Open Access Library Journal
2021, Volume 8, e7937
ISSN Online: 2333-9721
ISSN Print: 2333-9705

Effect of Silicon Application on Growth, Yield and Uptake of Rice (*Oryza sativa* L.) in Two Different Soils

Mya Mya Swe[1]*, Swe Swe Mar[1], Tin Tun Naing[2], Thu Zar[3], Kyaw Ngwe[1]

[1]Department of Soil and Water Science, Yezin Agricultural University, Naypyitaw, Myanmar
[2]Department of Agricultural Microbiology, Yezin Agricultural University, Naypyitaw, Myanmar
[3]Department of Agronomy, Yezin Agricultural University, Naypyitaw, Myanmar
Email: *myamyaswe.dar@gmail.com

How to cite this paper: Swe, M.M., Mar, S.S., Naing, T.T., Zar, T. and Ngwe, K. (2021) Effect of Silicon Application on Growth, Yield and Uptake of Rice (*Oryza sativa* L.) in Two Different Soils. *Open Access Library Journal*, **8**: e7937.
https://doi.org/10.4236/oalib.1107937

Received: September 8, 2021
Accepted: October 26, 2021
Published: October 29, 2021

Abstract

Two pot experiments were conducted to study the effect of silicon application on growth, yield and uptake of rice plant, to observe the response of silicon fertilization in relation to two different soils and to evaluate the optimum rate of silicon fertilizer for rice production in each soil during dry and wet season, 2019 at Department of Soil and Water Science, YAU. The experiment was laid out in split plot design with four replications. The main plots were soil types; Shwebo and Yezin soils and sub plots were levels of silicon with Si 0, Si 100, Si 150, Si 200 and Si 250 $kg \cdot ha^{-1}$. Urea, T-super and Potash fertilizers were applied at recommended dose of DAR (85:12:31 $kg \cdot ha^{-1}$ NPK). The calcium silicate fertilizer was used as a silicon source. In dry season, Shwebo soil provided the higher tiller numbers, grain yield, straw yield and nutrient uptake than Yezin soil. In both seasons, panicle numbers per hill were higher in Shwebo soil and panicle length and spikelets per panicle were higher in Yezin soil. The effect of silicon application on grain yield and Si uptake was found in the second season. The maximum grain yield was achieved from the application of Si 250 $kg \cdot ha^{-1}$ which was not statistically different from the application of Si 200 $kg \cdot ha^{-1}$. According to this study, the application of Si 200 $kg \cdot ha^{-1}$ in combination with the recommended dose of NPK fertilizers could be used to give the optimum grain yield in two soils. Silicon uptake of rice was significantly increased by all the silicon levels compared to control in two soils. A significant interaction was not observed in all parameters in this study.

Subject Areas

Agricultural Science

Keywords

Rice, Silicon Fertilizer, Growth, Yield, Si Uptake

1. Introduction

Rice is the most important cereal crop in the world and is the staple food for over half the world's population. In Myanmar, total rice sown area in was 7.22 million hectares with the annual production of 28.01 million metric tons and the average yield was 3.92 ton ha^{-1} in 2018-2019 [1]. Myanmar has lower agriculture productivity and the lowest profits from rice production compared to other rice bowls in Asia [2]. Increased agricultural productivity can be achieved by the combination of many factors such as introduction of new improved varieties, effective control of pests, diseases and weeds as well as improved cultural methods, effective use of water, soil improvement and increased use of fertilizers [3]. Fertilizer is very important input for intensive rice production and profitability of rice production systems. Silicon is a beneficial element for plant growth and is agronomically essential for improving and sustaining rice productivity [4]. Silicon (Si) is the second most abundant element in the earth crust [5]. Despite its abundance in the soil, Si exists mostly as silica (SiO_2) that is not available for plant uptake. To be absorbed by plants, Si must be of monosilicic acid (H_4SiO_4) form but the natural release of H_4SiO_4 from SiO_2 is a very slow [6]. The critical level of Si in soil is 40 $mg \cdot kg^{-1}$ and in rice is (leaf and straw) 5% [7]. Rice is a high silicon accumulating plant which contains Si at levels up to 10% in dry matter weight [8]. It is estimated that to produce a total grain yield of 5.0 $t \cdot ha^{-1}$, rice crop removes 230 - 470 kg $Si \cdot ha^{-1}$ from the soil [9]. The role of plant silicon is important to against biotic and abiotic stress including salinity and heavy metal pollution and to increase the efficiency of NPK fertilizers [10]. The problem of silicon depletion may be found mostly in geologically old soils and long term rice producing areas [11]. Intensive agriculture which brings high productivity together with high removal of silicon may be the reason of reduction of silicon level in soils [12]. The farmers commonly burn or take out rice straw from rice fields after the harvest for animal feed. As Si is continuously removed through harvested products, the Si status of agricultural soil becomes low. Furthermore, if soil nutrients were not replenished by fertilizer application, the Si may possibly decrease from season to season. Soil acidification in rice paddies can cause Si deficiency since pH affects Si availability in the soil [13]. Myanmar is one of the most vulnerable countries to climate change. Awareness of silicon uptake by rice and silicon fertilization is becoming important for rice production in Myanmar. However, salient research finding on the effect of silicon fertilizer in crop production is rare in Myanmar. Therefore, the pot experiment was conducted 1) to study the effect of silicon fertilizer application on growth, yield and uptake of rice; 2) to observe the response of silicon fertilization in relation to two locations of soil; and 3) to evaluate the optimum silicon fertilizer rate for rice production in each soil.

2. Materials and Methods

2.1. Site Description

This pot experiment was conducted at Department of Soil and Water Science, Yezin Agricultural University during the dry and wet seasons in 2019 and the area is situated at latitude 19˚50'N, longitude 96˚16'E, 102 meters above sea level (Figure 1).

2.2. Experimental Design and Pot Management

The experiment was set up as split plot design with four replications. The main plots were soil types; Shwebo soil and Yezin soil and sub plots were levels of silicon (Si). Five silicon levels were (0, 100, 150, 200 and 250 Si kg·ha^{-1}). Yadanartoe rice variety (125 days) was cultivated. The soils were collected from 0 - 15 cm depth in Yezin and Shwebo lowland rice field. Plastic pots were used and filled with 10 kg soil. All treatments were applied with similar recommended dose of fertilizers (RDF) at the rates of 85-12-31 (N-P-K) kg·ha^{-1}. Urea, Triple superphosphate (TSP) and Muriate of potash (MOP) were used as the sources of these nutrients. Urea was applied at recovery, maximum tillering and heading stages as three equal splits, TSP at basal and MOP at recovery and maximum tillering stages as two equal splits. The calcium silicate fertilizer was used as a silicon source and applied before transplanting. Twenty days old rice seedlings were transplanted with one rice seedling into each pot.

2.3. Soil and Plant Sampling

Physicochemical properties of soil samples were analyzed before sowing and

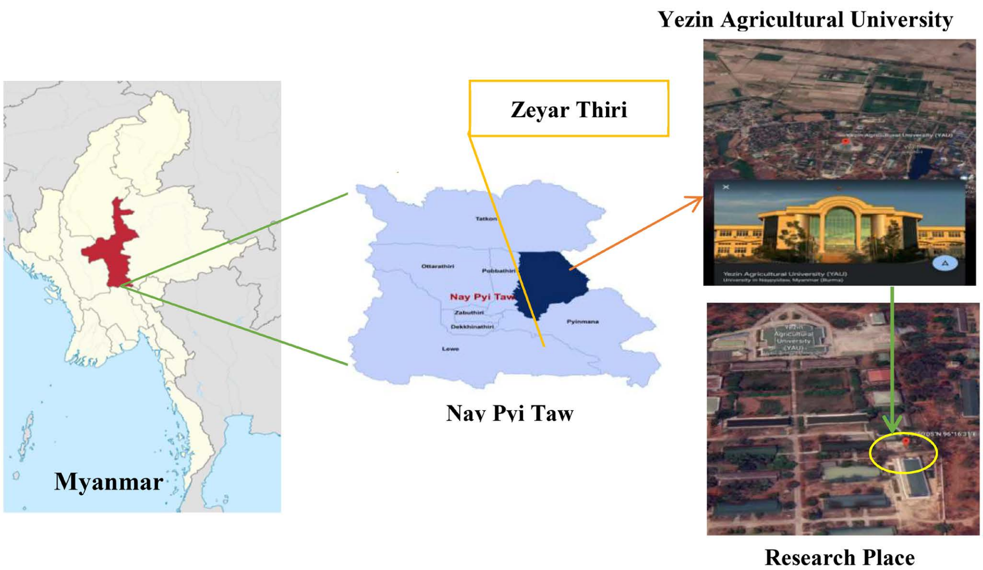

Figure 1. Location of study area in Myanmar.

after harvest of the second season of rice. The soil sample was air-dried and ground to pass through a 2 mm sieve. The soil samples were analyzed to determine soil texture, soil pH, available nitrogen, phosphorus and potassium, acid extractable Si, organic matter %, and electrical conductivity. Plant samples were collected at harvest stage and analyzed for the total uptake of N, P, K and Si. Plant and Soil samples were analyzed at the Soil and Plant Analysis laboratory, Soil Science Research Section, Agricultural Natural Resources Management Research Division, Department of Agricultural Research (DAR), Yezin, Nay Pyi Taw.

2.4. Crop Measurements

Growth parameters such that plant height and numbers of tillers per hill were collected two weeks intervals from 14 days after transplanting until harvest. For total dry matter (TDM), the rice plant from each pot was taken after harvesting and dried in an oven at 70˚C for 48 hours. After that, oven dry weight was used and computed for dry matter yield. The number of panicles per hill, panicle length, number of spikelets per panicle, filled grain%, 1000 grain weight and harvest index were measured after harvest. The grain yield was determined from each pot and adjusted to 14% moisture content.

2.5. Statistical Analysis

Experimental data were analyzed by analysis of variance (ANOVA) using statistix software (version 8). Mean value was compared using least significant differences (LSD) test at 5% probability level. Least significant difference is used to compare means of different treatments that have an equal number of replications.

2.6. Calculation

Harvest index (HI)

The harvest index was calculated by dividing the economic yield (grain yield) by biological yield (grain + straw yield) [14].

$$\text{Harvest Index} = \text{Economic yield/Biological yield}$$

Nutrient uptake

Nutrient uptakes were calculated by using the following formula [15].

$$\text{Nutrient uptake} = \left(Y_G \times N_G\right)/100 + \left(Y_S \times N_S\right)/100$$

where, Y_G = grain yield (g·pot^{-1}), Y_S = straw yield (g·pot^{-1}), N_G = nutrient concentration in grain (%), and Ns = nutrient concentration in straw (%)

Agronomic Silicon Use Efficiency (SiUE)

The agronomic SiUE refers to an increase in rice yield (g·pot^{-1}) per unit of Si applied [15].

$$\text{Agronomic SiUE} = \text{Yield}_\text{f} - \text{Yield}_0/\text{Si}$$

where, Yield_f = rice yield from Si application (g·pot^{-1}), Yield_0 = rice yield from without Si application (g·pot^{-1}), Si = amount of Si applied (g·pot^{-1}).

3. Result and Discussion

3.1. Plant Height (cm)

Plant height in all treatments continuously increased from 14 DAT to 84 DAT (Figure 2(a), Figure 2(b)). Plant height was significantly different in all growth stages between two soils except at 56 DAT. Shwebo soil provided a higher plant height than Yezin soil except at 84 DAT. At 84 DAT, Yezin soil gave significantly greater plant height (124.7 cm) than Shwebo soil (119.5 cm) in dry season. In wet season, there was significant difference in plant height only at 56 DAT. According to results, the effect of soil types on plant height was observed in dry season. Among the silicon levels, there was no significant difference in plant height at all growth stages in dry season and a significant difference at 14 DAT in wet season (Figure 3(a), Figure 3(b)). The effect of silicon fertilizer application on plant height was not significantly different [16]. The interaction between two soils and different silicon levels was not found on plant height in both seasons.

3.2. Number of Tillers per Hill

The highly significant difference of tiller numbers per hill was observed between two soils at all growth stages in dry season and significant difference at 84 DAT in wet season (Figure 4(a), Figure 4(b)). Shwebo soil gave significantly higher

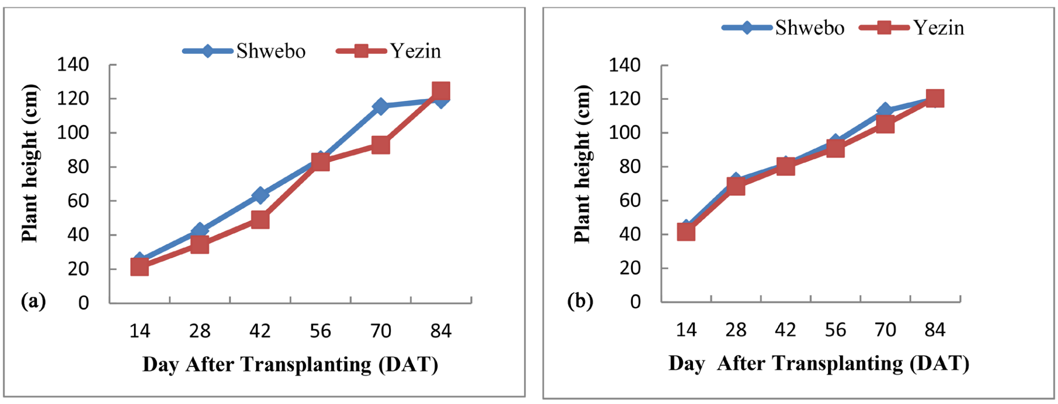

Figure 2. Plant height (cm) as affected by two soils in (a) dry season and (b) wet season.

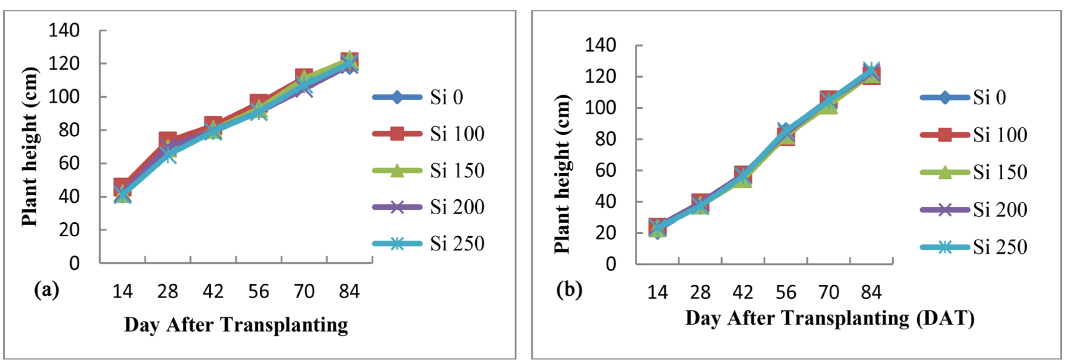

Figure 3. Plant height (cm) as affected by different levels of silicon fertilizer in (a) dry season and (b) wet season.

tiller numbers per hill than Yezin soil. This result may be due to the effect of soil texture and amount of organic matter content in two soils whereas Shwebo soil had high organic matter content and clay content than that of Yezin soil. In dry season, there was no significant effect of Si-fertilizer application on the number of tillers per hill but significant differences were observed at 56 and 70 DAT in wet season (**Figure 5(a)**, **Figure 5(b)**). The highest tiller number was observed at Si 250 kg·ha^{-1} and the lowest tiller number was found in control treatment. The number of tillers per hill was significantly increased with the application of silicon fertilizer [17]. The beneficial role of Si fertilizer was found in number of tillers per hill [18]. In both season, number of tillers·hill^{-1} was not a significant interaction between two soils and different silicon levels.

3.3. Total Dry Matter (TDM)

Mean values of total dry matter was shown in **Table 1**. There was a significant difference in total dry matter (TDM) between the two soils during dry season and no significant difference during the wet season. The maximum TDM value was resulted from shwebo soil (147.2 g·pot^{-1}) and the minimum TDM value was obtained from Yezin soil (119.9 g·pot^{-1}). The Si-fertilizer application was not significantly different on TDM in the dry season but a significant difference at 5% level in the wet season. The highest TDM value (95.3 g·pot^{-1}) was obtained from the application of Si 250 kg·ha^{-1} and the lowest TDM value (77.6 g·pot^{-1})

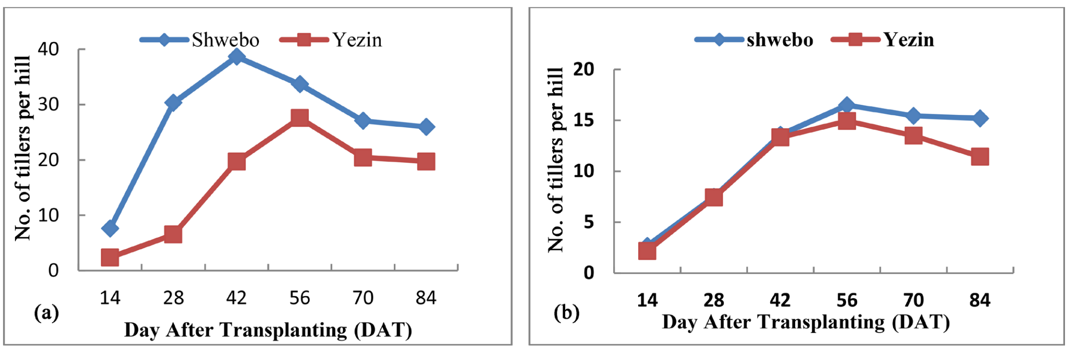

Figure 4. Number of tillers per hill as affected by two soils in (a) dry season and (b) wet season.

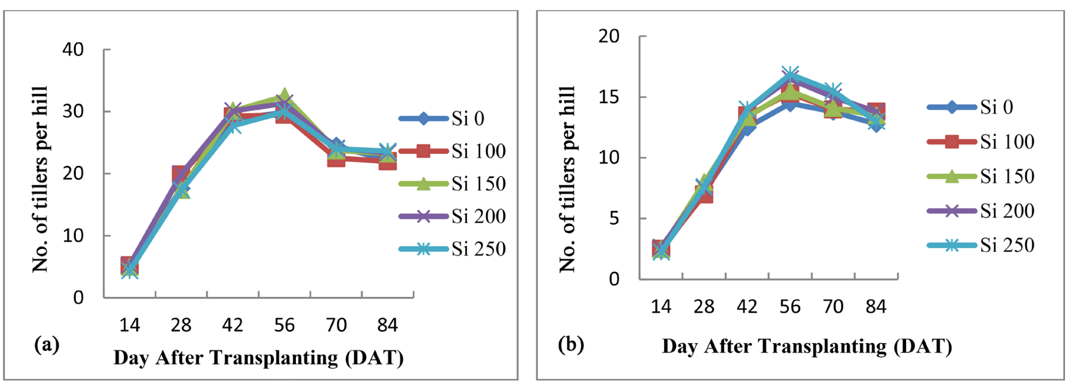

Figure 5. Number of tillers per hill as affected by different levels of silicon fertilizer in (a) dry season and (b) wet season.

Table 1. Mean effect of growth and some yield component parameters of rice as affected by different levels of silicon in two soils during dry and wet season, 2019.

Treatments	TDM (g·pot^{-1})		Number of panicles·hill^{-1}		Panicle length (cm)		Spikelets·panicle^{-1}	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Soils								
Shwebo	147.2a	92.2	26.0a	15.2a	22.82b	25.8b	90.30b	135b
Yezin	119.9b	80.6	19.8b	11.5b	25.18a	27.7a	108.25a	157a
LSD$_{0.05}$	**17.31**	**15.51**	**2.12**	**3.47**	**1.21**	**1.16**	**7.63**	**15.04**
Silicon levels								
Si 0	128.1	77.6c	22.1	12.8	24.16	26.7	102.13	135c
Si 100	131.0	83.4bc	22.o	13.8	23.46	26.8	102.13	139bc
Si 150	131.8	86.2abc	23.3	13.5	23.73	26.6	95.00	145bc
Si 200	140.2	89.7ab	23.4	13.8	24.11	27.0	98.25	151ab
Si 250	136.8	95.3a	23.6	13.0	24.51	26.6	98.88	160a
LSD$_{0.05}$	**14.78**	**10.36**	2.86	**1.83**	**1.05**	**1.11**	**11.04**	**12.13**
Pr > F								
Soils	*	ns	**	*	**	*	**	*
Silicon levels	ns	*	ns	ns	ns	ns	ns	**
Soils * Silicon	ns	ns	ns	ns	ns	ns	ns	ns
CV % (A)	**12.87**	**17.83**	**9.2**	**25.84**	**5.03**	**4.32**	**7.63**	**10.23**
CV % (B)	**10.71**	**11.61**	**12.1**	**13.29**	**4.26**	**4.02**	**10.78**	**8.05**

In each column, means followed by a same letters are not significantly different at LSD test 5% level. *Significant difference at 5% level, **Significant difference at 1% level, ns = non-significant difference, Si = Silicon (kg·ha^{-1}).

was found in control treatment. The increased levels of silicon fertilizer were significant increase in the dry matter·hill^{-1} [19].

3.4. Number of Panicles per Hill

In both seasons, the number of panicles per hill was a significant difference between the two soils (Table 1). The higher panicle numbers per hill was obtained from Shwebo soil. There was no significant difference in the number of panicles per hill among different silicon levels. The supplemental Si application was not significantly different on the number of panicles per hill [17]. No significant difference of panicle number was found among different silicon levels [20]. No significant interaction was observed between two soils and different silicon levels.

3.5. Panicle Length (cm)

The panicle length of yadanartoe rice variety was a highly significant difference at 1% level in dry season and at 5% level in wet season between two soils (Table 1). Yezin soil recorded significantly higher panicle length than Shwebo soil. There was no significant difference effect of Si-fertilizer application on panicle length at all growth stages in both seasons. Panicle length was not significant different effect by silicon levels [16]. No interaction was observed between two soils and Si application on the panicle length.

3.6. Number of Spikelets per Panicle

Number of spikelets per panicle was highly significant difference at 1% level in dry season and at 5% level in wet season between two soils (**Table 1**). The higher number of spikelets per panicle was observed in Yezin soil and the lower number of spikelets per panicle was recorded in Shwebo soil. This might be due to panicle length of yezin soil higher than Shwebo soil. Among the silicon levels, mean value of spikelets per panicle was not significantly different in dry season and was significant difference at 1% level in wet season. The maximum number of spikelets per panicle was obtained from the application of Si 250 kg·ha^{-1} followed by the application of Si 200 kg·ha^{-1}. The lowest number of spikelet per panicle was recorded in no silicon fertilizer application.] The silicon fertilizer application was increased the number of spikelets per panicle [21] [22]. The interaction effect between two soils and different levels of silicon was not significantly different in the number of spikelets per panicle.

3.7. Filled Grain (%)

There was no significant difference of filled grain percent between two soils and different levels of silicon fertilizer application in both seasons (**Table 2**). The mean values were statistically similar among different treatments. According to the results, the effect of silicon fertilizer application on filled grain percent was not significantly different in two different soils. The mean effect of Si-fertilizer application on filled grain percent was not significant difference [23]. Interaction effect between two soils and silicon fertilizer levels was not found in filled grain percent.

3.8. 1000 Grain Weight (g·pot^{-1})

Thousand grain weights showed no significant differences in two soil types, silicon levels and their interaction in both seasons (**Table 2**). Among the yield components, 1000 grain weight was less influenced by the treatment combinations because it is more or less genetically controlled characteristics. It is usually a stable varietal character and the management practice has less effect on its variation [24]. Interaction between the soil types and silicon levels was not statistically different.

3.9. Grain Yield (g·pot^{-1})

The results showed that the effects of soil types were significantly different on grain yield in dry season and no significant differences in wet season (**Table 2**). Shwebo soil showed a significantly higher grain yield than that of Yezin soil. This different grain yield may be supported from the Shwebo soil which had

Table 2. Mean effect of yield and yield component parameters of rice as affected by different levels of silicon in two soils during dry and wet season, 2019.

Treatments	Filled grain %		1000 grain wt. (g)		Grain yield (g·pot^{-1})		Straw yield (g·pot^{-1})		Harvest index (HI)	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Soils										
Shwebo	91.6	81.8	28.2	25.4	62.9a	43.8	84.3a	48.4	0.43b	0.48
Yezin	91.7	82.0	28.1	25.5	57.2b	38.8	62.7b	41.8	0.48a	0.48
$LSD_{0.05}$	**1.89**	**5.95**	**0.22**	**0.43**	**1.74**	**6.99**	**15.6**	**9.03**	**0.04**	**0.03**
Silicon levels										
Si 0	89.5	80.7	28.2	25.2	58.7	36.3c	69.4	41.3	0.46	0.47b
Si 100	91.2	80.7	28.1	25.3	58.6	39.4bc	72.4	43.9	0.45	0.48ab
Si 150	91.8	80.9	28.1	25.3	59.2	40.3bc	72.6	45.8	0.45	0.47b
Si 200	92.6	82.9	27.9	25.6	61.1	44.5ab	79.1	45.3	0.45	0.50a
Si 250	93.1	84.3	28.4	25.8	62.7	45.9a	74.2	49.3	0.47	0.49ab
$LSD_{0.05}$	**2.7**	**4.52**	**0.36**	**0.48**	**3.16**	**5.57**	**12.34**	**5.50**	**0.03**	**0.02**
Pr>F										
Soils	**ns**	**ns**	**ns**	**ns**	**	**ns**	*	**ns**	*	**ns**
Silicon levels	**ns**	**ns**	**ns**	**ns**	**ns**	*	**ns**	**ns**	**ns**	*
Soils * Silicon	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**
CV %(A)	**2.05**	**7.22**	**0.79**	**1.69**	**2.88**	**16.83**	**21.05**	**19.88**	**8.56**	**5.85**
CV %(B)	**2.86**	**5.34**	**1.23**	**1.84**	**5.10**	**13.08**	**16.27**	**11.82**	**6.20**	**4.62**

In each column, means followed by a same letters are not significantly different at LSD test 5% level. *Significant difference at 5% level, **Significant difference at 1% level, ns = non-significant difference, Si = Silicon (kg·ha^{-1})

higher number of panicles per hill than Yezin soil. There was no significant difference in the grain yield among the silicon levels in dry season but a significant difference at 5% level in wet season. The maximum grain yield was observed from the application of Si 250 kg·ha^{-1} and it was not significantly different with the application of Si 200 kg·ha^{-1}. The lowest grain yield was recorded in Si 0. It can be assumed that the effect of silicon fertilizer application on grain yield was significantly influenced. Significantly highest grain yield of rice was recorded from the application of recommended dose of fertilizers along with silicon at 200 kg·ha^{-1} [18]. The interaction effect between the soil types and silicon levels on grain yield was not significant difference in both seasons. The application of silicon fertilizer was increased in grain yield of 0.82% - 6.73% over the control in dry season and 8.5% - 26.4% over the control in wet season.

3.10. Straw Yield (g·pot^{-1})

There was significant difference of straw yield between two soils in dry season and no significant differences in wet season (Table 2). Shwebo soil produced higher straw yield than Yezin soil. In both seasons, the straw yield was not significantly influenced by different levels of silicon fertilizer application. The maximum straw yield (49.3 g·pot^{-1}) was recorded from the application of Si 250 kg·ha^{-1} which did not statistically differ with other Si treatments (100, 150, and 200 kg Si·ha^{-1}). The lowest straw yield (41.3 g·pot^{-1}) was observed in contro treatment. Interaction effect between two factors was not found to be significant on straw yield.

3.11. Harvest Index (HI)

Harvest index as affected by two soils was significantly different at 5% level in dry season although no significant difference was observed in wet season (Table 2). The maximum HI was produced by Shwebo soil in dry season. No significant response was observed among the silicon levels in the dry season. In wet season, there was significant difference at 5% levels of harvest index among the silicon levels. The application of Si 200 kg·ha^{-1} gave highest HI (0.50) whereas, application of Si 150 kgha^{-1} and Si 0 kg·ha^{-1} showed lowest harvest index (0.47). The response of rice to Si application was increased in harvest index over the control [25].

3.12. Nutrient Uptakes

Nutrient uptakes of yadanartoe rice variety after harvest were presented in Table 3.

Table 3. Mean effect of Si application on total nutrient uptake of rice in two different soils during dry and wet season, 2019

Treatments	Total N uptake (g·pot^{-1})		Total P uptake (g·pot^{-1})		Total K uptake (g·pot^{-1})		Total Si uptake (g·pot^{-1})		Silicon use efficiency	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Soils										
Shwebo	0.52a	0.43	0.24	0.22	1.70	0.96	5.84a	3.51	0.28	1.54
Yezin	0.45b	0.42	0.25	0.28	1.38	0.75	4.14b	3.40	0.17	0.52
$LSD_{0.05}$	**0.05**	**0.11**	**0.07**	**0.10**	**0.67**	**0.37**	**1.17**	**1.47**	0.48	**4.46**
Silicon levels										
Si 0	0.45	0.40	0.25	0.21c	1.49	0.75b	4.44	2.66b	-	-
Si 100	0.47	0.41	0.25	0.24bc	1.47	0.82b	4.76	3.27ab	-0.02	0.94
Si 150	0.53	0.43	0.24	0.24bc	1.58	0.87ab	5.02	3.67a	0.10	0.80
Si 200	0.49	0.42	0.26	0.26ab	1.69	0.86ab	5.51	3.71a	0.36	1.22
Si 250	0.51	0.48	0.24	0.30a	1.48	0.97a	5.23	3.98a	0.47	1.16
$LSD_{0.05}$	**0.06**	**0.08**	**0.03**	**0.05**	**0.30**	**0.13**	**1.07**	**0.73**	0.66	1.51
Pr > F										
Soils	*	**ns**	ns	ns	ns	ns	*	**ns**	ns	ns
Silicon levels	ns	ns	ns	**	ns	*	ns	*	ns	ns
Soils * Silicon	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV % (A)	6.63	15.66	18.22	26.24	27.66	27.76	21.14	27.05	186.3	384.8
CV % (B)	9.55	14.68	11.27	15.03	15.8	12.69	17.17	17.28	277.0	139.3

In each column, means followed by a same letters are not significantly different at LSD test 5% level. *Significant difference at 5% level, **Significant difference at 1% level, ns = non-significant difference, Si = Silicon (kg·ha^{-1}).

In dry season, N and Si uptakes were significantly influenced between two soils. Shwebo soil produced significantly highest N and Si uptake. There was no significant difference of Si-fertilizer application on total N, P K and Si uptake in dry season and a highly significant difference in P, K, and Si uptake in the wet season. The application of silicon at 250 kg·ha^{-1} was significantly highest total P uptake (0.30 g·pot^{-1}) followed by the application of silicon at 200 kg·ha^{-1} (0.26 g·pot^{-1}). The lowest P uptake was achieved in the control treatment. According to results, the silicon fertilizer application increased total P uptake by rice plants. This finding might be due to decreased phosphorus retaining capacity of soil and increased solubility of phosphorus by silicon fertilizer application [26]. The significant highest total K uptake (0.97 g·pot^{-1}) was obtained from the application of silicon at 250 kg·ha^{-1} but which was statistically similar with Si 200 kg·ha^{-1} and Si 150 kg·ha^{-1} (0.86 and 0.87 g·pot^{-1} respectively). The lowest value of total K uptake (0.75 g·pot^{-1}) was observed in control treatment. The application of silicon significantly increased total K uptake by rice plants [26]. Regarding of the Si uptake, the application of silicon at 250 kg·ha^{-1} was significantly different on total Si uptake (3.98 g·pot^{-1}) which was statistically similar to other silicon levels. The lowest total Si uptake (2.66 g·pot^{-1}) was observed from control treatment. The effect of silicon fertilizer application was influenced on silicon uptake by rice in this study. The application of silicon fertilizer significantly increased total uptake of N, P, K and Si [27].

3.13. Agronomic Silicon Use Efficiency (SiUE)

In both seasons, there were no significantly different of silicon fertilizer application on two soil types, different silicon levels (**Table 3**). The interaction between the soil types and silicon levels on SiUE was not significant difference in both seasons. The effect of silicon fertilizer application was not significant response on SiUE [28].

3.14. Effect of Silicon Fertilizer Application on Physicochemical Properties of Soil Samples at Initial and after Harvest in Two Soil Types

The status of soil nutrients was analyzed at initial, and after harvest of the second season (**Table 4**). The physicochemical properties of Shwebo soil was sandy clay loam with slightly acid condition having soil pH at 6.40. According to the electrical conductivity test, the soil was non-saline condition. The amount of organic matter and available K were medium levels while the levels of available N and P were low. Acid extractable Si was found as high level. The physicochemical properties of Yezin soil was sandy loam with moderately acid and non-saline conditions having soil pH at 5.60 and EC at 0.03 dS·m^{-1}, respectively. Soil organic matter and available N were found as low levels in this soil. The levels of available P and K were found to be medium. The amount of acid extractable Si was high level.

According to the soil analysis results after harvest of the second season, the

Table 4. Effect of silicon fertilizer application on physicochemical properties of soil samples at initial and after harvest in two soil types.

Soil sample		pH		EC (dS/m)		Available N (ppm)		Available P (ppm)		Available K (ppm)		Acid extractable Si (mg/kg)		Organic matter %	
		reading	rating	reading	rating	reading	rating	reading	rating	reading	rating	reading	rating	reading	rating
Shwebo	Initial	6.40	Slightly acid	0.04	Non saline	45	Low	3	Low	195	medium	443	High	2.58	Medium
	S1T1	6.51	Slightly acid	0.03	Non saline	29	Very low	8	Low	96	Low	433	High	1.37	Low
	S1T2	6.78	Neutral	0.03	Non saline	28	Very low	3	Low	95	Low	554	High	1.35	Low
	S1T3	7.23	Neutral	0.04	Non saline	34	Low	6	Low	89	Low	540	High	1.35	Low
	S1T4	7.49	Neutral	0.05	Non saline	35	Low	8	Low	88	Low	529	High	1.11	Low
	S1T5	7.26	Neutral	0.04	Non saline	37	Low	7	Low	91	Low	569	High	1.38	Low
Yezin	Initial	5.60	Moderately acid	0.03	Non saline	51	Low	11	Medium	178	medium	240	High	1.28	Low
	S2T1	5.92	Moderately acid	0.01	Non saline	37	Low	10	Medium	79	Low	159	High	1.49	Low
	S2T2	6.18	Slightly acid	0.01	Non saline	43	Low	10	Medium	79	Low	203	High	0.89	Low
	S2T3	6.31	Slightly acid	0.01	Non saline	26	Low	11	Medium	83	Low	230	High	1.13	Low
	S2T4	6.28	Slightly acid	0.01	Non saline	48	Low	12	Medium	81	Low	222	High	1.05	Low
	S2T5	6.61	Neutral	0.02	Non saline	47	Low	13	Medium	84	Low	357	High	0.97	Low

application of silicon fertilizer increased soil pH in both soils whereas the treatment without Si application remained as the initial status. The pH of Shwebo soil increased from slightly acid to neutral in all Si-treated soils. In Yezin soil, the pH increased from moderately acid to slightly acid in Si application rates at 100, 150 and 200 kg·ha^{-1} and to neutral in 250 kg Si·ha^{-1} application. The application of Si at 100, 150, 200 and 250 kg·ha^{-1} using calcium silicate fertilizer containing 30% CaO was equal to the application of lime at 382, 572, 763 and 954 lb·ac^{-1}. The pH value of soil between 6 and 7 are usually adequate in available Si, while pH value below 6 may be deficient in Si depending on texture, and if pH value is 9.8, maximum adsorption of Si can occur [29]. Soil pH is one of the most important Si solubility in soil solution [30]. Available N value in Shwebo was decreased from low to very low condition and was not changed in Yezin soil. Available P values were maintained and available K status was induced compare to initial value in two soil types. Soil organic matter content in Shwebo soil was decreased and was not changed in Yezin soil. The status of acid extractable Si in two soils can be maintained as the initial value.

4. Conclusion

According to the results, the silicon fertilizer application to rice was affected on grain yield and Si uptake of rice. The maximum grain yield was achieved from the application of Si 250 kg·ha^{-1} which was not significantly different from the application of Si 200 kg·ha^{-1}. Nutrient uptakes were significantly increased by the application of silicon fertilizer compared to control. Based on the results, it can be concluded that the application of silicon at 200 kg·ha^{-1} could be used to give the optimum grain yield in two soils. The significant interaction was not observed in all parameters in this study. Further investigation should be done to confirm the effect of silicon application in different rice growing areas under the field condition.

Acknowledgements

I deeply acknowledge to Rector, Pro-rectors, Professor and Head of Department of Soil and Water Science, and Supervisory Committee, Yezin Agricultural University for their guidance, valuable suggestions, constructive comments and encouragement throughout the study. I am also gratefully thanks the section head and colleagues from soil science research section, DAR for technical supports for this research. I also thank Myanma Awba Group for providing partial financial support.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] MOALI (Ministry of Agriculture, Livestock and Irrigation) (2019) Myanmar Agriculture Sector in Brief.

[2] Agriculture in Myanmar (2020) Flanders Investment and Trade market survey. https://www.flandersinvestmentandtrade.com/export/sites/trade/files/market_studies/Report%20Agriculture%20in%20Myanmar.pdf

[3] Jiraporncharoen, S. (1993) The Use of Chemical and Organic Fertilizers in Crop Production in Thailand. The Asia Pacific Network of Science and Technology Centres, Food & Fertilizer Technology Center, Taipei, Extension Bulletin No. 370.

[4] Ma, J.F. and Yamaji, N. (2008) Functions and Transport of Silicon in Plants. *Cellular and Molecular Life Sciences*, **65**, 3049-3057. https://doi.org/10.1007/s00018-008-7580-x

[5] Epstein, E. (1999) Silicon. *Annual Review of Plant Biology*, **50**, 641-664. https://doi.org/10.1146/annurev.arplant.50.1.641

[6] Raven, J.A. (1983) The Transport and Function of Silicon in Plants. *Biological Reviews*, **58**, 179-207. https://doi.org/10.1111/j.1469-185X.1983.tb00385.x

[7] Nagula, S., Joseph, B., Gladis, R., Raman, P.V. and Prabhakar, N. (2015) Silicon Nutrition of Crops with Special Reference to Rice. *Popular Kheti*, **3**, 111-114.

[8] Ma, J.F. and Yamaji, N. (2006) Silicon Uptake and Accumulation in Higher Plants. *Trends in Plant Science*, **11**, 392-397. https://doi.org/10.1016/j.tplants.2006.06.007

[9] Rodrigues, F.A. and Datnoff, L.E. (2005) Silicon and Rice Disease Management. *Fitopatologia Brasileira*, **30**, 457-469. https://doi.org/10.1590/S0100-41582005000500001

[10] Guntzer, F., Keller, C. and Meunier, J.D. (2012) Benefits of Plant Silicon for Crops: A Review. *Agronomy for Sustainable Development*, **32**, 201-213. https://doi.org/10.1007/s13593-011-0039-8

[11] Agostinho, F.B., Tubana, B.S., Martins, M.S. and Datnoff, L.E. (2017) Effect of Different Silicon Sources on Yield and Silicon Uptake of Rice Grown under Varying Phosphorus Rates. *Plants*, **6**, Article No. 35. https://doi.org/10.3390/plants6030035

[12] Mcginnity, P. (2015) Silicon and Its Role in Crop Production. *A Literature Review*, 27.

[13] Tavakkoli, E., Lyons, G., English, P. and Guppy, C.N. (2011) Silicon Nutrition of Rice Is Affected by Soil pH, Weathering and Silicon Fertilization. *Journal of Plant Nutrition and Soil Science*, **174**, 437-446. https://doi.org/10.1002/jpln.201000023

[14] Fageria, N.K. (2009) The Use of Nutrients in Crop Plants. CRC Press, Boca Raton, 131-158.

[15] Dobermann, A. and Fairhurst, T. (2000) Nutrient Disorders and Nutrient Management. Potash and Phosphate Institute, Potash & Phosphate Institute of Canada, and International Rice Research Institute, Los Baños, 50-119.

[16] Ahmad, A., Afzal, M., Ahmad, A.U.H. and Tahir, M. (2013) Effect of Foliar Application of Silicon on Yield and Quality of Rice (*Oryza sativa* L.). *Cercetări Agronomice în Moldova*, **46**, 21-28.

[17] Cuong, T.X., Ullah, H., Datta, A. and Hanh, T.C. (2017) Effects of Silicon-Based Fertilizer on Growth, Yield and Nutrient Uptake of Rice in Tropical Zone of Vietnam. *Rice Science*, **24**, 283-290. https://doi.org/10.1016/j.rsci.2017.06.002

[18] Pati, S., Pal, B., Badole, S., Hazra, G.C. and Mandal, B. (2016) Effect of Silicon Fertilization on Growth, Yield, and Nutrient Uptake of Rice. *Communications in Soil Science and Plant Analysis*, **47**, 284-290. https://doi.org/10.1080/00103624.2015.1122797

[19] Pati, S., Saha, S., Hazra, G.C., Saha, B.N., Pal, B. and Mandal, B. (2017) Distribution of Silicon in Rice Growing Soils of West Bengal in Relation to Some Important Soil Chemical Properties. *Journal of the Indian Society of Soil Science*, **65**, 181-188. https://doi.org/10.5958/0974-0228.2017.00021.4

[20] Carvalho, J.C. (2000) Growth Analysis and Production of Crop Grain of Rice by Sprinkling a Function of Steel Slags Application as Silicon Source. Master's Dissertation, UNESP/FCA, Botucatu, 119 p. *Field Crops Research*, **47**, 1-12

[21] Deren, C.W., Datnoff, L.E., Snyder, G.H. and Martin, F.G. (1994) Silicon Concentration, Disease Response, and Yield Components of Rice Genotypes Grown on Flooded Organic Histosols. *Crop Science*, **34**, 733-737. https://doi.org/10.2135/cropsci1994.0011183X003400030024x

[22] Takahashi, E. (1995) Uptake, Mode and Physiological Functions of Silica. *Science of Rice Plant*, **2**, 58-71.

[23] Ma, J., Nishimura, K. and Takahashi, E. (1989) Effect of Silicon on the Growth of Rice Plant at Different Growth Stages. *Soil Science and Plant Nutrition*, **35**, 347-356. https://doi.org/10.1080/00380768.1989.10434768

[24] Yoshida, S. (1981) Fundamentals of Rice Crop Science. International Rice Research

Institute, Los Baños.

[25] Detmann, K.C., Araújo, W.L., Martins, S.C., Sanglard, L.M., Reis, J.V., Detmann, E. and DaMatta, F.M. (2012) Silicon Nutrition Increases Grain Yield, Which, in Turn, Exerts a Feed-Forward Stimulation of Photosynthetic Rates via Enhanced Mesophyll Conductance and Alters Primary Metabolism in Rice. *New Phytologist*, **196**, 752-762. https://doi.org/10.1111/j.1469-8137.2012.04299.x

[26] Patil, A.A., Durgude, A.G., and Pharande, A.L. (2018) Effect of Silicon Application along with Chemical Fertilizers on Nutrient Uptake and Nutrient Availability for Rice Plants. *International Journal of Communication Systems*, **6**, 260-266.

[27] Wader, S.B., Pawar, R.B. and Pharande, A.L. (2013) Effect of Different Levels of Silicon on Growth, Yield and Nutrient Uptake of Upland Paddy in an Inceptisol. *Journal of Agriculture Research and Technology*, **38**, 326-328.

[28] Tun, S., Win, K.K., Htwe, N.N. and Khanig, T.T. (2015) Effect of Nitrogen and Silicon Fertilization on Growth and Yield of Rice (*Oryza Sativa* L.). *Journal of Agricultural Research*, **2**, 1-9.

[29] Szulc, W., Rutkowska, B., Hoch, M., Spychaj-Fabisiak, E. and Murawska, B. (2015) Exchangeable Silicon Content of Soil in a Long-Term Fertilization Experiment. *Plant, Soil and Environmen*t, **61**, 458-461. https://doi.org/10.17221/438/2015-PSE

[30] Matichenkov, V.V., Bocharnikova, E.A., Calvert, D.V. and Snyder, G.H. (2000) Comparison Study of Soil Silicon Status in Sandy Soils of South Florida. *In Proceedings-Soil and Crop Science Society of Florida*, **59**, 132-137.