Magnesium and silicon fertilizer application to promote rice growth and production

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Abstract. The global demand for rice continues to increase due to population growth. In Indonesia, various innovations have been implemented for improving rice production, while magnesium silicate fertilizer application is still limited. The study was undertaken to investigate the effect of Mg and Si (MgSi Fert) on rice growth and productivity. This study was conducted at Luhur Jaya Village, Cipanas District, Lebak Regency, Banten Province in a rainy season. A randomized complete block design with ten treatments and three replications was set. The treatment was MgSi Fert with multiple dosages. Results showed that NPK fertilizer combined with 100 kg ha⁻¹ MgSi fertilizer gave the highest yield. Based on the quadratic equation \( y = -0.1301x^2 + 28.812x + 5474.2 \), it was known that highest slope on the equation was reached at dosage less than 150 kg ha⁻¹ of MgSi Fert. The optimum dosage of MgSi Fert for Ciherang rice variety was achieved at 110 kg ha⁻¹ with yield as 7.07 t ha⁻¹. This present study showed that MgSi Fert application improved rice growth and yield.

1. Introduction

Rice is one of the important staple food and Indonesian people rely on it as a single staple food. Indonesian government has been intensely to achieve national self-sufficiency in rice production. Recently, the cultivated area is continuously decreasing due to industrial development, urbanization, and others [1]. Meanwhile, the demand for staple food continues to increase. Therefore, various innovations have been implemented for improving rice production in Indonesia.

Soil properties accompanied with an effective soil nutrient management are an essential component of crop production for increasing and sustaining crop yield. Managing plant nutrients to increase crop yield is a very critical aspect where balanced fertilization has played an important role on this issue [2]. Apart from macro nutrients as nitrogen (N), phosphorous (P) and potassium (K), rice plant also needs magnesium (Mg) and silicon (Si) to increase plant growth and productivity.

Magnesium quiet to be neglected however it plays important role in crop production [3] especially in acid soil with low Mg availability. Previous research has proven the effect of Mg on plant shoot and root formation and Mg is as important part of the chlorophyll molecule which plays an important role in the photosynthesis process [4–7].

Root plant take up Mg in the ionic form as Mg²⁺ from soil solution. The availability of Mg in soil depends on various factors such as the distribution and chemical properties of soil parent material and its weathering level, climatic and anthropogenic, and agronomic management practices including crop types, rotation and intensity, as well as organic and inorganic fertilizations [8,9]. Furthermore, Cakmak

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[4] stated that low soil pH and/or high levels of potassium (K) and calcium (Ca), low temperatures, and dry soil conditions can all contribute to Mg deficiency. However, balanced fertilization has played an important role in increasing the rice yield.

Recently due to intensive crop production system, the lack of plant available Mg and Si deficiency are increasingly becoming an important limiting factor especially in soils fertilized only with N, P, and K. Particularly in Mg depletion in soils is a growing concern for high-productivity agriculture. Mg deficiency inhibits plant growth and has become a growing problem for crop productions in agriculture. This deficient condition could reduce photosynthetic rate and disrupts the distribution of carbohydrates from source to sink [10].

Not classified as an essential element, silicon (Si) is a beneficial element and dominantly present as $\text{H}_4\text{SiO}_4$, an uncharged monomeric ortho silicic acid [11]. Rice is one of the Si accumulator plant. Si uptake of rice is performed by lateral roots [12]. Si is deposited mainly in the epidermis and sheath cells of vascular bundles that occurs in cell walls, cell lumens, inter-cellular matrix, and a layer under the wax cuticle [13,14].

The beneficial effects of Si on improving plant growth and plant resistance to biotic and abiotic stresses have been demonstrated by many studies [15–17]. Under biotic stress, it proved agronomically that Si could improve rice plant resistance on stalk rot ($\text{Leptosphaeria salvinii}$), rice blast ($\text{Magnaporthe grisea}$), and fusarium wilt ($\text{Fusarium}$) [18]. In agreement, Siregar et al. [19] stated that Si application on rice cultivation increased plant resistance on blast disease under intermittent water management.

Si has been shown to alleviate the deleterious effects of an impressive range on abiotic stresses including salinity, metal toxicity, nutrient imbalance, lodging and drought in many plants [16,20]. Related to rice, Si application has proven that Si deposition beneath cuticle could reduce water loss through transpiration and increase stem strength [21]. Moreover Bray et al. [22] stated that crops yields could decrease due to abiotic stress up to 51% to 82%.

Respecting all the benefits of Mg and Si in rice growth, Mg and Si application are not fully practiced yet in Indonesia especially on Si fertilizer. The need for proper Mg and Si management to increase and sustain crop productivity appears to be necessary. Regarding to that issue, the study was undertaken to investigate the effect of Mg and Si (MgSi) fertilizer on rice growth and productivity.

2. Materials and methods

2.1. Study site

The field study was conducted during rainy season from August to December 2017 at Luhur Jaya Village, Cipanas District, Lebak Regency, Banten Province (06°53.7’53”S and 106° 40.1’00” E). This field study was set in randomized complete block design with ten treatments and three replicates. The treatments are shown on Table 1. The plot size was 5 m x 4 m and completed with inlet and outlet channels at each plot for irrigation purposes. Cipanas rice variety was planted in this study.

2.2. Plant cultivation

The field was prepared with ploughing followed by levelling. This study used three weeks old of rice seedling then transplanted as two seedlings with path row (jajar legowo) planting space. The recommendation dosage for MgSi Fert was 100 kg ha$^{-1}$ and applied once at 7 days after transplanting (DAT). The fertilizer dosages were 250 kg ha$^{-1}$ urea, 100 kg ha$^{-1}$ SP-36, and 75 kg ha$^{-1}$ KCl. Urea was applied three times at 7, 21, and 35 DAT meanwhile SP-36 and KCl fertilizers were applied once at 7 DAT. Fertilizer analysis of MgSi used in this research is acknowledged as Mg fertilizer and completed with Si. Fertilizer analysis showed that MgSi Fert contained 36.02% MgO and 5.15% available SiO$_2$, meanwhile crude SiO$_2$ was 50.17%. The fertilizers were applied by broadcasting way and during the cultivation stage, fungicide for controlling blast disease was not applied.
Table 1. List of treatments.

| No | Treatments                        | Dossage (kg ha⁻¹) |
|----|-----------------------------------|-------------------|
|    |                                   | MgSi Fert | Urea | SP-36 | KCl | MgO | Silica gel |
| 1  | Control                           | -         | -    | -     | -   | -   | -          |
| 2  | NPK                               | -         | 250  | 100   | 75  | -   | -          |
| 3  | NPK + Mg                          | -         | 250  | 100   | 75  | 37.92 | -          |
| 4  | NPK + Si                          | -         | 250  | 100   | 75  | -   | 55.17     |
| 5  | NPK rekomendasi + Si + Mg         | -         | 250  | 100   | 75  | 37.92 | 55.17     |
| 6  | 75% MgSi Fert + NPK               | 75        | 250  | 100   | 75  | -   | -          |
| 7  | 100% MgSi Fert + NPK              | 100       | 250  | 100   | 75  | -   | -          |
| 8  | 125% MgSi Fert + NPK              | 125       | 250  | 100   | 75  | -   | -          |
| 9  | 150% MgSi Fert + NPK              | 150       | 250  | 100   | 75  | -   | -          |
| 10 | 100% MgSi Fert                    | 100       | -    | -     | -   | -   | -          |

Note: MgSi Fert ; MgSi Fertilizer.

2.3. Sampling and analysis methods

Soil sample was taken before land preparation for initial soil analysis and before harvest from each treatment. Soil analysis for available Si for initial soil was extracted using the acetate buffer method [23] as cited in Darmawan et al. [24] and the extraction was measured using atomic absorption spectrophotometer (AAS, Z-5000; Hitachi, Tokyo, Japan). Mg was extracted by NH₄OAc 1N pH 7 and measured using AAS.

Plant growth parameters as plant height and number of tillers were observed at 30, 60 DAT and before harvest. Ten rice plants were selected randomly as plant samples. Stem strength and blast disease were observed at 75 DAT. Dry grain and straw weights were observed after harvest. Statistical analysis was conducted using SPSS 22.0 with analysis of variance (ANOVA) and followed with Duncan Multiple Range Test (p<0.05).

The effectiveness of MgSi fertilizer was calculated using Relative Agronomic Effectiveness (RAE). RAE is comparison of yield increment between tested fertilizer and standard fertilizer in percentage [25, 26].

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\text{RAE} = \frac{\text{Yield of tested fertilizer} - \text{yield of control}}{\text{Yield of standard fertilizer} - \text{yield of control}} \times 100\%
\]

3. Results and discussion

3.1. Initial soil characteristics

Initial soil analysis is shown in table 2. Soil analysis indicated that it had a low pH with clay loam texture. Carbon organic and nitrogen (N) contents were categorized in low meanwhile phosphorous (P) and potassium (K) HCl extracted were categorized in very low levels. Available P extracted by Bray 1 and CEC were categorized in low levels and base saturation was 51%. Soil exchangeable Mg was categorized low (1.04 Cmol(-1).kg⁻¹) and soil available Si was 65 mg kg⁻¹. The result showed that the soil in this study area needs addition of MgSi fertilization due to low availability.

3.2. Effect of MgSi fertilizer on rice plant morphology

The effect of treatments on plant height is presented on Table 3. It showed that control treatment had the lowest plant height throughout observations and significantly different (P<0.05) with others. As stated by [27], to obtain optimum growth, rice plants need enough N, P, and K nutrients during the
growth stage. It is known that nitrogen application could enhance photosynthesis rate which will enhance the translocation of nutrients for developing panicle and increasing plant height [28].

At 90 DAT, the highest plant height as 105.84 cm high was achieved at NPK + Mg + Si treatment and statistically similar with the MgSi Fert treatments combined with NPK. MgSi Fert treatments with different dosage levels combined with NPK showed no significant difference on plant height but statistically different with MgSi treatment solely. It is known that Mg has a role specifically in photosynthetic process [5], therefore an inadequate amount of Mg could reduce rates of biomass formation such as plant height. Related to fertilizer efficiency. Grzebisz [29] stated that Mg is considered important for the uptake and efficiency of nitrogen. Related to Si role on plant growth, it is confirmed that Si supports in improving leaves erectness which could increase photosynthetic rate and result in increasing plant height [30].

Table 2. Initial soil analysis used for field experiment at Luhur Jaya Village, Cipanas.

| Parameters                      | Unit          | Result | Criteria   |
|---------------------------------|---------------|--------|------------|
| Texture                         |               |        |            |
| Sand                            | %             | 25     | Clay loam  |
| Silt                            | %             | 46     |            |
| Clay                            | %             | 29     |            |
| pH H2O                          |              | 4.9    | Acid       |
| KCl 1 N                         |              | 3.8    |            |
| Organic matter                  |               |        |            |
| C-organic                       | %             | 1.17   | Low        |
| N-total                         | %             | 0.12   | Low        |
| C/N                             |              | 10     | Low        |
| HCl 25% Extraction              |               |        |            |
| P2O5 mg 100 g⁻¹                 |              | 61     | Very high  |
| K₂O mg 100 g⁻¹                  |              | 7      | Very low   |
| Bray 1 mg P₂O₅ kg⁻¹             |              | 12.4   | High       |
| NH₄OAc 1 N pH 7 Extraction      |               |        |            |
| Ca cmol(+) kg⁻¹                 |              | 5.16   | Low        |
| Mg cmol(+) kg⁻¹                 |              | 1.04   | Low        |
| K cmol(+) kg⁻¹                  |              | 0.08   | Very low   |
| Na cmol(+) kg⁻¹                 |              | 0.18   | Low        |
| CEC cmol(+) kg⁻¹                |              | 12.69  | Low        |
| BS %                            |              | 51     | Medium     |
| KCl 1 N Extraction              |               |        |            |
| Al cmol(+) kg⁻¹                 |              | 2.23   |            |
| H cmol(+) kg⁻¹                  |              | 0.64   |            |
| Buffer CH₃COOH pH 4 mg Si kg⁻¹  |              | 65     |            |
| Morgan Wolf mg kg⁻¹             |              | 170    |            |

Criteria based on Indonesian Soil Research Institute, 2009 [31].
Table 3. Effect of treatments on plant height and tillers number of rice plant at 30, 60, and 90 DAT.

| Treatment                  | 30 DAT | 60 DAT | 90 DAT | 30 DAT | 60 DAT | 90 DAT |
|---------------------------|--------|--------|--------|--------|--------|--------|
| Control                   | 59.38 a| 93.30 b| 95.23 b| 19.73 c| 14.77 b| 15.83 c|
| NPK                       | 67.00 a| 103.37 a| 103.78 a| 26.70 ab| 20.03 a| 20.67 ab|
| NPK+Mg                    | 66.35 a| 103.00 a| 103.73 a| 25.50 ab| 19.50 a| 20.03 ab|
| NPK+Si                    | 68.84 a| 102.94 a| 103.58 a| 25.40 ab| 20.40 a| 21.70 ab|
| NPK+Mg+Si                 | 68.35 a| 105.57 a| 105.84 a| 27.80 ab| 21.27 a| 23.33 a|
| 75% MgSi Fert.+NPK        | 68.42 a| 103.62 a| 103.99 a| 26.17 ab| 19.43 a| 19.87 ab|
| 100% MgSi Fert.+NPK       | 66.30 a| 102.36 a| 102.85 a| 28.07 a| 19.50 a| 20.67 ab|
| 125% MgSi Fert.+NPK       | 67.42 a| 103.69 a| 105.17 a| 25.70 ab| 17.53 a| 20.83 ab|
| 150% MgSi Fert.+NPK       | 66.12 a| 102.61 a| 102.98 a| 24.40 b| 17.70 ab| 20.50 ab|
| 100% MgSi Fert.           | 60.07 b| 95.58 b| 96.03 b| 18.93 c| 14.33 b| 17.97 b|
| CV (%)                    | 6.28   | 4.84   | 4.55   | 13.38  | 15.81  | 13.59  |

Notes: Values in the same column followed by similar letter are not statistically different at α = 5%.

The effect of treatments on number of tillers at 30, 60, and 90 DAT is shown at table 3. The result showed that at first observation at 30 DAT, application of 100% MgSi Fert + NPK has the highest number of tillers and significant different with 100% MgSi Fert treatment. Under 60 and 90 DAT observations, the highest number of tillers was achieved at NPK + Mg + Si treatment, however, it is not statistically different with 100% MgSi Fert + NPK.

Similar result achieved on plant height and number of tillers was in the absence of N, P, and K fertilization having the lowest number of tillers. Previous results have shown that applications of N in rice lead to an increase in plant height, number of tillers, leaf size, number of spikelets and grain yield [32]. Si application shows benefit in increasing number of tillers therefore it could boost up plant growth and gain more photo-assimilates from source to sink [33].

Among different levels of MgSi Fert combined with NPK showed that the lowest of MgSi Fert dosage as 75% MgSi Fert + NPK had the lowest number of productive tillers at 90 DAT. This might be related to the reduced photosynthesis rate and loss of chlorophyll in leaves of rice as Mg plays role on it [34]. Plant growing under insufficient amount of Mg could be affected on reduction on net CO2 assimilation and the biomass formation [35].

Related to Si, the endogenous Si application has been proven to increase the plant growth and mitigate abiotic and biotic stresses [36]. Previous research reported that Si application could enhance the number of productive tillers [37,38]. The present result showed that addition of Mg and Si in combination with NPK gave better plant growth compared to NPK solely.

3.3. Effect of MgSi fertilizer on stem strength and lodging tolerance

MgSi fertilization combined with NPK tended to increase the stem strength of rice plants by 1% to 31% even though it was not statistically significant (Figure 1a). However, the application of MgSi Fert significantly increased lodging tolerance for rice plants as shown in Figure 1b. The role of silica was very prominent in increasing lodging tolerance than magnesium, especially when compared to control or NPK fertilization without silica and magnesium. The increase in lodging tolerance as the effect of silica application ranged from 9.2 to 28.8%. This is consistent with the results of research by Datnoff et al. [39] which states that silica application significantly increases the Si content of rice straw compared to without Si fertilization. According to Mitani and Ma [40] silicon effectively enhanced stem strength of rice plant by increasing the thickness of the culm wall and the size of the vascular bundles.
3.4. Effect of MgSi fertilizer on rice yield and biomass

The effect of treatments on rice yield is shown on Table 4. The result showed that MgSi Fertilizer with different dosages combined with NPK produced better yield compared to NPK solely and significantly different with MgSi Fert solely. Similar trend also occurred on fresh straw weight (Table 5). It is noticed that Magnesium application could promoted yield for most crops depending on crop species, soil conditions, and Mg fertilization rates [41] which is similar with present result.

It is recognized that N, P, K as the essential macro nutrient play important role on crop metabolism, growth and yield. As stated by Fageria [42], rice plant needs the essential nutrients as phosphorous and potassium depend on the cultivar, nutrient supply, crop management and climatic factor.

Regarding to Si role, previous research has found that Si as beneficial nutrient for rice could enhance photosynthesis efficiency, pest and pathogen resistance, and also increase yields and quality (Ma et al. 2001). Moreover Corndorfer et al. [43] stated that the Si could improve crop yield indirectly through its role as a physical mechanism of defence, lodging reduction, increasing photosynthesis rate, and decreasing transpiration losses.

Relation between rice yield on different dosage of MgSi Fert is shown on Table 4. The result showed that MgSi Fert in combination with NPK fertilizer could increase rice yield in this present study. The highest yield was at 100% MgSi Fert + NPK. Based on the quadratic equation $y= -0.1301x^2 + 28.812x + 5474.2$ (Figure 2), it is known that highest slope on this equation is reached at MgSi Fert dosage less than 150 kg.ha$^{-1}$ and then starting to decline. The optimum dosage of MgSi Fert for rice in this present study based on the equation is 110 kg.ha$^{-1}$ + NPK producing 7.07 t.ha$^{-1}$ yield.

The RAE values of MgSi Fert on the Ciherang rice yield is presented on Table 5. The highest RAE value on MgSi Fert was achieved at 100 kg ha$^{-1}$ MgSi Fert combined with NPK being 113%. This113% RAE value showed that application of 100 kg ha$^{-1}$ MgSi Fert combined with NPK is effective for rice cultivation to support the rice growth.
Figure 2. Relation between MgSi Fertilizer dosage with rice yield.

Table 4. Effect of treatments on number of rice yield and fresh straw weight.

| Treatment                      | Yield       | Fresh straw weight |
|--------------------------------|-------------|--------------------|
| Control                        | 5,471.60 b  | 13,851.85 b        |
| NPK                            | 6,839.51 a  | 19,688.88 a        |
| NPK + Mg                       | 6,883.95 a  | 18,582.72 a        |
| NPK + Si                       | 7,308.64 a  | 19,560.49 a        |
| NPK + Mg + Si                  | 7,111.11 a  | 19,333.33 a        |
| 75% MgSi Fert. + NPK           | 6,913.58 a  | 19,279.01 a        |
| 100% MgSi Fert. + NPK          | 7,061.73 a  | 20,187.65 a        |
| 125% MgSi Fert. + NPK          | 7,012.35 a  | 20,804.94 a        |
| 150% MgSi Fert. + NPK          | 6,883.95 a  | 18,839.51 a        |
| 100% MgSi Fert.                | 5,866.67 b  | 12,338.27 b        |
| CV (%)                         | 11.00       | 8.72               |

Notes: Values in the same column followed by similar letter are not statistically different at $\alpha = 5\%$.

Table 5. RAE value of MgSi Fert based on the yield.

| Treatment                      | Yield       | RAE   |
|--------------------------------|-------------|-------|
| Control                        | 5,471.60 b  | -     |
| NPK                            | 6,839.51 a  | 97    |
| NPK + Mg                       | 6,883.95 a  | 100   |
| NPK + Si                       | 7,308.64 a  | 130   |
| NPK + Mg + Si                  | 7,111.11 a  | 116   |
| 75% MgSi Fert. + NPK           | 6,913.58 a  | 102   |
| 100% MgSi Fert. + NPK          | 7,061.73 a  | 113   |
| 125% MgSi Fert. + NPK          | 7,012.35 a  | 109   |
| 150% MgSi Fert. + NPK          | 6,883.95 a  | 100   |
| 100% MgSi Fert.                | 5,866.67 b  | 28    |

RAE = Relative Agronomic Effectiveness.
3.5. MgSi content in plant tissue

The effect of treatments on Mg and Si contents in plant tissue is presented on table 6. The result showed that Mg content in plant tissue is not significantly different throughout the treatments. However, the application of MgSi Fert was able to increase Mg levels in plants by 2.36 to 13.27%. The highest Mg content in plant tissue was at 100% MgSi Fert combined with NPK. This result supported the yield in this present study where by getting essential nutrients as N, P, K, and also Mg and Si, the plant could improve the yield. Because the initial soil Si content was low (1.04 cmol), it was possible that magnesium from MgSi Fert could be absorbed properly by plants if containing more than 2% Mg. The amount of magnesium in the leaves of rice plant varies. Mg is very mobile in plant tissue and usually stored in older plant parts as Mg pools for younger [44]. According to Hauer-Jakli and Trankner [35] the critical level of Mg contained in rice leaves was 0.2% indicating that the plants needs on Mg had been met during the plant growth period.

Table 6. Effect of treatments on Mg and Si contents in plant tissue.

| Treatment                        | Mg  | Si  |
|----------------------------------|-----|-----|
| Control                          | 2.11 a | 11.80 b |
| NPK                              | 2.11 a | 14.74 ab |
| NPK + Mg                         | 2.20 a | 15.18 ab |
| NPK + Si                         | 2.14 a | 16.59 a |
| NPK + Mg + Si                    | 2.23 a | 14.84 ab |
| 75% MgSi Fert. + NPK             | 2.18 a | 13.64 ab |
| 100% MgSi Fert. + NPK            | 2.39 a | 15.38 a |
| 125% MgSi Fert. + NPK            | 2.19 a | 14.07 ab |
| 150% MgSi Fert. + NPK            | 2.00 a | 13.85 ab |
| 100% MgSi Fert.                  | 2.16 a | 13.31 ab |
| CV (%)                           | 11.52 | 13.45 |

Notes: Values in the same column followed by similar letter are not statistically different at α = 5%. NPK dosage based on soil analysis result; MgSi Fert = MgSi Fertilizer.

Si content in plant tissue in this present study showed varied among treatments. The highest Si content was at NPK + Si treatment as 16.59% and significantly different with control. The Si source on NPK and Si treatment was silica gel containing 90% SiO₂ being higher than in MgSi Fert. Si content in plant tissue under MgSi Fert treatments showed no significant different with NPK + Si and the highest Si content was at 100% MgSi Fert + NPK. The result on Si content in plant tissue had same trend with the yield and this proved that Si has influence on increasing the yield. As in this present study that both treatments with higher Si content of plant tissue have the higher yield as well.

4. Conclusions

Present study concluded that MgSi fertilizers promote plant growth and uptake on Mg and Si, and increase stem strength and lodging resistance of rice plant. Maximum MgSi fertilization dose of 110 kg ha⁻¹ + NPK recommendation increased the yield of Cihergang rice variety to produce 7.07 t ha⁻¹. The recommended dosage of fertilization for the research location is 100 kg ha⁻¹ MgSi Fert, 250 kg ha⁻¹ urea, 100 kg ha⁻¹ SP-36, and 75 kg ha⁻¹ KCl because it is agronomically effective and economically increases rice yields as indicated by the RAE value > 100% and IBCR > 1.

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