ASSESSMENT OF EFFECTS OF SILICON APPLICATION AND IMPROVED WATER MANAGEMENT ON RICE PRODUCTION IN INDONESIA

(インドネシアの米生産におけるケイ酸施用と水管理改善の効果の評価)

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Approval Sheet

This thesis enclosed herewith, **"ASSESSMENT OF EFFECTS OF SILICON APPLICATION AND IMPROVED WATER MANAGEMENT ON RICE PRODUCTION IN INDONESIA",** prepared and submitted by Adha Fatmah Siregar in partial fulfillment of the requirement for the award of degree of Doctor of Philosophy, is hereby approved as to style and contents.

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Dedication,

This dissertation work is dedicated to :

In memory of my father Drs. ParningotanSiregar, my role model who gave me inspiration, and always supported me, whatever path I took.

To my mother Hj. SitiRahmahSaragih, BBA and my sister ArdhikaNur Iman Siregar, A.Md AKT, S.E, for their encouragement and unconditional supports throughout this process. All the supports they have provided me over the years was the greatest give anyone has ever given me.

It is He who made the earth tame for you - so walk among its slopes
and eat ofHis provision - and to Him is the resurrection (Al Mulk : 15)

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CHAPTER 1

General Introduction

1.1. Rice production in Indonesia : current condition and constraints

Indonesian agriculture is one of the sectors that occupies a central position in the national economy and rice is a major component for national food security in this sector. Rice is the main staple food of the Indonesian people and it contributes as an essential element of rural development in Indonesia. Although, Indonesia is the third largest country in terms of global rice production after China and India (FAOSTAT, 2016), the domestic rice production is still not enough to meet the domestic demand and feed the people (Haryati and Aji, 2005).

Table 1.1. Agricultural land area by utilization in Indonesia, 2010-1014 (in ha)

No.	Land Type	Year					Growth 2014 over 2013 (%)
		2010	2011	2012	2013	2014	
1.	Sawah	8,002.552	8,094,862	8,132,346	8,128,499	8,114,829	-0.17
	a. Irrigated sawah	4,893,128	4,924,172	4,417,582	4,817,170	4,760,580	-1.17
	b. Non irrigated sawah	3,109,424	3,170,690	3,714,764	3,311,329	3,354,249	1.30
2.	Dry field/garden	11,877,777	11,626,219	11,947,956	11,838,770	12,011,952	1.46
3.	Shifting cultivation	5,332,301	5,694,927	5,262,030	5,123,625	5,021,954	-1.98
4.	Temporarily unused land	14,754,249	14,378,586	14,245,408	14,162,875	11,679,611	-17.53
	Total	39,966,879	39,794,594	39,587,740	39,253,769	36,828,346	-6.18

Source : Statistic Indonesia (2015).

Major locations for rice production are in Jawa, Sumatera, Bali and Sulawesi islands and mostly strengthened by irrigation networks. However, there was a decrease of total area for lowland rice cultivation (sawah) especially irrigated sawah (Table 1.1). Sawah is heavily concentrated in Java. It is shown that Jawa is the highest producer at 55% and then followed by Sumatera at 22% and Sulawesi at about 10%. Specifically, West Java was the highest contributor of rice and had the largest area as well (Panuju et al., 2013).

Rice supply has become a major problem in Indonesia particularly in the last two decades when self-sufficiency is unable to be maintained. The rice is cultivated mostly 2 – 3 times a year at lowland sawah with average rice productivity about 5.3 $ton.ha^{-1}$ (Ministry of Agriculture of Republic Indonesia, 2013),nevertheless we still import rice from others country to fulfill our necessity. Moreover, the agricultural statistic data showed that in 2015, rice import stood of 815.285 ton in 2014, increased up to 72.5% compared to 2013 (Ministry of Agriculture of Republic of Indonesia, 2015).

This condition might be because of several factors such as change inclimatic factors and also the decline of soil fertility (Husnain, 2009). The term sawah in this present study refers to a leveled and bounded rice field with an inlet and an outlet for irrigation and drainage, respectively (Wakatsuki et al., 1998).

Reduction in soil quality particularly nutrient depletion becomes one of the important factor that affected declining of crop yields (Roy et al., 2003). This nutrient depletion can be attributed to insufficient fertilizer use and unbalanced fertilization on continuous cropping system. So far, in our agriculture development plan, nitrogen, phosphorus and potassium as macro nutrients are considered as the three major plant nutrients needed by the high yielding varieties. However, the recent situation is quite different and additional plant nutrients are needed to sustain the yield, including micronutrients and beneficial nutrients such as silica (Si).

Indonesian farmers commonly apply nitrogen (urea), phosphate i.e. triple super phosphate (TSP) and super phosphate (SP-36), potassium i.e. KCl and compound fertilizer containing N, P and K for rice cultivation. Meanwhile Si fertilizer have not been applied yet. In addition, rice plants also require large amounts of Si besides N, P, and K. Moreover, with continuous rice cropping system that depends only on Si supply from soil and irrigation water, it could enhance depletion of Si available for plant since there is no additional Si supply. This condition might be related to the declining of rice yield.

1.2. Silicon as beneficial nutrient for rice and its availability in Indonesia's sawah soil

Silicon (Si) is the second most abundant mineral element in soil comprising approximately 28% of the earth's crust (Elawad and Green, 1979; Epstein, 1991). Si is not considered an essential nutrient for plant function. Nevertheless, Si is absorbed from soil in large amounts that are several fold higher than those of other essential macronutrients in certain plant species (Rodrigues and Datnoff, 2005). Si is accumulated at levels equal to or greater than essential nutrients in plant species belonging to the families Poaceae, Equisetaceae, and Cyperaceae (Savant et al., 1997). In rice, for example, Si accumulation is about 108% greater than that of nitrogen. It is estimated that a rice crop producing a total grain yield of 5000 kg/ha will remove Si at 230 to 470 kg/ha from the soil (Savant et al., 1997).

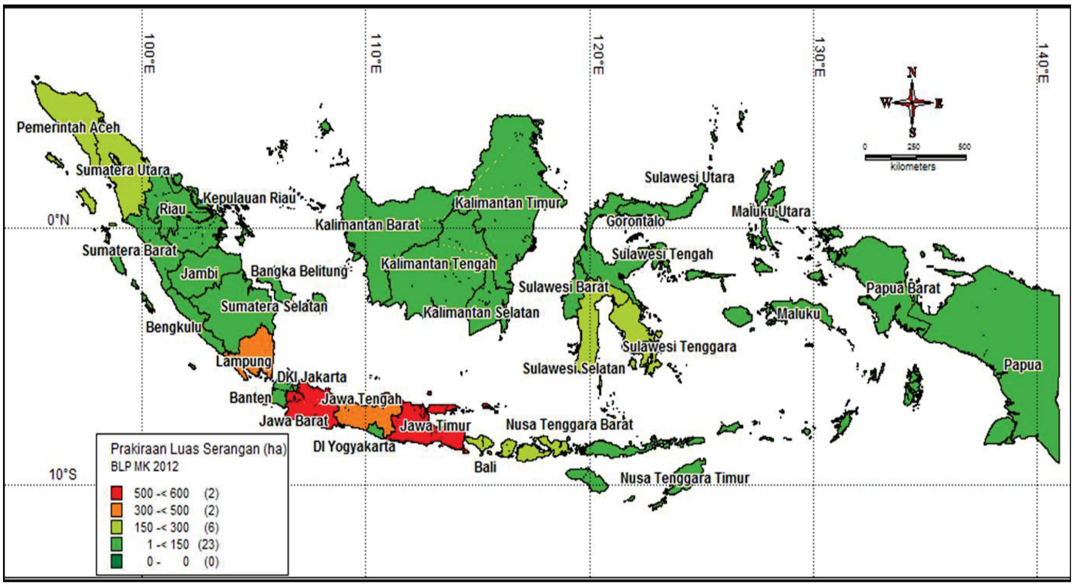
Typically, silica is deposited in rice plants in the form of silica gel or biogenetic opal as amorphous $SiO_2 \cdot nH_2O$, which are formed in epidermal cells, silica cells and bulliform cells (Yoshida et al., 1962; Yoshida, 1965; Kaufman et al., 1981). Silicon can also be found in the form of monosilicic acid, colloidal silicic acid, or organosilicone compounds in plant tissues (Yoshida et al., 1962; Inanaga et al., 1995). Once deposited, silica gel is immobile and is not redistributed to actively growing tissues (Elawad and Green, 1979; Ma et al., 1989; Epstein, 1991).

The beneficial effects of Si to plants under biotic and/or abiotic stresses have been reported to occur in a wide variety of crops such as rice, oat, barley, wheat, cucumber, and sugarcane. Related to biotic stress particularly blast disease, our farmers only use fungicide to overcome the disease. Due to blast disease infection, various hypotheses have been proposed to explain mechanisms by which Si confers resistance of rice plants against the blast disease (Ishiguro, 2001). These hypotheses can be categorized into two types. One is the so called physiological resistance hypothesis in which Si must mediate some physiological changes of rice plants to confer disease resistance. The other hypothesis is the physical barrier hypothesis in which Si mustconfer physical resistance against appressorial penetration (Hayasaka et al., 2008).

Concerning on abiotic stress such as lodging problem, known that it is one of the important constraints to high yield, stable production and high-quality in rice. Lodging in rice can be affected by many factors i.e. length and diameter of basal internodes (Wan and Ma, 2003), weight (Ma et al., 2000), silicon content (Ma and Yamaji, 2006), as well as lodging resistance and cultivation conditions such as water management and yield (Guo et al., 2003; Yang et al., 2009). Related to the role of Si, known that deposition of Si in plant cell walls can increase the mechanical strength of the organ (Gong et al., 2004). As Si deposited, it can improve sclerenchyma cell lignifications and silicification, increase the cellulose content and stem diameter and decrease lodging index, thus increasing lodging resistance (Zhang et al., 2010). This lodging problem occur in some rice production area in Indonesia. However, the lost that caused by lodging is not well documented. Improving and planting rice variety with higher lodging resistance such as Way Seputih, Cilamaya, IR-36 is the common way that we do to reduce lodging problem. Therefore related to those issues, recent study was conducted to study the effect of water management combine with Si application on improving rice production.

Based on ongoing discussion, the current condition might be an indication of Si depletion or deficiency in sawah soil in Indonesia. As the occurrence of blast disease that has threatened rice production from time to time (Ministry of Agriculture of Indonesia, 2005) which could be an indication of Si depletion in sawah soils.Shown on Fig. 1.1, the present study locations (Lampung, West Java and Central Java) are facing blast disease problem. Previous study stated that the average of total area with blast disease infection was up to 9778 ha.year^{-1} (Soetarto et al. 2001) blast disease and this infection could reduce rice yield up to 50-90% for susceptible rice varieties of blast disease (Amir and Kardin. 1991). The most endemic area for blast disease in Indonesia are Lampung, South Sumatera, West Sumatera,West Java and Central Sulawesi provinces (Yuliani and Maryana. 2014).

Moreover, the lodging problem found in some rice production area in Indonesia could be another indication of Si depletion. Up till now, Si input in sawah soil is only derived from soil Si supply, irrigation water and rice straw, if farmers return to the field without any addition from Si fertilizer (Fig. 1.2). This condition could create unbalanced Si concentration in soil due to the high loss of Si removed by harvest which is about 234-470 kg ha^{-1} (Savant et al. 1997).



Source: Forecast of Plant Pest and Disease Institute, Ministry of Agriculture of Republic Indonesia.

Figure 1.1. Blast disease distribution map in Indonesia (2014).

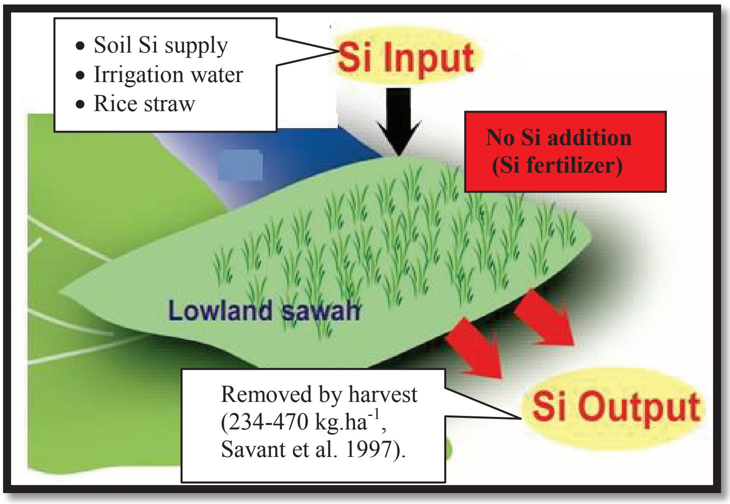


Figure. 1.2. Illustration of current condition of soil available Si in sawah soil in Indonesia.

However Si application in rice production has not been appreciated in Indonesia because it was not considered as an essential nutrient. This is as a result of limited research on soil available Si and its role in rice growth in Indonesia. Among the few research, reports state that over the past three decades, soil Si availability has decreased by 11-20% (Darmawan et al., 2006) and dissolved Si (DSi) concentration in irrigation water in Indonesia has also decreased by 10-20% (Husnain et al., 2008). Due to this limited research, it is required to study about the effect of Si application on blast disease and lodging problem to improve rice cultivation in Indonesia.

1.3. Water management in rice cultivation

Mostly, central rice production area are already strengthened by irrigation networks. The current status of agricultural water management in sawah in Indonesia is still dominated by continuous flooding. This continuous flooding is suitable to apply in Indonesia because there is natural abundant water in the form of high rainfall in Indonesia with annual rainfall of 2000-3000 mm year^{-1} (Statistics Indonesia, 2006). Conversely, certain areas such as Jakenan, Central Java province experience occasional water shortage with annual rainfall of 1100-2000 mm.year^{-1}. As stated by Sembiring et al. (2012) about 1 million ha out of 5.14 million ha of land in Java and Sumatera is sensitive to drought. Within 1-2 decades this water shortage affected area increased from 0.3 – 1.4% to 3.1 – 7.8%.

As a result of water scarcity,farmers in the area practice two cropping season. At the onset of the rainy season, a directseeding crop (locally they call “gogo rancah”) is grown with rainfall as the source for irrigation. Immediatelyafter the harvest of direct seeding crop, the second tranplanted crop (walik jerami) is grown under minimumtillage in submerged water condition.

Previous 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 continuous 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). Based on field condition, as this area faced water scarcity, lodging and blast disease, recent study was conducted to study the influence of water management combined with Si application on improving rice growth and productivity.

As mentioned above that in Indonesia, commonly rice is cultivated under continuous flooding by maintaining the depth of water between 2 to 5 cm. This conventional water management could help to control weeds, reduce the frequency of irrigation and secure against possible future shortage of water due to the unreliable water delivery system (Arif et al., 2013). However this continuous flooding is less efficient due to larger water quantity than actual water requirement, it exhibit diminishing water productivity since as more water is applied, there is no proportional increases in rice production and also causing large amounts of surface runoff, seepage and percolation (Bouman, 2001; Bouman and Tuong, 2001). Another disadvantage of continuous flooding as stated by Shi et al. (2002) and Nyamai et al. (2012) is the rice plant roots could not develop fully. Therefore the roots will degenerate prematurely and become less functional and effective, taking up less soil nutrients and water also will cause lodging problem due to the degeneration of surface roots that grow within the top 5 cm of the soil (Kar et al., 1974).

Furthermore, related to water shortage issue in some rice cultivation area, there is needto develop another water management beside continuous flooding, such as intermittent water management. Intermittent is one of water management where the field is kept saturated or under shallow standing water and then keep the soil in aerobic condition for particular periods instead of continuously flooding.

It is known that intermittent is one of the strategies that could promote water saving particularly in areas with water shortage condition. Previous studies showed that intermittent water management resulted in better yield and plant performances, enhanced shoot activities when optimal water and oxygen is available, also promoted the establishment of a larger and deeper root system (Yang and Zhang, 2010; Uphoff and Kassam, 2008). However, there is lack of information about intermittent water management for rice cultivation in Indonesia compared to continuous flooding .

1.4. The Study Objective

Based on the discussion above, and the fact that the fluctuation and stagnation in rice productivity in Indonesia could be caused by nutrient imbalance particularly, the less attention on beneficial nutrient requirement such as Si and the need of water management improvement. This recent study is conducted to :

1. Investigate and clarify Si available status in sawah soil particularly in relation with rice blast disease and relation between soil Si availability and Si content in rice plant.
2. Evaluate the effect of Si application on blast disease infection together with the effects of Si application on plant morphology including plant height, tiller numbers and stomata formation.
3. Evaluate the effect of two water saving methods and Si application on improving rice plant growth and blast disease infection in Central Java, Indonesia.
4. Assess the effect of water management and Si application on improving rice productivity and grain quality in Central Java, Indonesia.

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CHAPTER 2

Available Si Status of Selected Sawah Soils and Its Relationship With Blast Disease and Si Concentration of Rice Plant in West Java and Lampung Province

2.1. Introduction

Nowdays, known that the rice productivity in Indonesia has fluctuated and stagnated over the past decade (FAOSTAT2005-2015) even though the rice is cultivated mostly 2 – 3 times a year but we still import rice from other country to fulfill our necessity and the import reached up 1.9 million ton in 2012 white the average rice productivity in Indonesia is about 5.3 ton.ha^{-1} (Ministry of Agriculture of Republic Indonesia, 2013). This condition could have been because of several factors such as change in climatic factors and also the decline of soil fertility (Husnain, 2009). Declining crop yields are strongly related to soil quality degradation, particularly nutrient depletion (Roy et al., 2003). This nutrient depletion can be attributed to insufficient fertilizer use and unbalanced fertilization.

As the second most abundant element of the earth's crust, silicon (Si) has long been neglected by ecologists, presumably since not considered an essential nutrient for plants (Epstein, 1999). However, recent studies showed strong beneficial effects of Si for plant growth. It is known that Si plays beneficial roles in rice and sugarcane cultivation (Epstein, 1999; Imaizumi and Yoshida, 1958; Matichenkov and Calvert, 2002). Moreover, rice plant requires higher levels of Si than nitrogen and other nutrients. An adequate uptake of Si can substantially increase the tolerance of rice to abiotic and biotic stresses such as blast disease, lodging problem, photosynthesis enhancement and absorption of elements such as N, P, and K (Savant et al., 1997; Datnoff et al., 2001;

Matoh et al., 1991; Ma and Takahashi, 2002). Silica is defined as the silicon content in the weight of SiO_2 in soil and water.

Several cultivation methods have been adopted to improve rice production in Indonesia, however, silicon (Si) application in rice production has not been applied in Indonesia. Meanwhile, the common fertilizers applied in Indonesia are nitrogen (Urea), phosphate i.e. triple super phosphate and super phosphate (SP-36), potassium (KCl) and compound fertilizer containing N, P and K. Recent condition in Indonesia, with long-term intensive rice cultivation, particularly in Java, without artificial Si addition has mined Si from soils, and transported it away from the field, mainly through the harvesting process. In case of Indonesia, the survey of available Si in soil and irrigation water were recently reported. Darmawan et al. (2006) reported that available Si in rice soils in Java Island over the past three decades has decreased by approximately 11-20%. In addition, Husnain et al. (2008) has found that lower soil Si content was found in intensive rice field where enormous Si uptake was not followed by sufficient Si replenishment.

Moreover, Husnain et al. (2011) also reported about soil Si content in soil and its distribution in Indonesia as presented in Table 2.1. The soils contained less than 300 mg SiO2 $kg^{-1}$and were distributed about 76% of total 92 sites in West Sumatra, 22.5 % of total 59 sites in West Java while in Central Java and East Java less than 3% of total sites in both provinces. From these result, there were many sites that contained less Si for rice plant. Although there was no report on the deficiency of Si in Indonesian sawah soil, the huge loss of rice production due to plant diseases and failed to harvest might be an indication of the imbalance of nutrients, particularly Si. Considering the current status of soil Si availability, it is necessary to consider additional Si input.The term sawah, in the present study refers to a leveled and bounded rice field with and inlet and outlet for irrigation and drainage, respectively (Wakatsuki et al., 1998).

Based on the previous study, decreasing of rice productivity is also caused by loss of harvest attacked by rice disease such as blast. In the present study, we investigated and clarified the general Si availability status of sawah soil particularly in relation to rice blast disease and relation between soil Si availability and Si content in rice plant.

Table 2.1. The distribution of Si content in rice soils in Indonesia.

Location	Number of sampling site (n/site)	Available Si (mg SiO2 kg^{-1})	Percentage
West Sumatera	92	< 100	1 (1%)
		100 – 200	30 (32.6%)
		200 – 300	39 (42.4%)
		300 – 400	15 (16.3%)
		>400	7 (7.6%)
West Java	59	< 100	2 (3.4%)
		100 – 200	1 (1.7%)
		200 – 300	10 (16.9%)
		300 – 400	13 (22.0%)
		400 – 600	21 (35.6%)
		>600	12 (20.3%)
Central Java	28	< 100	0 (0%)
		100 – 200	0 (0%)
		200 – 300	1 (3.6%)
		300 – 400	5 (17.9%)
		400 – 600	15 (53.6%)
		>600	7 (25.0%)
East Java	15	<300	0 (0%)
		300 – 400	1 (6.7%)
		400 – 600	6 (40.0%)
		>600	8 (53.3%)

Source : Husnain et al.(2011).

2.2. Materials and Methods

2.2.1. Study site

Surveyed study sites were sawah field at West Java and Lampung province, Indonesia(Fig. 2.1). The study sites consists of two different level of blast disease attack. Samples were taken under two conditions of susceptibility to blast (Bs+) and resistant to blast (Bs-). Sampling site location and parent material were presented in Table 2.2.

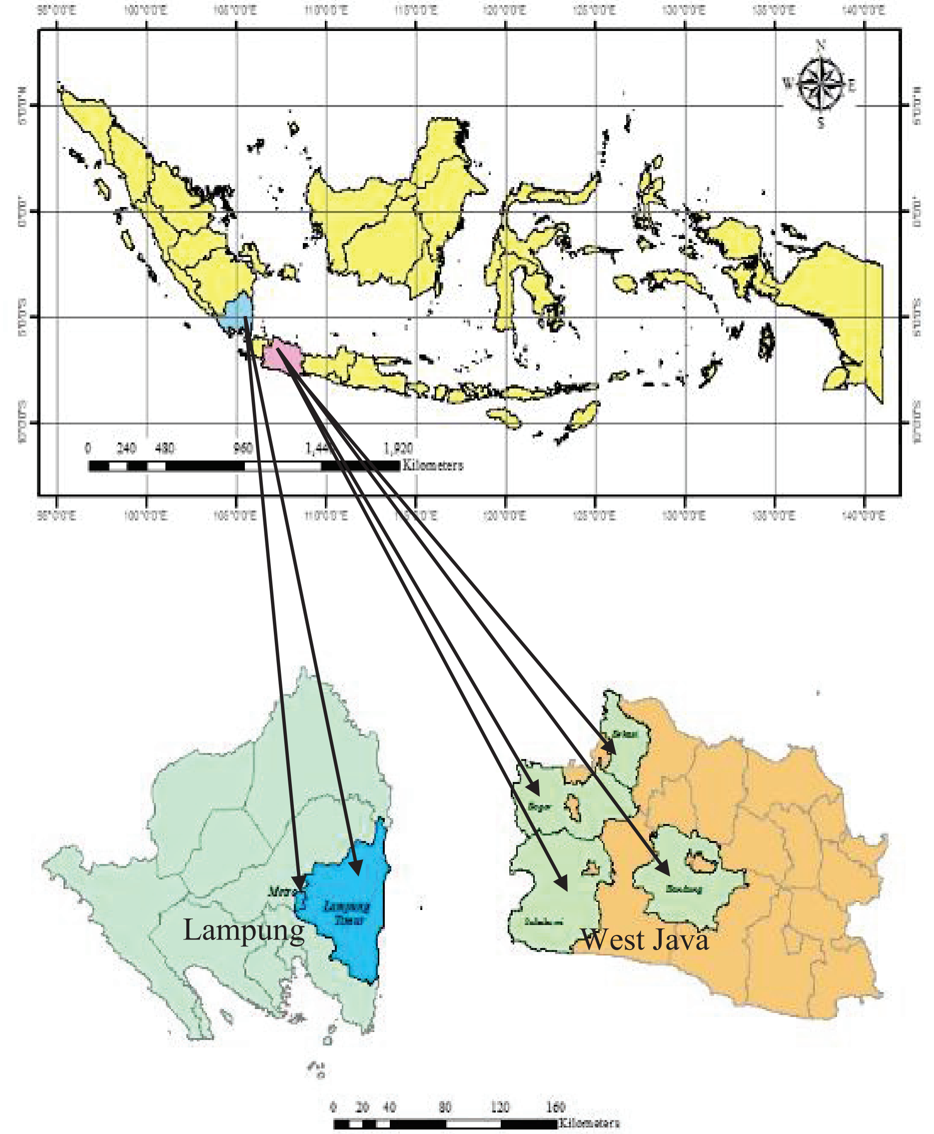

Figure2.1. Sampling site locations in West Java and Lampung Province.

Table 2.2. Sampling sites and parent materials

Sampling code	Location	Geographical position	Parent material
West Java Province			
MC – Bs+	Muara Cilamaya	S06° 14’17.6” E107°36’07.1”	Flood plain deposits (tuffaceous clay, silt and fine sand).
MC – Bs-	Muara Cilamaya	S06° 14’40.3” E107°35’10.2”	
ST – Bs+	Suka Tani, Bekasi	S06° 12’26.4” E107° 10’22.1”	Flood plain deposits (tuffaceous clay, silt and fine sand).
ST – Bs-	Suka Tani, Bekasi	S06°12’26.6” E107°10’22.1”	
SM – Bs+	Suka Mulya, Bekasi	S06°09’29.2” E107°10’20.5”	Flood plain deposits (tuffaceous clay, silt and fine sand).
SM – Bs-	Suka Mulya, Bekasi	S06°09’29.2” E107°10’20.6”	
Clb – Bs+	Cilubang, Bogor	S06°33’24.4 “ E106°44’46.4”	Alluvium fans (mainly silt, sandstone, gravels and boulders from quartenary volcanic rocks).
Clb – Bs-	Cilubang, Bogor	S06°33’25.1“ E106°44’48.5”	
Cnk – Bs+	Cinangka, Bogor	S06°35’28.0” E106°41’46.5”	Alluvium fans (mainly silt, sandstone, gravels and boulders from quartenary volcanic rocks).
Cnk – Bs-	Cinangka, Bogor	S06°35’29.1” E106°41’45.2”	
Pbr – Bs+	Pabuaran, Sukabumi	S07°12’06.2” E106°49’53.5”	Lower part of Bentang formation (with volcanic rock members).
Pbr – Bs-	Pabuaran, Sukabumi	S07°12’06.1” E106°49’51.3”	
Sgt – Bs+	Sagarenten, Sukabumi	S07°12’38.4” E106°53’47.7”	Lower part of Bentang formation (with volcanic rock members).
Sgt – Bs-	Sagarenten, Sukabumi	S07°12’38.5” E106°53’45.1”	
Bj1 – Bs+	Bojong, Sukabumi	S06°58’07.7” E106°49’30.2”	Alluvium fans (mainly silt, sandstone, gravels and boulders from quartenary volcanic rocks).
Bj1 – Bs-	Bojong, Sukabumi	S06°58’01.5” E106°49’30.4”	

Bj2 – Bs+	Bojong, Sukabumi	S06° 57’45.5” E106°49’48.8”	Alluvium fans (mainly silt, sandstone, gravels and boulders from quartenary volcanic rocks).
Bj2 – Bs-	Bojong, Sukabumi	S06° 57’45.1” E106°49’47.5”	
KS – Bs+	Karang Setia, Bekasi	S06°11’22.7” E107°12’13.3”	Flood plain deposits (tuffaceous clay, silt and fine sand).
BK – Bs+	Bojong Kunci, Soreang	S07° 01’10.6” E107°34’08.0”	
TR – Bs+	Tiang Roke, Banjaran, Bandung	S07°02’48.6” E107°34’21.9”	Lake deposits (tuffaceous clay, sandstone, gravel, and conglomerate).
Sdk – Bs+	Saduk, Soreang, Bandung	S07° 01’20.4” E107°31’27.7”	Lake deposits (tuffaceous clay, sandstone, gravel, and conglomerate).
Chl – Bs+	Ciheulang, Ciparay, Bandung	S07° 01’21.9” E107°41’02.3”	Lake deposits (tuffaceous clay, sandstone, gravel, and conglomerate).
Skm – Bs+	Sukamanah, Bandung	S06°59’14.9” E107°42’51.2”	Lake deposits (tuffaceous clay, sandstone, gravel, and conglomerate).
CL – Bs+	Curug Luhur, Sukabumi	S07° 13’37.3” E106°50’30.4”	Lower part of Bentang formation (with volcanic rock members).
Lampung Province			
TB – Bs+	Taman Bogo, Purbolinggo, Lampung Timur	S05°00’44.8” E105°30’25.2”	Terbanggi formation (sandstone with clay stone intercalations).
TB – Bs-	Taman Bogo, Purbolinggo, Lampung Timur	S05°00’45.3” E105°30’25.4”	
TD – Bs+	Tambah Dadi, Purbolinggo, Lampung Timur	S05°00’19.5” E105°31’27.5”	Terbanggi formation (sandstone with clay stone intercalations).
TD – Bs-	Tambah Dadi, Purbolinggo, Lampung Timur	S05°00’20.9” E105°31’27.8”	
TY – Bs+	Tegal Yoso, Purbolinggo, Lampung Timur	S04°58’03.2” E105°32’55.0”	Terbanggi formation (sandstone with clay stone intercalations).
TY – Bs-	Tegal Yoso, Purbolinggo, Lampung Timur	S04°57’54.9” E105°32’59.1”	
TG – Bs+	Tegal Gondo, Purbolinggo, Lampung Timur	S04°58’10.0” E105°28’53.5”	Terbanggi formation (sandstone with clay stone intercalations).
TG – Bs-	Tegal Gondo, Purbolinggo Lampung Timur	S04°58’10.5” E105°28’53.0”	

RA – Bs+	Raman Aji, Raman Utara, Lampung Timur	S04^{O} 59’44.9” E105^{O}25’18.0”	Terbanggi formation (sandstone with clay stone intercalations).
RA – Bs-	Raman Aji, Raman Utara, Lampung Timur	S04^{o} 59’42.8” E105^{o}25’17.7”	
RS – Bs+	Rukti Sedio, Raman Utara, Lampung Timur	S04^{o}59’47.8” E105^{o}26’25.1”	Terbanggi formation (sandstone with clay stone intercalations).
RS – Bs-	Rukti Sedio, Raman Utara, Lampung Timur	S04^{o}59’46.7” E105^{o}26’27.8”	
TC – Bs+	Taman Cari, Purbolinggo, Lampung Timur	S04^{o}59’24.6” E105^{o}29’14.3”	Terbanggi formation (sandstone with clay stone intercalations).
TC – Bs-	Taman Cari, Purbolinggo, Lampung Timur	S04^{o} 59’25.8” E105^{o}29’14.8”	
TS – Bs+	Tejo Sari, Metro Timur, Lampung Timur	S05^{o}08’39.2” E105^{o}19’44.3”	Terbanggi formation (sandstone with clay stone intercalations).
TS – Bs-	Tejo Sari, Metro Timur,Lampung Timur	S05^{o}08’40.4” E105^{o}19’45.9”	
SS – Bs+	Sumber Sari, Metro Selatan, Lampung Timur	S05^{o}09’53.6” E105^{o}17’22.5”	Terbanggi formation (sandstone with clay stone intercalations).
SS – Bs-	Sumber Sari, Metro Selatan, Lampung Timur	S05^{o}09’52.3” E105^{o}17’22.2”	
RB – Bs+	Rejo Binangun, Raman Utara, Lampung Timur	S04^{o}57’56.4” E105^{o}25’51.9”	Terbanggi formation (sandstone with clay stone intercalations).

Source : Hermanto et al. (1998) and Mangga et al. (1993).

2.2.2. Soil and plant sampling

Field survey was conducted to compare two types of sawah categorized as Bs+ (site which has blast disease occurrence) and Bs- (site which has no blast disease occurrence) in West Java and Lampung Provinces, respectively. Soil and plant samples (rice flag leaves)were collected from several sawah field. We expected that these differences have led to different soil and rice farming systems,which influence on the silica content and rice productivity.

Soil samples were collected from 16 sites from West Java and 10 sites from Lampung from both condition Bs+ and Bs-. Soil samples were taken at depths of 0 – 15 cm. Plant samples were also collected from the same site with soil sample. Meanwhile at Lampung province, there were no plant samples to collect because it has been harvested already.

2.2.3. Soil and plant analyses

The soil samples were air-dried and crushed to pass through a 2 mm sieve. The available Si in soils was determined using the acetate buffer method (Imaizumi and Yoshida, 1958). Although Sumida (1991) reported that the acetate buffer method was not suitable for soils previously amended with silicate fertilizer such as slags application because acetate buffer is strong enough to extract Al-bound Si in slags. However, this was not aproblem in Indonesia because no silicate fertilizer had been applied. Soil samples were extracted in 1 mol L^{-1} acetate buffer (pH 4.0) at a ratio 1:10 for 5 h at $40^{o}C$ with occasional shaking. Si availability from sampling sites where plant samples are collected also evaluated by extracting solution with 0.01M $CaCl_2$(at ratio 1:20 with 16 hours shaking) (Haysom and Chapman, 1975), 0.1M HCl (at ratio 1:10 with 1 hours shaking) (Barsykova and Rochev, 1979) and with H_2O (at ratio 1:10 with 1 hours shaking) (Korndörfer et al., 1999). The Si content in the soil samples was determined using an atomic absorption spectrophotometer (Z-5000; Hitachi, Tokyo, Japan).

The soil pH wasmeasured 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 1MNH4OAc at pH 7 (Thomas, 1982) and measured by Inductive Coupled Plasma Spectroscopy (ICPE-9000 Shimadzu Co, Kyoto, Japan). Total carbon (TC) and total nitrogen (TN) of the soil samples were determined by thedry combustion method (Nelson and Sommers, 1982) using a NC analyzer (MT-700; J-Science, Kyoto, Japan).

Plant samples (rice leaves) were analyzed for Si content in rice leaf. Rice leaves were cut and oven-dried at 80^{o}C for 48 hours then samples were ground into fine powder by a ball mill and analyzed for total Si content. Plant samples were digested with HNO3 in a high pressure Tefflon Vessel (Quaker et al., 1979; Koyama and 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).

2.2.4. Statistical analysis

We classified the data with tabulation. Then to analyze the relation between Si concentration in rice leaves with several extraction methods, we did correlation analysis using SPSS version 20 software for windows at the 5% significance level.

2.3. Results

2.3.1. Soil available Si status and other nutrients content

The result showed that in West Java Province, the available Si at Bs- sites is generally higher than Bs+ sites (Fig. 2.2). Out of 16 sites of soil samples collected from lowlands sawah, 6.25% of the sites showed a lower soil SiO_2 availability compared to critical level by Sumida (1992).According to Sumida (1992), the critical value of available-soil Si content for rice growth is 300mgSiO_2kg^{-1}; Bollich and Matichenkov (2002) described values less than 300 mgSiO_2kg^{-1} as deficient and values less than 600 mgSiO_2kg^{-1} as low for rice and silicate (i.e. the soils might need silicate amendments) and the Si critical level proposed by Dobermann and Fairhurst (2000)is 86 mg SiO_2kg^{-1}.

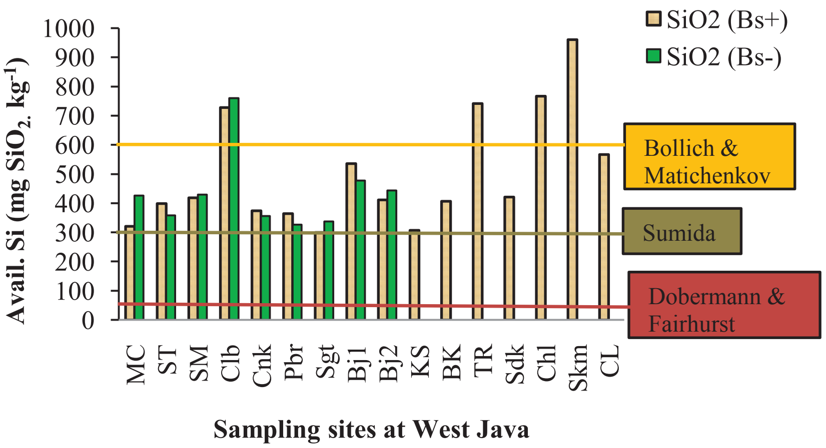

Figure 2.2. Soil available Si in West Java sampling sites

Meanwhile for Lampung Province, the result showed that available Si was ranged from 61 – 188 mgSiO_2kg^{-1} (Fig. 2.3). Generally, the available Si at Bs- sites is generally higher than Bs+ sites and blast disease symptom was found in Bs+ sites.

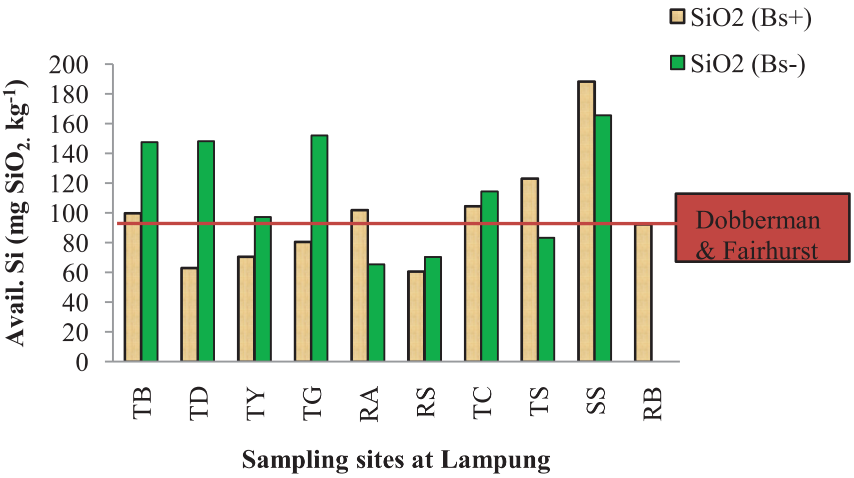

Figure 2.3. Soil available Si in Lampung sampling sites

Other nutrients content from all the sites were also analyzed (Table 2.3). The result of soil analyses showed that sawah sites in West Java province having pH ranged from

4.89 to 6.64 and categorized as very strong acid to slight acid soil. Meanwhile from sawah sites in Lampung province, the soils of Bs- sites have higher pH than Bs+ sites which ranged from 4.66 to 5.24 and classified as acid soil.

2.3.2. Si content in rice leaves

Plant analysis showed that total Si content in rice leaf from sampling site in West Java was ranged from 2.7 – 8.0% or equal to 57.8 – 171.2 $gSiO_2kg^{-1}$ (Fig. 2.4). As there have been no studies examining the Si content in rice leaves in Indonesia, we referred report from Ma and Takahashi (2002), the critical value of Si content in rice leaves is defined as 75 $gSiO_2kg^{-1}$ and levels less than 125 $gSiO_2kg^{-1}$ are considered to be deficient.

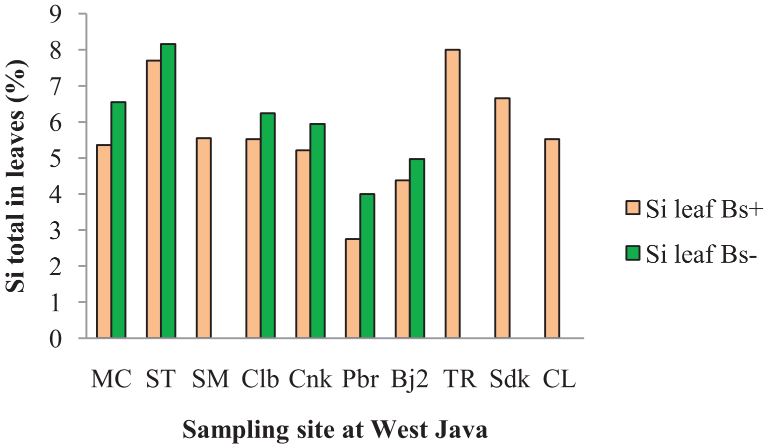

Figure 2.4. Si Content in rice leaves from West Java sampling sites

Table 2.3. Soil total N, available P and exchangeable cations in all sampling sites

Location	Condition	Total N	Avail. P	Exchangeable cations (cmol(+) kg^{-1})			
		(gkg^{-1})	(mgP$_2$O$_5$kg^{-1})	Ca	K	Mg	Na
West Java province							
MC	Bs+	2.20	88.75	26.71	0.35	8.16	1.20
MC	Bs-	1.64	76.32	24.97	0.42	9.76	1.99
ST	Bs+	1.30	25.62	24.98	0.39	5.53	1.17
ST	Bs-	1.68	28.53	28.74	0.49	6.52	1.56
SM	Bs+	2.15	76.05	30.35	0.48	7.31	0.95
SM	Bs-	1.00	13.49	21.47	0.34	4.54	0.93
Clb	Bs+	1.66	33.82	10.36	0.30	1.41	0.39
Clb	Bs-	1.66	26.12	10.06	0.33	2.59	0.36
Cnk	Bs+	1.76	69.68	4.01	0.17	1.41	0.18
Cnk	Bs-	1.74	87.52	4.42	0.27	1.44	0.19
Pbr	Bs+	1.99	40.27	12.89	0.32	7.27	0.34
Pbr	Bs-	1.66	22.24	15.01	0.22	8.04	0.28
Sgt	Bs+	1.86	35.97	11.05	0.27	5.17	0.21
Sgt	Bs-	1.51	36.98	117.72	0.33	9.11	0.36
Bj1	Bs+	1.69	40.88	12.64	0.67	2.52	0.16
Bj1	Bs-	1.79	39.29	11.40	0.49	2.43	0.18
Bj2	Bs+	2.26	71.46	7.42	0.35	1.38	0.16
Bj2	Bs-	2.08	65.95	25.28	0.39	2.73	0.19
KS	Bs+	1.82	22.32	26.22	0.49	8.52	2.05
BK	Bs+	2.87	90.88	7.84	0.23	3.15	0.27
TR	Bs+	3.38	90.92	14.24	0.20	2.99	0.31
Sdk	Bs+	6.75	95.55	14.61	0.18	3.92	0.79
Chl	Bs+	2.16	30.35	13.05	0.28	5.47	0.37
Skm	Bs+	2.07	19.74	15.37	0.48	6.37	4.47
CL	Bs+	2.00	82.23	27.00	0.62	5.93	0.31
Lampung province							
TB	Bs+	0.99	108.46	1.21	0.11	0.30	0.10
TB	Bs-	0.93	57.41	1.94	0.07	0.42	0.11
TD	Bs+	0.71	132.17	0.55	0.09	0.12	0.07
TD	Bs-	0.89	55.82	2.11	0.13	0.46	0.10
TY	Bs+	0.73	185.99	1.38	0.13	0.31	0.08
TY	Bs-	0.70	45.66	1.56	0.20	0.30	0.09
TG	Bs+	11.04	263.38	1.11	0.17	0.28	0.09
TG	Bs-	1.08	205.73	2.58	0.19	0.48	0.13
RA	Bs+	1.54	224.13	2.14	0.15	0.70	0.11
RA	Bs-	1.06	112.43	1.68	0.11	0.32	0.09
RS	Bs+	0.83	245.27	1.08	0.12	0.24	0.08
RS	Bs-	0.93	93.56	0.85	0.10	0.23	0.07
TC	Bs+	1.39	492.64	3.15	0.26	0.41	0.09
TC	Bs-	1.03	105.85	1.87	0.20	0.40	0.12
TS	Bs+	0.77	165.39	2.06	0.23	0.31	0.11
TS	Bs-	0.93	370.98	1.74	0.19	0.32	0.13
SS	Bs+	1.00	123.84	4.32	0.39	1.21	0.14
SS	Bs-	0.95	44.93	3.07	0.18	0.93	0.14
RB	Bs+	1.06	516.53	1.49	0.14	0.43	0.09

2.3.3. Relations between soil available Si with Si content in rice leaves

Among four extractions that were used to evaluated soil available Si, showed that soil available Si extracted with 0.1M HCl had significant correlation ($p<0.01$; $r=0.66^{**}$) with Si content in rice leaves (Fig. 2.5). From four extractions, soil available SiO_2 was higher in order of 0.1M HCl > acetic acid > $CaCl_2$> H_2O.

The 0.1M HCl extractant presented the best correlation between soil available SiO_2 and plant Si concentration (Fig.2.5). The better correlation of Si concentration in rice plant with the 0.01M HCl-extractable SiO_2 indicates that the 0.01M HCl method has a superior capacity of assessing SiO_2 availability in studied soils.

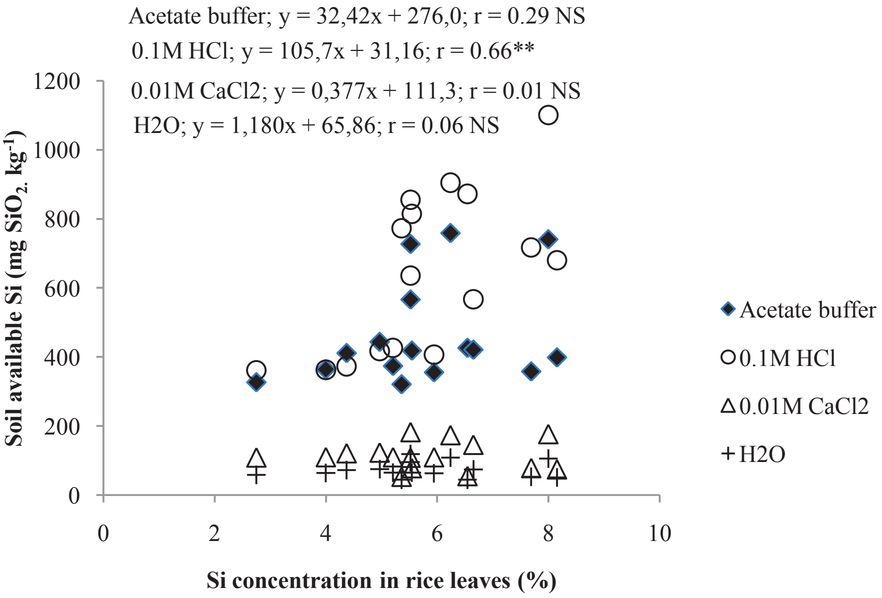

Figure 2.5. Relation between soil available Si with several extractions and Si content in rice leaves (** significant $p < 0.01$; NS = not significant).

2.4. Discussion

As there have been no studies examining the status of available Si in Indonesian soil, we consulted reports from Japan and Russia where silicon research has been conducted. According to Sumida (1992), the critical value of available-soil Si content for rice growth is 300 $mgSiO_2kg^{-1}$; Bollich and Matichenkov (2002) described values less than 300 $mgSiO_2kg^{-1}$ as deficient and values less than 600 $mgSiO_2kg^{-1}$ as low for rice and silicate (i.e. the soils might need silicate amendments) and the Si critical level proposed by Dobermann and Fairhurst (2000) is 86 mg SiO_2kg^{-1}.

The result showed that available Si at West Java sampling sites ranged from 300 – 960 $mgSiO_2kg^{-1}$.The previous research which had been conducted by Kawaguchi and Kyuma (1977) reported that the soil available Si content in tropical Asia ranged from 104 to 629 $mgSiO_2kg^{-1}$. This high content of Si at West Java sampling sites might be related to the parent material. Parent material in sampling sites was dominated by tuffaceous clay, sandstone, and volcanic rock which have high content of total Si.Blast disease symptom was found in Bs+ sites, althoughall of the sites were not below the Si critical level proposed by Dobermann and Fairhurst (2000) (86 mg SiO_2kg^{-1}) and only one sampling site was below the critical level recommended by Sumida (1992) (300 $mgSiO_2kg^{-1}$).It showed that the existing critical level of soil available Si is not enough for these study areas.

In contrary with West Java province, the available Si at all sampling sites was below the critical level of Sumida (1992). Beside soil management, low available Si at Lampung province caused by parent materials. As the parent material for all sampling sites in Lampung province was sandstone with claystone intercalation meanwhile in West Java, the parent material is dominated with tuffaceous clay, sandstone, and volcanic rock.

According to Imaizumi and Yoshida (1958), soil that derived from the parent material of volcanic ash contains higher Si.

Soil analyses result showed that total N at Bs+ sites showed higher value in average than that of Bs- which is 2.37 and 1.63 g kg^{-1} respectively (Table 2.3). The higher total N at Bs+ might be due to excessive application of nitrogen fertilizer which would increase susceptibility to blast disease. Meanwhile total N at Lampung sites were not much different among study sites, the average value was 1.01 gkg^{-1} for Bs+ and 0.95gkg^{-1} for Bs-.

Under continuous cultivation, the farmers are forced to increase their nitrogen application rates in order to increase the rice productivity. But this condition also could decrease the rice production due to the decreasing plant resistant to disease especially blast and lodging. The excessive nitrogen application makes the leaf blades droopy, resulting in mutual shading and thereby reduction of photosynthesis. Moreover, it also increases susceptibility to disease and lodging (Ma and Takahashi, 2002).

Soil available P showed that at Bs+ sites in West Java had higher soil available P than Bs- sites and the similar pattern also happened in sites at Lampung (Table 2.3). Generally, in West Java, the average value of available P at Bs+ and Bs- sites was 57.16 and 44.05 mg $P_2O_5kg^{-1}$ respectively. Meanwhile in Lampung, the average available P at Bs+ and Bs- sites was 245.78 and 121.37 mg $P_2O_5kg^{-1}$ respectively. Furthermore, we found out that soil available P in West Java is lower than Lampung province. This condition might be related to the mineral type of the parent material that affect on available P. Soil which derived from volcanic rock as the parent material has a great effect on P sorption since volcanic soils contain large amounts of amorphous material.

Therefore as West Java is dominated with volcanic rock, it tends to has lower soil available P than Lampung province.

The average values of exchangeable Ca, K, Mg and Na for West Java sampling sites were 16.17, 0.36, 4.78 and 0.83 cmol(+)kg^{-1} for Bs+, respectively. On Bs- the average values of exchangeable Ca, K, Mg and Na were 17.68, 0.37, 5.24 and 0.67 cmol(+) kg^{-1} respectively. Meanwhile sampling sites at Lampung province, the average values of exchangeable Ca, K, Mg and Na of Bs+ were 1.89, 0.18, 0.43 and 0.10 cmol(+)kg^{-1}, respectively and for Bs- were 1.95, 0.15, 0.43 and 0.11 of Ca, K, Mg and Na respectively.

Generally, West Java has higher soil exchangeable Ca than Lampung province. Low soil exchangeable Ca at Lampung province might be due to the type of parent material which was dominated with sandstone that tends to have lower levels of Ca.Further, it shows that soil exchangeable Ca in West Java and Lampung at Bs- was higher than Bs(+). As the soil provide higher exchangeable Ca that could taken up by rice plant, it could reduce blast disease infection. It has been appreciated that Ca^{2+} plays a crucial role in determining the structural rigidity of the cell wall (Wyn Jones and Lunt, 1967; Dobermann and Fairhurst, 2000). The increasing of cell wall rigidity could be achieved if the Ca availability in soil is sufficient for plant up take. Meanwhile, Ca deficiency is likely when soil exchangeable Ca is <1 cmol(+) kg^{-1}, or when the Ca saturation is <8% of the CEC (Dobermann and Fairhurst, 2000).

Related to blast infection, although all sampling sites in West Java have high silica availability still blast disease occurred (Fig. 2.6). This condition might be related to high rainfall. Total annual rainfall during the year 2007-2011 at sampling sites in West Java ranged from 1949 – 3109 mm and in Lampung ranged from 1288 – 2948 mm. As

Shafaullah et al. (2011) reported that rainfall influenced positive effect on rice blast severity which is consistent with West Java condition.

Figure 2.6. Leaf blast infection in Bojong Village (left) and Pabuaran Village (right), Sukabumi District.

Analysis of Si concentration in rice plant showed that only Pabuaran site that had Si concentration below critical level. It was 57.8 g SiO_2kg^{-1} or equal to 2.7% of total Si and categorized below critical level proposed by Ma and Takahashi (2002) (Fig. 2.4). As shown on Figure2.4, known that Bs- sites has higher Si content in rice leaves than Bs+ sites. This condition is an agreement with many previous researches stated that Si could improve plant resistant on blast disease. As Si deposited on the tissue surface, it will act as a physical barrier by thickening the Si layer in the cuticle and improved stomata control have been suggested as contributing factor (Okuda and Takahashi, 1961; Yoshida, 1965). Presumably, after rice roots uptake Si from soil solution, it will rapidly translocate to the top along with the translocation stream. Furthermore it will gradually accumulate on leaf surfaces as SiO_2 as describe in Figure 2.7. This SiO_2 will be deposited beneath the cuticule and form Si-cuticle double layer. Si-cuticle double layer might limit hypha penetration and invasion by acting as a physical barrier (Kim et al., 2002).

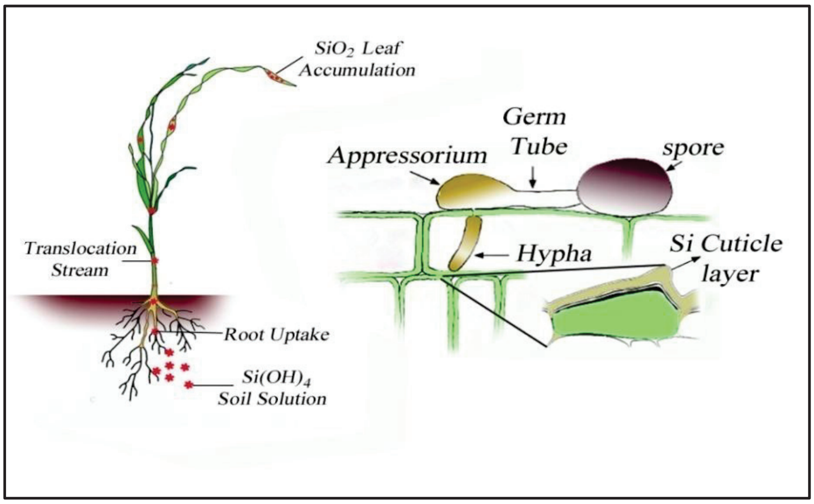

Figure 2.7. Mechanism of Si on improving plant resistance to blast disease. (Modified from Janislampi. 2012)

Plants deficient in Si are more susceptible to fungal disease, insect feeding, as well as other biotic and abiotic stresses that adversely affect crop production. Low Si uptake has been shown to increase the susceptibility of rice to blast (*Magnaporthe grisea* (Hebert) Barr), leaf blight (*Xanthomonas oryzae* pv. oryzae), brown spot (*Cochliobolus miyabeanus*), stem rot (*Magnaporthe salvinii* Catt.), scald (*Monographella albescens* Theum), and grain discoloration (Datanoff et al., 1997; Epstein, 1999; Kobayashi et al., 2001; Massey and Hartley, 2006; Savant et al., 1997; Volk et al., 1958; Webster and Gunnell, 1992; Winslow, 1992).

Comparison of several extraction methods for assessing soil available Si, showed that soil available $SiO_2$was ranged from 321-760, 362-1101, 54-183 and 45-119 mgSiO_2kg^{-1} for acetate, 0.1M HCl, 0.01M $CaCl_2$ and H_2O extraction respectively. The result showed that H_2O extraction had the lowest soil available SiO_2 compared the other extractions. This could be due the low ionic strength of the solution will cause dispersion as stated by Lindsay (1979).

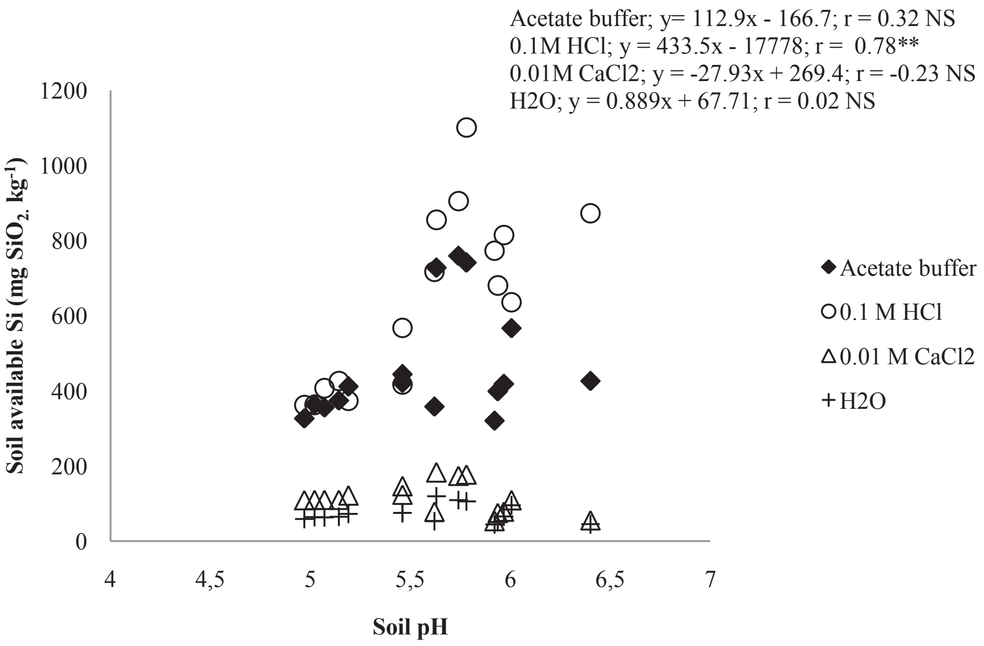

Figure 2.8. Relation between soil pH and soil available Si with several extractions (** significant $p < 0.01$; NS = not significant)

Moreover, the present study showed that 0.01M HCl extractable SiO_2 showed significant correlation with Si content in rice leaves compared to other extractions. As stated by Berthelsen and Korndorfer (2005) and Sumida (2005), that in general, the most successful extractions are acid rather than neutral solutions, and dissolution is further increased by chelating agents (due to decreased Si sorption resulting from the lower concentration of Al and Fe in solution). This could be the reason why 0.01M HCl gave significant correlation compared with other extractions. Further,there is a strong correlation between 0.01M HCl extractable SiO_2 and soil pH (Fig. 2.8). The higher extraction power of 0.01M HCl is explained by the pH, which soil pH at sampling site was ranged from 4.9 to 6.4. As stated by Brown & Mahler (1987), acidity and anions could additively impact Si release from soils, as showed by Wang et al. (2004).

The different extractants tended to target Si held within different components of the soil matrix, as the Si solubilized was related to other soil properties specific to the soil type. Dilute salt solutions (e.g. 0.01M $CaCl_2$) provided a measure of the readily available Si present in the soil solution, while results obtained using NH4OAc and acetic acid indicated that the Si solubilized was likely to be the more simple polymers affected by changes in pH, CEC and the ratio of soluble Si:Al in the soil solution. As most of the soluble Si below pH 8 is uncharged monosilicic acid, changes in ionic strength should not significantly alter extractable levels in most soils. H_2O extraction or a dilute salt solution to provide a solution concentration near equilibrium with the soil system (an 'intensity' factor), meanwhile using a stronger extractant such as phosphate acetate, citric acid, 0.005M H_2SO_4 and 0.01M HCl is to provide an index of the adsorbed soil Si (a 'capacity' factor) (Khalid and Silva.,1978; Berthelsen et al., 2003). Interpreting soil Si status using strong extractants should be done with caution due to the variability of results, particularly on soils with poor drainage or high Si sorption ability and high organic matter content.

2.5. Conclusions

The result from field survey activities showed that soil available Si in West Java was relatively high than in Lampung as effect of different parent material. Soil available Si at West Java Province sampling site ranged from 300 – 960 mg SiO_2kg^{-1}. Meanwhile at Lampung Province sampling sites, ranged from 61 – 188 mg SiO_2kg^{-1}. However, with higher soil available Si compared to critical level proposed by Sumida (1992) (300 mg $SiO_2.kg^{-1}$) and Dobermann and Fairhurst (2000) (78 mg $SiO_2.kg^{-1}$), it still experienced severe rice blast disease. It showed that the existing critical level of soil available Si is not enough for these study areas.

Comparison to the relation between soil Si available with Si content in rice leaves showed that 0.01M HCl has a superior capacity of assessing SiO_2 availability in studied soils.

Based on this preliminary survey, it is necessary to consider on additional Si fertilizer in order to improve rice productivity due to the occurrence of blast disease infection although mostly the sites in West Java had higher soil available Si.

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CHAPTER 3

Empirical Study on Effect of Silicon Application on Rice Blast Disease and Plant Morphology in Indonesia

3.1. Introduction

Indonesia is a major producer of agricultural products in the world. The major food crops, ranked by area harvested are rice, corn, cassava, soybeans and peanuts (Ministry of Agriculture, 2015). Indonesia is known as the world's third-largest rice producer following China and India (FAO, 2015) and is also one of the world's biggest rice consumers, indicating that rice is the most important food crop in Indonesia. Rice production is heavily concentrated on the islands of Java and Sumatera, with nearly 60% of total production emanating from Java island. At the same time, Java is the most densely populated island in the world and home to nearly 60% of the nation's population (approximately 143.8 million). In Indonesia, rice cultivation is rise up to three crop rotation per year with an average rice productivity of about 5.3 $tonha^{-1}$. Mostly Indonesian farmers cultivate ricein lowland area which known as *sawah*. The term "sawah" in the present study refers to a leveled and bounded rice field with an inlet and an outlet for irrigation and drainage respectively (Wakatsuki et al., 1998). However, nowdays, known that the rice productivity in Indonesia has fluctuated and stagnated over the past decade (FAOSTAT 2005-2015). This situation might be because of several factors such as changes climatic factors and also the decline in soil fertility (Husnain, 2009). Declining crop yields are strongly related to soil quality degradation, particularly nutrient depletion (Roy et al., 2003). Apart from nutrient depletion, the occurrence of plant disease also plays a role on decreasing yield.

Beforehand due to the stagnated condition of rice yields, several cultivation methods have been adopted to improve rice production in Indonesia such as the extension of fertilizer, irrigation systems and also use high yielding rice varieties which are components of the green revolution technologies. The common fertilizers applied in Indonesia are nitrogen (Urea), phosphorous in form of triple super phosphate and super phosphate(SP-36), potassium (KCl) and compound fertilizer containing N, P and K. However silicon (Si) application in rice production has not been appreciated in Indonesia because it was not considered as an essential nutrient. The non application of silica fertilizer on rice cultivation trigger the occurrence of blast disease in rice plants.

Silicon (Si) is the second most abundant element on earth, 26. 8% by weight and is present in all mineral soils(Ingri, 1978; Iller, 1979; Faure, 1991; Klein and Hurlburt, 1985). Kawaguchi and Kyuma (1977) reported that the soil-available Si content in tropical Asia ranged from 104 to 629 mg SiO_2 kg^{-1}. Si is not an essential element, but it has been proved to be beneficial elements for the growth and development of rice and sugarcane (Ma et al.,2006; Matichenkov and Calvert, 2002; Epstein, 1999; Imaizumi and Yoshida, 1958). Absorption of Si by crops is in the form of silicic acid which changes to irreversible amorphous silica. Therefore, availability of Si is very little as most sources of Si are insoluble and not available to crops (Epstein, 1994). Many species of wetland grasses, notably rice (*Oryza sativa* L.), accumulate 5% Si or more in their leaf tissue. High concentrations of Si in rice plants enhance canopy photosynthesis, increased biotic and abiotic stress resistance, and contribute to healthy growth and high yield (Ma and Takahashi, 2002).

Application of Si fertilizer is routine for rice or sugarcane in Japan, China, Brazil and other countries (Ma and Takahashi, 2002; Korndorfer, 2001), while in Indonesia, Si fertilizer were never use in rice cultivation by farmers. This is as a result of limited research on soil available Si and its role in rice growth in Indonesia. Among the few research, report state that over the past three decades, soil Si availability has decreased by 11-20%(Darmawan et al., 2006) and dissolved Si (DSi) concentration in irrigation water in Indonesia has also decreased by 10-20% (Husnain et al., 2008). Kawaguchi (1966) and Miyake (1993) stated that Si depletion can occur in traditional rice soil from the continuous monoculture of high-yielding cultivars with intensive cultivation practice especially if farmers are nor replacing Si remove by rice uptake. In essence, decreasing rice productivity in Indonesia might be due to the depletion of available Si in the soil (Husnain et al., 2008). Husnain et al. (2011)stated that 76% from about 200 sawah sites studied in Sumatera and Java Islands, 76% of total 92 sites in West Sumatera, 22.5% of total 59 sites in West Java while in Central Java and East Java less than 3% of total sites in both provinces were found to contain less than 300 mg SiO_2 kg^{-1}. This condition is reflected on the occurrence of blast disease in Indonesian rice cultivation which might affect rice productivity. Rice blast caused by the fungus *Pyricularia grisea* (Cooke) Sacc. [= *Magnaporthe grisea* (Hebert) Barr], is one of the most devastating diseases of rice plant. In Indonesia, this disease has been reported to cause severe damage to plant in many parts of the country. Hasanuddin (2004) stated that blast disease caused significant yield losses in area of 1,781, 1,084, 624,395, and 200 ha in West Java, South Sumatera, North Sumatera, Central Kalimantan, and West Nusa Tenggara provinces, respectively. There is a tendency that the disease has become increasingly important, on account of the 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 but not with Si application. In the present study, a field experiment was conducted to evaluate the effect of Si application on blast disease infection which greatly influence rice yield in Indonesia together with the effects of Si application on plant morphology including plant height, tiller numbers, and stomata formation were also evaluated.

3. 2. Materials and Methods

3. 2.1. Sites and soils

Field experiment was conducted in farmer's field in Bojong Village, Sukabumi District, West Java province during the 2013 rainy season. Sukabumi district is one of endemic area for blast disease specialy neck blast. This location lies on 6°58′1.5″S-106°49′30.4″E. Rice variety "Ciherang" was used which is common variety recommended by Ministry of Agriculture of Republic of Indonesia. Ciherang rice variety which was released in2000 is an indica rice categorized as short-duration variety (116-120 days). It has an average yield of 6 ton ha^{-1}and is suitable for planting in rainy and dry season. This study consisted of two treatments, Si+ (with Si application of 1000 kg·ha^{-1} of silica gel) and Si- (without Si application). We used a silica gel fertilizer "Super Inergy" imported from Japan. Randomized complete block design with 8 replications was used. The plot size was 3 m × 3 m for each treatment. We installed plastic sheet on the treatments boarders from the soil depth of 30cm to avoid contamination from surrounding plots. Each plots had an inlet and outlet for irrigation.

Initial soil analysis (Table 3.1) showed that the soil in experimental site had soil available Si of 426 mg SiO_2 kg^{-1} which is higher than 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 study site is dominated by volcanic breccia, breccia andesitic-basaltic, locally agglomerate (Effendi et al., 1998). Andesitic-basaltic was known to contain 53-57 wt% SiO_2 (Le Maitre, 2005)which influenced of high soil Si available in this experimental site.

Table 3.1. Initial soil analyses

Soil Properties	Values	Criteria*
pH (H_2O)	5.57	Slightly acid
EC (dSm^{-1})	3.41	
Total C (gkg^{-1})	21.63	Moderate
Total N (gkg^{-1})	2.09	Moderate
Exchangeable cations ($cmol_c kg^{-1}$)		
Ca	9.01	Moderate
K	0.21	Low
Mg	1.36	Moderate
Na	0.17	Low
Available Si (mg SiO_2 kg^{-1})	426.54	High**

*Refered to Indonesian Soil Research Institute (2005).
**Refered to Sumida (1992).

3.2.2. Plant cultivation

Land preparation was done by conventional tillage with two times plowing followed by leveling. Silica gel was applied before transplanting. Seedling from 21 days old nursery was transplanted into the puddled field with two seedlings per hill and row spacing of 25 cm × 25 cm. The fertilizer dosage was 300 kgha-1 of NPK compound fertilizer (15:15:15) and 50 kg·ha^{-1} for Urea. NPK compound fertilizer was applied in three times, at 7, 30 and 45days after transplanting (DAT). Meanwhile, Urea was applied once time at 7 DAT. For seedling, 2 kg Urea and10 kg of commercial organic fertilizer 'Petroganik' per seedbad (10 m × 5 m) were applied. Irrigation was applied one week prior to transplanting. On water condition, flooding condition about 5 cm water depth was kept from transplanting until 15 days before harvest and then the field was drained.

3.2.3. Sampling and analysis

Soil samples for initial analysis were collected at depths of 0-15 cm, air dried, grinded and sieved through 2 mm diameter (USDA No. 10) sieve. The soil available Si was extracted by 1 mol L^{-1} acetate buffer (pH 4.0) at a ratio of 1:10 for 5 h at 40 °C with occasional shaking (Imaizumi and Yoshida, 1958). Although Sumida (1991) reported that the acetate buffer method was not suitable for soils previously amended with silicate fertilizer, this was not a problem in Indonesia because no silicate fertilizer had been applied. 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 1 M NH_4OAc at pH 7 (Thomas, 1982)and measured by Inductive Coupled Plasma Spectroscopy (ICPE-9000 Shimadzu Co, Kyoto, Japan).

Stomata samples were collected with clear nail polish method (Radoglou and Jarvis, 1990). 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. These impressions were observed by light microscopy (Olympus BX51) and number of stomata were investigated in a field of 0.03 mm^2 then we calculated the number of stomata in mm^2 leaf area.

Blast disease infection was observed at 30, 45 and 60 DAT for leaf blast and 75 and 90 DAT for neck blast. Sixteen plant samples were observed from each treatment for blast disease intensity. We observed leaf blast disease intensity using score value which was employed by IRRI System (1996). Score value for each symptom category of blast disease are 0: no lesions; 1: small brown specks of pin-point size or large brown specks without speculating centre; 2: small roundish to slightly elongated, necrotic grey spots about 1-2 mm in diameter with distinct brown margin; 3: same as score 2, but a significant number of lesions are on the upper leaves; 4: typical susceptible blast lesions 3 mm or longer, infecting less than 4% of leaf area; 5: typical blast lesion infecting 4-10% 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. Moreover plant growth paramater consists of plant height and number of tillers also observed.

SPSS software for Windows version 20 was used for the statistical analysis. Values were expressed as means±SD. Student's t-test was performed at $p < 0.01$ to compare the effect of Si application.

3.3. Results

3.3.1. Effect of Si application on leaf blast

The results of Si application on percentage of leaf blast infection are shown in Figure 3.1. Si application significantly ($p <0.01$) reduce leaf blast disease infection throughout the observation periods. The percentage were 0.6 ±0.2 and 1.4 ± 0.4 at 30 DAT, 0.4 ± 0.3 and 1.3 ± 0.2 at 45 DAT and 0.3 ± 0.2 and 1.1 ± 0.3 at 60 DAT for Si+ and Si- treatments, respectively.

The Si application could also suppress the severity of leaf blast infection (Fig. 3.1). Known that Si- had severer infection up to score 4 in 45 DAT and score 5 at 60 DAT. On the other hand, in Si+ the leaf blast infection never reached score 4 and 5 at 45 and

60 DAT respectively. The difference in the leaf blast infection at the onset of the experiment, at 30 DAT and the last observation at 60 DAT, showed that Si+ had higher recovery rate on score 1 than Si- by 60% and 28% for Si+ and Si- respectively. Moreover Si+ also showed recovery rate on score 3 (24%) but not in Si-.

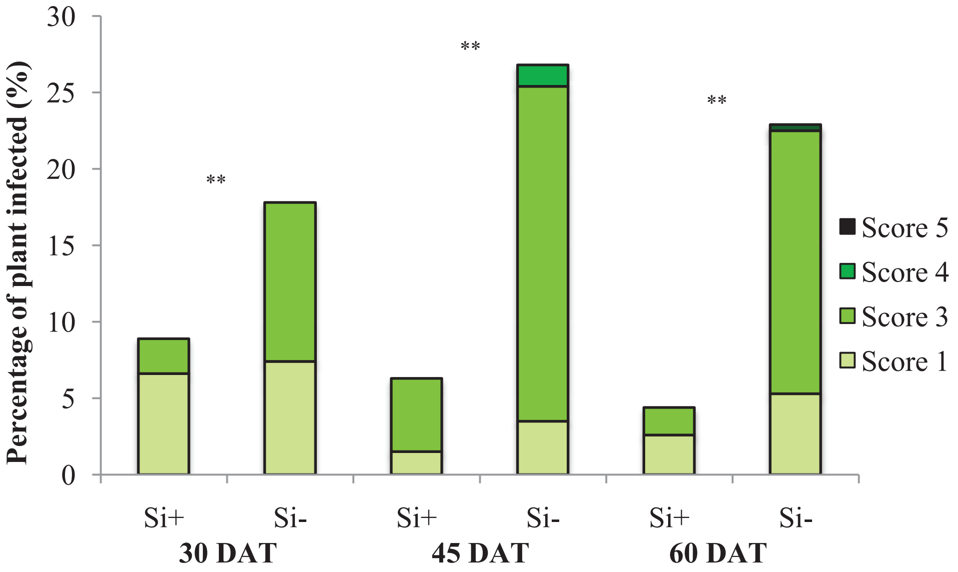

Figure 3.1.Percentage of plant infected by blast infection based on scoring value

*Note.***: Significant different at $p < 0.01$ between Si+ and Si- at each observation stage.

The percentages of neck blast infection were 1.1 ± 0.8% and 3.0 ± 1.9%at 75 DAT and 10.2 ± 3.9% and 16. 9 ± 7.9% at 90 DAT for Si+ and Si- treatments, respectively (Fig.3.2). Si application could also decrease significantly ($p < 0.05$) neck blast infection by 63.1 and 39.7% at 75 and 90 DAT respectively.

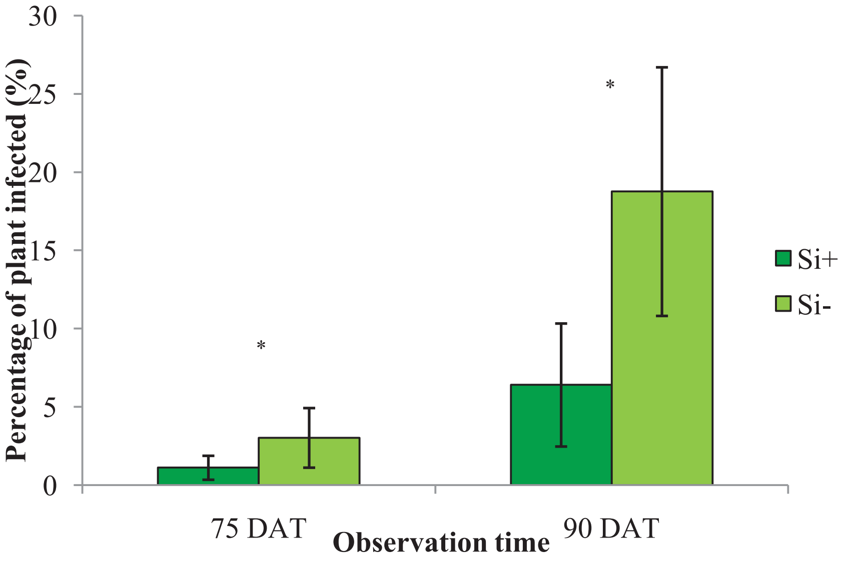

Figure 3.2.Percentage of neck blast infection at 75 and 90 DAT

Note.*: Significant different at p < 0.05.

3. 3.2. Effect of Si application on rice plant growth and yield

The effect of Si application on plant growth and yield are shown on Table 3.2. Statistically there was no significant difference between Si+ and Si- treatment on number of tillers, dry matter and yield. In yield even though not significant, but was slightly higher in Si+ treatment when compare to Si- treatment.

Table 3.2. Effect of treatments on plant growth and yield of Ciherang variety

Treatment	Plant growth			Yield
	Plant height (cm)	Tillers	Dry matter (g)	(kg/plot)
Si+	92.1 ± 1.2 ns	17.4 ±1.5 ns	59.2 ± 6.7 ns	4 ± 0.2 ns
Si-	92.1 ± 1.1 ns	16.7 ± 1 ns	55.4 ± 10.9 ns	3.9± 0.3 ns

Note.ns: There was no significant difference (p<0.05) between Si+ and Si-.

3.3.3. Effect of Si application on stomata density

Observations of stomata density showed that Si application significantly ($p < 0.01$) increased stomata density at7, 40 and 90 DAT for abaxial and 40 and 90 DAT for adaxial (Fig. 3.3). The average of stomata density in abaxial leaf epidermis were 326 ± 59 and 276 ± 76 at 7 DAT, 526 ± 60 and 353 ± 23 at 40 DAT and 638 ± 102and 455 ± 111 mm^{-2} at 90 DAT for Si+ and Si- treatments, respectively. For adaxial leaf epidermis, it was 299 ±40 and 217 ± 29 at 7 DAT, 366 ± 33 and 265 ± 28 at 40 DAT and 342 ± 54 and 247 ± 20 mm^{-2} at 90 DAT for Si+ and Si- treatments, respectively. Stomata density of Ciherang rice variety was higher on abaxial surface than adaxial surface of which coincide with what is obtainable with other rice varieties in previous study (Willmer and Fricker, 1996a; Gao et al., 2006).

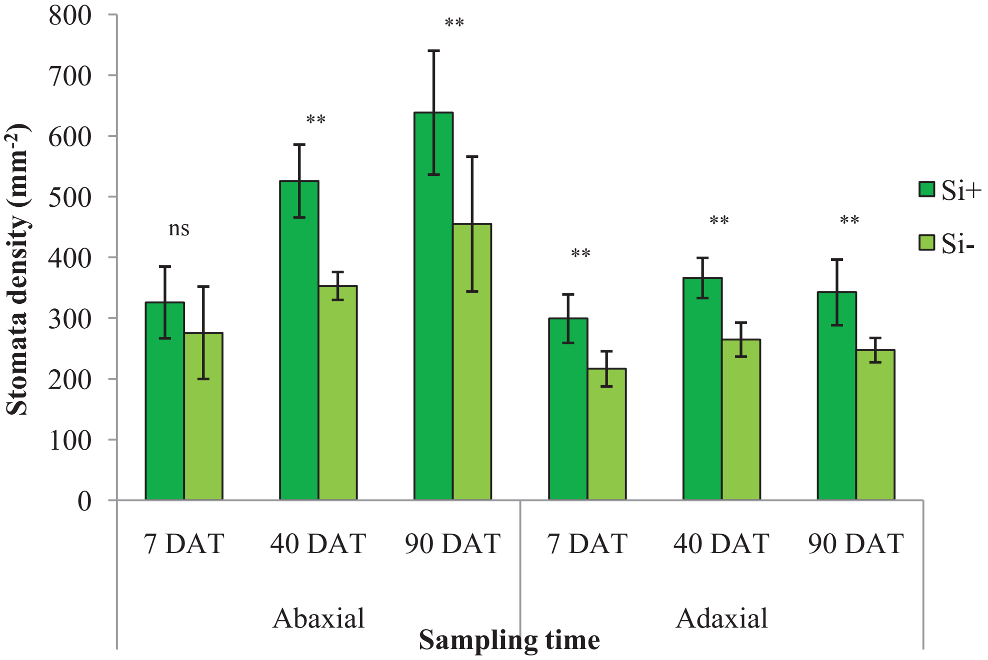

Figure 3.3. Stomata density of Ciherang variety

*Note.***: Significant different at $p < 0.01$.

3.3.4. Effect of Si application on stomata length

The results of stomata length was listed on Table 3.3. The data showed that Si application on stomata length were not significant on both in abaxial and adaxial surface. Moreover, the results from three observations (7, 40 and 60 DAT) showed that the stomata length tends to decrease slightly as the stomata density increases in both treatments.

Table 3.3.Effect of treatments on stomata length (mm)

Treatment	Stomata length (× 10^{-9} mm)		
	7 DAT	40 DAT	90 DAT
	Abaxial		
Si+	16 ± 2.2 a	14 ± 1.4 a	12 ± 0.6 a
Si-	15± 2.2 a	14± 0.9 a	11 ± 0.7 a
	Adaxial		
Si+	15 ± 0.9 a	14 ± 0.5 a	13 ± 0.4 a
Si-	15 ± 0.9 a	14 ± 0.1 a	13 ± 0.7 a

Note. Means followed by the same latter in the colum do notdiffer significantly at $p<0.05$.

3.4. Discussion

The result showed that Si application could suppress the severity of leaf blast infection (Fig. 3.1). This indicates that Si application reduces the expansion of lesion as score 4 and 5 only appeared on Si- treatment. This might be as a result of physical barrier created by Si in the cuticle layer to reduce lesion, through organo silicon compound that accumulated in the wall of epidermal cell (Volk et al., 1958; Rodrigues et al., 2001).

Si application clearly gave the positive effect on decreasing leaf and neck blast infection on Ciherang variety as reported in 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 specific mechanisms responsible for Si ability to increase plant resistant to blast disease are not fully understood. Related to our result, we believe that Si deposited on the tissue surface acts as a physical barrier by thickening the Si layer in the cuticle known as Si-cuticle double layer which could decrease the number of blast lessions on leaf blades and also improved stomata control (Yoshida, 1965; Datnoff and Rodrigues, 2005). Also Si-cuticle double layer probably limits hypa penetration and invasion by acting as a physical barrier (Kim et al., 2002).

The usage of fungicides is the most common method to control blast disease in Indonesia because it is easy to access and to apply for local farmers. Yuliani and Maryana (2014) stated that fungicide application could suppress leaf and neck blast infection by 40-60% and 60-80% respectively. However when the farmers delay the planting season, fungicide application will be ineffective on suppressing blast disease. Delaying planting season cause the heading stage to coincide with the period of high dew which is favorable for blast disease infestation (Santoso and Nasution, 2009). In addition, the study site had experienced severe blast incidence for the past five years due to continuous use of the fungicides on rice cultivar against *Pyricularia grisea*. The fungus over time tends to shift in population as it become resistance to fungicides, making the rice cultivar susceptible to the attack (Tangdiabang and Pakki, 2006). On this regard Si application could be an effective and sustainable strategy to control blast disease.

The soil initially contained available Si of 427 $mg \cdot kg^{-1}$ which was 4.5 times higher than the criterion of Si deficient level by Dobermann and Fairhurst (2000). Nevertheless, Si application could give significant effect on reducing leaf and neck blast disease infection in this site. This agreed with previous studies, Si application in soil that had available Si level higher than the critical level, about 437-581 mg·kg^{-1} still gave significant effect on increasing the yield (IRRI, 1964; Su et al., 1983) and decreasing blast disease severity (Wattanapayapkul et al.,2011) without any toxic side effects as Ma et al. (2001) reported. In the present study also, we have not observed any negative effect of Si application although it resulted in no significant effect on the yield but reduces blast disease infection.

Generally previous studies reported that addition of Si could increase the rice yield due to the balanced nutrient management that includes Si fertilization (Savant et al., 1997; Epstein, 1999). However, our result did not show significant difference. This might be due to application period of Si fertilizer. The most effective period of Si application for increasing yields was reproductive stage in which Si uptake and dry matter production are most vigorous (Savant et al., 1997). In the present study, we applied Si fertilizer before transplanting in order to improve plant resistance to blast disease from early growth stage. As rice plant takes up Si, it gradually accumulates in the leaf and creates Si cuticle double layer which can act as physical barrier against to blast disease infection (Ma, 2004). Although the yield was not increased by Si application, in this present study Si application has potential to improve the yield through suppressing blast disease especially neck blast since it often causes severe yield losses due to the reducing the number of filled grains.

In relation to Si application on stomatal behaviour, i.e. stomata conductance has been focused on while less attention has been paid to stomatal formation, observed as morphology and density. Some of previous studies presumed that Si plays a role in decreasing the transpiration rate by changing the stomatal movement rather than affecting its morphology and density (Gao et al., 2006; Zargar and Agnihotri, 2013). In contrast, Dias et al. (2014) showed similiar result with the present study which stated that there is indication that addition of Si as sodium silicate promoted the development of higher stomata density.

Salisbury (1927) reported that stomatal density is determined by stomatal initiation during ontogenesis and by epidermal cell expansion at a later leaf growth stage. In this research, it was observed that stomata density increases at the leaf growth stage in both Si+ and Si- treatments. Stomata density in abaxial surface increased from 7 to 40 DAT by 61 and 28 % in Si+ and Si- treatment respectively. The increase in stomata density at 40DAT to 90 DAT were 21 and 29 % for Si+ and Si- treatment respectively. Meanwhile in adaxial surface, the increase only occurred from 7 DAT to 40 DAT and it was relatively small, about 22% and was the same for Si+ and Si-. Although it is not clearly understood how stomatal density is controlled during leaf growth (Bergmann,2004).

The increament of stomata density on Si+ treatment might be related to the Si deposition that caused the cuticle layer to become thicker. As Si is deposited beneath cuticle layer and forming a fine cuticle-Si double layer, it acts as physical barrier that protects against various environmental stresses (Shepherd and Griffiths, 2006). Alternatively cuticle layer profile may alter permeability to water, CO2 and other signalling compound that influences stomata development. CO2 and light levels have also been known to elicit changes in stomata numbers (Woodward, 1987). In many species, the trend is for a reduction in stomata density and index with increases in CO_2 level. On the other hand, Soares et al. (2012) stated that Si treatments reduced the development of the stomata characteristic such as stomata density and also stated that in the absence of Si, the stomata might be more capable of capturing CO_2 and preventing water loss.

Stomata are cell complexes specialized for gas exchange between plants and their environments. Stomatal movement, density, and distribution determine plant water and CO_2 exchange, including photosynthesis and transpiration. Stomatal density affects gas exchange, transpiration, conductance, and instantaneous water use efficiency where it was a plant respond to a reduction in the partial pressure of CO_2 by an increase in stomata density (Woodward and Bazzaz, 1988).

In relation to yield, some previous study stated that the improvement on morphological characteristics of stomata such as stomata density could improve the yield (Jones, 1992; Ishimaru et al., 2001). However, in the present study the result of the yield showed not significant different although Si+ was significantly higher than Si- in stomata density. This result showed that stomata density indirectly regulates photosynthesis rate and transpiration rate which affect yield improvement. This present result was in agreement with Ohsumi et al. (2007), who stated that improvement of the morphological characteristic of stomata on the yield is not evident because consistent relationship have not been proven between morphological characteristic of stomata with stomatal conductance in correlated with photosynthesis. This explained why with higher stomata density in Si+ treatment showed no significant different on yield compared to Si- treatment. However, the potential of Si application on improvement of plant growth and yield through blast disease suppression and increasing stomata density is visible in the present study.

From the observation on stomata at 40 and 90 DAT in abaxial surface, we found that for Si+ treatment the pattern of stomata is arranged in single file in low phyllotaxis leaves with two adjacent stomata rows, meanwhile for Si- treatment the pattern is arranged only in single file (Fig. 3.4). This appearance of adjancent stomata rows in Si+

treatment might be the reason for the increase in stomata density per unit area which was observed in abaxial surface of the flag leaves in Si+ treatment compared to Si- treatment. Stomata were usually arranged in a single file in low phylotaxis leaves and two or more adjacent stomatal rows (Luo et al., 2012) which was observed in Si+ treatment.

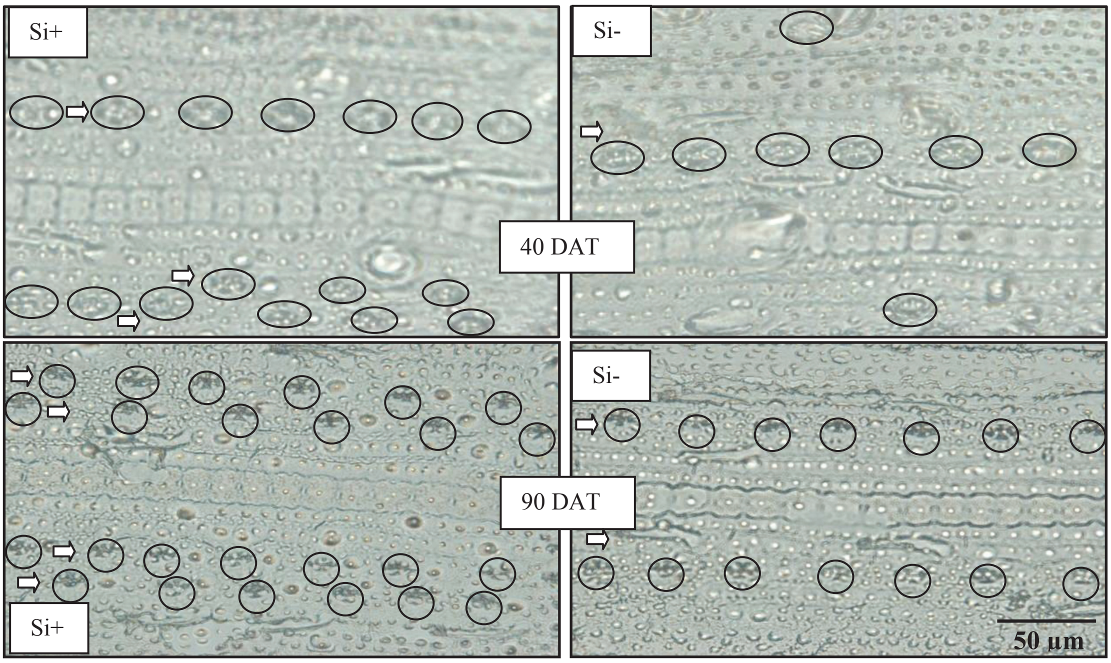

Figure 3.4.The difference of stomata pattern on Si+ and Si- at 40 DAT (upper) and 90 DAT (lower) with area observation 0.03 mm^2

Deposition of Si in the cell walls had been considered a common phenomenon in many plants, especially in graminaceous like rice (Parry and Winslow, 1977). Si accumulates in the lower epidermis around the stomata, including guard cells of blueberry (*Vaccinum corymbosus* L. cv) ‘Bluecrop’ as found by Morikawa and Saigusa (2004). There was no report about this phenomenon in rice plant which could prove whether Si deposition around stomata will improve or change the stomata density. Previous research only mentioned that stomatal density is affected by environmental factors and its genetic control is evident (Hetherington and Woodward, 2003).

Moreover, the results from three observations (7, 40 and 60 DAT) showed that the stomata length tends to decrease slightly as the stomata density increases in both treatments. Beerling and Woodward (1997) stated that plants with high stomatal density tend to have smaller size of stomata. This condition was also observed in the experiment with plant growth increasing with increase in stomata density while the stomata length decreases.

3.5. Conclusions

These results demonstrate that Si application showed positive effect on suppressing leaf and neck blast disease attack on Ciherang rice variety. Although the study site had soil available Si above critical level as proposed by Sumida (1992), Si application gave significant effect. Si application also significantly increases stomata density. The results confirmed that Si application have potential to improve rice growth and yield through the improvement of resistance to blast infection and increment of stomata density in Indonesia although they did not result in the yield increment in the present study. Regarding to blast disease, Si application could be an alternative strategy instead of fungicide application that has been commonly practiced which has resulted to the problem of fungicide tolerant over blast disease. Since Si application has not been applied yet in Indonesia, this study is a good reference for Si application in Indonesian rice cultivation. Due to this issue, Si fertilizer has not been produced yet in Indonesia. Therefore, it is necessary to find cost effective local source of Si fertilizer and to produce it. Furthermore, related to the effect Si application on stomata density further study needs to be conducted to find out the mechanism on it.

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CHAPTER 4

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

4.1. 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 flooding 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 “gogorancah”) 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 continuous 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 and 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 and 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 and 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 and 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 and Takahashi, 2002; Korndorfer and 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.

4.2. Materials and Methods

4.2.1. 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 (Fig. 4.1). 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 management. 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.

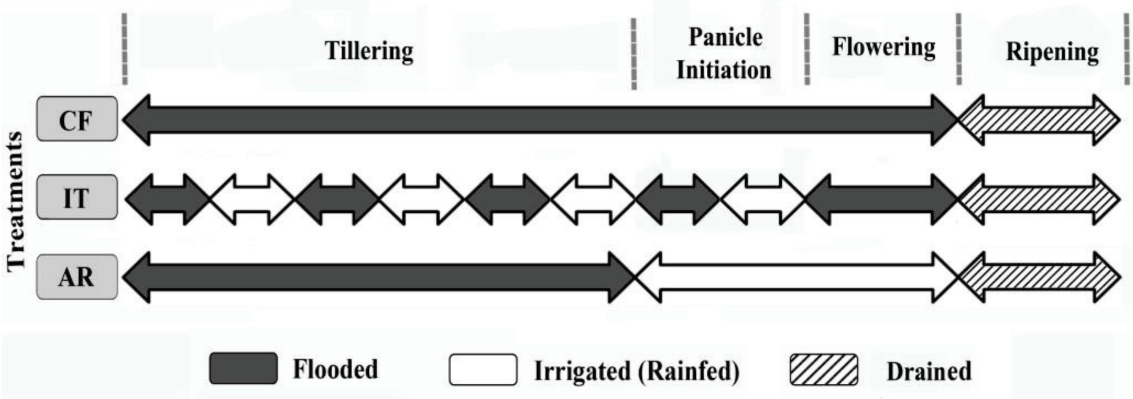

Figure 4.1. Diagram of water management

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 for28 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 $gg^{-1}24h^{-1}$ compare to Japanese Si fertilizer, Super Inergia, 0.3 $gg^{-1}24h^{-1}$. 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 4.1) 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 and Sudijono, 1993).

4.2.2. 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.

Table 4.1. Initial soil properties

Soil Properties	Values	Criteria[a]
pH (H_2O)	4.90	Acid
Total C (gkg^{-1})	7.6	Very low
Total N (gkg^{-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_2kg^{-1})	31.3	Low[b]

Note. [a]Refered to Indonesian Soil Research Institute (2005).
[b]Refered to Sumida (1992).

4.2.3 Sampling and analysis

The available Si for initial soil analysis was determined using the acetate buffer method (Imaizumi and 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., 1979; Koyama and 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 and 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 and Glover, 2007). Less stomata density on adaxial surface could decrease leaf water transpiration rate (Wang and 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 management 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 $p< 0.05$. Values were expressed as means±SD. Student's t-test was performed at $p < 0.01$ to compare the effect of Si application.All statistical analysis was performed using IBM SPSS Statistic version 20.0 (IBM SPSS, 2011. Chicago IL, USA).

4.3. Results

4.3.1. Plant growth

Table 4.2 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 4.2).

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

Table 4.2. Effect of treatments on root and shoot weight, and number of tillers at harvest

Si application	Water management		
	CF	IT	AR
Root (gm^{-2})			
Si+	360 ± 26.2ab	449 ± 96.5b	314 ± 46.8a
Si-	349 ± 66.1ab	401 ± 72.6b	344 ± 37.2a
Shoot (kgm^{-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.

4.3.2. 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 (Fig.4.2). Si application gave significant effect ($p< 0.01$) on reducing leaf blast infection throughout the observation periods in all water management (Fig.4.2). 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 (Fig. 4.3). 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.

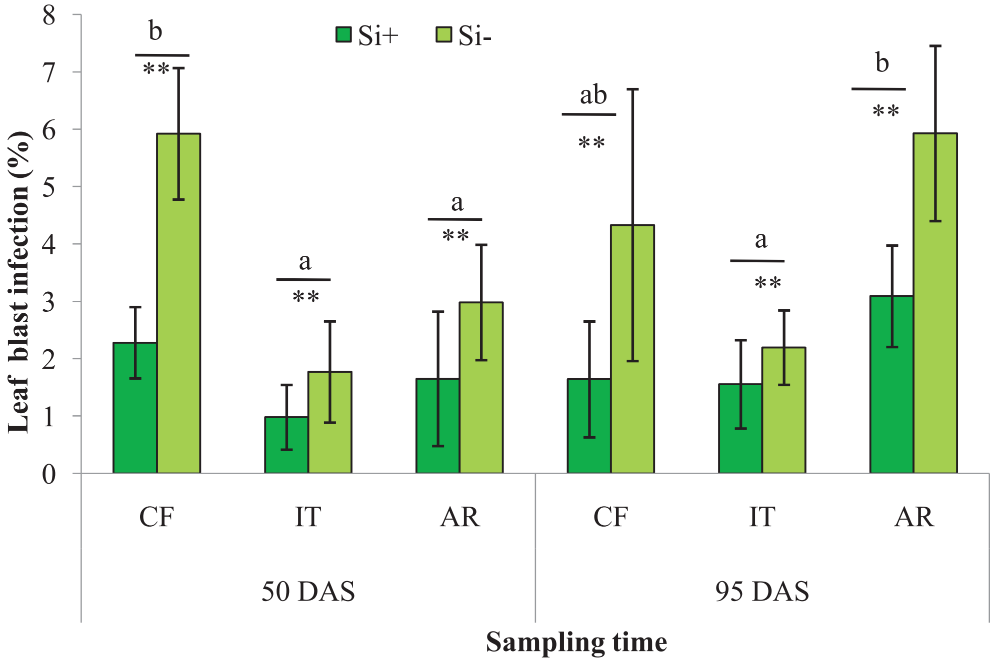

Figure 4.2. Effect of treatments on leaf blast infection

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 (n=12); Error bars indicate standard deviation among the mean values.

4.3.3. 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 4.3). Meanwhile on Si application, there was no significant difference on rice yield.

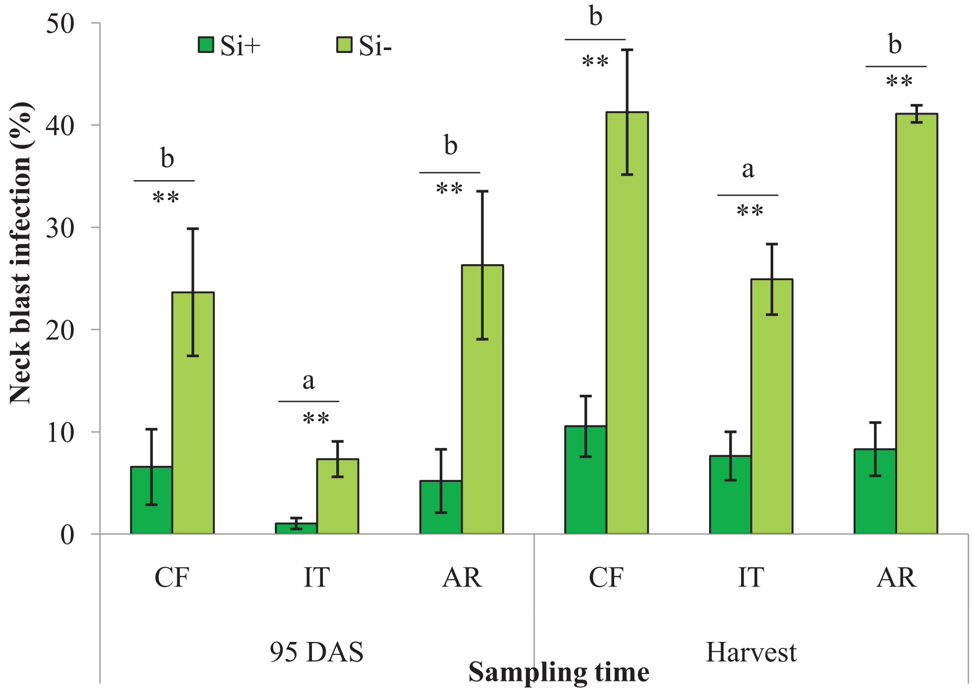

Figure 4.3. Effect of treatments on neck blast infection

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 (n=12); Error bars indicate standard deviation among the mean values.

Table 4.3. Effect of treatments on rice yield and yield component

Si application	Water management		
	CF	IT	AR
Yield (gm^{-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.

4.3.4. Lodging resistance

For The result of lodging resistance at 95 and 110 DAS is shown in Figure 4.4. 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.

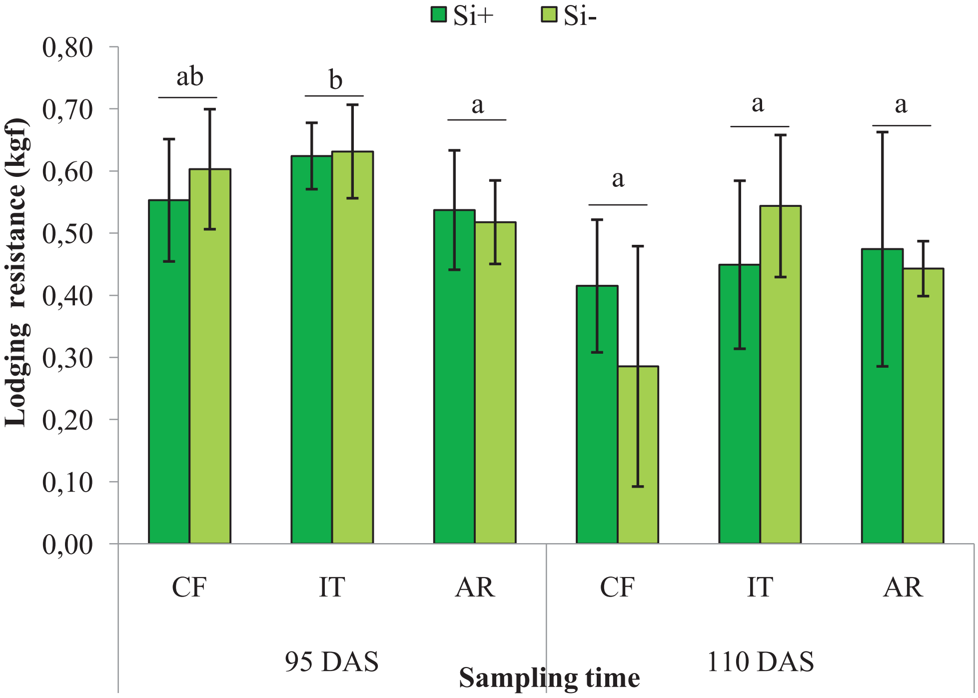

Figure 4.4. Effect of treatments on lodging resistance

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 (n=12); Error bars indicate standard deviation among the mean values.

4.3.5. 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 4.4).

Table 4.4. 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.

4.4. 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 and 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 repeatedly 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 than CF at harvest (Fig. 4.5). 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.

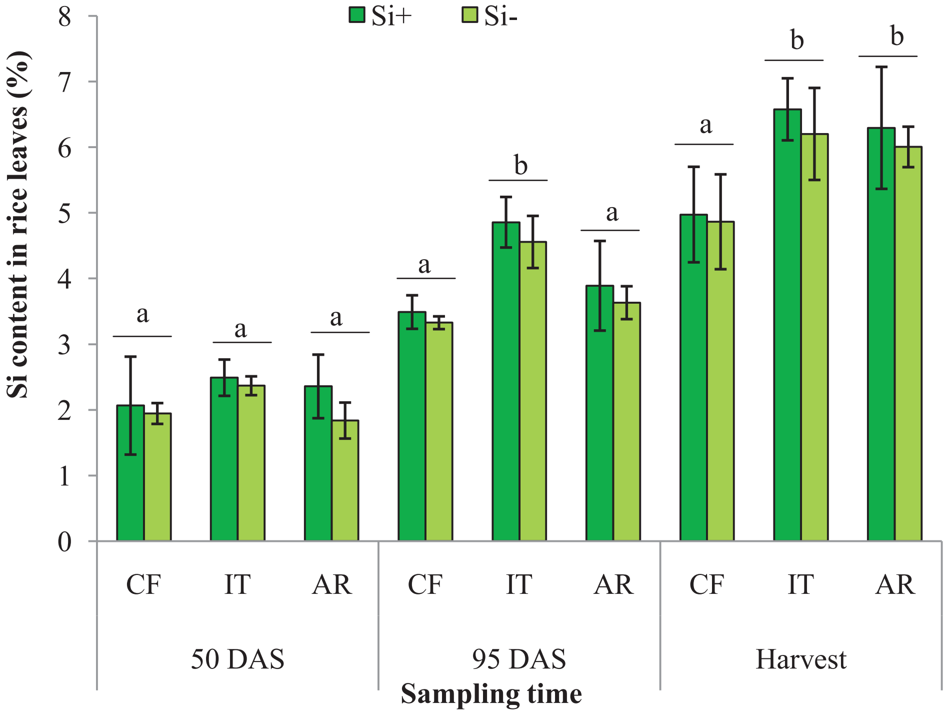

Figure 4.5. Effect of treatments on Si content in rice leaves

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 (n=12); 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_2kg^{-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_2kg^{-1}, lower than critical level proposed by Dobermann and Fairhust (2000) 86 mg SiO_2kg^{-1}.

The Si content in rice leaves was not significant different between Si treatment but tended to increase on Si+ treatment (Fig. 4.5). 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 and Rodrigues, 2005).

In rice cultivation, the yield could be affected by water and nutrients availability (Dobermann and 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 4.2) as well as higher yield compare to CF and AR did (Table 4.3). 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; $p<0.05$) (Fig. 4.6). 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.

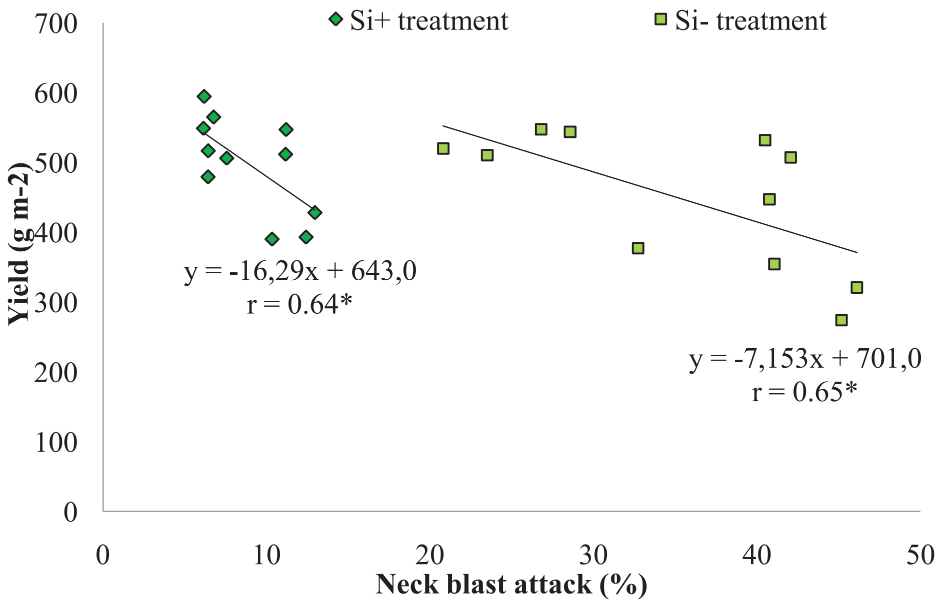

Figure 4.6**.** Correlation between neck blast attack with the yield ($p<0.05$)

Moreover, IT showed higher stomata density compare to CF and AR (Table 4.4). 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 4.5, 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 and 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 4.2). 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 4.4). 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.O_2

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 and 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 and Takahasi, 2002).

4.5. 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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CHAPTER 5

ImprovingRice Productivity and Grain Quality byWater Management and Silicon Application in Central Java, Indonesia

5.1. Introduction

Rice is the most important staple food in Indonesia. The total harvested area and rice production in 2013 were 13.8 million ha and 81.2 million tons, respectively (Ministry of Agriculture of Republic Indonesia, 2016). With high annual precipitation, Indonesia is suitable for rice cultivation and is commonly cultivated under continuous flooding irrigation by maintaining the depth of water between 2 and 5 cm (Arif et al., 2013).

Yield stagnation or even decline has been observed in some rice growing areas of Asia including Indonesia since the early 1980s (Cassman and Pingali, 1994). Therefore, the challenges to improve rice productivity in Indonesia have been increasing recently due to nutrient depletion, water shortage issue and also increasing population and reduced arable area.

Furthermore, on water shortage, climate change issue has been affecting rice field irrigation water requirements during rainy and dry season (De Silva et al., 2007). Rice is known as the largest user of water, which accounts for more than half of overall irrigation water withdrawals in Asia (Dawe,2005). Consequently water becomes the single most important component for sustainable rice production, especially in the traditional growing areas. Reduction or large withdrawal of water from the field can significantly lower the sustainability of rice production (Belder et al., 2008; Farooq et al., 2006). With water becoming more and more a limiting resource, the present challenge in rice production is to produce more rice with less water use (Guerra et al., 1998; Nguyen et al., 2009).

The study site in this present study is a rainfed lowland rice cultivation area located in Jakenan, Central Java. In Central Java province, there is about 83,638 ha of rainfed lowland rice area (Ministry of Agriculture of Republic of Indonesia, 2016) where farmers practice a high degree of crop intensification. This present study was conducted in rainy season (locally known as “walik jerami”) where at this season farmers cultívate the rice with transplanting seeding under minimum tillage in submerged water condition. Meanwhile during dry season, a direct seeding crop (locally known as “gogo rancah”) is grown.

Mostly, farmers in Indonesia grow the rice plant in lowland areas under continuous flooded conditions, as a result intermittent water management is not fully adopted. This is also as a result of limited research on intermittent water management and its effect in rice cultivation. Previous report as conducted in Indonesia stated that intermittent water management could enhance water use efficiency index significantly by up 37.7% in the rainy season and also could save water input up to 26.07% compared to continuous flooding (Arif et al. 2013).

According to Sharma (1989), the continuous flooding method is inefficient as about 50–80% of the total water input is wasted and causing large amounts of surface runoff, seepage and percolation (Bouman, 2001). Continuous flooding could have suppressive effects on yield by causing alterations in rice root systems, most notably the deformation of their cortex and creation of aerenchyma (air pockets) (Kirk and Bouldin, 1991), with consequent degeneration of roots up to 78% (Kar et al., 1974). Further, hypoxic soil conditions could reduced mineralization and nutrient release from the soil complexes, blocking of soil microbial activities (Uphoff and Randriamiharisoa, 2002). Prolonged submerged condition as a manifest of continuous flooding also could cause zinc deficiency (Das, 2014) therefore it will influence on plant uptake and grain quality for micronutrient content. Rice grain quality has become a subject of importance to many farmers, researchers and consumers. Rice quality is of great importance for all people involved in producing, processing, and consuming, since it affects the nutritional and commercial value of grains.

Intermittent water management allows the field in saturated or under shallow standing then keep dry condition for particular periods instead of continuously flooding (Arif et al., 2013). This pattern could give advantages for rice growth due to the aerobic condition that was created which could promoted higher activity of the plants for the establishment of a larger and deeper root system (Uphoff and Kassam, 2008). It also will enhance shoot activities as optimal water and oxygen are available and increase grain-filling rate (Yang and Zhang, 2010; Zhang et al., 2012).

An alternative irrigation system that produces more rice with less water input is needed to improve rice production in order to ensure a sufficient food supply due to a lower yield that is achieved with continuous flooding as stated by (Mamaril et al., 1994; Wihardjaka et al., 1999). Intermittent has been developed as a water-saving technique and adopted in many countries such as China, Bangladesh, and India (Xiaoping et al., 2004).

Apart from appropriate water management, beneficial nutrient application such as silicon (Si) is also required to increase rice productivity. Si is not considered an essential nutrient for plant function. Nevertheless, Si is absorbed from soil in large amounts that are several fold higher than those of other essential macronutrients in certain plant species (Rodrigues and Datnoff, 2005). There has been a considerable amount of research showing the positive effect of Si. Beneficial effects of Si in rice plant have been described to prevent lodging, fungal and insect attack, to improve posture for light interception and decrease mutual shading in the community (Miyake and Ikeda, 1932; Takahashi, 1987).

Meanwhile in Indonesia, the farmers have never used Si in rice cultivation and this is as a result of limited research on the role of Si on rice growth in Indonesia. Previous studies reported that over the past three decades, soil Si availability has decreased by 11-20% (Darmawan et al., 2006). Husnain et al. (2008) also reported that dissolved Si concentration in irrigation water in Indonesia has also decreased by 10-20% in the same period.

Due to inadequate attention on benefit of Si on rice growth this could be one of the factors that affect the declining rice productivity in Indonesia. Moreover, recent condition showed that there is an indication of Si deficiency on our rice cultivation as reflected on blast disease occurrence. Known that under Si deficient conditions, some diseases such as blast, brown spot and sheath blight can be extremely threatening to rice cultivation (Rodrigues and Datnoff, 2005).

Based on this current condition, present study on area with water shortage problem was conducted to study the effect of water management and Si application on improving rice productivity and grain quality as illustrated on Figure 5.1.

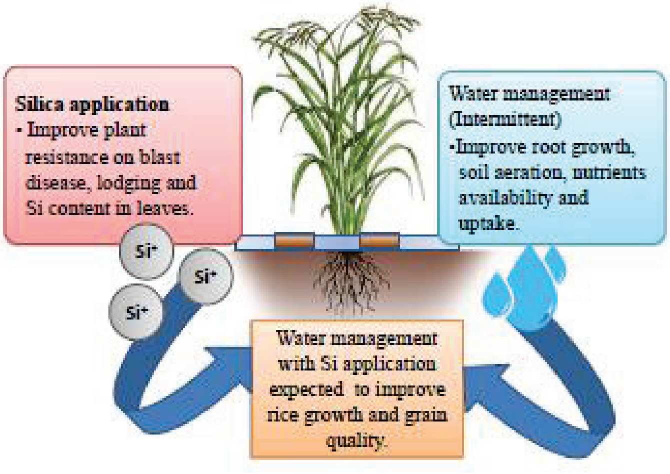

Figure. 5.1. Hypothesis on how water management and Si application improve rice growth and grain quality.

5.2. Materials and Methods

5.2.1 Sites and soils

This experiment was conducted in the rainy season in 2015 at experimental site of Balai Penelitian Lingkungan Pertanian(Indonesian Agricultural Environment Research Institute-IAERI), Jakenan, Central Java province, Indonesia. The experimental site lies on 06^{o}46’66.7” S – 111^{o}11’91.4” E.

The experiment was designed as split plot in randomized complete block design with 4 replications. The main plot consists of three water management namely continuous flooding (CF), Intermittent (IT) and Aerobic rice (AR) as main plots (Fig.5.2). The sub plot was characterized by two treatments including Si+ and Si- (with and without Si fertilizer).The plot size was 4 m x 5 m for each treatment. 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.

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 transplanting (DAT), 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 controlled the water supply in following condition until harvest, i.e. when the water level drop to 15 cm below the soil surface, we irrigated the field until it reached 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. 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).

Imported silica gel from Japan "Super Inergia" which had water solubility as 0.3 $gg^{-1}24h^{-1}$ was used as Si source. 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 was 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.

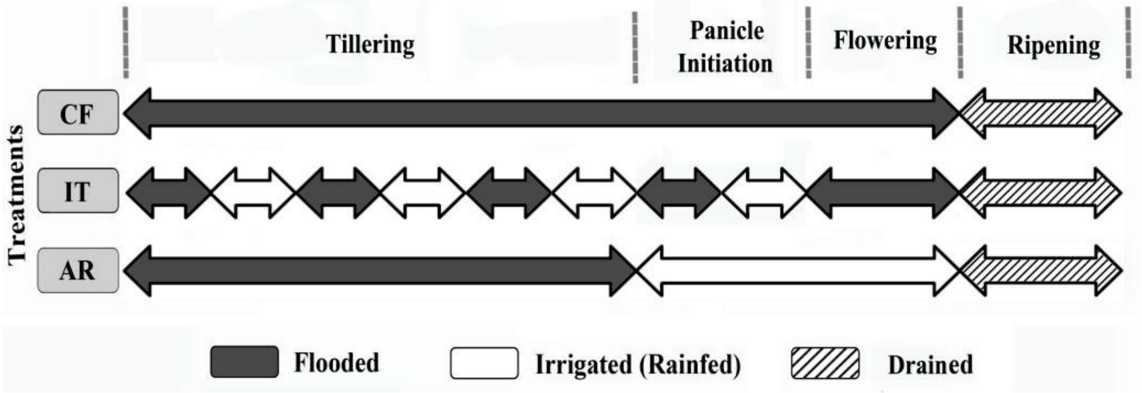

Figure 5.2. Three water management that employed in the experiment

Note. CF: 5 cm depth of water until 105 DAT 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 for28 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.

5.2.2 Plant cultivation

Land preparation was done by conventional tillage with two times plowing followed by leveling. 500 kg ha^{-1} of silica gel was applied before transplanting. Seedling from 21 days old nursery were transplanted into the puddled field with two seedlings per hill and row spacing of 20 cm x 20 cm. 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 7 and 30 DAS. Meanwhile for SP-36 was applied one time at 7 days after transplanting (DAT). During this cultivation we did not apply any fungicide for blast disease.

5.2.3. Sampling and analysis

The available Si for initial soil analysis was determined using the acetate buffer method (Imaizumi and 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. The extracted Si content in the soil samples was determined using atomic absorption spectrophotometer (Z-5000; Hitachi, Tokyo, Japan).

Rice leaf samples, the Y-leaf, were collected at 50 DAT, 90 DAT and harvest then analyzed for total Si content. Samples were digested with HNO_3 in a high pressure Tefflon Vessel (Quaker et al., 1979; Koyama and 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).

Rice grain samples were analyzed for total micro nutrients content (Cu, Fe, Mn and Zn). Rice grains were ground into powder using a ball mill and analyzed for total micro nutrients content. Plant samples were digested with HNO3 in a high pressure Tefflon Vessel (Quaker et al., 1979; Koyama and Sutoh, 1987). The extracted micro nutrients content in the grain samples was measured by Inductive Coupled Plasma Spectroscopy (ICPE-9000 Shimadzu Co, Kyoto, Japan).

Lodging resistance was measured using Force Gauge at 75 DAT and before harvest (115 DAT) (Fig. 5.3). 10 plant samples and 15 stems were selected from each treatment for lodging resistance and stem strength measurement. To measured lodging resistance, the stem was bent at 15 cm from the surface of the soil at to establish an angle 45^o (Yoshinaga, 2005).

Figure 5.3. Lodging resistance measurement

Blast disease infection was observed at 30 and 60 DAT for leaf blast and 75 DAT and before harvest (115 DAT) for neck blast. 10 plant samples were observed from each treatment plot 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 speek 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 management 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 $p < 0.05$. Values were expressed as means±SD. Student's t-test was performed at $p < 0.01$ to compare the effect of Si application. All statistical analysis was performed using IBM SPSS Statistic version 20.0 (IBM SPSS, 2011. Chicago IL, USA).

5.3. Results

5.3.1. Effect of treatments on plant growth

The effects of treatments on plant growth such as root weight, shoot weight, number of tillers and plant height is shown on Table 5.1. The result showed that IT was significantly higher comparing to CF and AR for root and shoot weight and plant height. IT was higher up to 16 and 29% for root weight, 11 and 13% for shoot weight, 5 and 4% for plant height comparing to CF and AR respectively.

On Si application, there was no significant difference on root weight, number of tillers and plant height but significantly different ($p < 0.01$) on shoot weight. Si application had higher shoot weight on CF and IT treatments.

5.3.2. Effect of treatments on improving lodging resistance

The result of lodging resistance at 75 DAT and harvest is shown in Figure 5.4. Lodging resistance in IT at 75 DAT increased by 70 and 13% comparing to CF and AR in Si+ treatments, and 75 and 31% to CF and AR in Si- treatment, respectively. Meanwhile at harvest, it increased 9 and 30% comparing to CF and AR in Si+ treatments, and 11 and 42% to CF and AR in Si- treatment, respectively. Meanwhile, Si application showed no significant effect in all the water management.

Table 5.1. Effect of treatments on plant growth parameters at harvest

Si application	Water management		
	CF	IT	AR
		Root (g)	
Si+	20 ± 4.3ab	23 ± 3.6b	18 ± 1.9a
Si-	19 ± 1.7ab	22 ± 1.5b	17 ± 1.8a
		Shoot (g)	
Si+	82 ± 4.4a**	89 ± 4.3b**	79 ± 5.1a
Si-	73 ± 5.6a**	81 ± 4.9b**	76 ± 7.8a
		Number of tillers	
Si+	11 ± 0.4a	11 ± 1.1a	10 ± 1.3a
Si-	10 ± 0.8a	10 ± 1.3a	9 ± 0.6a
		Plant height (cm)	
Si+	84 ± 2.9a	88 ± 2.4b	84 ± 1.8a
Si-	82 ± 0.7a	86 ± 1.7b	83 ± 1.2a

Means followed by the same latter do not differ significantly at 5%.
** Significant different at $p < 0.01$ between Si+ and Si- at each water treatment.

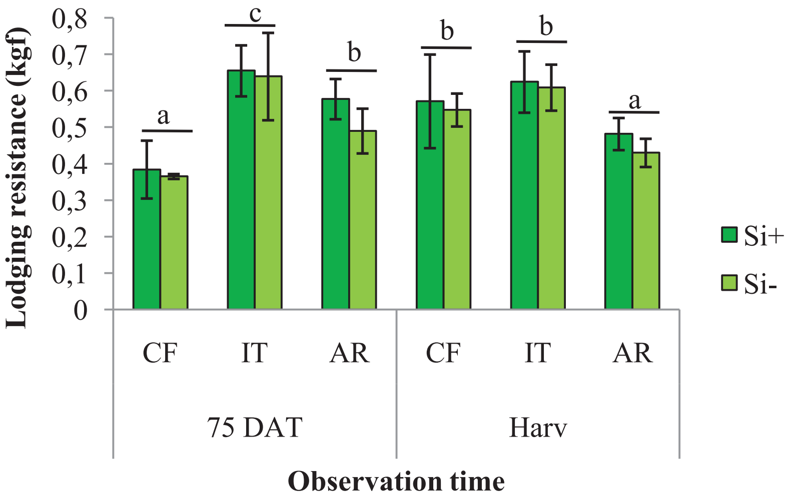

Figure 5.4. Effect of treatments on lodging resistance

Note. The different letters indicates significant difference among water managements for each sampling time; There was no significant difference between Si+ and Si- at each sampling time (n=12); Error bars indicate standard deviation among the mean values.

5.3.3. Micronutrients content in rice grain

The effects of treatments on micronutrients content in rice grain is showed on Figure5.5. The result showed that IT was significantly higher in Cu, Mn and Zn compared to CF and AR. However Si application showed no significant effect on micronutrients content in rice grain.

5.3.4. Effect of treatments on reducing rice blast infection

The result showed that Si application gave significant effect ($p< 0.01$) on reducing leaf blast infection throughout the observation periods in all water management (Fig. 5.6). Si application decreased the leaf blast infection by 42, 30, and 32% at 30 DAT and 43, 69, and 62% at 60 DAT for CF, IT and AR treatments, respectively. Water management also showed significant effect on reducing leaf blast infection at 30 and 60 DAT where CF had the higher leaf blast infection throughout the observation.

On neck blast infection, 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 (Fig. 5.7). Si application could decrease significantly ($p < 0.01$) the neck blast infection by 47, 28 and 8% at 75 DAT and 32, 22, and 12 % at harvest for CF, IT and AR management compared to Si- treatments, respectively. On the effect of water management, IT showed significant effect on reducing neck blast infection at harvest. Present study showed no significant effect on interaction between water management and Si application.

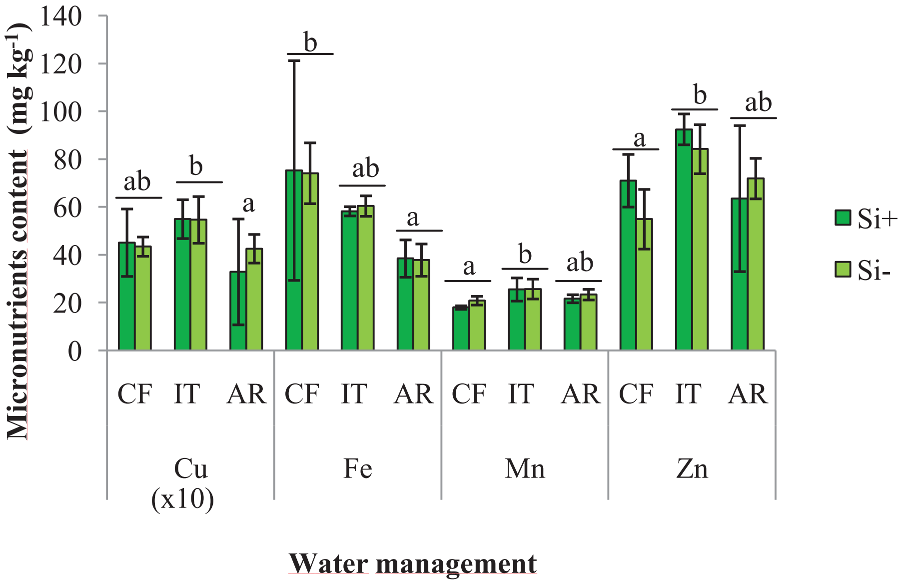

Figure 5.5. Effect of treatments on micronutrients content in rice grain

Note. The different letters indicates significant difference among water managements each sampling time; There was no significant difference between Si+ and Si- at each sampling time (n=12); Error bars indicate standard deviation among the mean values.

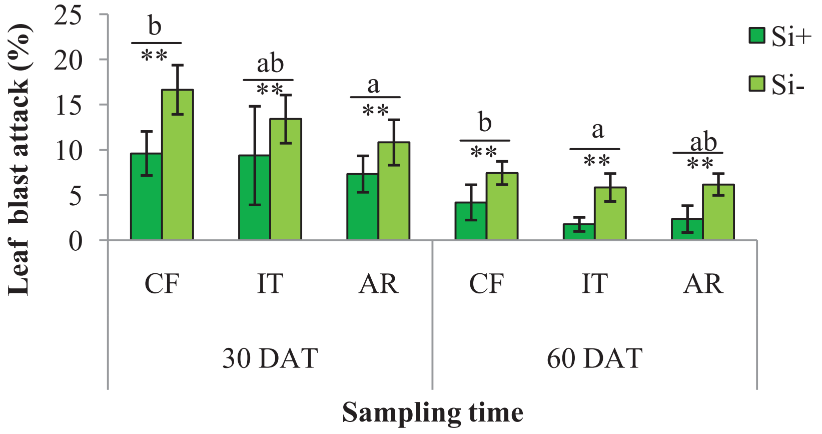

Figure 5.6. Effect of treatments on leaf blast infection

The different letters indicates significant difference among water managements each sampling time.
**Significant difference at $p < 0.01$ between Si+ and Si- at each sampling time (n=12).

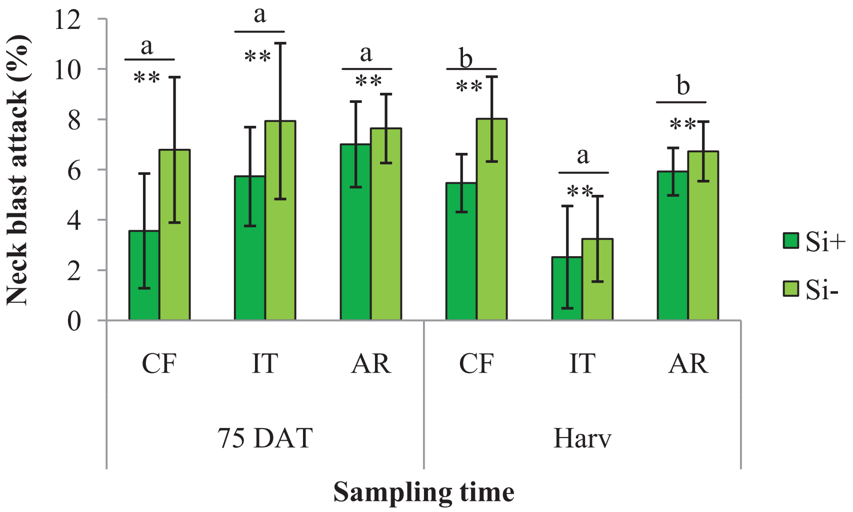

Figure 5.7. Effect of treatments on neck blast infection

The different letters indicates significant difference among water managements each sampling time.
**Significant difference at $p < 0.01$ between Si+ and Si- at each sampling time (n=12).

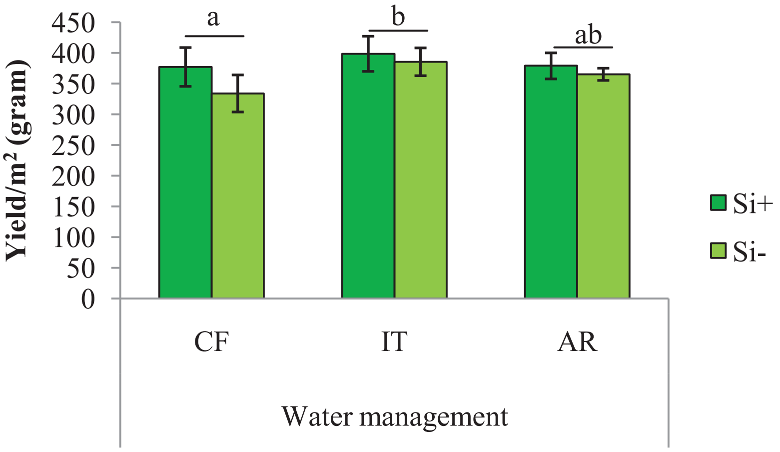

Figure 5.8. Effect of treatments on rice yield

Note. The different letters indicates significant difference among water managements each sampling time; There was no significant difference between Si+ and Si- at each sampling time (n=12); Error bars indicate standard deviation among the mean values.

5.3.5.Effect of treatments on rice yield

Present study showed that water management gave significant effect on yield (Fig. 5.8).

The rice yield in IT increased 5.7 and 5.2% compared to CF and AR in Si+

treatments,and 15 and 6% to CF and AR in Si- treatment, respectively. Meanwhile on Si application, there was no significant difference on rice yield.

5.4. Discussion

The improvement in root weight on IT management as shown in this present study (Table 5.1) might be due to better soil aeration. Under IT management, aerobic condition was created which could have promoted higher activity of the plants for the establishment of a larger and deeper root system (Uphoff and Kassam, 2008). Therefore, it will enhance shoot activities when optimal water and oxygen are available under intermittent water management (Yang and Zhang, 2010). Meanwhile AR management tend to have the lowest plant growth compared to IT and CF. Under aerobic soil condition, due to the emerging water shortage, it could change the nutrient dynamic in the soil which in turn may affect the crop performance.

Furthermore, present result showed that Si application gave significant effect on shoot weight at CF and IT (Table 5.1). The shoot including the stem is one of the factors that affects lodging resistance, as stated by Neenan and Spencer-Smith (1975), susceptibility of a variety to lodging also depends on the bending strength of the stem and its resistance to lodging. However, in this present study Si application did not give significant effect on improving lodging resistance(Fig. 5.4). This result showed that Si application had a beneficial but indirect effect on lodging resistance through improving the shoot weight.

As the improvement of root growth in IT, it will also affect the shoot weight and plant height (Table 5.1). By inducing larger root systems on rice plants, it could enhance water and nutrients uptake for its higher shoot weight and plant height. Moreover, as stated by Patrick and Tusneem (1972) that large amounts of nitrogen are lost from rice field during flooding condition, these losses result from leaching and from the volatilization of ammonia and nitrogen gas produced by denitrification. Therefore, as IT is employed it will enhance the nutrient availability such as nitrogen where nitrogen plays a role on promoting the growth and development of vegetative organs such as leaves, stem and also stimulates root growth (Bloom, 2015).

Related to lodging resistance, IT showed significant effect on improving lodging resistance (Fig. 5.4) which might be affected by the better root growth (Table 5.1). As stated by Terashima et al. (1994) and Feng-zhuan et al. (2010), higher lodging resistance would require heavier roots and deeper root system which is in agreement with this present study. However, Si application did not show significant effect in this present study.

Present study showed that IT could improve grain quality by improving the concentration of Cu, Mn and Zn in grain. The shifting from anaerobic to aerobic in IT also could enhance micronutrient solubility in soil as well as better root uptake.

Grain analysis result showed that water management showed significant effect on Cu content in grain, however Si application did not show the same effect (Fig. 5.5). The highest Cu concentration in grain appeared on IT followed by CF then AR. The shifting from flooding to aerobic condition that took place in IT might have changed the Eh that either increase the availability of Cu and Zn or inhibit the toxicity of Fe and Mn reduction (Dobermann and Fairhurst, 2000). Therefore as Cu availability on soil increase, it will improve plant up take and as a result will increase Cu content in rice grain.

The Fe concentration in rice grain decrease sharply from CF to IT and to AR management (Fig. 5.5). The average Fe concentration in rice grain at CF was 75.2 ± 45.9 mg kg^{-1} , 58.2 ± 1.9 mg kg^{-1} at IT then decrease to 38.5 ± 7.8 mg kg^{-1} at AR for Si+ treatment. Meanwhile for Si- treatment was 74.1 ± 12.7 mg kg^{-1} at CF, 60.4 ± 4.3 mg kg^{-1} at IT then decrease to 37.8 ± 6.7 mg kg^{-1} at AR (Fig. 5.5). This condition could be related to the solubility of Fe in soil. The solubility of Fe is low in aerated soil like in AR, as stated by Lemanceau et al. (2009), in aerated system in the physiological pH range, the concentration of ionic Fe^{3+} and Fe^{2+} are below 10^{-15}M due to formation of Fe hydroxides, oxyhydroxides and oxides. With low solubility of Fe in AR, rice plant could not up take Fe as much as like in CF and IT, therefore Fe content in rice grain was the lowest compared to CF and IT (Fig. 5.5).

Moreover, under constant flooding condition such in CF, when oxygen is depleted from the growing medium, changes in the redox potential occur; in such a case, NO_3^-, Mn, and Fe serve as alternative electron acceptors for microbial respiration, and are transformed into reduced ionic species. This process increases the solubility and availability of Fe and Mn for plant up take (Rengel. 2015). However, in this present study showed that CF did not increase availability of Mn which reflect on Mn content in rice grain.

Water management showed significant effect on Zn content in rice grain (Fig. 5.5). The result showed that IT had the highest Zn content in rice grain meanwhile CF had the lowest one. Continuous flooding may diminish the quantity of available zinc ions due to formation of sulphates and carbonates. Further, soil in IT management experienced flooded-drying condition which caused the adsorption of Zn to the soil to decrease and more Zn can be taken up by the plant (Mandal and Hazra, 1997).

Leaf and neck blast infection significantly ($p<0.01$) decreased by Si application (Fig. 5.6 and 5.7). This could be related to Si content in rice leaves, as Si application gave significant effect on improving Si content in rice leaves (Fig. 5.9). Additional Si in Si+ treatment provided more available Si for plant up take for all water management. Therefore, as Si is taken up by the roots it will be translocated and deposited on the tissue surface to act as physical barrier. It prevents physical penetration and / or makes the plant cells less susceptible to enzymatic degradation by fungal pathogens (Ma, 2004). It has been demonstrated that Si deposition seems to be more efficient in enhancing rice resistance against fungal infection when this element is taken up by roots (Datnoff et al., 2007).

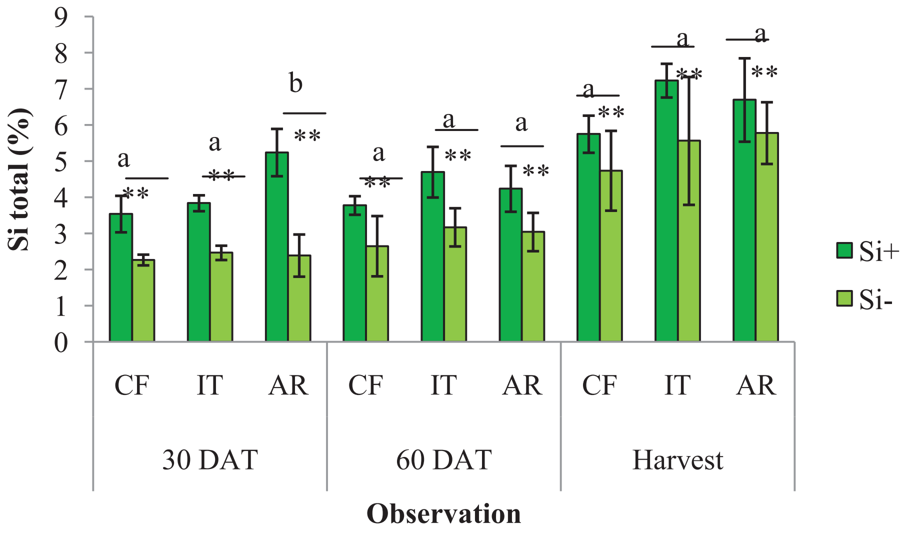

Figure 5.9. Effect of treatments on Si content in rice leaves

The different letters indicates significant difference among water managements each sampling time.
**Significant difference at $p < 0.01$ between Si+ and Si- at each sampling time (n=12).

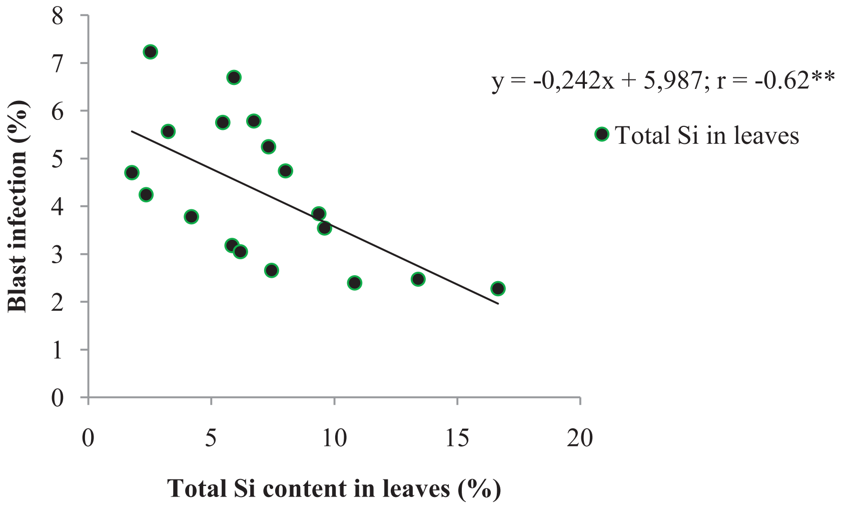

Figure 5.10.Correlation between total Si content in leaves with blast infection (** significant, $p < 0.01$).

In relation to water management, in general IT showed 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; Bin, 2008).

Apart from the aspect of soil moisture condition, the result showed that IT tend to have higher Si content at 60 DAT and harvest than CF and AR at those sampling time (Fig. 5.9), IT also had the lowest leaf and neck blast infection compared to CF and AR. It clearly showed the role of Si as a physical barrier to prevent blast infection. Furthermore, there is significant correlation between Si content in leaves with blast infection (Fig. 5.10). It showed clearly the role of Si on blast infection, as Si content in leaves increased, blast infection decreased.

Moreover, notice that CF tends to have the lowest Si content compared to IT and AR in both Si+ and Si- treatment (Fig. 5.9).As soil in CF is in reductive condition then some of the Si in the soil solution may have co-precipitated with Fe oxides/hydroxides. It has been proposed that Si combined with free iron dissolves when soil reductive conditions develop (Schwertmann, 1991). Therefore, rice plant up takes smaller amount of Si compared to IT and AR.

Initial soil analysis showed that soil Si available in study site is low as 31 mg SiO_2 kg^{-1} which is below the critical level proposed by Sumida (1992) and Dobermann and Fairhurst (2000): 300 and 86 mg SiO_2 kg^{-1} respectively. As stated by Seebold et al. (2000), rice that grows in soil with low Si availability, therefore Si application is an alternative to control blast infection.

The result showed that water management gave significant effect ($p<0.05$) on improving rice yield (Fig. 5.8). IT had higher yield up to 6 and 15% than CF for Si+ and Si- respectively and up to 5% than AR for both Si+ and Si-. Meanwhile Si application showed no significant effect in this present study.

Sufficient amount of water and nutrients availability is needed to achieve high yield (Dobermann and Fairhust, 2000). To get those factors, rice plant requires a good root growth and in this present study, IT showed a better root growth compared to CF and AR (Table 5.1). This could be the reason for higher yield that is achieved on IT (Fig. 5.8). Larger root systems enable rice plants to access a greater volume of soil and to acquire more water and nutrients and contributing to higher photosynthetic rate (Osaki et al., 1997) then manifest on improving the yield.

The soil in IT treatment repeatedly experienced submerged and aerobic condition which led to a fluctuation of NH_4^+ and NO_3^- in the soil solution. As stated by Kronzucker et al. (1999), having a mix of NH_4^+–N and NO^3–N in the soil enhances rice production, by as much as 40–60% compared to having N available only in ammonium form, which is predominant in continuously flooded soil. Therefore in this present study IT tend to have higher yield than CF and AR, apart from better root growth also due to better nutrients availability, such as nitrogen. Further, as aerobic condition is created in IT, it will provide suitable environment for soil microorganism therefore will provide nutrients due to the increasing of their activity.

Furthermore, IT management also had the lowest blast infection notably for neck blast infection compared to AR and CF management throughout observation period. As better root growth in IT, it could enhance higher Si uptake which followed by improving the blast resistance of rice plant in IT. It is known that blast disease is one of the most destructive disease for rice production. And neck blast is considered the most destructive symptom of rice blast characterized by infection at panicle base. When the fungus colonizes the panicle neck node and adjacent tissues the flow of photosynthates to the developing grains can be inhibited, resulting in lighter grains or even an empty panicles that caused yield loss (Bonman et al.1988; Zhu et al., 2005).

5.5. Conclusions

Mostly, Indonesia farmers including the farmers in this present study area employ continuous flooding in their rice cultivation with assumption that continuous flooding could produce high yield. However their assumption is no longer appropriate because there is water shortage issue like the one that occurs in this present study area.In this present study, we evaluated the effect of two water management with the conventional one and combine with Si application to improve rice productivity and grain quality.

The present study demonstrated that water management significantly increases yield compared to conventional flooding management. The highest yield was at IT management. This result could be related to a better root growth as occurred in IT which lead to improve plant growth parameter i.e shoot weight and plant height. Moreover, with a better root growth, it improved the lodging resistance and tended to improve Si uptake as seen on the increasing of Si content in rice leaves. Further, higher Si content in leaves on IT also led to the reducing of leaf and neck blast infection as it is known that intensity of blast infection especially neck blast could influence rice yield reduction due to an empty rice grain, less favorable soil moisture condition in IT which could suppress the blast disease life-cycle. Related to rice grain quality, IT management showed significantly to improve Cu, Mn, and Zn.

On Si application, it clearly improved plant resistance to both leaf and neck blast infection and Si content in rice leaves. In this present study, these phenomena did not result in the higher yield but exhibited potential to improving rice plant growth and production in Central Java region.

As a conclusion, there is a potential to improve rice productivity and grain quality in water shortage area such as Central Java by practicing IT management combine with Si application. Further studies are recommended.

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CHAPTER 6

SUMMARY

Various innovations have been made in rice production systems in Indonesia to increase the productivity. However, the rice production has fluctuated and stagnated over the past decade. Among those innovations, silicon (Si) application has not been appreciated in Indonesia because it was not an essential nutrient and also due to limited study about role of Si for rice plant in Indonesia. About water management, mostly Indonesian farmers employ continuous flooding in rice cultivation with assumption that continuous flooding could produce high yield. However, this water management is no longer suitable due to water shortage in some rice production area. This study is to assess effects of Si application and appropriate water management on improving rice productivity in Indonesia. Field surveys and rice cultivation experiments were conducted in three major rice producing provinces, namely Lampung, West Java and East Java province based on this present condition.

Field surveys were conducted in West Java and Lampung province in order to examine and to clarify the general Si status of sawah soil in relation with blast infection of rice categorized into two types of sawah: Bs+ (site which has blast disease occurrence) and Bs- (site which has no blast disease occurrence) at Lampung and West Java province. The result showed that soil available Si in West Java (300 – 960 mg SiO_2kg^{-1}) was higher than in Lampung (61 – 188 mg SiO_2kg^{-1}) as an effect of different parent material. West Java province, has parent material that is dominated by tuffaceous sandstone and volcanic rock. Soils developed from tuffaceous parent materials are known to contain higher Si than other parent material. Although West Java had higher soil available Si compared to critical level proposed by Sumida (1992) and Dobermann and Fairhurst (2000) at 300 and 86 mg SiO_2 kg^{-1} respectively, it still experienced severe rice blast disease. It showed that the existing critical level of soil available Si is not enough for these study areas. Moreover, silicon content in rice leaves from West Java was ranged from 2.7 – 8.0% or equal to 57.8 – 171.2 g SiO_2kg^{-1}. Revealed that Bs- sites had higher Si content in rice leaves than Bs+ sites which is in agreement with many previous researches that stated Si accumulation in rice plant could improve plant resistant to blast disease. Comparison of several extraction methods for assessing soil available Si, showed that 0.01M HCl extraction gave significant correlation ($p<0.01$; $r=0.66$) with Si content in rice leaves, which indicated that the 0.01M HCl method was better assessing SiO_2 availability in studied soils.

Based on field survey results, we conducted a field experiment to study the response of Si application at the site with high soil available Si. A field experiment was conducted in Sukabumi, West Java to evaluate the effect of Si application on blast disease infection, plant morphology and stomata formation of rice. The results demonstrate that Si application showed significant effect on suppressing leaf ($p <0.01$) and neck blast disease ($p < 0.05$) attack on Ciherang rice variety although the soil in study site had soil available Si of 426.54 $mgSiO_2kg^{-1}$ which is above critical level. The results confirmed that Si application have potential to improve rice growth and yield through the improvement of resistance to blast infection and increment of stomata density significantly ($p < 0. 01$) in Indonesia although they did not result in the yield increment in the present study.

On the water management method, intermittent irrigation (IT) water management significantly increased the yield during dry season (direct seeding) compared to continuous flooding (CF) water management. IT also tended to be higher in the yield than AR although it was not statistically different. The yield increase was attributed to better grain filling status shown in the 1000-grains weight. IT demonstrated a better root growth compared to continuous flooding (CF) and Aerobic Rice (AR), which exhibited possibility to improve lodging resistance, and shoot growth and decreased blast disease infection. Moreover, leaf Si content in IT and AR was higher than that of CF, which could promote higher photosynthetic rate as Si in leaf takes role to stimulate photosynthesis through improving light interception and the translocation of photo-assimilated carbon to the panicle in rice. In this experiment also, Si application clearly improved plant resistance to both leaf and neck blast infection ($p< 0.01$) and increased stomata density ($p< 0.01$) in all water treatments.

In wet season (transplanted seedling), IT showed significantly increases yield compared to CF. Better root growth performance with IT could lead to enhance growth (shoot weight and plant height) and yield, and Si uptake which had effect on improving resistances to lodging and blast infection. With respect to brown rice grain quality, IT management significantly increased micronutrients (Cu, Mn, and Zn) contents. Meanwhile Si application, obviously exhibited the beneficial effect on improving plant resistance to blast infection. Although, the Si application did not result in the higher yield in this experiment, it exhibited potential in improving rice plant growth and production in Central Java region.

Practicing Si application combined with intermittent irrigation could be a promising method to improve rice production. Moreover, Si application could be an alternative method which is environmentally friendly instead of fungicide application that has been a common practice for blast disease control. Therefore, these methods should be considered as practical options for improving rice production in Indonesia. It is necessary to develop a governmental program in order to extend these methods to the farmers.

インドネシアの米生産におけるケイ酸施用と水管理改善の効果の評価

インドネシアにおいて米生産性向上のために、種々の生産システム革新がなされてきている。しかし、過去10年において米生産量は変動し停滞している。インドネシアで実施されてきた種々の革新の中で、ケイ素（Si）施用はSiが必須元素では無い事と、インドネシアで稲に対するSiの働きに関する研究がほとんどないため行われてきていない。水管理について、ほとんどのインドネシアの稲作農家は、高収量をもたらすと信じて継続的な湛水灌漑を実施している。しかし、いくつかの稲作地域では水不足のため、この水管理はもはや適切ではなくなっている。本研究では、インドネシアの米生産性改善におよぼすケイ酸施用および適切な水管理の影響の評価を行った。野外調査および稲栽培試験を主要な米生産地の3州、Lampung, West Java とEast Javaで実施した。

West Java とLampung州において土壌中の可給態Siレベルとイモチの関係を調査した。水田はイモチ病の発生しているBs+と発生していないBs-に分類した。結果、West Java州の土壌の可給態Si（300 - 960 mg $SiO_2.kg^{-1}$）はLampung（61 - 188 mg $SiO_2.kg^{-1}$）よりも高く、母材の違いが原因と考えられた。West Javaの土壌可給態SiはSumida (1992) とDobermann and Fairhurst (2000) の示す基準 300 and 86 mg SiO_2 kg^{-1}よりも高かったが深刻なイモチ被害が発生しており、本調査地域におけるケイ酸可給度についてこれらの基準では不十分だと考えられた。稲の葉のSi含有量は2.7 - 8.0%（57.8 - 171.2 g $SiO_2.kg^{-1}$.）であり、Bs+サイトはBs-よりも高く稲植物体へのSi蓄積がイモチ耐性を向上させる既往の研究報告と一致していた。いくつかの土壌可給態Si評価法を比較した結果、0.01M HClの結果が葉中Si含有量と有意な相関を示した（$p<0.01$; $r=0.66$）。このことは、調査地土壌におけるSi可給度評価には0.01M HClが良い事を示している。

West Java州のSukabumiにおいて、稲のイモチ病感染、形態と気孔形成に対するSi施用の影響評価のために圃場試験を行った。土壌中可給態Siは欠乏基準値を超える426.54 mg$SiO_2$$kg^{-1}$であったが、Si施用はCiherang種の栽培において葉および穂イモチ感染を有意に抑制した（それぞれ$p<0.01, 0.05$）。本試験では稲収量は増加しなかったが、Si施用はイモチ病耐性の向上および気孔密度の増加（$p<0.01$）により稲生育と収量改善のポテンシャルを有する事を示した。

水管理方法に関して、間断灌漑(IT)水管理は乾期作（直播栽培）において従来の常時湛水(CF)管理に比べて収量を増やした。有意ではなかったがITの収量はARよりも高い傾向にあった。この収量増は、千粒重に示された登熟度（籾の実入り）の高さによる。さらにITはCFやAerobic Rice(AR)よりも根の生長が良く耐倒伏性を改善しうると考えられ、また地上部生長の増加とイモチ病感染の減少をもたらした。葉中Si含有量はITとARでCFよりも高く、葉中のSiは受光体勢の改善と光合成同化炭素の穂への転流促進により光合成速度を高めるうる事が考えられた。この試験でも同様に、すべての水管理条件でSi施用は葉と穂イモチ感染を低減させ($p< 0.01$)、気孔密度を増加させた($p< 0.01$)。

雨期作（移植栽培）においても、ITはCFよりも高い収量を示した。ITでの根の生長促進は地上部生長（地上部収量と草丈）と収量、および倒伏耐性とイモチ病耐性を改善するSi吸収の増加をもたらしたと考えられる。玄米質において、ITは微量（Cu,Mn,Zn)

含有量の増加させた。一方Si施用は、イモチ病耐性を改善する効果を示した。本試験ではSi施用は収量を増加させなかったが、中央ジャワ地域における稲生育と生産を改善する可能性を示した。

Si施用と間断灌漑の組み合わせはインドネシアの米生産性を改善する技術になりえる。さらにSi施用はイモチ病制御のために一般的に施用される殺菌剤に代わる環境親和性のある方法になりえる。従って、これらの方法はインドネシアの米生産改善のための実用的な技術選択肢として考慮すべきであり、技術普及のための政府事業を検討する必要がある。

List of Publications

Empirical Study on Effect of Silicon Application on Rice Blast Disease and Plant Morphology in Indonesia. Adha Fatmah Siregar, Husnain, Kuniaki Sato, Toshiyuki Wakatsuki, Tsugiyuki Masunaga. Journal of Agricultural Science Vol. 8, 6: 137-148, http://dx.doi.org/10.5539/jas.v8n6p137**(Chapter 3)**.

Influence of Water Management and Silica Application on Rice Growth and Productivity in Central Java, Indonesia. Adha Fatmah Siregar, Ibrahim Adamy Sipahutar, Husnain, Heri Wibowo, Kuniaki Sato, Toshiyuki Wakatsuki, Tsugiyuki Masunaga. Journal of Agricultural Science Vol. 8, 12: 86-99, http://dx.doi.org/10.5539/jas.v8n12p86**(Chapter 4)**.

PLATES

Plate 1. Some of sampling site locations in West Java province.

Plate 2. Some of sampling site locations in Lampung province.

Plate 3. Field experiment in Sukabumi, West Java province.

Plate 4. Field experiment in Jakenan, East Java province (direct seedling-dry season).

Plate 5. Field experiment in Jakenan, East Java province (transplanted seedling-rainy season).