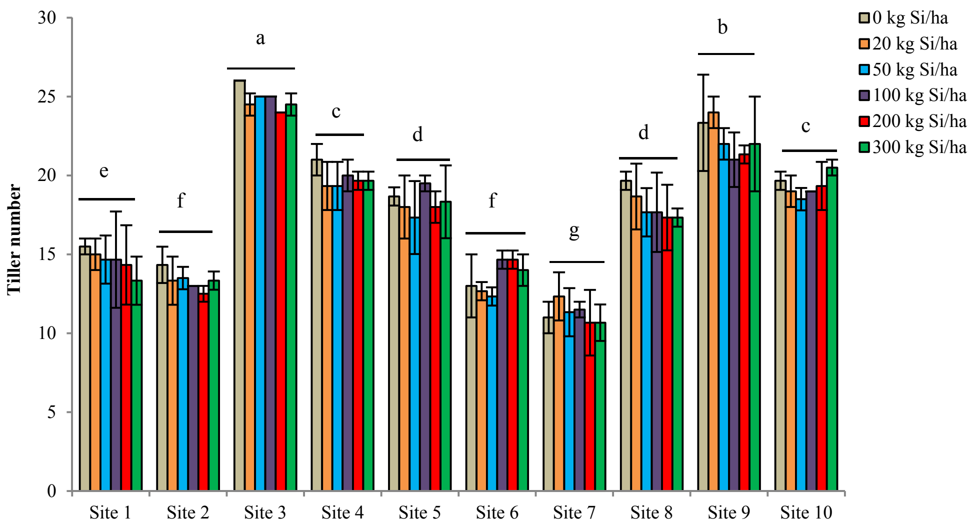


Figure 1. The effect of added silica on tiller number

Between sites 5 and 8 were not significantly different due to avail. Si in the original soil which was almost the same (940 and 966 mg $SiO_2$/kg). The tiller number of sites 2 and 6 were not significant as these sites had the same clay content (64%). Sites 4 and 10 were not significantly different, probably because exchangeable Na of these sites were almost the same (0.27 and 0.23 $cmol_c$/kg, respectively). Tiller number in site 1 was low due to low CEC and available Si (17.74 $cmol_c$/kg and 65 mg/kg, respectively) than other sites except site 10 for CEC.

The highest number of tillers was produced from site 3 and the lowest tiller number was site 7. The high tiller number in site 3 was due to soil properties in which TC, TN and available P were high; meanwhile site 7 had low available P and TN. Nitrogen content probably affected the tiller number, as Islam et al. (2013) found tiller number significantly higher with N application than control. The results are in conformity with Pramanik and Bera (2013), where N level increasing of effective tillers hill of rice due to favorable root growth and higher mobility of N in soil solution and its absorption by plant root. Moreover, available Si in original soil was also high in site 3. According to De Datta (1981), Si makes soil P available to rice.

3.3.2 Plant Height

The significant difference among soil types on plant height were show in Figure 2 with the letter indicating significant difference.

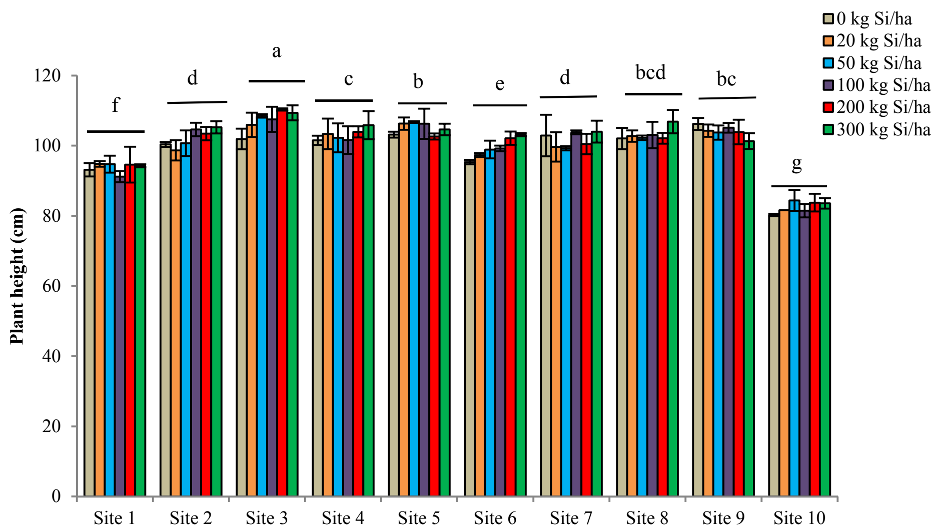


Figure 2. The effect of silica on plant height

Based on site, the highest plant height was site 3 and the lowest was site 10 and followed by sites 1 and 6, probably because these three sites had low available Si, pH and BS compared to other sites. Fallah (2012) reported that plant height increased under Si application, as plant height in site 3 was high due to high available Si. Regardless of the treatments, our results indicate that rice plants exposed to Si enrichment significantly increased plant height with additional of 300 kg Si/ha compared to control (Table 8).

Table 8. Effect of Si application on plant height

| Doses | 0 | 20 | 50 | 100 | 200 | 300 |
|---|---|---|---|---|---|---|
| | -----------------------------kg Si/ha----------------------------- | | | | | |
| Plant height | 99.2 c | 100.6 bc | 100.7 b | 100.8 b | 100.5 bc | 102.3 a |

*Note*. Values with different letter within same column show significant differences at $p < 0.05$ level between treatments according to the Duncan's multiple range test.

These findings are in accordance with earlier reports by Wattanapayapkul et al. (2011), where increasing the rate of Si application significantly increased plant height. According to Moghadam and Heidarzadeh (2014) and Hosseini et al. (2011), plant height was significantly increased with Si application. Support for this result also comes from Okuda and Takahashi (1961) observed that the plant height was higher when Si was added at later growth stage (after panicle initiation stages). Further, Increase in plant height of Si treatments might owe to increased cell division, elongation and expansion caused by silicon (Jawahar et al., 2015). Yavezadah et al. (2008) reported that deposition of Si on plant tissues caused erectness of leaves and stems resulted increase in plant height.

3.3.3 Straw and Grain Yield

Yields of rice in relation to the amount of steel slug applied are shown in Figures 3 and 4 with the letter indicating significant difference.

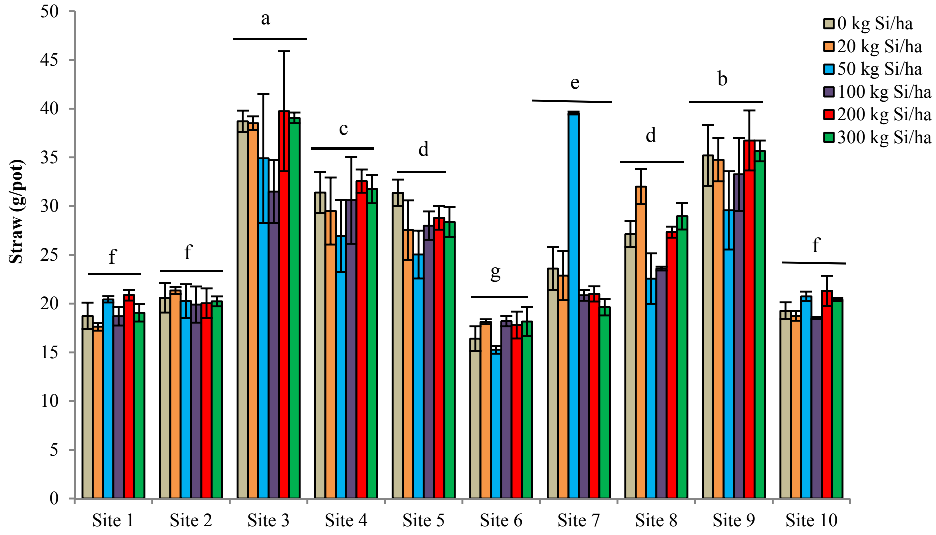


Figure 3. Response of straw yield to Si application

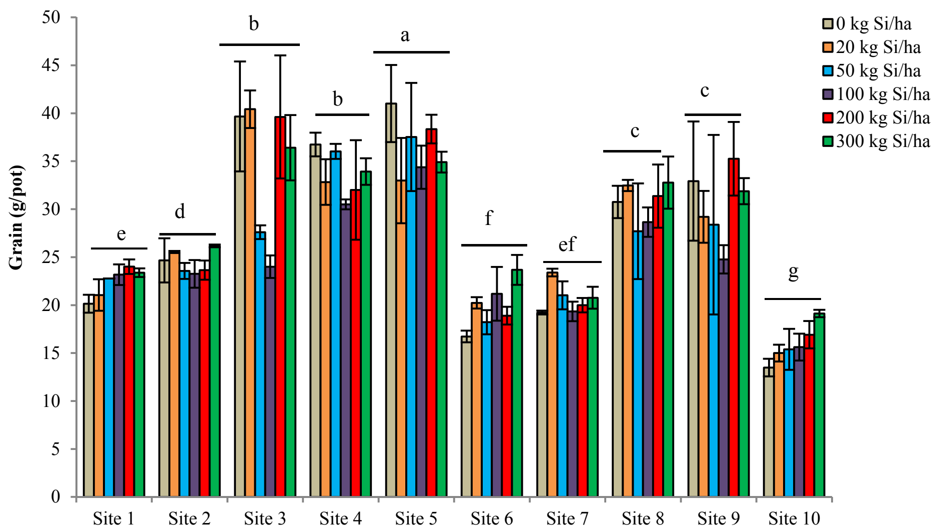


Figure 4. Response of grain yield to Si application

These results indicated that soil properties affected straw and grain yield. The highest yield of straw and grain were from sites 3 and 5, respectively. It was similar with tiller number and plant height, where available Si, TC, TN and were high in site 3. Hence, grain yield was high in site 5 due to high TN, TC and available Si. The lowest straw and grain yield were sites 6 and 10, respectively. As sites 6 and 10 had lower available Si than other sites. Besides that, site 10 had low available Si, TN, TC, CEC and BS.

Furthermore, as a two-way ANOVA was not effective in determining the overall contributions of soil and treatment for each soil sample. Than it is more appropriate with one-way ANOVA. Table 9 show results of statistical one-way ANOVA data of straw and grain yield.

Table 9. Results of one-way ANOVA for straw and grain yield of rice exposed to variations in soil type and silica application

| Gram | Doses (kg Si/ha) | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 | Site 7 | Site 8 | Site 9 | Site 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Straw | 0 | 18.7 c | 20.6 a | 38.7 ab | 31.4 a | 31.4 a | 16.4 ab | 23.6 b | 27.1 b | 35.2 ab | 19.3 bc |
| | 20 | 17.6 c | 21.4 a | 38.5 ab | 29.5 a | 27.5 b | 18.1 a | 22.9 b | 32.0 a | 34.8 ab | 18.7 c |
| | 50 | 20.4 ab | 20.3 a | 34.9 ab | 26.9 a | 25.0 b | 15.3 b | 39.6 a | 22.6 c | 29.6 b | 20.7 a |
| | 100 | 18.7 c | 20.0 a | 31.5 b | 30.6 a | 28.0 ab | 18.2 a | 20.9 bc | 23.6 c | 33.3 ab | 18.5 c |
| | 200 | 20.9 a | 20.0 a | 39.7 a | 32.6 a | 28.8 ab | 17.8 a | 21.0 bc | 27.3 b | 36.7 a | 21.3 a |
| | 300 | 19.1 bc | 20.2 a | 39.1 ab | 31.8 a | 28.4 ab | 18.2 a | 19.6 c | 29.0 b | 35.7 a | 20.4 ab |
| Grain | 0 | 20.1 b | 24.7 ab | 39.7 a | 36.7 a | 41.0 a | 16.7 c | 19.2 b | 30.8 a | 32.9 ab | 13.5 c |
| | 20 | 21.1 b | 25.5 ab | 40.4 a | 32.8 ab | 33.0 b | 20.2 b | 23.4 a | 32.5 a | 29.2 ab | 15.0 bc |
| | 50 | 22.8 a | 23.6 b | 27.6 b | 36.0 a | 37.5 ab | 18.2 bc | 21.0 b | 27.7 a | 28.4 ab | 15.4 bc |
| | 100 | 23.2 a | 23.3 b | 24.0 b | 30.5 b | 34.4 ab | 21.2 ab | 19.3 b | 28.7 a | 24.8 b | 15.6 bc |
| | 200 | 24.0 a | 23.7 b | 39.6 a | 32.0 ab | 38.3 ab | 18.9 bc | 20.0 b | 31.4 a | 35.3 a | 16.9 ab |
| | 300 | 23.4 a | 26.2 a | 36.4 a | 33.9 ab | 34.9 ab | 23.7 a | 20.8 b | 32.8 a | 31.9 ab | 19.1 a |

*Note*. Values with different letter within same column show significant differences at $p<0.05$ level between treatments according to the Duncan's multiple range test.

In general, both straw and grain yields of sites 2, 3, 4, 5, 8 and 9 did not respond to Si application. Meanwhile sites 1, 6, 7 and 10 responded to added Si. Straw and grain yield of site 5 was not significantly different with control. Straw and grain of site 3 was not significantly different between Si treatments and control. However, the highest straw was treatment 200 kg Si/ha and grain was treatment 20 kg Si/ha in site 3. The results showed site 2, either straw or grain yield were not significant difference between control and Si treatments. However, the highest straw and grain yield was obtained by 20 and 300 kg Si/ha, respectively.

Straw dry weight was significantly increased with 20 kg Si/ha for site 8 but decreased with high Si treatment (50-300 kg/ha), while there was no significant difference between control and Si treatments of grain yield. Straw and grain were not significantly different between control and Si treatments of site 9. However, the highest grain and straw yield was found in 200 kg Si/ha which was higher than control. In this case, we assume that sites 3, 4, 5 and 9 had similar reason. In which TN of those sites were higher compared to other sites. High N in soil induce the number of stalks and leaves, creating unfavorable conditions to yielding, such as shading and lodging (Barbosa, 1987, 1991). When plants receive too much N, they also become more attractive to insects and diseases. In this research, added Si into soil was used to restore conditions caused by high N in the soil. Besides TN, exchangeable Na was also higher in sites 2, 3, 4, 5, 8 and 9 compared to other sites (Table 2). Sodium probably induced the level of soil salinity. Thus Si application was also used to reduce salinity. Silica has been shown to be effective in mitigating soil salinity according to Liang et al. (2007).

The beneficial effect of Si treatment in increased straw and grain of sites 1, 6 and 10 seemed to be the results of lower initial available Si in soil. Indicating low available Si in soil made plants respond to Si application. The adequate Si supply might have improved the photosynthetic activity that enables the rice plant to accumulate sufficient photosynthates. Hence, resulted in increased dry matter production. These factors coupled with efficient translocation of photosynthates resulted in more number of filled grains and straw as reported by Jawahar et al. (2015). These finding were corroborated by the results of Makabe-Sasaki et al. (2013) who found the amount of dissolved Si in soil solution is increased by slag silicate fertilizer (SSF). Moreover, the grain yield response to Si application may be due to increased leaf erectness, decreased mutual shading caused by dense planting.

Although straw yield of site 6 was not significantly different between treatment and control, the highest straw was 100 kg Si/ha. While, Si application significantly increased the grain yield which the highest was 300 kg Si/ha. Treatment of 50 and 20 kg Si/ha significantly increased straw and grain, respectively in site 7. Site 7 had low pH and high clay (70%), as phyllosilicates are clay minerals that are an important source of silicic acid in agricultural soils (Mark, 1995). However, the solubility of Si from original soil was probably low due to high clay content bind Si, then Si was not in soil solution and less Si was extracted by rice plants. By adding steel slug, soil pH increased and Si might be release into soil solution. According to Kato and Owa (1997), the application of the slags increased the soil solution pH when large alkalinity of the applied slag was high. Therefore, Si from steel slug would be directly used by plant. In other words, plants respond to Si application. Furthermore, available P content in soil was also low (3.7 mg $P_2O_5$/kg), where with high Si content had a beneficial indirect effect on plant growth. The Si caused a decrease in Fe and Mn uptake when P was low, thus promoted P availability within plant (Ma & Takahashi, 1990).

The effect of Si treatments in straw and grain yield of site10 was significant. Whereas at 50 kg Si/ha enhanced the straw and 200 kg Si/ha increased grain yield. Salman et al. (2012) reported straw had significant effect under silicon treatment (5% probability level), where the maximum straws yield was observed for 300 kg Si/ha. Among the different level of Si, application of 300 kg/ha recorded maximum grain yield of rice, which was closely followed by 200 kg Si/ha. Increasing levels of Si increased the grain yield. The response of plant with Si application also due to the available Si, pH and exchangeable Ca in this site was low compared to other sites.

## 4. Conclusions

Among the different sites, tiller number and plant height were highest in the site with high available Si content. Silica enrichment significantly increased plant height with additional of 300 kg Si/ha compared to control. Soils responded to the applied Si in achieving higher grain yields over the control due to its low available Si content. The increase grain yield was high with 50 – 300 Si kg/ha for site 1, 6 and 10. In contrast, although grain yield of some soil with high available Si content was higher than soil with low available Si but these soils did not respond significantly to Si application. This indicates that other soil properties such as pH-KCl and exchangeable Na affected the grain yield while CEC serves as indicator to predict plant height in this experiment. Exchangeable Na was the factor to predict tiller number and straw. It was very unique that exchangeable Na could be an indicator of tiller number, straw and grain yield.

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