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Influence of Water Management and Silica Application on Rice Growth and Productivity in Central Java, Indonesia

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Abstract

Rice cultivation in our study site at Central Java, Indonesia, is constrained by water scarcity and blast disease problems. A field experiment was thus conducted to evaluate the effect of water management and silicon (Si) application (with 500 kg ha^{-1} of silica gel) on improving rice growth and productivity and blast disease infection in Jakenan, Central Java. Split plot in randomized complete block design with 4 replications was used. The results showed that two water saving methods, intermittent (IT) and aerobic rice (AR) increased rice yield compared to conventional flooding water management. Further, IT showed better root growth and hence lodging resistance and decreased blast disease infection. IT had higher yield potential compared to AR although the yield of IT and AR were not statistically different. Si application gave significant effect on reducing leaf and neck blast infection and also increased stomata density ($p < 0.01$) in all water treatments. Si application did not result in increased yield but exhibited potential towards improving rice plant growth and production. Since Si fertilizer was never used in rice cultivation in Indonesia, the study reveals that IT combine with Si application was a suitable management for rice production in dry season in water limited Central Java region.

Keywords: blast disease, rice yield, Si application, stomata density, water management

1. Introduction

Indonesia is a country with a diverse tropical environment and plentiful annual precipitation, rice is widely grown and become the most important crop in Indonesia. The current condition of water management in our rice cultivation is still dominated by continuous flooding. This continuous fooding is suitable to apply in Indonesia because there is uncountable natural abundance water in the form of high rainfall in Indonesia. Conversely, certain areas such as Jakenan, Central Java province experience occasional water shortage. Annual rainfall in Indonesia is 2000-3000 mm year^{-1} (Statistics Indonesia, 2016). However certain areas such as in Jakenan, Central Java, annual rainfal is 1100-2000 mm year^{-1}.

Rainfed lowland rice in Central Java covers about 83,638 ha (Ministry of Agriculture of Republic of Indonesia, 2016) where farmers practice a high degree of crop intensification. At the onset of the rainy season, a direct seeding crop (locally they call "gogo rancah") is grown with and rainfall is the source for irrigation. Immediately after the harvest of direct seeding crop, the second tranplanted crop (walik jerami) is grown under minimum tillage in submerged water condition. Earlier studies showed that the direct seeding crop season had higher yield than the second transplanted crop season, about 3.5-6.5 Mg ha^{-1} and 1.2-3.0 Mg ha^{-1} respectively (Mamaril et al., 1994; Wihardjaka et al., 1999). It showed that continous flooding as employed in the second transplanted crop season did not improve the yield. On the other hand, the direct seeding method had disadvantages such as poor seedling establishment and plant lodging occurrence which could influence on the yield (Yoshinaga, 2005).

Several cultivation methods have been adopted to improve rice production in Indonesia such as improved varieties, fertilizers, and irrigation. However, appropriate water management and silica (Si) application have not been applied in Indonesia. Related to water management, as mostly Indonesian farmers apply continuous flooding, intermittent as water management is not fully adopted. Nevertheless, previous study stated that continuous flooding can results in lodging due to the degeneration of surface roots that grow within the top 5 cm of the soil (Kar et al., 1974). Rice plants grown in aerated soil condition develop larger root systems than rice grown under continuous flooding conditions, where root die back due to lack of oxygen. Lodging is a major constraint to rice production, especially in high yielding varieties with long stem. It causes direct loss in grain yield and quality and has some indirect effects such as hindering harvesting operations (Fallah, 2000). Lodging problem could be affected by many factors i.e root growth, panicle type, plant height, starch content, silica content as well as cultivation condition (Li et al., 2009; Yang et al., 2000; Ma & Yamaji, 2006).

Silicon (Si) is the second most abundant element after oxygen in the earth's crust and most soils contain considerable quantities of the element (Savant et al., 1997; Singer & Munns, 2006). However, certain soils are low in plant-available Si which occurred in soil with highly weathered, leached, acidic and low in base saturation. Si has been shown to be a beneficial element for rice which contributes to improve resistance of rice to blast disease, lodging problem, absorption of elements such as N, P, and K. Si is absorbed by plants as monosilicic acid (H_4SiO_4) (Jones & Handreck, 1967). Once absorbed, silicic acid condenses into a hard polymerized silica gel known as plant opal on epidermal surfaces (Yoshida et al., 1962).

Related to lodging resistance, as Si deposited on epidermal surface, it is supposed to stiffen stems and leaves of rice plants to improve rice plant resistance to lodging. Previous study reported that Si treatment serves to impart more strength to the stem to resist breaking than those plants in non Si treatments by increasing the number of silicated cells and Si content in stalks even at higher levels of nitrogen (Sadanandan & Varghese, 1968). Si contributes to increase the mechanical strength as the culm wall and a vascular bundle become thicker and larger (Shimoyama, 1958).

Application of Si fertilizer is routine for rice cultivation in Japan, China, Brazil and other countries (Ma & Takahashi, 2002; Korndorfer & Lepsch, 2001). Meanwhile in Indonesia, the farmers have never used it in rice cultivation. There are some studies on soil available Si on paddy field of Indonesia. Darmawan et al. (2006) reported that over the past three decades, soil Si availability has decreased by 11-20%. Husnain et al. (2008) reported that dissolved Si concentration in irrigation water in Indonesia has also decreased by 10-20% in the same period. Husnain et al. (2011) stated that paddy soils contained available Si less than 300 mg SiO_2 kg^{-1}, a deficiency criterion proposed by Sumida (1992), in 76% out of total 92 paddy soils examined in West Sumatra, and 22.5% out of total 59 paddy soils in West Java, while in Central Java and East Java, it was less than 3% out of total 43 paddy soils in both provinces. These studies stated increasing risks on rice cultivation such disease and pest attacks, lodging and so on that read in reduction and unstabilization of rice production, and also stated necessity of Si application for rice cultivation in Indonesia. However none of the study examining the effect of Si application on rice cultivation in Indonesia.

Blast disease caused by fungus *Pyricularia grisea* (Cooke) Sacc. [= *Magnaporthe grisea* (Hebert) Barr] is one of the most devastating diseases of rice plant. This disease has become increasingly important, as reflected by the most recent data indicating that 10,604 ha and 11,929 ha of rice field throughout the country were damaged by blast disease in 2010 and 2011, respectively (Wibowo, 2011). Up to the present, fungicides have been used effectively to control blast disease but not with Si application. Our study site has faced water scarcity and blast disease problem in rice cultivation, however up to present the farmers have been applying only continuous flooding as their water management and using fungicide for blast disease control. Therefore in the present study, we conducted a field experiment to evaluate the effect of two water saving methods and Si application on improving rice plant growth and blast disease infection in Central Java.

2. Materials and Methods

2.1 Sites and Soils

Field experiment was conducted at experimental site of *Balai Penelitian Lingkungan Pertanian* (Indonesian Agricultural Environment Research Institute-IAERI), Jakenan, Central Java province, Indonesia during the dry season. This location lies on 06°46′66.7″ S-111°11′91.4″ E.

A field experiment was carried in 2014 to comparing three water management consist of continuous flooding (CF), Intermittent (IT) and Aerobic rice (AR) as main plots (Figure 1). Aerobic rice is a water saving technique for rice cultivation regions where rice is grown without ponded water because of low water availability (Bouman et al., 2007). The plots were in aerobic condition due to water scarcity before we started the water management. Then three weeks after sowing when the rain started, we started to employ three water managements. In CF management, the field was maintained with 5 cm depth of ponded water until flowering stage then at ripening stage of 105 days after sowing (DAS), about 15 days before harvest the field was dried and the outlet was opened. On IT management, the field was flooded about 5 cm water layer for 3 consecutive days then start to interrupt the water supply for 7 consecutive days with closed outlet. This pattern was conducted until panicle initiation stage. Then during flowering stage, the field was in flooding condition about 5 cm water layer and 15 days prior to harvest, the field was dried with opened outlet. In AR management, the field was in flooding condition for 28 days (tillering stage) with 5 cm water layer, after that we started the aerobic condition with closed inlet in following condition until harvest, *i.e.* when the water level drop to 15 cm below the soil surface, we irrigate the field until it reaches 15 cm. 15 days prior to harvest, the field was dried with opened outlet. Field water tube was installed in AR treatment to monitor the water level.

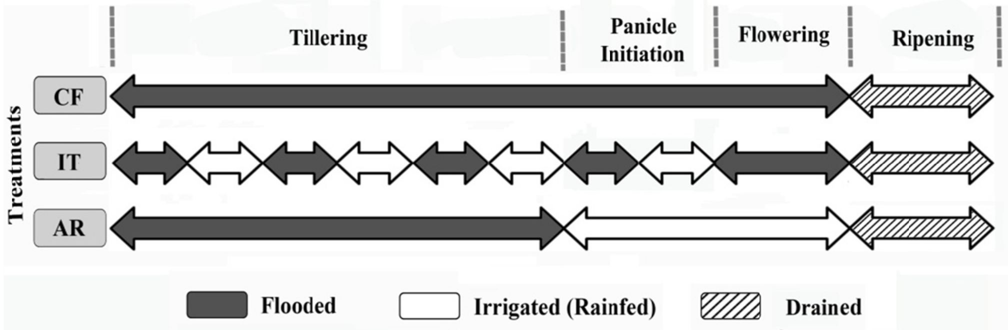

Figure 1. Diagram of water management

Note. CF: 5 cm depth of water until 105 DAS then dried for 15 days before harvest. IT: the field was flooded with 5 cm depth for 3 days then interrupted water supply for 7 days (closed outlet), with this pattern employed until panicle initiation. At flowering stage, IT was in flooding condition with 5 cm depth then the field was dried 15 days before harvest (opened outlet). AR, the field was flooded with 5 cm depth for 28 days (tillering stage) then the field was set in aerobic condition until flowering (keeping water level higher than the soil depth of 15 cm), then the field was dried 15 days before harvest.

Direct seeding was employed, therefore the plots were dried for three weeks before water managements were started.

The sub plot was characterized by two treatments including Si+ and Si- (with and without Si fertilizer). We used local silica gel “Silica gel White” sold as desiccant by IMCO Co. as Si fertilizer. This local silica gel has the spherical shape with the diameter of 2-4 mm and has lower water solubility, 0.1 gg^{-1} 24 h^{-1} compare to Japanese Si fertilizer, Super Inergia, 0.3 gg^{-1} 24 h^{-1}. A rice variety “Ciherang” was used for this study as it is a very common variety recommended by Ministry of Agriculture of Republic of Indonesia. Ciherang rice variety which released in 2000 is an indica rice categorized as short-duration variety (116-120 days) with average yield of 6 ton ha^{-1} and is suitable for planting in rainy and dry season. Split plot in randomized complete block design with 4 replications was used. The plot size was 4 m × 5 m for each treatments. During plotting, we installed plastic sheet about 30 cm into the soil between treatments at the border sides to avoid contamination. Each plots had an inlet and outlet for irrigation.

Initial soil properties (Table 1) showed that the soil in experimental site had low soil available silica below the critical level proposed by Sumida (1992) and Dobermann and Fairhurst (2000): 300 and 86 mg SiO_2 kg^{-1} respectively. The parent material of the experimental site is alluvial (Kadar & Sudijono, 1993).

Table 1. Initial soil properties

Soil Properties	Values	Criteria[a]
pH (H_2O)	4.90	Acid
Total C (g kg^{-1})	7.6	Very low
Total N (g kg^{-1})	0.3	Very low
Exchangeable cations ($cmol_c$ kg^{-1})		
Ca	2.14	Low
K	0.04	Very low
Mg	0.25	Very low
Na	0.15	Low
Available Si (mg SiO_2 kg^{-1})	31.3	Low[b]

Note. [a] Refered to Indonesian Soil Research Institute (2005).

[b] Refered to Sumida (1992).

2.2 Plant Cultivation

Rice cultivation was conducted with direct seeding method due to water scarcity with row spacing 20 cm × 20 cm. Land preparation was done by conventional tillage. Silica gel was applied before sowing the seed as 500 kg ha^{-1}. The rainfall collected in the pond is used for irrigation. The fertilizer dosage was 350 kg ha^{-1} of Urea, 100 kg ha^{-1} of SP-36 and 50 kg ha^{-1} of KCl. Urea and KCl fertilizer were applied two times, at 24 DAS (days after sowing) and 50 DAS. Meanwhile for SP-36 was applied one time at 24 DAS. During this cultivation we did not apply any fungicide for blast disease.

2.3 Sampling and Analysis

The available Si for initial soil analysis was determined using the acetate buffer method (Imaizumi & Yoshida, 1958). 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. Although Sumida (1991) reported that the acetate buffer method was not suitable for soils previously amended with silicate fertilizer, this was not a problem because no silicate fertilizer had been applied previously in this experimental site. The extracted Si content in the soil samples was determined using atomic absorption spectrophotometer (Z-5000; Hitachi, Tokyo, Japan). The soil pH was measured using the glass electrode method with a soil:water ratio of 1:2.5 (IITA, 1979; McLean, 1982). For determining soil exchangeable cation, soil samples were extracted with 1M NH_4OAc at pH 7 (Thomas, 1982) and measured by Inductively Coupled Plasma (ICPE-9000 Shimadzu Co, Kyoto, Japan).

Rice leaf samples, the Y-leaf, were collected at 50 DAS, 90 DAS and harvest then analyzed for total Si content. Samples were digested with HNO_3 in a high pressure Tefflon Vessel (Quaker et al., 1970; Koyama & Sutoh, 1987). After heating and digest in 160 °C for 5 hours and cooling overnight, then adding HF 10% and H_3BO_3 4%. The extracted Si content in the plant samples was determined using atomic absorption spectrophotometer (Z-5000; Hitachi, Tokyo, Japan).

Lodging resistance was measured using Force Gauge at 75 and 110 DAS. 10 plant samples were selected from each treatment for lodging resistance measurement. To measured lodging resistance, the stem was bent at 15 cm from the surface of the soil to establish an angle 45° (Yoshinaga, 2005).

Stomata samples were collected with clear nail polish method (Radoglou & Jarvis, 1990) at 50, 80 and 95 DAS. Epidermal impression was prepared by coating the rice leaf surface with nail polish which was peeled off, once nail polish was dried, it was mounted onto a slide by a cello tape. The impression approach was used to determine the number of stomata. The sample was collected only from abaxial leaf surface since the abaxial leaf surface has greater stomata density than the adaxial surface exposed to sun light (Martin & Glover, 2007). Less stomata density on adaxial surface could decrease leaf water transpiration rate (Wang & Clarke, 1993b). These impressions were observed by light microscopy (Olympus BX51) and number of stomata were investigated in a field of 0.04 mm^2 then we calculated the number of stomata per mm^2 leaf area.

Blast disease infection was observed at 50 and 95 DAS for leaf blast and 95 DAS and harvest for neck blast. 10 plant samples were observed from each treatment for blast disease infection. We observed leaf blast disease infection using score value which employed by IRRI System (1996). Score value for each symptom category of blast disease are 0: no lessions; 1: small brown speaks of pin point size or large brown speak without speculating centre; 2: small round dish to slightly elongated necrotic grey spots about 1-2 mm in diameter with distinct brown margin lessions are mostly found on upper leaves; 3: same as score 2, but significant number of lesions are on upper leaves; 4: typical susceptible blast lesion, 3 mm or longer infecting lesions than 2% of leaf area; 5: typical blast lesion infecting 2-10% of leaf area; 6: typical blast lesion infecting 11-25% of the leaf area; 7: typical blast lesion infecting 26-50% of the leaf area; 8: typical blast lesion infecting 51-75% of the leaf area and 9: more than 75% leaf are affected.

Normality test was conducted before analyze the effect of treatments and the outlier data was excluded. To determine the influence of water managements and Si application on parameters, data were statistically analyzed by two way analysis of variance (ANOVA). Significances among the treatments were determined by Tukey's honestly significant difference test at $p < 0.05$. All statistical analysis was performed using IBM SPSS Statistic version 20.0 (IBM SPSS, 2011. Chicago IL, USA).

3. Results

3.1 Plant Growth

Table 2 shows the effects of treatments on plant growth as root weight, shoot weight and number of tillers. On root weight, IT was higher by 25 and 43% for Si+ and 15 and 16% for Si- comparing to CF and AR respectively. IT management also showed higher shoot weight than CF and 5% significant with AR (Table 2).

On Si application, there was no significant difference on root weight, shoot weight and number of tillers.

Table 2. Effect of treatments on root and shoot weight, and number of tillers at harvest

Si application	Water management		
	CF	IT	AR
Root (g m^{-2})			
Si+	360 ± 26.2ab	449 ± 96.5b	314 ± 46.8a
Si-	349 ± 66.1ab	401 ± 72.6b	344 ± 37.2a
Shoot (kg m^{-2})			
Si+	2 ± 0.5ab	2.2 ± 0.4b	1.8 ± 0.2a
Si-	2 ± 0.2ab	2.1 ± 0.3b	1.6 ± 0.1a
Number of tillers (per m^2)			
Si+	349 ± 15.8b	304 ± 41.3b	274 ± 36.5a
Si-	358 ± 23.5b	356 ± 44.8b	279 ± 14.9a

Note. Means followed by the same latter do not differ significantly at 5%; No statistical difference was observed between Si treatments; ± denotes standard deviation.

3.2 Leaf and Neck Blast Infection

On the effect of Si application, the leaf blast infection at 50 and 95 DAS was the lowest in IT (Figure 2). Si application gave significant effect ($p < 0.01$) on reducing leaf blast infection throughout the observation periods in all water management (Figure 2). Si application decreased the leaf blast infection by 62, 45 and 45% at 50 DAS and 62, 29 and 48% at 95 DAS for CF, IT and AR management, respectively. Si application gave significant effect ($p < 0.01$) on reducing neck blast infection throughout the observation periods in all water management as well as it did for the leaf blast (Figure 3). Si application could decrease significantly ($p < 0.01$) the neck blast infection by 72, 86 and 80% at 95 DAS and 75, 69, and 80 % at harvest for CF, IT and AR management comparing to Si- treatments, respectively. Describe, neck blast infection was severer and effect of Si was clearer. Si application clearly showed significant effect on decreasing both leaf and neck blast in the present study.

On the effect of water management, IT had effect on reducing leaf and neck blast infection.

3.3 Rice Yield

The result showed that water management showed significant effect on yield. The rice yield in IT increased 29 and 4% comparing to CF and AR in Si+ treatments, and 60 and 5% to CF and AR in Si- treatment, respectively. We also observed yield component that probably contributed the yield difference among treatments. The 1000-grains weight of IT and AR were not significantly different but were higher than that of CF (Table 3).

Meanwhile on Si application, there was no significant difference on rice yield.

3.4 Lodging Resistance

For The result of lodging resistance at 95 and 110 DAS is shown in Figure 4. The lodging resistance tended to decrease from 95 to 110 DAS in all water management because the shoot weight increase with grain filling and leaf senescence occurs (Yoshida, 1981). IT showed slightly higher lodging resistance than AR did at 95 DAS. Meanwhile, Si application showed no significant effect in all the water management.

3.5 Stomata Density and Length

In all water management, Si application increased stomata density by 8-44% for all the observation period. Meanwhile on stomata length, Si application had no significant effect. Generally in IT, the increase rate was higher than CF and AR. IT and AR had higher stomata density than CF in both Si treatment condition at 80 DAS (Table 4).

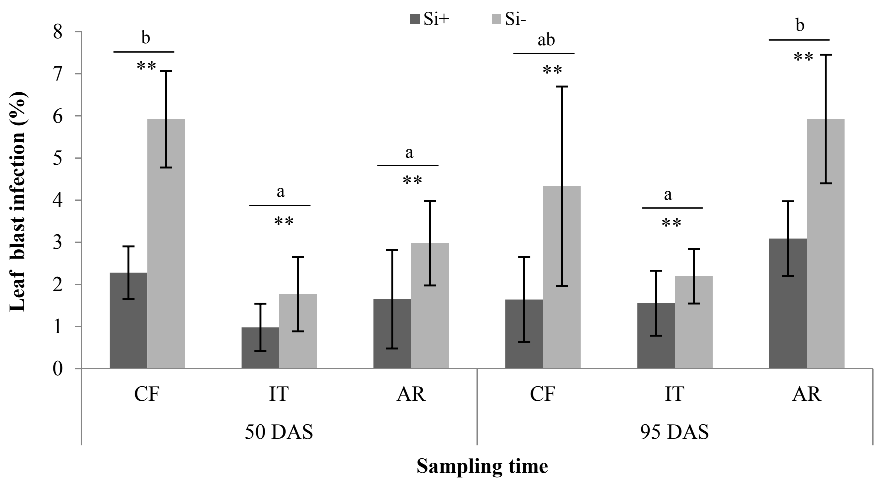

Figure 2. Effect of treatments on leaf blast infection

Note. The different alphabet letters indicates significant difference among water managements each sampling time; ** Significant difference at p < 0.01 between Si+ and Si- at each sampling time; Error bars indicate standard deviation among the mean values.

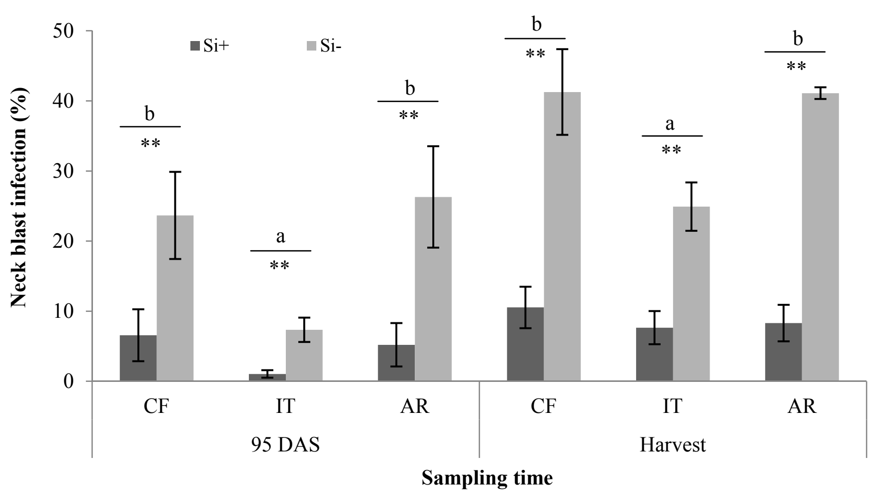

Figure 3. Effect of treatments on neck blast infection

Note. The different alphabet letters indicates significant difference among water managements each sampling time; ** Significant difference at p < 0.01 between Si+ and Si- at each sampling time; Error bars indicate standard deviation among the mean values.

Table 3. Effect of treatments on rice yield and yield component

Si application	Water management		
	CF	IT	AR
Yield (g m^{-2})			
Si±	423 ± 41.5a	547 ± 39.7b	524 ± 28.4b
Si-	332 ± 44.7a	530 ± 18.0b	507 ± 42.3b
The 1000-grains weight (g)			
Si±	30 ± 1.5a	32 ± 0.8b	31 ± 0.9b
Si-	29 ± 1.9a	31 ± 0.6b	30 ± 0.8b

Note. Means followed by the same latter do not differ significantly at 5%; No statistical difference was observed between Si treatments; ± denotes standard deviation.

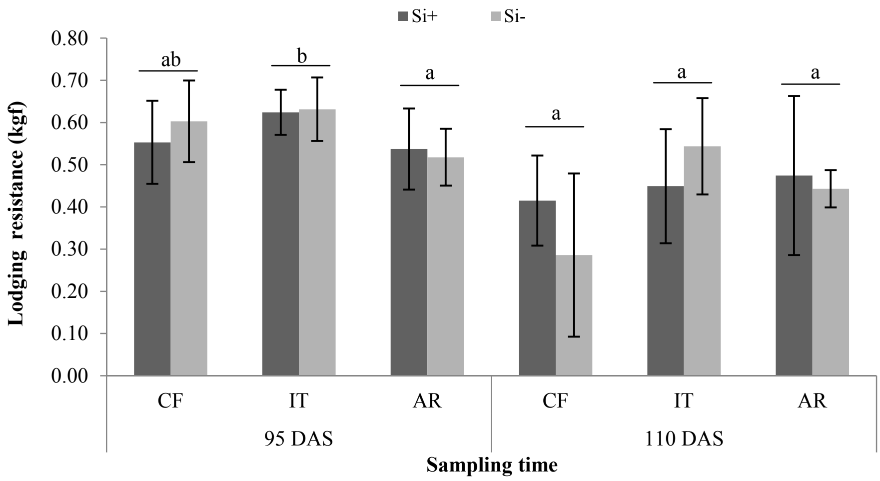

Figure 4. Effect of treatments on lodging resistance

Note. The different alphabet letters indicates significant difference among water managements each sampling time; There was no significant difference between Si+ and Si- at each sampling time; Error bars indicate standard deviation among the mean values.

Table 4. Effect of treatments on stomata density and length

Si Application	Water management								
	50 DAS			80 DAS			95 DAS		
	CF	IT	AR	CF	IT	AR	CF	IT	AR
Stomata density (per mm^2)									
Si+	591±76a	610±33a	534±62a	668±49a	795±45c	724±5b	630±21a	721±19a	730±14a
Si-	464±35a	435±53a	588±25a	519±45a	608±29c	588±25b	580±35a	536±26a	508±43a
	**	**	**	**	**	**	**	**	**
Stomata length (× 10^{-3} mm)									
Si+	11±0.2a	12±0.6a	15±3.2b	14±0.7a	14±0.4b	14±0.4ab	11±0.4a	13±0.7b	13±0.5b
Si-	12±0.7a	13±0.6a	14±0.7b	13±0.3a	14±0.2b	13±0.6ab	13±0.1a	12±0.4b	13±0.5b
	ns	ns	ns	ns	ns	ns	ns	ns	ns

Note. Means followed by the same latter do not differ significantly at 5%; No statistical difference was observed between Si treatments; ± denotes standard deviation.

4. Discussion

The result showed that IT had higher root weight that possibly due to better soil aeration which could increase root growth. Xu et al. (2007) stated that root biomass in intermittent irrigation was higher than in continuous flooding. Moreover, Mishra (2012) found that intermittent irrigation positively affected root length, density and total root mass in rice growth. These were consistent with the results of the present study. On the other hand, several works reported possible negative effects of CF and AR water condition on plant growth. Continuous flooding could degenerate and has been proved to be detrimental to the rice root growth (Kar et al., 1974; Sahrawat, 2000). Low soil water availability and high soil impedance of paddy field could inhibit root growth (Taylor & Gardner, 1963; Cornish et al., 1984). Therefore as the shoot drives water uptake through a plant, root system, properties and distribution include the weight, ultimately determine plant access to water and thus set limit on shoot weight and functioning (Nardini et al., 2002).

Furthermore, higher shoot weigh in IT might be due to better root growth which could enhance water and nutrient uptakes for its higher shoot growth in IT. On number of tillers, CF and IT had higher number of tiller than did AR. Lower number of tiller in AR could be related to the low soil moisture which could induced impaired and reduced tillering numbers (Yoshida, 1981).

Related to blast disease infection, IT had lesser leaf and neck blast infection. This might be because IT had a less favorable soil moisture condition for blast disease life-cycles (Chapagain et al., 2011). In IT, the soil moisture condition repeteadly changed from submerged to non-saturated, rather dry. When the soil became unsaturated, the soil temperature could increase in the day time and could lower the relative humidity in the fields comparing to that in CF. The lower relative humidity were less favorable for rice disease and insect pest (Bin, 2008). Moreover, Xuan and Gergon (2016) stated that to reduce blast development, intermittent irrigation during seedling stage was also effective.

In the aspect of soil moisture condition, AR must have been the driest and should have an advantage in blast infection. However, AR tended to have higher leaf and neck blast infection than IT did. This could be attributed in the difference of rice Si uptake in each water management. Aerobic soil condition observed in AR could decrease the solubility of Si (Winslow, 1995) which could reduce rice Si uptake. Meanwhile the soil in IT treatment repeatedly experienced submerged condition which increases soil Si availability (Fageria et al., 2011).

Regarding with rice Si uptake, IT had higher leaf Si content ($p < 0.05$) than CF and AR at 95 DAS and than CF at harvest (Figure 5). IT water condition could enhance plant Si uptake through both better root growth and higher soil Si availability. Then, higher plant Si content probably reduced blast disease infection as Ma and Takahashi (2002) reviewed several literatures.

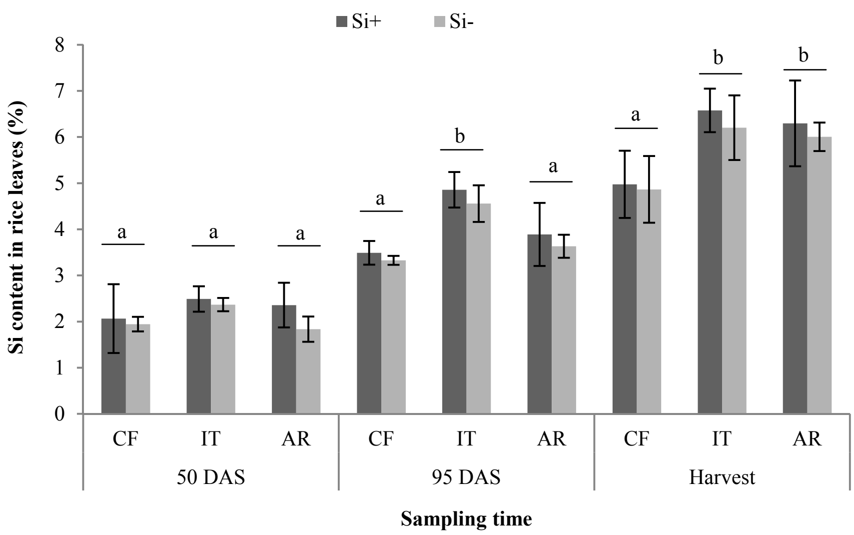

Figure 5. Effect of treatments on Si content in rice leaves

Note. The different alphabet letters indicates significant difference among water managements each sampling time; There was no significant difference between Si+ and Si- at each sampling time; Error bars indicate standard deviation among the mean values.

Si application clearly gave the positive effect on reducing leaf blast infection on Ciherang variety, which agreed with the research results found in West Java (Siregar et al., 2016) where soil Si available was 426.54 mg SiO_2 kg^{-1} and for the other rice varieties in different countries such as in Japan, Brazil and Thailand (Seebold, 1988; Prabhu et al., 2001; Hayasaka et al., 2005; Wattanapayapkul et al., 2011). The present result showed that Si application showed clearer effect on reducing blast disease on rice plant with soil Si available is 31.27 mg SiO_2 kg^{-1}, lower than critical level proposed by Dobermann and Fairhust (2000) 86 mg SiO_2 kg^{-1}.

The Si content in rice leaves was not significant different between Si treatment but tended to increase on Si+ treatment (Figure 5). The mechanism of Si-induced blast resistance has been hypothesized that silicic acid uptake by plant form hard glass-like coating of polymerized SiO_2, so called plant opal, on the epidermal surfaces and this coating will acts as a physical barrier which could block the fungi penetration (Yoshida, 1965; Winslow et al., 1997; Datnoff & Rodrigues, 2005).

In rice cultivation, the yield could be affected by water and nutrients availability (Dobermann & Fairhust, 2000) and to achieve sufficient amounts of these factors, rice plant requires a good rooting ability. Related to root condition, where IT had higher root growth (Table 2) as well as higher yield compare to CF and AR did (Table 3). Higher yield achieved in IT treatment could due to better root growth which could enhance water and nutrient uptake contributing to higher photosynthetic rate (Osaki et al., 1997).

Beside the fact that IT had better root growth, overall IT management also had the lowest leaf and neck blast infection compared to AR and CF management throughout observation period. As water condition in IT with better root growth, it could enhance higher Si uptake which followed by improving the blast resistance of rice plant in IT. The present study showed significant negative correlation between neck blast infection and the rice yield ($r = 0.64$ and $r = 0.65$ at Si+ and Si- treatment respectively; $p < 0.05$) (Figure 6). In general, it is known that blast disease is one of the most destructive for rice production. And neck blast is considered the most important symptom of rice blast because it is more closely related to yield loss (Zhu et al., 2005). Bastiaans (1993) reported that leaf blast could reduce the photosynthetic rate. This meant leaf blast also possibly reduce rice growth and yield. However, blast infection could not fully explain the difference on rice yield shown in Table 3.

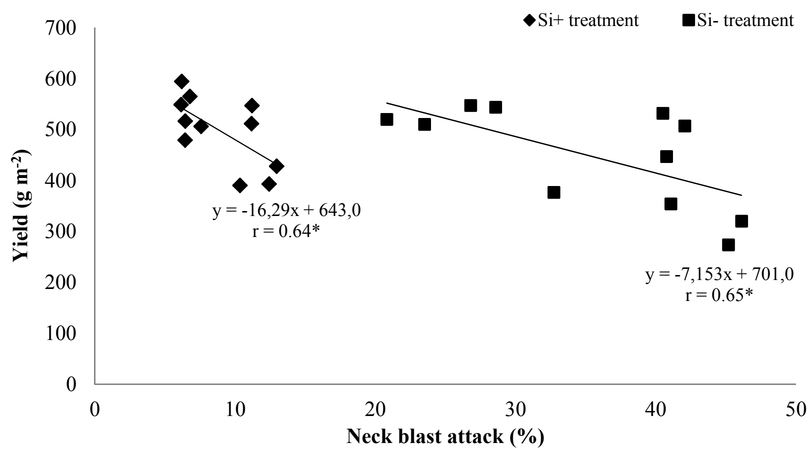

Figure 6**.** Correlation between neck blast attack with the yield ($p < 0.05$)

Moreover, IT showed higher stomata density compare to CF and AR (Table 4). This result could be took part on increasing the rice yield in IT. Some previous studies (Jones, 1992; Ishimaru et al., 2001) stated that the improvement on morphological characteristics of stomata such as stomata density could improve the yield.

In this present study, although IT had higher yield but it was not significant different with AR. This result might be related with the Si content in rice leaf and the transpiration rate. As shown in Figure 5, the Si content in rice leaves at harvest was not significant different between the IT and AR and higher compare to CF. Transpiration plays a certain role in translocation and accumulation of Si to the tops of rice, i.e leaves and husk, where the transpiration rate is higher at those plant organs. Along with higher Si content in leaves, it will stimulate the translocation of photoassimilated CO_2 to the panicle in rice (Ma & Takahasi, 2002) which could influence on the yield.

IT management showed possibility to improve lodging resistance, which might be due to better root growth. The higher lodging resistance in IT was attributed to higher root weight (Table 2). Previous studies stated that root system was responsible for lodging in rice plant. Higher lodging resistance would require heavier roots and deeper root system (Terashima et al., 1994; Feng-zhuan at al., 2010). Therefore with better root growth in IT management it could improve lodging resistant of rice plant. Meanwhile, Si application showed no significant relationship with the lodging resistance in the present study.

Stomata density showed that generally the increase rate of stomata in IT was higher. However at 80 DAS, showed that IT and AR had higher stomata density than CF in both Si treatment condition (Table 4). On stomata length, the result showed that IT and AR tend to have higher stomata length than CF. It probably indicated the adaptation of rice plant to water limited condition as reported by Spence et al. (1986) and Kramer (1988). The present study showed that Si application clearly gave the positive effect on increasing stomata density on Ciherang variety throughout observation, which agreed with the previous results found in West Java (Siregar et al., 2016). These are in line with the result from Dias et al. (2014), stated that there is indication of Si addition promoted the development of higher stomata density. Si application combined with water saving condition had the highest effect on stomata density increment.

Some of previous studies presumed that Si plays a role in decreasing the transpiration rate by changing the stomata movement rather than affecting its morphology and density (Gao et al., 2006; Zargar & Agnihotri, 2013). According to Marin (2003) benefits of Si application to plants includes direct effect such as structural development and indirect effect like in increasing the photosynthetic rate by improving stomata density. Moreover, apart from the present result that showed Si could improve stomata density, Si also could keep the leaf erect as it is deposited in the leaf therefore Si could stimulate canopy photosynthesis by improving light interception (Ma & Takahasi, 2002).

5. Conclusions

The present study demonstrated that two water saving management increased rice yield comparing with conventional flooding water management. This probable attributed to better grain filling status shown of the 1000-grains weight. Besides this result, IT had better root growth that possibly leaded to improve lodging resistance and shoot growth and also decreased blast disease infection. These results suggested that IT had higher yield potential comparing to AR although the rice yield of IT and AR were not statistically different in this time. This result might be due to Si uptake which IT and AR had higher Si content in leaves, and could promoted on photosynthetic rate.

On Si application, it clearly improved plant resistance to both leaf and neck blast infection and increased stomata density in all water treatments. In this time, these phenomena did not result in the higher yield but exhibited potential improving rice plant growth and production in Central Java region. In conclusion, IT combine with Si application was a suitable management for rice production in dry season in water limited Central Java region.

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