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Effects of Silicon in Suppressing Blast Disease and Increasing Grain Yield of Organic Rice in Northeast Thailand

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ABSTRACT

Infestation of rice by the leaf blast disease caused by *Pyricularia oryzae* is frequent and results in severe yield losses and high production costs. Silicon has been reported to have potential for controlling the blast disease in rice. The objectives of this study were to determine the effects of silicon in suppressing the blast disease and increasing the grain yield of organic rice in northeast Thailand. Field experiments were conducted in farmers' fields in two locations in Northeast Thailand, Buriram (experiment 1) and Surin (experiment 2) provinces. Both experiments used a randomized complete block design with four replications. Treatments consisted of four silicon application rates of 0, 250, 500 and 1,000 kg ha^{-1}. Results showed that silicon applied to rice suppressed occurrence of the blast disease. Values of a severity index of leaf blast and neck blast were significantly decreased when silicon was applied at the rate of 250 to 1,000 kg ha^{-1} in comparison with the control treatment without silicon in both locations. At the highest silicon application rate, 1000 kg ha^{-1}, leaf and neck blast severity were reduced by 83 and 75% in experiment 1 and 81 and 77% in experiment 2, respectively. Grain yield when silicon was applied was 19-43% higher than the control in experiment 1 and 2-14% higher than the control in experiment 2. The maximum grain yield was obtained at the rate of 1,000 kg ha^{-1} in both locations (4,538 and 4,070 kg ha^{-1} in experiments 1 and 2, respectively). The yield obtained when silicon was applied at the rate of 1000 kg ha^{-1} was not significantly different from that obtained at the rate of 500 kg ha^{-1} in experiment 1, but it was significantly higher in experiment 2.

Key words: Khao dawk mali 105, organic system, rice blast, silicon, yield

INTRODUCTION

About 66% of arable land is devoted to rice production in Northeast Thailand. Khao Dawk Mali 105 (KDML 105) is the most popular rice variety grown in this region, covered 47% of paddy areas. It is in high demand on both the local and world markets, because it produces the best quality grain. This variety thus receives a higher price than other varieties. Organic rice production has played an important role in recent years in boosting the income of farmers in Northeast Thailand due to expanding market demand in European countries since 2003. Rice blast, caused by *Pyricularia oryzae,* is the most destructive fungal disease of rice, particularly in irrigated rice crop grown in temperate zone and tropical upland rice (Thurston, 1984; Ou, 1985).

The pathogen can infect all above-ground parts of the rice plant, but it is most commonly found on leaves, causing leaf blast during the vegetative stage of growth, and on neck nodes and panicle branches during the reproductive stage, causing neck blast (Thurston, 1984; Bonman, 1992). Since the use of fungicides to control fungal pathogens is not allowed in organic rice production, alternate methods of control are needed.

Many researchers have investigated the use of silicon for controlling rice diseases (Lee *et al.*, 1981; Nanda and Gangopadhyay, 1984; Datnoff *et al.*, 1991; Savant *et al.*, 1997). The application of silicon to deficient soils has been shown to reduce the severity of rice blast (Seebold *et al.*, 2000).

Silicon fertilizer also has many other positive effects on plants including rice directly or indirectly through soil reclamation. Rice has a high percentage of silicon in its culm and can endure drought well (Surapornpiboon, 2007). Other positive effects of silicon are stimulation of mineral absorption for increased yield and maintenance of nutrient balance in rice (Savant *et al.*, 1997; Epstein, 1999; Nakata *et al.*, 2008).

This study had as its objectives to assess the effects of silicon application on suppression of blast disease and on increasing grain yield of KDML 105 rice in an organic production system.

MATERIALS AND METHODS

Sites and soils: Field experiments were conducted in farmers' farms in two locations in Northeast Thailand, Buriram (Experiment 1) and Surin Provinces (Experiment 2), during the 2010 rainy season. The two experiments differed in soil texture with Experiment 1 having a sandy loam soil and Experiment 2 a sandy soil. The soils in both experimental sites were considered to be low in fertility (Table 1). However, the soil in Experiment 1 had higher fertility than that of Experiment 2, especially in K content. Silicon content was also higher in the soil of Experiment 1 than in that of Experiment 2 (Table 1).

Both experiments used a Randomized Complete Block design with four replications. Treatments consisted of silicon applied as monosilicic acid (H_4SiO_4) at four rates of 0, 250, 500 and 1,000 kg ha^{-1}.

Cultural practices: Soil preparation was done by conventional tillage, plowing two times followed by leveling, and then buds were built to divide the field into a total of 16 plots at each

Table 1: Soil physico-chemical characteristics of the experimental fields in Buriram (experiment 1) and Surin (experiment 2), Northeast Thailand, 2010

	Values	
Soil characteristics	Experiment 1	Experiment 2
pH^A	5.12	4.88
EC(dS m^{-1})^B	0.001	0.02
Organic matter (%)^C	0.90	0.63
Total N (%)^D	0.02	0.03
Available P(mg kg^{-1})^E	2.69	2.47
Extractable K (mg kg^{-1})^F	48.72	27.18
Silicon content (mg kg^{-1})^G	580.97	436.57
Soil texture^H	Sandy loam	Sandy

Methods used for determining each characteristic: ^{A}pH: 1:1 H_2O; ^{B}EC: soil 1: H_2O 5; ^{C}Organic matter: Walkley and Black method; ^{D}Total N: Kjeldahl method; ^{E}Available P: Bray II extraction method; ^{F}Extractable K: Frame spectrophotometer method; ^{G}Silicon content: 1:10 soil: water method using atomic absorption; ^{H}Soil texture: Hydrometer method

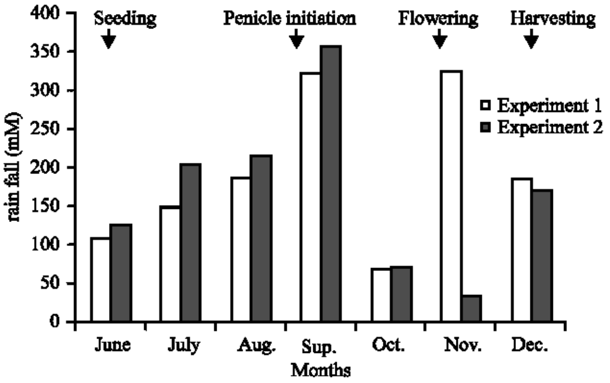

Fig. 1: Monthly rainfall distribution during growing season in Buriram (experiment 1) and Surin (experiment 2), Northeast Thailand, 2010

experimental site. Plot size was 12x18 m. Cattle manure at the rate of 6,250 kg ha^{-1} was incorporated into the soil during the last plowing. Silicon was applied four times: at tillering 15 Days After Sowing (DAS), during the vegetative growth stage (30 DAS), at the panicle initiation growth stage (60 DAS) and during the panicle growth stage (90 DAS).

Rice was direct seeded by broadcasting at both sites. Seeds were treated with neem powder (37.50 kg ha^{-1}) to control soil-borne and seed-borne diseases before sowing. The seeding rate was 94 kg ha^{-1}. KDML 105 (*Orysa sativa*) rice cultivar was used in both experiments.

Golden apple snail was controlled manually for both mature snails and eggs by using baits and making shelters during hot days, followed by removal of the trapped snails from the plots. Toxic herb including sarponin (*Cassia fistula* Linn.) was also used at the rate of 18.75-31.25 kg ha^{-1} to kill snails. Crabs were controlled in a similar way using tamarind (*Tamarindus indica* Linn.) seeds, cassava (*Manihot esculenta* (L.) Crantz) leaves mixed with steamed rice, and fermented fish as baits, and traps were also used. Weeds were controlled by incorporation into the soil during land preparation.

Data collection and measurements: Data on monthly rainfall were obtained from the nearest weather stations of the Thai Meteorological Service. The total amounts of rainfall throughout the growing season (June-December 2009) were 1,340 and 1,010 milliliters for Experiment 1 and Experiment 2, respectively. The month with the highest amount of rain was November in experiment 1 and September in experiment 2 (Fig. 1). The plants were not subjected to drought during the growing season at either site.

The following disease rating scale was used to evaluate disease severity for both leaf blast and neck blast: 0 = No symptoms; 1 = Small brown specks of pin-point size or larger brown specks without a sporulating center; 2 = Small roundish to slightly elongated, necrotic gray spots, about 1-2 mm in diameter, with a distinct brown margin, with lesions found mostly on the lower leaves; 3 = Lesion type is the same as in 2, but a significant number of lesions on the upper leaves; 4 = Typical susceptible blast lesions 3 mm or longer, infecting less than 4% of the leaf area; 5 = Typical blast lesions infecting 4-10% of the leaf area; 6 = Typical blast lesions infecting 11-25% of the leaf area; 7 = Typical blast lesions infecting 26-50% of the leaf area; 8 = Typical blast lesions infecting 51-75% of the leaf area and many leaves dead; 9 = More than 75% of the leaf area affected (IRRI, 1996).

Plant height was measured from the soil surface to the highest point of the leaves and panicles of all plants in 1 m^2 at 30, 60 and 90 DAS. Plants with in the same area of height measurement were cut at the soil surface and oven-dried at 80°C for 48 h to determine above ground dry weight at 60 and 150 DAS.

Yield components and grain yield: Data on the following yield components were taken: panicle number per square meter, grain number per panicle, percentage of filled grains per panicle and 1000 grain weight. Grain yield was recorded from a harvest area of 12 m^2 per plot. Grain weight was determined at 14% moisture and converted into grain weight per hectare.

Silicon content: Silicon in leaves, culm, straw, and seed waste was measured by the gravimetric method. Silicon content was measured as crude silica (Yoshida *et al.*, 1976), and total Si (%) was then calculated by dividing crude silica (g) by rice plant weight (g) and multiplied by 100.

Analysis of variance: Analysis of variance of measured variables was performed with the Least Significant Difference (LSD) Test used for means separation (Gomez and Gomez, 1984). All statistical analyses were carried out using Statistix 8 (Analytical Software, Tallahassee, Florida, USA).

RESULTS

Effect of silicon application on leaf blast: Increasing the rate of silicon application significantly decreased the severity index of leaf blast at both sites (Table 2). The lowest value of the severity index was observed when silicon applied at the rate of 1,000 kg ha^{-1} in experiment 1. However, there were no significant differences in severity index levels between silicon applied at rate of 1,000 kg ha^{-1} and rates of 250 and 500 kg ha^{-1} in experiment 1. In experiment 2, there was no significant difference in the severity index of leaf blast between silicon applied at the rates of 500 and 1,000 kg ha^{-1}.

Effect of silicon application on neck blast: Increasing the rate of silicon application significantly decreased the severity index of neck blast at both sites (Table 2). The lowest severity index was observed when silicon applied at the rate of 1,000 kg ha^{-1} in both sites. However, there were no significant differences in neck blast severity between silicon applied at the rate of 1000 kg ha^{-1} and rates of 250 and 500 kg ha^{-1} at either site (Table 2).

Table 2: Effect of silicon application rate on the severity index (%) of leaf blast and neck blast of rice cultivar KDML105 in Buriram (experiment 1) and Surin (experiment 2), Northeast Thailand, 2010

	Experiment 1		Experiment 2	
Silicon rate (kg ha^{-1})	Leaf blast	Neck blast	Leaf blast	Neck blast
0	29.16a	41.67a	29.86a	44.44a
250	6.94b	14.58b	15.28ab	13.20b
500	10.42b	14.59b	2.78b	14.59b
1,000	4.87b	10.42b	5.56b	10.42b
F-test	**	**	**	**
C.V.	19.41	23.28	64.24	35.30

Means followed by the same letter in the same column were not significantly different by the LSD test at $p<0.01$. **Significant at $p<0.01$

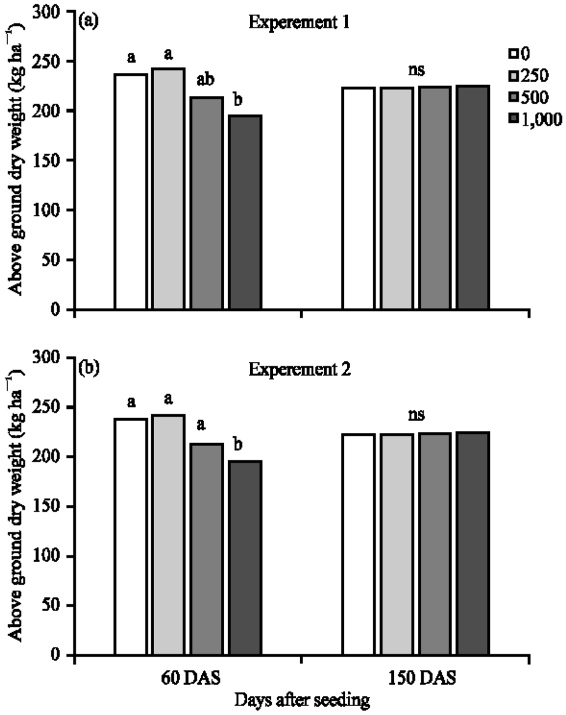

Fig. 2(a-b): Effect of silicon rates (kg ha^{-1}) on above-ground dry weight (kg ha^{-1}) of rice cultivar KDML 105 at 60 and 150 days after seeding (DAS) in Buriram (experiment 1) (a) and Surin (experiment 2) (b), Northeast Thailand, 2010. Means followed by the same letter at the same date were not significantly different by LSD at $p<0.05$. Ns: Not significant

Effect of silicon application on above ground dry weight: Increasing the rate of silicon application significantly decreased above-ground dry weight at 60 DAS, but there were no significant differences in above-ground dry weight at 150 DAS in either site (Fig. 2). The maximum above-ground dry weight was obtained at the rate of 250 kg ha^{-1}. However, there were no significant differences in above-ground dry weight when silicon was applied at the rate of 250 kg ha^{-1} with the control in experiment 1, or with the control and the rate of 500 kg ha^{-1} in experiment 2.

Effect of silicon application on plant height: Increasing the rate of silicon application significantly increased plant height at 60 and 120 DAS, but it had no effect on plant height at 30, 90, and 150 DAS in experiment 1 (Fig. 3a), Maximum plant height at 60 and 120 DAS was observed at the rate of 500 kg ha^{-1}. For experiment 2, increasing the rate of silicon had a significant effect on plant height only at 120 DAS (Fig. 3b). The maximum plant height at 120 DAS was observed at the rate of 500 kg ha^{-1}, but the difference with other rates was very small.

Effect of silicon on yield and yield components: Increasing the rate of silicon application increased grain yield at both sites. Silicon applied at the rate of 1,000 kg ha^{-1} had the highest grain yield at both sites (Table 3 and 4). However, grain yield obtained at the rate of 1,000 kg ha^{-1} was not significantly different from grain yield at the rate of 500 kg ha^{-1} in experiment 1 (Table 3),

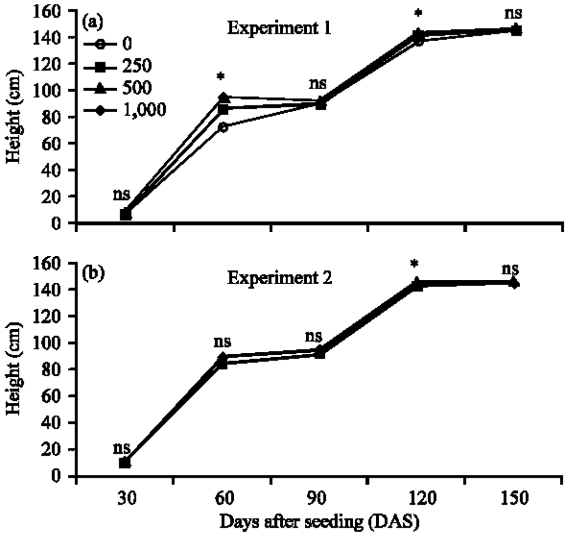

Fig. 3(a-b): Title of figure should change to “Effect of silicon rates (kg ha-^{1}) on plant height (cm) of rice cultivar KDML 105 at 30, 60, 90, 120 and 150 DAS (days after seeding) in Buriram (experiment 1(a) and Surin (experiment 2)(b), Northeast, Thailand, 2010. * Significant at $p<0.05$, NS: Not significant”

Table 3: Effect of silicon application rate on grain yield and yield components of rice cultivar KDML105 in Buriram (experiment 1), Northeast Thailand, 2010

Si rate (kg ha^{-1})	Grain yield (kg ha^{-1})	Panicle (no. per m^{2})	Grain (no. per panicle)	Filled grain (%)	1000 grain weight (g)
0	3179.3c	252.50c	195.50	89.00c	22.63
250	3769.6b	256.00b	194.00	93.00b	15.04
500	4373.6a	277.75a	231.50	94.75ab	19.36
1000	4538.0a	280.00a	271.50	97.25a	17.76
F-test	**	**	ns	**	ns
CV(%)	6.34	0.43	22.22	1.29	27.31

Means followed by the same letter in the same column were not significantly different by the LSD test at $p<0.01$ **Significant at $p<0.05$, Ns: not significant

Table 4: Effect of silicon application rate on grain yield and yield components of KDML105 in Surin (experiment 2), Northeast Thailand, 2010

Si rate (kg ha^{-1})	Grain yield (kg ha^{-1})	Panicle (no. per m^{2})	Grain (no. per panicle)	Filled grain (%)	1000 grain weight (g)
0	3530.7c	251.25c	99.75	79.00b	28.733
250	3611.4c	256.50b	140.00	88.50ab	28.398
500	3830.0b	277.75a	127.00	90.00a	29.387
1000	4070.0a	279.75a	184.75	95.25a	27.123
F-test	**	**	ns	**	ns
CV(%)	2.52	0.38	29.19	5.23	6.64

Means followed by the same letter in the same column were not significantly different by the LSD test at $p<0.01$ **Significant at $p<0.01$, Ns: Not significant

whereas it was significantly higher in experiment 2 (Table 4). Increasing the rate of silicon application increased the number of panicles per m^{2} and the percentage of filled grain at both sites,

Table 5: Silicon content in plant parts at 30, 60 and 90 DAS (days after seeding) in Buriram (experiment 1), Northeast Thailand, 2010

	30 DAS		60 DAS		90 DAS		
Si rates (kg ha^{-1})	Leaf	Stem	Leaf	Stem	Stubble	Straw	Seed
0	13.89	18.61b	10.72b	13.02	9.38	11.72	3.72
250	14.99	17.77b	12.73a	12.91	10.62	11.83	3.57
500	18.63	25.05a	12.05a	12.02	10.35	12.06	3.81
1,000	16.15	18.34b	12.02a	12.27	10.29	12.27	3.89
F-test	ns	*	*	ns	ns	ns	ns
CV(%)	23.26	14.25	5.44	7.45	7.87	8.91	10.11

Means followed by the same letter in the same column were not significantly different by the LSD test at $p<0.05$. *Significant at $p<0.05$, Ns: not significant

Table 6: Silicon content in plant parts at 30, 60 and 90 days after seeding (DAS) in Surin (experiment 2), Northeast Thailand, 2010

	30 DAS		60 DAS		90 DAS		
Si rates (kg ka^{-1})	Leaf	Stem	Leaf	Stem	Stubble	Straw	Seed
0	14.50	17.34	11.75b	11.31	11.66	12.35	4.57
250	13.50	18.71	13.07b	12.97	11.61	11.70	4.59
500	16.39	20.67	13.09ab	12.20	11.50	12.46	4.33
1,000	19.54	19.93	14.48a	13.91	12.70	12.61	4.94
F-test	ns	ns	*	ns	ns	ns	ns
CV (%)	22.49	10.12	6.66	9.05	5.30	4.42	10.50

Means followed by the same letter in the same column were not significantly different by the LSD test at $p<0.05$. *Significant at $p<0.05$, Ns: Not significant

but it had no significant effect on the number of seeds per panicle or 1000 grain weight in either experiment 1 (Table 3) or experiment 2 (Table 4). In both locations, the maximum number of panicles per m^2 and the highest percentage of filled grain were obtained at the rate of 1000 kg ha^{-1} (Table 3 and 4).

Silicon content in plant tissues: In Experiment 1, increasing the rate of silicon only had significant effects on silica (SiO_2) content in the stem at 30 DAS and in leaves at 60 DAS but had no effects on the SiO_2 content of plant tissues at 90 DAS (Table 5). At 30 DAS, the maximum SiO_2 content was obtained at the rate of 500 kg ha^{-1} (Table 5). At 60 DAS, silicon applied at rates of 250 kg ha^{-1} or more had significantly higher SiO_2 content in leaves (Table 5). In experiment 2, increasing the rate of silicon had no significant effects on SiO_2 content in plant parts at 30 DAS, but SiO_2 content was increased in the leaves at 60 DAS (Table 6). Silicon application at the highest rate of 1,000 kg ha^{-1} had the highest SiO_2 content in leaves at 60 DAS. At 90 DAS, SiO_2 content in stubble, straw and seed was not affected by silicon application rates (Table 6). At harvest, silicon application at different rates had no significant effects on SiO_2 content in stubble, straw or seeds in experiment 2, but significant effects were observed in straw in experiment 1. The maximum SiO_2 content in straw was obtained in the control treatment without silicon application (Table 7).

DISCUSSION

Effect of silicon on suppression of blast disease: The results of this study showed that application of silicon to rice crops decreased leaf and neck blast as compared to the control in both

Table 7: Silicon content in plant parts at harvest in Buriram (experiment 1) and Surin (experiment 2), Northeast Thailand, 2010

	Silicon content (%) in plant parts at harvest					
	Experiment 1			Experiment 2		
Si rate (kg ha^{-1})	Stubble	Straw	Seed	Stubble	Straw	Seed
0	8.39	7.41a	2.27	10.73	4.87	1.93
250	9.29	5.78c	2.13	9.72	5.23	1.97
500	9.23	5.87c	2.11	10.12	4.77	1.80
1000	9.16	6.96b	2.21	9.53	5.41	1.83
F-test	ns	**	ns	Ns	ns	ns
CV (%)	10.05	2.74	8.82	13.49	8.64	5.99

Means followed by the same letter in the same column were not significantly different by LSD at $p<0.01$. **Significant at $p<0.01$, Ns: Not significant

locations. This finding is in agreement with previous studies (Seebold *et al.*, 2000; Hayasaka *et al.*, 2005; Ranganathan *et al.*, 2006). Using of microelement of Molybdenum and Cobalt has also been found successfully in controlling of damping of in lentil (*Lens esculenta*) (El-Hersh *et al.*, 2011).

The mechanism of silicon-induced blast resistance is not well understood. It has been hypothesized that the capacity of silicic acid to form into a hard, glass-like coating of polymerized SiO_2, or plant opal, on the epidermal surfaces may physically block penetration by fungi (Volk *et al.*, 1958; Yoshida *et al.*, 1962a, b; Lanning, 1963; Winslow *et al.*, 1997). Seebold *et al.* (2000) also reported delayed onset of the disease when silicon was applied to rice. The results obtained by Ranganathan *et al.* (2006) who found significant silicon accumulation in leaf bundle sheath cells in rice, appear to confirm this point of view. However, rather than formation of a physical barrier to initial penetration, Rodrigues *et al.* (2001) emphasized on silicon's effect in reducing the expansion of lesions as the likely mechanism of silicon-induced sheath blight resistance in rice. In these experiments, no significant differences in the values of a severity index of leaf and neck blast were found among the rates of silicon (250, 500 and 1000 kg ha^{-1}). This result conflicts with previous findings which indicated that leaf and neck blast were reduced as the rate of silicon application was increased, particularly with partially resistant and susceptible rice cultivars (Seebold *et al.*, 2000; Hayasaka *et al.*, 2005). It also conflicts with the previous finding that silicon was effective in controlling sheath blight (Rodrigues *et al.*, 2003).

The above differences may be due to varying Si availability in the soil. In the present study, high amounts of available Si were observed (581 and 432 ppm in experiments 1 and 2, respectively. Based on the sufficiency level of Sumida (1992), who found that dissoluble silica content in paddy soil greater than 400 ppm was sufficient for rice, the soils used in these experiments would be considered as sufficient in Si. Nevertheless, given the considerable reduction in the severity of leaf and neck blast obtained with silicon application in this study, it is likely that silicon had a positive effect on one or more types of partial resistance, as defined by Parlevliet (1979), including the time of onset of the disease and the epidemic rate, in the susceptible cultivar, KDML 105, used in this study.

The response of rice to Si fertilizer depends not only on Si availability to the plant but also the Si content of plant tissue. Significant correlations between Si content of leaf or stem tissue and disease severity have been found (Seebold *et al.*, 2000). However, no such correlation was found in these experiments. Hayasaka *et al.* (2005) reported that the critical SiO_2 content of seedlings for controlling seedling blast was 5%. In this study, SiO_2 content in the leaves and stem was greater

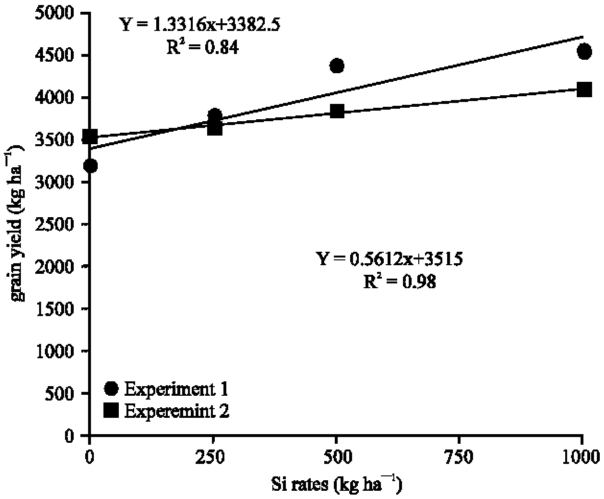

Fig. 4: Relationship between mean grain yield and silicon rates in Buriram (experiment 1) and Surin (experiment 2), Northeast Thailand, 2010

than the critical value calculated at 5% of plant tissue weight at all growth stages except in straw when silicon was applied at 500 kg ha^{-1} or in the control in experiment 2. Plant tissue content may be lower when the crop is grown in fields with lower soil Si content than the soils in this study and additional silicon may be needed in such soils.

Effect of silicon on growth and yield of rice: In the present experiments, grain yield of rice was significantly increased in both sites by increased silicon application rates. The maximum rate (1,000 kg ha^{-1}) increased grain yield by 43 and 14% in experiment 1 and 2, respectively. Grain yield had positive linear regressions on the rate of silicon application at both locations (Fig. 4). These findings are in accordance with earlier reports by Seebold *et al.* (2000). However, Datnoff *et al.* (1991) reported a quadratic regression of rice yield on calcium silicate gave the best fit, in results obtained in the United States. In other words, rice yield could be increased by applying silicon only up to a certain limiting rate. At what level such a limiting rate might be found may depend upon Si availability in the soil. In northeast Thailand, further research is needed on rice grown in soils with different Si content to determine the limiting silicon application rate for maximum rice yield in each type of soil.

The results from these experiments showed that increasing the rate of silicon application contributed to yield primarily through increased panicle numbers per m^2 and higher percentages of filled grain. This is consistent with the findings of the Thailand Rice Research Institute (2006) which indicated that silicon deficiency decreased panicle numbers per m^2 and the percentage of filled grain.

Based on the physiological functions of silica in rice plants, we can expect the application of silicon to enhance the mechanical strength of epidermal cells on the rice leaf surface, and thereby keep rice leaves erect and compact, avoiding mutual shading. This in turn will increase canopy photosynthetic efficiency. Recently, Ranganathan *et al.* (2006) reported that application of silicon to rice plants restored chlorophyll content (SPAD value) and the efficiency of photosystem II in infected rice leaves. Plants receiving silicon were also phenotypically stronger than control plants, with significant increases in leaf length and width observed. Furthermore, the accumulation of silicon forms a thick silicated layer on the leaf surface that may effectively reduce cuticular transpiration. Silicon may enhance the resistance of the rice plant to lodging by increasing the absorption of phosphorous, which can improve the ability of the plant to absorb more calcium and potassium. These elements help to strengthen rice plants against lodging (Kashiwagi and Ishimaru, 2004).

CONCLUSION

Increasing the rate of silicon application increased grain yield and significantly decreased the severity index of leaf blast at both sites. The above results have shown that when blast severity is high and a susceptible rice cultivar is used, application of silicon even in Si-sufficient soils suppressed blast disease and increased grain yield. In an organic rice production system where chemical fertilizer and fungicide are not allowed, silicon application thus could be a potential means of controlling blast severity and improving rice yield.

However, more widespread analysis of soil Si content would need to be done to determine which soils in the Northeast have Si contents at or above sufficiency levels, or if they deficient, to what extent are they deficient. Then research would be needed to determine the limiting rate of silicon application for Si deficient soils. This research should include analysis of economic benefits of increasing silicon application, because the economically viable level of silicon application may likely be lower than the agronomic maximum level. In addition, research in irrigated rice production systems as well as experiments in wet vs. dry seasons at the same locations are needed to determine the effects of silicon under varying growing conditions and seasons.

In the long term, research to identify an indigenous plant possessing compounds effective for reducing rice blast could create another control measure suitable for organic rice production. A precedent for this approach can be seen in the control of *Pythium* sp. infecting tomato seedling using extracts of garlic (Alhussaen *et al*., 2011) or suppressing fungi infection and increasing seed yield of sorghum and Perl millet by using aqueous extracts of *Acacia gourmaensis* A. Chev and *Eclipta alba* (L.) Hassk (Zida *et al*., 2010).

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