Improving rice growth and yield with silicon addition in Oxisols

A F Siregar¹, I A Sipahutar¹, L Anggria¹, Husnain² and M P Yufdi³

¹ Indonesian Soil Research Institute, Bogor, Indonesia
² Indonesian Center for Agricultural Land Resources Research and Development, Bogor, Indonesia
³ Indonesian Center for Horticulture Research and Development, Bogor, Indonesia

E-mail: adha_siregar@yahoo.com

Abstract. The addition of beneficial nutrients as silicon (Si) has become a concern in rice cultivation in some countries. However, it is not fully adopted in Indonesia. It is known that Si plays an important role on improving plant resistance on biotic and abiotic stresses. A pot experiment was conducted to study the response of rice plant growth on Si addition in Oxisols. A completely randomized design was set with eight treatments as varying Si rates (0, 100, 200, 300, 400, 500, 600 and 700 kg SiO₂ ha⁻¹) and three replications. Some variables were observed as plant height, number of tillers, stem strength, lodging resistance, biomass and yield components. Related to stem strength and lodging resistance, the observation was conducted prior to harvest. The results showed that initial soil Si available was 264 mg SiO₂ kg⁻¹ and categorized below the critical level. Si application showed significant effect on increasing number of tillers, stem strength, lodging resistance and the yield which occurred at 700 kg SiO₂ ha⁻¹ treatments. The rice yield increase by 34.66% at 700 kg SiO₂ ha⁻¹ treatments compared to control. This current result showed that addition of Si fertilizer has showed the effect on improving rice growth and yield in Oxisols.

1. Introduction

Rice is one of the leading food crops in the world and the main staple food in Indonesia that plays important role in agricultural and economic sector. In order to meets the demand that steadily increasing due to the increase in population and to achieve national production target, innovation technology especially on nutrient management on improving rice productivity is needed.

Regarding agriculture activities, Oxisols with several constraints is used for agriculture activities. Oxisols, with a clay fraction consisting of kaolinite and sesquioxide, are strongly and deeply weathered soils. It is characterized by a low inherent fertility but good physical properties and a low erodibility index. Moreover, Oxisols is known for low level of plant nutrients, low cation exchange capacity and weak retention of bases applied as fertilizers or amendments with strong fixation and phosphorus deficiency on fine-textured soils [1].

Recently, intensive cultivation faces certain constraints namely water scarcity, pest, and disease, inadequate and unbalance fertilization [2]. The absence of an appropriate nutrient management practice could lead to nutrient depletion in soil and correlated to yield decline. Regarding silicon (Si) fertilization, it is noticed that mostly Indonesian farmers only apply nitrogen, phosphorus and potassium, meanwhile
Si has not been noticed yet. This present condition could lead to yield decline due to the depletion of soil available Si especially under continuous monoculture of high-yielding variety [3].

The understanding of Si availability in the agricultural aspect is assessed and highlighted. Si is classified as a beneficial plant nutrient where the effect of its application on plant growth and yield mostly demonstrated on rice and sugarcane as the Si-accumulator plants [4]. Silicon is the second most abundant constituent in the earth’s crust [5] and is mostly found as silicon dioxide (SiO₂) in association with a wide array of Si-bearing minerals in crystalline, poorly crystalline, and amorphous phases [6]. The availability of Si in clay soil ranges from 200 to 300 g Si kg⁻¹ in clay soil and 450 g Si kg⁻¹ in sandy soils [7, 8].

Many studies have proved the effect of Si on improving plant growth and yield, especially under biotic and abiotic stress [3, 9, 10]. Silicon has an important role in enhancing plant tolerance to biotic stresses such as blast disease, pathogen and abiotic stresses such as drought, heavy metal toxicity, salinity which lead to improving plant productivity [9, 11]. In this present work, the objective is to study the response of rice plant growth on Si addition in Oxisols.

2. Materials and methods
A pot experiment was conducted from August to November 2017 at the greenhouse of Indonesian Soil Research Institute, Bogor, West Java. A completely randomized design was set with eight treatments as varying silicon (Si) rates (0, 100, 200, 300, 400, 500, 600, and 700 kg SiO₂ ha⁻¹) and three replications. Each pot contained 8 kg of Oxisols soil and Inpari 33 rice variety was used as a plant indicator. Three seedlings were transplanted to each pot after 15 days of seeding. The water level was maintained about 5 cm from the soil surface and drained fourteen days prior to harvest.

Silica gel fertilizer imported from Japan was used in this present study. Si fertilizer was applied two weeks before transplanting. The basic fertilizer as Urea, SP-36 and KCl were based on soil test. Urea and KCl were applied twice each 50% of the dosage at 7 days after transplanting (DAT) dan 30 DAT. SP-36 was applied at 7 DAT. Harvesting was conducted at 105 DAT.

Plant height, stem strength, lodging resistance, yield and its component were observed. Lodging resistance and stem strength were measured prior to harvest by using Force Gauge. The stem was bent at 15 cm from the surface of the soil to establish an angle of 45° [12] for measuring lodging resistance.

Soil samples from 0-20 cm depth were collected for initial soil analysis. The soil samples were air-dried, ground and passed through a 2 mm mesh sieve. Available Si was determined using the acetate buffer method [13]. Soil samples were extracted in 1 mol L⁻¹ acetate buffer (pH 4.0) at a ratio of 1:10 for 5 h at 40 °C with occasional shaking. This method is suitable for soil with no Si fertilization history previously [14].

Statistical analysis was conducted with analysis of variance (ANOVA) and followed with Duncan’s Multiple Range Test (DMRT) procedures at P <0.01. SPSS 20.0 was used for statistical analysis.

3. Results and discussion

3.1. Soil characteristic
Initial soil analysis was presented in table 1. The soil is categorized as slightly acid with soil pH 5.6 and soil texture classified as clay. Soil organic carbon and nitrogen were classified as low. Regarding soil available SiO₂, the initial analysis showed that soil available SiO₂ is below the critical level of 300 mg SiO₂ kg⁻¹ [14].

3.2. Effect of treatments on plant growth and yield
The effect of Si fertilizer on plant growth parameter as plant height and number of tillers is presented in table 2. The result showed that an increase in plant height was observed with the increasing of Si fertilizer dosage for Si-1 up to Si-6, however over all the difference was not statistically significant among the treatments. The highest plant height was noted at Si-6 with 600 kg Si ha⁻¹ as 118.3 cm (table 2).
Si fertilizer application showed a significant effect at the 5% level on the number of tiller (table 2). It showed that Si-7 treatment had the highest number of tillers. This present result is in agreement with previous studies [15, 16] stated that Si fertilizer application could increase vegetative stage growth as well as the number of tillers. Increasing amount of Si supply could lead to increasing number of tillers [17].

### Table 1. Initial soil analysis of Oxisols, West Java.

| Soil Properties       | Values | Criteria [18] |
|-----------------------|--------|---------------|
| pH (1:5)              |        |               |
| H₂O                   | 5.6    | Slightly acid |
| KCl                   | 4.1    |               |
| Texture               |        |               |
| Sand (%)              | 3      | Clay          |
| Silt (%)              | 34     |               |
| Clay (%)              | 63     |               |
| Organic matter        | 1.59   | Low           |
| C (%)                 | 0.15   | Low           |
| N (%)                 | 10.6   | Low           |
| C/N                   |        |               |
| P₂O₅ (HCl 25%) (mg/100 g) | 14 | Very low |
| K₂O (HCl 25%) (mg/100 g) | 5  | Very low    |
| SiO₂ (mg.kg⁻¹)        | 264    |               |
| CEC (cmol(+).kg⁻¹)    | 33.72  | High          |
| Base saturation (%)   | 64     | High          |

### Table 2. Effect of Si applications on plant growth parameters of rice plant

| Si fertilizer dosage (kg ha⁻¹) | Parameters               | Plant height (cm) | Number of tillers |
|-------------------------------|--------------------------|-------------------|-------------------|
| Si-0 (0)                      |                          | 115.8a            | 20.7bc            |
| Si-1 (100)                    |                          | 111.5a            | 24.3abc           |
| Si-2 (200)                    |                          | 113.7a            | 20.0c             |
| Si-3 (300)                    |                          | 115.2a            | 25.7ab            |
| Si-4 (400)                    |                          | 115.5a            | 23.7abc           |
| Si-5 (500)                    |                          | 116.8a            | 23.0abc           |
| Si-6 (600)                    |                          | 118.3a            | 25.3ab            |
| Si-7 (700)                    |                          | 113.3a            | 26.3a             |

Notes: Values followed by similar alphabet is statistically similar at α = 5%

### Table 3. Effect of Si applications on yield component of the rice plant

| Si fertilizer dosage (kg ha⁻¹) | Parameters               | Yield (g/pot) | Weight of 1000 grains (g) |
|-------------------------------|--------------------------|---------------|---------------------------|
| Si-0 (0)                      |                          | 45.3cd        | 25.2 a                    |
| Si-1 (100)                    |                          | 51.4bcd       | 25.1 a                    |
| Si-2 (200)                    |                          | 43.1d         | 25.2 a                    |
| Si-3 (300)                    |                          | 55.0abc       | 24.4 a                    |
| Si-4 (400)                    |                          | 54.0abc       | 25.1 a                    |
| Si-5 (500)                    |                          | 47.2bcd       | 25.0 a                    |
| Si-6 (600)                    |                          | 56.6ab        | 25.4 a                    |
| Si-7 (700)                    |                          | 61.0a         | 25.7 a                    |

Notes: Values followed by similar alphabet is statistically similar at α = 5%
Present study showed that the application of Si fertilizer with a multi-level dosage significantly increases the yield. The highest yield was noticed at Si-7 and significantly different with control. Meanwhile the others Si level treatments, the yield increase in varied. The yield at Si-7 increased up to 34.66% compared to control. The yield is reliant on the number of tiller as it is associated with the number of panicles [19]. Our finding in agreement with [19] where as the highest dose Si as in Si-7 resulted the highest both on yield and number of tillers (table 2 and 3). Regarding the weight of 1,000 grains, the result showed no significant difference between treatments.

Sufficient amounts of Si supply to rice plants from the tillering stage until the elongation stage could give a significant effect on increasing the yield and boost the ripening process [20]. The previous study has proved that the application of Si fertilizer could increase the yield and this increase is affected by the type of Si sources and the dosage [21,22].

3.3. Effect of treatments on stem strength and lodging resistance
The effect of Si application on stem strength and lodging resistance is presented in table 4. The result showed that Si application with multi-level of dosage gave significant effect both on stem strength and lodging resistance at the 5% level compare to control. Si-7 as 700 kg Si ha⁻¹ had the highest stem strength and lodging resistance as 12.8 and 8.2 N, respectively (table 4).

This present might be due to the role of Si in preventing lodging. As increasing Si deposition in cell wall, it could increase the physical strength of the rice culm, the leaves and stem more erect and improve the stem strength and lodging resistance [23, 24]. It is noticed that Si has correlation with improving the plant sturdiness and rigidity [25].

| Si fertilizer dosage (kg ha⁻¹) | Parameters             | Stem strength (N) | Lodging resistance (N) |
|--------------------------------|------------------------|-------------------|------------------------|
| Si-0 (0)                       |                        | 6.7d              | 4.5c                   |
| Si-1 (100)                     |                        | 10.9 ab           | 7.4ab                  |
| Si-2 (200)                     |                        | 7.6cd             | 6.2bc                  |
| Si-3 (300)                     |                        | 9.6bc             | 6.5ab                  |
| Si-4 (400)                     |                        | 10.3b             | 6.3bc                  |
| Si-5 (500)                     |                        | 10.3b             | 6.5ab                  |
| Si-6 (600)                     |                        | 10.6ab            | 7.7ab                  |
| Si-7 (700)                     |                        | 12.8a             | 8.2a                   |

Notes: Values followed by similar alphabet is statistically similar at α = 5%

3.4. Effect of treatments on biomass
The effect of Si application with a multi-level dosage on fresh and dry weight of rice straw is presented in table 5. The result showed that Si application with a multi-level of dosage gave significant effect both on the fresh and dry weight of rice straw at the 5% level compared to control. The highest weight of fresh and dry rice straw was noted in Si-5 and Si-7 (table 5). The highest number of tillers was followed by the highest weight of the dry weight of rice straw. As stated by [15, 26], Si application could improve the vegetative growth parameter and dry weight of rice straw.
Table 5. Effect of Si applications on biomass or rice plant

| Si fertilizer dosage (kg ha\(^{-1}\)) | Parameters (g/pot) | Fresh weight of rice straw | Dry weight of rice straw |
|--------------------------------------|--------------------|-----------------------------|--------------------------|
| Si-0 (0)                             |                    | 162.5 c                     | 51.0 b                   |
| Si-1 (100)                           |                    | 159.3 c                     | 46.2 c                   |
| Si-2 (200)                           |                    | 163.8 c                     | 48.3 b                   |
| Si-3 (300)                           |                    | 154.3 c                     | 54.4 b                   |
| Si-4 (400)                           |                    | 177.1 ab                    | 62.9 a                   |
| Si-5 (500)                           |                    | 189.2 a                     | 60.2 ab                  |
| Si-6 (600)                           |                    | 166.6 b                     | 54.3 b                   |
| Si-7 (700)                           |                    | 176.4 ab                    | 63.0 a                   |

Notes: Values followed by similar alphabet is statistically similar at \(\alpha = 5\%\)

4. Conclusions

The present study showed that the exogenous application of Si could improve the number of tillers, stem strength, lodging resistance, biomass weight and rice yield in Oxisols that initially has low soil available Si. This finding confirms that Si application with dosage up to 700 kg Si ha\(^{-1}\) has the potential on improving rice growth and yield. Further study is needed to find out the optimum dosage for different soil types.

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