

Original Research Article

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## Status of Silicon in Rice (*Oryza sativa* L.) and its Correlation with Other Nutrients under *Typic ustochrepts* Soil

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### ABSTRACT

#### Keywords

Silicon, Rice, Nutrient status, Correlation, Nutrient ratio.

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The survey work was carried out in rice growing area of middle Gujarat region to assess the available Si content in rice and find out the relationship of Si content with plant. The silicon content of rice grain collected from the region ranged from 1.20 to 5.99 per cent with an average value of 3.01 per cent, respectively and the rice straw Si content varied from 3.52 to 9.80 per cent with an overall mean of 6.30 per cent of different districts. The total uptake of Si by rice was 88, 114, 87, 91, 73 and 102 kg ha<sup>-1</sup> in different districts of middle Gujarat and the uptake of Si was nearly 2 to 45 times more as compared to N, P, K and S uptake by rice. The ratio of silicon and other nutrient contents in rice grain and straw indicated that amongst N, P, K, S and Na, the higher ratio was observed in Si: P indicating lower content of P in comparison with silicon. The correlation of coefficient (r) between Si content in rice and other nutrients indicated that Si content in rice grain and straw was positively correlated with N, P, K, Mn and Cu contents and negatively correlated with Fe content of grain.

### Introduction

Rice is heavy feeder of silicon, it's content as well as Si / Ca ratio is higher than 1% and therefore, it requires high amounts of silicon for sustained productivity. Although agricultural soils are largely composed of silicate minerals, many soils contain an inadequate supply or are naturally low in plant available silicon. Most likely, silicon content in some regions might be limiting to sustainable rice production. In addition, silicon depletion can occur in traditional rice soils from the continuous monoculture of high yielding cultivars with intensive cultivation

practices (Kawaguchi, 1966 and Miyake, 1993) especially if farmers are not applying the silicon removed by rice. The form of silicon absorbed by plant roots is silicic acid which is transported to the shoot. It is concentrated due to loss of water and is polymerized to colloidal silicic acid and finally to silica gel with increasing silicic acid concentration.

Rice is known as silicon accumulator and plant benefits much from silicon nutrition (Takahashi, 1995). Consequently, there is a

definitive need to consider silicon as an agronomically essential element for increasing and /or sustaining rice production (Takahashi and Miyake, 1977). Silica is required for healthy and productive development of the rice plant (Yoshida, 1975). This element is absorbed by rice from the soil in large amounts that is several fold greater than those of other macro- nutrients. On an average, it is estimated that a rice crop producing a total grain yield of about 5 tonnes ha<sup>-1</sup> will normally remove 230 to 470 Si kg ha<sup>-1</sup> (500-1000 SiO<sub>2</sub> kg ha<sup>-1</sup>) from soil (Savant *et al.*, 1997). Recent research and advances in physiology, biochemistry and genetics suggest that silicon interacts with other native or applied nutrients and has the potential to induce resistance/ tolerance in the rice plant to biotic (insects, pests and diseases) and abiotic stresses like Al, Fe and Mn toxicity; salt injury, lodging, etc. (Epstein, 1994). Thus, by and large, there is a general consensus that silicon is a quasi-essential element for rice plant.

Silicon is absorbed by rice from the soil in large amounts that is several fold greater than those of other macro- nutrients. On an average, it is estimated that a rice crop producing a total grain yield of about 5 tonnes ha<sup>-1</sup> will normally remove 230 to 470 kg Si ha<sup>-1</sup> (500-1000 kg SiO<sub>2</sub> ha<sup>-1</sup>) from soil (Savant *et al.*, 1997). In Middle Gujarat, total area under rice cultivation is 4.30 lakh ha with total production of 7.20 lakh M. T. and productivity of 1540 kg ha<sup>-1</sup> during 2008-09 (Anon., 2009). But, there is a progressive decline in yield in rice ecosystems may be due to the depletion of plant available silicon in soil. Hence, considering this problem, it was felt essential to identify soil and plant silicon profiles within intensively cultivated rice ecosystems throughout middle Gujarat region as till date the issue of silicon nutrition in rice production remains largely unexplored. By identifying and implementing ideal silicon

nutrition management strategies, declining yield trends in many rice production systems could be reversed. Therefore, the paper deals with status of silicon in rice (*Oryza sativa*) and its correlation with other nutrients under *Typic Ustochrepts* soil.

## **Materials and Methods**

### **Collection of rice samples**

Twenty representative samples from pre-identified 20 locations in each district were collected after harvest of rice crop in the month of October- November in 2009 and analyzed as per standard methods.

### **Method of plant analysis**

Nitrogen, phosphorous, potassium and micronutrients (Fe, Mn, Zn and Cu) were estimated by standard method suggested by Jackson (1973). Sulphur was analyzed by turbidimetric method as given by Chaudhari and Cornfield (1966). Silicon from plant was estimated by colorimetric method as per Dai *et al.*, (2005).

### **Statistical analysis**

Simple correlation coefficients of silicon with physical and chemical properties of soils and nutrient contents of plants were worked out by multiple regression technique (Steel and Torrie, 1982).

## **Results and Discussion**

### **Silicon content in rice**

The grain and plant samples each of analysed for silicon content and result given in Table 1 showed that the silicon content of rice grain in middle Gujarat region was ranged from 1.20 to 5.99 per cent with an average value of 3.01 per cent, respectively and the rice straw silica

content varied from 3.52 to 9.80 per cent with an overall mean of 6.30 percent of different districts of middle Gujarat region. The district wise mean silicon content of rice grain was 2.43, 4.89, 3.28, 2.13, 1.81 and 3.45 per cent, respectively. The average silicon content of rice straw of different districts was 6.40, 6.53, 5.40, 6.98, 5.54 and 6.76 per cent, respectively. The lower value of Si uptake by grain and straw in Dahod districts was mainly due to the lower availability of Si as compared to other districts. Similar ranges for Si content of rice grain and straw were reported by many researchers. Nayar *et al.*, (1977) reported that silicon content in harvested rice straw and grain was 7.13 and 2.67 per cent, respectively. The SiO<sub>2</sub> content of rice straw ranged from 4.4 to 19.6 per cent with an average of 11.0 per cent (Yoshida, 1981) and likewise, Si contents in harvested rice grain and straw were 3.35 and 9.40 per cent, respectively (Nayar *et al.*, 1975).

The categorization of 120 soil samples was done as per available Si status in different categories viz., < 25.0, 25 – 50, 50 – 75 and > 75 mg Si kg<sup>-1</sup> soil. The data given in Table 2 showed that around 60 per cent soils of different districts had less than 50.0 mg Si kg<sup>-1</sup> and on hectare basis; it was 2.93 lakh hectares of rice growing areas of middle Gujarat region. The lower available Si status may be attributed to the adoption of integrated nutrient management systems (INMS) for sustainable rice production, wherein silicon was not a part of INMS.

### **Nutrients content in rice**

From the six districts of middle Gujarat region of rice growing areas, rice grain and straw samples were also collected along with soil samples and analyzed for their silicon content by colorimetric method (Dai *et al.*, 2005). The data given in Table 2 revealed that the overall silicon content in rice grain ranged

from 1.20 to 5.99 per cent with mean of 3.01 per cent and the silicon content in rice straw ranged from 3.52 to 9.80 per cent with mean of 6.30 per cent. The silicon content in rice grain was found higher in Kheda district ranged from 3.58 to 5.78 per cent with mean of 4.89 per cent and lowest was found in Dahod district ranged from 1.28 to 3.02 per cent with mean of 1.81 per cent. The mean silicon content of rice grain of different districts was 2.43, 4.89, 3.28, 2.13, 1.81 and 3.45 per cent, respectively. The lowest content of Si in rice grain resulted due to low availability of silicon in soils of Dahod district and reverse in Kheda district where soil contain high available silicon. Silicon content in rice straw was found high in Panchmahals district ranged from 5.01 to 9.27 per cent with mean of 6.98 per cent. The silicon content in rice straw was found lower in Anand district ranged from 3.52 to 7.21 per cent with mean of 5.40 per cent. The average silicon content of rice straw of different districts was 6.40, 6.53, 5.40, 6.98, 5.54 and 6.76 per cent, respectively (Table 3).

The collected rice grain samples were also analyzed for important nutrient elements viz., N, P, K, S and Na and presented in Table 2. The analytical results revealed that the average content of nitrogen in rice grain samples was 1.32, 1.40, 1.15, 1.37, 1.33 and 1.11 per cent respectively in different districts of middle Gujarat region. Whereas mean P content were 0.13, 0.10, 0.09, 0.10, 0.08 and 0.11 per cent, respectively. The average content of K was found 0.21, 0.27, 0.19, 0.18, 0.19 and 0.27 per cent, respectively. The mean S content was 0.27, 0.12, 0.20, 0.13, 0.16 and 0.14 per cent respectively among different districts. Whereas mean content of Na in rice grain samples was 0.10, 0.08, 0.07, 0.07, 0.06 and 0.07 per cent respectively in rice grain samples of different districts of middle Gujarat region. The overall mean content of N, P, K, S and Na in grain was

1.28, 0.09, 0.22, 0.17 and 0.08 per cent, respectively. The data of nutrients content in rice grain showed that the Si accumulation was higher than other nutrients. The silicon content in grain was around double than N, 30 times more than P and Na, while 15 times more than K and S content in rice grain.

The rice straw samples were analyzed for important nutrient elements viz., N, P, K, S and Na and their contents were presented in Table 3. The analytical results indicated that the average content of nitrogen in rice straw samples was 3.05, 2.21, 2.92, 2.50, 2.74 and 2.42 per cent, respectively in different districts of middle Gujarat region. Whereas mean P content was 0.14, 0.12, 0.10, 0.10, 0.20 and 0.19 per cent, respectively. The average content of K was found 0.22, 0.32, 0.36, 0.37, 0.31 and 0.44 per cent, respectively. The mean S content was 0.47, 0.66, 0.36, 0.66, 0.60 and 0.76 per cent, respectively among different districts. The overall N, P, K, S and Na content in rice straw ranged from 1.82-3.58, 0.05-0.29, 0.19-0.49, 0.1-1.01 and 0.13-0.44 per cent, respectively.

Remarkable differences found in the micronutrient content of rice grain given in Table 2. Analytical results showed that the highest value of Fe was found in the Anand district (663 mg kg<sup>-1</sup>) and minimum (28 mg kg<sup>-1</sup>) was found in Kheda district. The average content of Fe was found 170, 301, 291, 218, 200, 148 mg kg<sup>-1</sup> in different districts. Average Mn content was found 30, 61, 49, 22, 35, 79 mg kg<sup>-1</sup> while mean Zn content was observed 19, 31, 33, 24, 30, 23 mg kg<sup>-1</sup> respectively in the different districts of middle Gujarat region. The Cu content was ranged from 3.0 to 21.0 mg kg<sup>-1</sup> in rice grain with mean value 7.0 mg kg<sup>-1</sup>.

The rice straw samples were also analyzed for micronutrients content and data presented in Table 3. The average Fe content of rice straw

samples was 259, 387, 401, 270, 399 and 300 mg kg<sup>-1</sup>, respectively in different districts of middle Gujarat. The mean Mn content was found 166, 189, 113, 254, 189 and 316 mg kg<sup>-1</sup>, respectively. The average Zn content of straw samples was 30, 21, 39, 30, 32 and 31 mg kg<sup>-1</sup>, respectively. Whereas, the average Cu content of straw samples was 6, 10, 10, 5, 8 and 7 mg kg<sup>-1</sup>, respectively. The overall mean content of Fe, Mn, Zn and Cu was 401, 238, 30 and 8.0 mg kg<sup>-1</sup>, respectively. Similar ranges for Si content of rice grain and straw were reported by many researchers. Nayar *et al.*, (1977) reported that silicon content in harvested straw and grain was 7.13 and 2.67 per cent, respectively. The SiO<sub>2</sub> content of straw ranged from 4.4 to 19.6 per cent with an average of 11.0 per cent (Imaizumi and Yoshida, 1958) and likewise, Si contents in harvested grain and straw were 3.35 and 9.40 per cent, respectively (Nayar *et al.*, 1975).

#### **Uptake of silicon and other nutrients by rice**

The results of nutrients uptake by of rice grain and straw in different districts of middle Gujarat was reported in Table 4. The average silicon uptake by rice grain was 23.6, 48.9, 32.8, 21.1, 18.1, 34.5 kg ha<sup>-1</sup> and 64.0, 65.3, 54.0, 69.8, 55.4 and 67.6 kg ha<sup>-1</sup> by straw in Ahmedabad, Kheda, Anand, Panchmahals, Dahod and Vadodara, respectively. The lower value of Si uptake by grain and straw in Dahod districts resulted due to availability of Si was low in soils as compared different districts. The maximum total uptake of Si recorded as 114.2 kg ha<sup>-1</sup> in the Kheda districts and minimum as 73.4 kg ha<sup>-1</sup> in the Dahod district. The average total uptake of silicon by rice was 87.6, 114.2, 86.8, 90.9, 73.4, 102.1 kg ha<sup>-1</sup> in the different districts of middle Gujarat region (Table 6).

The uptake pattern of N, P, K, S and Na by rice grain was in descending order: N > K > S

> P > Na. The uptake of Si was nearly 2 to 20 times more as compared to major nutrients uptake which indicated that more requirement of silicon by rice as compared to others nutrients. The overall mean uptake of N, P, K, S and Na by rice grain was 12.7, 1.04, 2.17, 1.71 and 0.73 kg ha<sup>-1</sup>, respectively (Table 4). The SiO<sub>2</sub> uptake or content of the plants might be increased to some extent by applying silicate material. Similar results were also reported by Ganaie *et al.*, (2015) and Korndorfer *et al.*, (2001) in some soils of Florida and Meshram *et al.*, (2015) in soils of Sri Lanka, Singh *et al.*, (2006) in soils of India.

The Si uptake by straw was nearly two times more than N uptake and 40, 20 and 12 times more as compared to P, K and S uptake by rice straw, respectively (Table 5). The overall mean uptake of Fe, Mn, Zn and Cu in rice grain was 220.8, 45.9, 26.5 and 6.91 g ha<sup>-1</sup>, respectively in the different districts of middle Gujarat region. Because of higher available Fe the uptake of Fe by rice grain was also found higher as compared to other micro nutrients (Table 4). The average micronutrients (Fe, Mn, Zn and Cu) uptake by rice straw was 336.1, 204.6, 30.4 and 7.6 g ha<sup>-1</sup> in different districts of middle Gujarat region, respectively (Table 5). The total uptake of silicon by rice was nearly 2, 45, 18, 13 and 30 times more than uptake of N, P, K, S and Na, respectively in middle Gujarat region (Table 6). The average uptake of Fe, Mn, Zn and Cu by rice was 645.0, 245.2, 56.9 and 14.4 g ha<sup>-1</sup>, respectively in different districts.

The results obtained for different nutrients present in rice grain and straw with respect to Si can be supported by many research findings. Okuda and Takahashi (1962 b) noticed that the added silicon increased the translocation rate of absorbed phosphorous to the grain especially at the phosphorus

deficient level. This effect might have resulted from the action of silicon, in which the increasing amount of silicon decreased the iron content of rice plant and increased the phosphorous / iron ratio in the plant, especially at the phosphorus deficient level.

From these experiments, it concluded that silicon seems to retard the excessive uptake of phosphorous by rice to promote the translocation of phosphorous in rice plant. Islam and Saha (1969) inferred that the application of silicon generally decreased the nitrogen, protein and potassium content of rice plants. Its application also decreased the iron and manganese contents. The use of silicon resulted in an increase in phosphorous, calcium, magnesium, silicon and carbohydrate contents of rice plant.

Analysis of straw by Takijima *et al.*, (1970) showed that addition of dolomite slag lowered N and Fe and raised the contents of P, K and Mg as well as Si. According to Elawad and Green (1979) due to synergistic effect, applied silicon had the potential to raise optimum rate of N, thus helping to enhance yield due to N inputs. Cheng (1982) informed that yield response over the control would not be obtained if available silicon exceeded 11 SiO<sub>2</sub> mg 100 g<sup>-1</sup> in the soil. There was an increase in Ca, Mg, Si and carbohydrate contents after the addition of silicon to the culture solution @ 75 ppm silicon which also decreased the accumulation of Mn, Fe, Zn, Cu, N, P and transpiration rate. It is concluded that addition of silicon is particularly effective when combined with heavy doses of nitrogen and magnesium. Ma and Takahashi (1989) observed that both content and uptake of phosphorous were decreased by the addition of silicic acid and the effect was more pronounced at the vegetative stage than at the reproductive stage. Verma and Minhas (1989) indicated uptake of Mn was not affected by silicon addition.

**Table.1** Status of available silicon content in rice in different districts of middle Gujarat

Sr. No.	District	No. of Taluka covered	No. of sample	Grain Si (%)		Straw Si (%)	
				Range	Mean	Range	Mean
1	Ahmedabad	5	20	1.20-5.99	2.43	4.97-8.63	6.40
2	Kheda	3	20	3.58-5.78	4.89	4.30-9.48	6.53
3	Anand	5	20	1.40-5.44	3.28	3.52-7.21	5.40
4	Panchmahals	3	20	1.22-3.58	2.13	5.01-9.27	6.98
5	Dahod	2	20	1.28-3.02	1.81	4.19-7.53	5.54
6	Vadodara	3	20	1.92-5.78	3.45	3.84-9.80	6.76
<b>Overall</b>			<b>120</b>	<b>1.20-5.99</b>	<b>3.01</b>	<b>3.52-9.80</b>	<b>6.30</b>

**Table.2** Nutrients content in rice grain in different districts of middle Gujarat

Sr. No.	District	N	P	K	S	Na	Fe	Mn	Zn	Cu
		(% )						(mg kg <sup>-1</sup> )		
1	Ahmedabad	1.06-1.62 (1.32)	0.03-0.21 (0.13)	0.15-0.28 (0.21)	0.15-0.39 (0.27)	0.06-0.16 (0.10)	121-228 (170)	17-42 (30)	11-24 (19)	3-10 (5.0)
2	Kheda	1.20-1.60 (1.40)	0.03-0.18 (0.11)	0.21-0.30 (0.27)	0.06-0.21 (0.12)	0.06-0.11 (0.08)	28-576 (301)	15-124 (61)	16-68 (31)	4-16 (8.0)
3	Anand	0.87-1.43 (1.15)	0.07-0.12 (0.09)	0.16-0.28 (0.19)	0.10-0.30 (0.20)	0.05-0.08 (0.07)	78-663 (291)	21-83 (49)	20-66 (33)	4-21 (9.0)
4	Panchmahals	1.06-1.65 (1.37)	0.07-0.17 (0.10)	0.15-0.26 (0.18)	0.06-0.25 (0.13)	0.04-0.09 (0.07)	42-661 (218)	7-37 (22)	9-41 (24)	3-18 (7.0)
5	Dahod	1.15-1.48 (1.33)	0.04-0.10 (0.08)	0.15-0.30 (0.19)	0.07-0.28 (0.16)	0.05-0.07 (0.06)	30-483 (200)	19-78 (35)	20-46 (30)	3-12 (7.0)
6	Vadodara	0.84-1.37 (1.11)	0.03-0.21 (0.11)	0.17-0.33 (0.27)	0.08-0.23 (0.14)	0.06-0.08 (0.07)	37-531 (148)	41-162 (79)	12-36 (23)	3-10 (6.0)
<b>Overall</b>		<b>0.84-1.65 (1.28)</b>	<b>0.03-0.21 (0.09)</b>	<b>0.15-0.33 (0.22)</b>	<b>0.06-0.39 (0.17)</b>	<b>0.04-0.16 (0.08)</b>	<b>28-663 (221)</b>	<b>7-162 (46)</b>	<b>9-68 (27)</b>	<b>3-21 (7.0)</b>

**Table.3** Nutrients content in rice straw in different districts of middle Gujarat

Sr. No.	District	N	P	K	S	Na	Fe	Mn	Zn	Cu	
		N P K S Na					Fe Mn Zn Cu				
		(%)					(mg kg <sup>-1</sup> )				
1	Ahmedabad	2.74-3.58 (3.05)	0.05-0.22 (0.14)	0.19-0.29 (0.22)	0.25-0.74 (0.47)	0.22-0.44 (0.33)	72-487 (259)	51-289 (166)	11-46 (30)	2-10 (6.0)	
2	Kheda	1.82-2.74 (2.21)	0.09-0.19 (0.12)	0.29-0.37 (0.32)	0.31-0.93 (0.66)	0.23-0.31 (0.26)	66-626 (387)	66-513 (189)	4-35 (21)	5-18 (10.0)	
3	Anand	2.49-3.58 (2.92)	0.07-0.13 (0.10)	0.31-0.40 (0.36)	0.19-0.48 (0.36)	0.14-0.26 (0.19)	33-761 (401)	28-289 (113)	21-66 (39)	3-17 (10.0)	
4	Panchmahals	1.99-3.11 (2.50)	0.07-0.17 (0.10)	0.32-0.41 (0.37)	0.25-0.85 (0.66)	0.13-0.33 (0.24)	53-687 (270)	67-684 (254)	15-55 (30)	1-11 (5.0)	
5	Dahod	2.32-3.11 (2.74)	0.10-0.29 (0.20)	0.25-0.39 (0.31)	0.24-0.89 (0.60)	0.22-0.31 (0.27)	181-869 (399)	125-323 (189)	17-48 (32)	3-18 (8.0)	
6	Vadodara	2.24-2.60 (2.42)	0.13-0.23 (0.19)	0.40-0.49 (0.44)	0.57-1.01 (0.76)	0.13-0.22 (0.18)	151-614 (300)	113-629 (316)	15-65 (31)	2-15 (7.0)	
<b>Overall</b>		<b>1.82-3.58 (2.64)</b>	<b>0.05-0.29 (0.14)</b>	<b>0.19-0.49 (0.34)</b>	<b>0.10-1.01 (0.56)</b>	<b>0.13-0.44 (0.25)</b>	<b>33-869 (401)</b>	<b>28-684 (238)</b>	<b>4-66 (30)</b>	<b>1-18 (8.0)</b>	

**Table.4** Nutrients uptake by one tonne of rice grain in different districts of middle Gujarat

Sr. No.	District	Grain uptake (kg ha <sup>-1</sup> )					Grain uptake (g ha <sup>-1</sup> )				
		N	P	K	S	Na	Fe	Mn	Zn	Cu	
1	Ahmedabad	10.6-16.2 (13.2)	0.32-2.09 (1.30)	1.45-2.76 (2.06)	1.46-3.87 (2.73)	0.55-1.62 (1.01)	72-487 (169.6)	17-42 (30.4)	11-24 (18.6)	3-10 (5.4)	
2	Kheda	12.0-16.5 (14.0)	0.28-2.13 (1.15)	2.06-3.02 (2.68)	0.61-2.09 (1.24)	0.58-0.76 (0.66)	28-576 (300.9)	15-124 (61.0)	16-68 (30.9)	4-16 (7.8)	
3	Anand	8.70-14.3 (11.5)	0.71-1.32 (0.91)	1.56-2.83 (1.92)	0.98-2.97 (1.95)	0.45-0.81 (0.68)	78-663 (291.1)	21-83 (48.6)	20-66 (33.2)	4-21 (8.5)	
4	Panchmahals	10.6-16.5 (13.7)	0.72-1.76 (1.07)	1.51-2.56 (1.84)	0.56-2.48 (1.34)	0.39-0.86 (0.65)	42-661 (218.1)	7-37 (21.5)	9-41 (24.1)	3-18 (7.2)	
5	Dahod	11.5-14.8 (13.3)	0.42-1.04 (0.78)	1.49-2.96 (1.87)	0.65-2.82 (1.60)	0.49-0.68 (0.58)	30-483 (199.8)	19-78 (35.1)	20-46 (29.9)	3-12 (7.0)	
6	Vadodara	8.40-13.7 (11.1)	0.28-1.81 (1.04)	1.65-3.33 (2.67)	0.84-2.33 (1.38)	0.62-1.05 (0.80)	37-531 (148.1)	41-162 (78.9)	12-36 (22.7)	3-10 (5.6)	
<b>Overall</b>		<b>8.40-16.5 (12.7)</b>	<b>0.28-2.13 (1.04)</b>	<b>1.45-3.33 (2.17)</b>	<b>0.56-3.87 (1.71)</b>	<b>0.39-1.62 (0.73)</b>	<b>28-663 (220.8)</b>	<b>7-162 (45.9)</b>	<b>9-68 (26.5)</b>	<b>3-21 (6.91)</b>	

**Table.5** Nutrients uptake by one tonne of rice straw in different districts of middle Gujarat

Sr. No.	District	Straw uptake (kg ha <sup>-1</sup> )					Straw uptake (g ha <sup>-1</sup> )			
		N	P	K	S	Na	Fe	Mn	Zn	Cu
1	Ahmedabad	27.4-35.8 (30.5)	0.50-2.23 (1.97)	1.77-2.89 (2.17)	1.00-5.77 (3.18)	2.21-4.41 (3.30)	72-487 (259.4)	51-289 (165.9)	11-46 (29.6)	2-10 (5.5)
2	Kheda	18.2-27.4 (22.1)	0.93-1.93 (1.22)	2.87-3.72 (3.25)	3.12-9.26 (6.58)	2.26-3.08 (2.63)	66-626 (387.1)	66-513 (189.1)	4-35 (20.5)	5-18 (9.6)
3	Anand	24.9-35.8 (29.2)	0.70-1.34 (0.96)	3.09-4.01 (3.57)	1.94-4.84 (3.61)	1.39-2.57 (1.86)	33-761 (401.1)	28-289 (113.4)	21-66 (39.1)	3-17 (10.1)
4	Panchmahals	19.9-31.1 (25.0)	0.65-1.74 (0.95)	3.24-4.12 (3.65)	2.48-8.53 (6.61)	1.28-3.28 (2.45)	53-687 (270.8)	67-684 (254.2)	15-55 (29.9)	1-11 (5.2)
5	Dahod	23.2-31.1 (27.4)	1.21-3.27 (2.25)	2.52-3.92 (3.06)	2.43-8.92 (5.96)	2.12-3.12 (2.69)	181-869 (398.7)	125-323 (189.0)	17-48 (32.3)	3-18 (7.8)
6	Vadodara	22.4-26.0 (24.2)	1.30-2.29 (1.87)	4.02-4.87 (4.41)	5.67-10.12 (7.59)	0.75-1.68 (1.32)	151-614 (299.8)	113-629 (316.3)	15-65 (31.0)	2-15 (7.4)
<b>Overall</b>		<b>18.2-35.8</b> <b>(26.4)</b>	<b>0.50-3.27</b> <b>(1.54)</b>	<b>1.77-4.87</b> <b>(3.35)</b>	<b>1.00-10.12</b> <b>(5.59)</b>	<b>0.75-4.41</b> <b>(2.38)</b>	<b>33-869</b> <b>(336.1)</b>	<b>28-684</b> <b>(204.6)</b>	<b>4-66</b> <b>(30.4)</b>	<b>1-18</b> <b>(7.6)</b>

**Table.6** Total uptake of nutrients by two tonne of rice produce in different districts of middle Gujarat

Sr. No.	District	Total uptake (kg ha <sup>-1</sup> )					Total uptake (g ha <sup>-1</sup> )			
		N	P	K	S	Na	Fe	Mn	Zn	Cu
1	Ahmedabad	38.6-49.6 (43.7)	1.01-3.72 (2.67)	3.53-5.35 (4.23)	3.36-8.68 (5.91)	3.21-5.54 (4.32)	125-652 (429.0)	84-327 (196.3)	34-66 (48.1)	5-20 (10.9)
2	Kheda	30.8-42.8 (36.0)	1.29-3.28 (2.37)	5.47-6.44 (5.93)	4.63-10.6 (7.82)	2.90-3.67 (3.30)	399-1537 (975.2)	182-603 (318.4)	27-77 (51.3)	10-32 (17.3)
3	Anand	37.5-47.0 (40.7)	1.01-2.14 (1.47)	4.92-6.52 (5.48)	3.40-7.17 (5.56)	2.05-3.19 (2.54)	257-1479 (792.2)	58-339 (161.9)	46-129 (72.3)	9-32 (18.5)
4	Panchmahals	33.0-43.7 (38.7)	0.96-2.69 (1.57)	4.82-6.27 (5.49)	4.66-11.01 (7.95)	1.90-3.99 (3.10)	106-1052 (488.9)	83-691 (275.7)	30-80 (54.0)	4-21 (12.4)
5	Dahod	36.7-44.8 (40.7)	1.86-3.83 (2.93)	4.40-5.67 (4.94)	3.37-11.40 (7.56)	2.73-3.69 (3.27)	268-1232 (598.5)	45-279 (124.0)	41-94 (62.2)	7-25 (14.8)
6	Vadodara	32.2-38.1 (35.3)	2.11-3.64 (2.92)	5.93-9.36 (3.68)	6.65-11.01 (8.97)	1.50-2.67 (2.11)	261-692 (447.9)	181-715 (395.2)	28-89 (53.7)	6-25 (13.0)
<b>Overall</b>		<b>30.8-60.8</b> <b>(41.05)</b>	<b>0.96-4.2</b> <b>(2.33)</b>	<b>3.53-9.36</b> <b>(4.95)</b>	<b>3.36-11.4</b> <b>(7.29)</b>	<b>1.5-5.5</b> <b>(3.1)</b>	<b>106-1787</b> <b>(645.0)</b>	<b>45-715</b> <b>(245.2)</b>	<b>27-129</b> <b>(56.9)</b>	<b>4-32 (14.4)</b>

**Table.7** Ratio between silicon, major, secondary and micronutrients nutrients in rice grain in different districts of middle Gujarat

Sr. No	District	Si : Nutrients ratio in grain								
		Si: N	Si: P	Si: K	Si: S	Si: Na	Si: Fe	Si: Mn	Si: Zn	Si: Cu
1	Ahmedabad	1.01-3.69 (1.81)	6.3-60.6 (23.9)	4.4-28.3 (12.0)	3.8-24.2 (9.2)	7.5-95.1 (26.8)	89-958 (405)	201-1426 (729)	392-2604 (1265)	1308-14971 (4986)
2	Kheda	2.61-4.58 (3.54)	16.8-124.0 (53.7)	13.4-23.5 (18.3)	12.4-30.7 (21.5)	37.2-59.6 (56.8)	43-304 (117)	213-837 (407)	718-2743 (1789)	2817-9642 (6802)
3	Anand	1.22-4.85 (2.86)	13.2-79.7 (37.4)	6.1-24.9 (17.3)	6.1-42.8 (19.1)	20.2-77.7 (48.4)	22-514 (166)	172-1542 (786)	279-2006 (1131)	1308-9477 (4779)
4	Panchmahals	1.01-2.55 (1.56)	10.3-43.6 (21.1)	6.9-17.1 (11.7)	7.3-51.0 (19.3)	19.4-62.6 (33.6)	30-595 (182)	395-1471 (825)	260-3165 (1080)	969-8915 (3700)
5	Dahod	1.00-2.08 (1.36)	13.8-39.3 (24.4)	4.7-15.0 (9.9)	5.9-25.4 (13.4)	23.1-48.8 (31.3)	33-446 (164)	215-1005 (587)	433-1078 (622)	1421-6299 (2916)
6	Vadodara	1.70-5.69 (3.20)	11.5-108.3 (41.7)	6.8-23.0 (13.3)	10.9-45.8 (26.6)	24.9-72.0 (44.3)	45-934 (387)	191-788 (472)	646-3616 (1705)	2326-11570 (6546)
	<b>Overall</b>	<b>1.00-5.69 (2.37)</b>	<b>6.3- 124.0 (33.7)</b>	<b>4.4-28.3 (13.0)</b>	<b>3.8-51.0 (20.3)</b>	<b>7.5-95.1 (41.4)</b>	<b>22-958 (237)</b>	<b>172-1542 (634)</b>	<b>260-3616 (1265)</b>	<b>969-14971 (4955)</b>

**Table.8** Ratio between silicon, major, secondary and micronutrients nutrients in rice straw in different districts of middle Gujarat

Sr. No	District	Si : Nutrients ratio in straw								
		Si: N	Si: P	Si: K	Si: S	Si: Na	Si: Fe	Si: Mn	Si: Zn	Si: Cu
1	Ahmedabad	1.06-2.19 (1.54)	21.7-111.2 (53.1)	19.0-46.2 (30.1)	7.31-28.72 (15.5)	14.0-33.5 (20.0)	116-989 (308)	219-783 (426)	1156-4748 (2333)	5233-18702 (12068)
2	Kheda	2.10-4.10 (2.97)	31.3-90.8 (55.9)	12.2-31.8 (20.3)	4.8-30.4 (11.2)	19.0-39.8 (24.9)	59-263 (113)	164-947 (471)	1655-9477 (3757)	3214-11725 (7407)
3	Anand	1.08-2.45 (1.87)	30.4-85.1 (58.2)	9.6-20.2 (15.2)	9.6-25.1 (15.5)	16.4-39.2 (29.6)	41-453 (176)	168-1595 (629)	640-3277 (1536)	2856-12016 (6143)
4	Panchmahals	1.52-4.24 (2.85)	21.6-72.1 (50.4)	10.4-26.6 (19.2)	5.9-20.3 (11.3)	13.9-62.7 (31.1)	81-997 (432)	95-1280 (479)	771-4850 (2673)	4123-23183 (13049)
5	Dahod	1.42-2.99 (2.04)	15.6-43.3 (26.5)	13.4-28.2 (18.3)	5.5-19.2 (10.3)	13.9-27.7 (20.8)	48-406 (173)	223-1126 (679)	1060-3181 (1859)	2326-16958 (8462)
6	Vadodara	1.56-4.32 (2.82)	18.9-54.5 (36.6)	8.7-24.4 (15.4)	4.3-17.3 (9.3)	26.5-90.2 (53.2)	108-470 (251)	66-723 (303)	662-5892 (2551)	1780-17675 (10055)
	<b>Overall</b>	<b>1.06-4.32 (2.35)</b>	<b>15.6-111.2 (46.8)</b>	<b>8.7-46.2 (19.7)</b>	<b>4.3-61.6 (14.0)</b>	<b>13.9-90.2 (29.9)</b>	<b>41-989 (242)</b>	<b>66-1595 (498)</b>	<b>640-9477 (2451)</b>	<b>1780-23183 (9530)</b>

**Table.9** Correlation coefficients (r) between silicon content in grain with other nutrient contents of rice

Grain Content	Districts					
	Ahmedabad	Kheda	Anand	Panchmahals	Dahod	Vadodara
<b>N (%)</b>	0.551**	-0.339**	0.237**	0.343**	0.378**	-0.182*
<b>P (%)</b>	-0.126	-0.061	-0.130	0.419**	0.167	-0.161
<b>K (%)</b>	0.187*	-0.058	0.016	0.288**	-0.158	-0.011
<b>S (%)</b>	0.198*	-0.117	-0.238**	0.086	-0.038	0.078
<b>Na (%)</b>	-0.141	-0.034	0.280**	-0.069	0.031	-0.088
<b>Fe (ppm)</b>	-0.092	-0.192*	-0.154	-0.116	-0.676**	-0.221*
<b>Mn (ppm)</b>	0.067	0.127	0.179*	0.044	0.506**	0.248**
<b>Zn (ppm)</b>	0.474**	0.082	-0.140	0.162	0.275**	-0.199*
<b>Cu (ppm)</b>	-0.028	0.068	-0.144	-0.033	0.261**	-0.057

**Table.10** Correlation coefficient (r) between silicon content in straw with other nutrient contents of rice

Straw Content	Districts					
	Ahmedabad	Kheda	Anand	Panchmahals	Dahod	Vadodara
<b>N (%)</b>	-0.290**	0.430**	-0.153	0.002	0.069	-0.528**
<b>P (%)</b>	0.317**	-0.171	0.112	-0.245**	0.174	0.138
<b>K (%)</b>	-0.318**	-0.124	0.229*	0.148	0.051	-0.250**
<b>S (%)</b>	-0.383**	-0.329**	0.255**	0.166	0.125	-0.626**
<b>Na (%)</b>	-0.179*	0.319**	0.219*	-0.059	0.123	0.095
<b>Fe (ppm)</b>	0.272**	0.103	-0.361**	-0.340**	-0.310**	0.148
<b>Mn (ppm)</b>	0.399**	0.001	-0.082	-0.182*	-0.623**	-0.257**
<b>Zn (ppm)</b>	-0.444**	-0.104	-0.038	-0.184*	-0.098	-0.115
<b>Cu (ppm)</b>	-0.173	0.210*	0.151	-0.262**	0.072	0.160

At national level, field experiment conducted at Varanasi centre (Singh *et al.*, 2005) showed increased N, P, K concentration and uptake due to silicon application @ 180 kg ha<sup>-1</sup> full as basal. Similar results were found that Sudhakar *et al.*, (2006), increasing the fertility level significantly improved nitrogen, phosphorus and silicon uptake by grain and straw, whereas significant improvement in potassium uptake by grain and straw was recorded. The increase in nutrient uptake with the increase in fertility levels could be attributed to the better availability of nutrients and their transport to the plant from the soil, as the nutrient application leads to its enhanced uptake by plant (Rani *et al.*, 1997).

The similar findings have been also reported by Meshram *et al.*, (2015), the higher nutrient uptake was mainly due to higher biological (straw + grain) yield.

#### **Ratio of silicon with other nutrients in rice**

The results on silicon and other nutrients ratio in rice grain and straw was reported in Table 7 and 8. The ratio of silicon and other nutrient contents in rice grain indicated that amongst N, P, K, S and Na, the higher ratio was observed in Si: P indicating lower content of P in comparison with silicon. The ascending order of ratio of Si with nutrients was: N > K > S > Na > P in rice grain.

The lower content of P may be attributed the low status of available  $P_2O_5$  and dominance of Si at root level entry on phosphorous (Table 7). Similar results were also observed in case of straw that lower P content in straw followed by Na, K, S and N. The soils of the region having more per cent of sufficiency in available  $K_2O$  and S resulted in high content of respective nutrients in rice. The ratio also indicated that Si accumulation in rice straw was almost 2, 47, 20, 14 and 30 times higher than N, P, K, S and Na content, respectively (Table 8) (Malav *et al.*, 2015). The overall Si: micronutrients (Fe, Mn, Zn, Cu) ratio in rice grain was 237, 634, 1265 and 4955 indicates the high contents of Fe and Mn as compared to Zn and Cu (Table 7). The soils of rice growing areas having medium to high status of available Fe and Mn attributed the sufficient supply of Fe and Mn during crop growth. Similar results were observed of micronutrients ratio with silicon in rice straw. The ascending order of ratio of Si with micronutrients was  $Fe > Mn > Zn > Cu$  indicates the higher accumulation of Fe in straw as compared to Mn, Zn and Cu (Table 8). According to Ma and Takahashi (1991), the beneficial effect of silicon may be attributed to a higher P: Mn ratio in the shoot due to the decreased Mn and Fe uptake and thus indirectly to improve P utilization within the rice plants. They had concluded that the interaction between phosphorus and silicon was indirect in phosphorus deficient soil.

The results of wider values for ratios of Si with nutrients (Fe, Mn, Zn and Cu) can be supported by Cheng (1982) reported that addition of silicon to the culture solution at the rate of 75 ppm silicon, decreased the accumulation of Mn, Cu, Fe, Zn, N, P and transpiration rate but increased Ca, Mg, Si and carbohydrate content of the plant. Further, Park (1976) reported that the response of rice to  $SiO_2$  application was also related to the supply of other nutrients in the

top soil (N, P, K, Ca and Mg) and it seems if a proper balance of nutrients were required if we obtain the maximum yield of rice (i.e.  $SiO_2/N$ ,  $K_2O/N$ ,  $SiO_2/K_2O$  ratios in the straw should be around 11, 1.5 and 7.4, respectively). The  $SiO_2$  material usually contains Ca and Mg and these bases influence the uptake of K and minor elements such as Zn and B probably owing to antagonism and the change in the availability of these elements in the topsoil (Nayak *et al.*, 2014). These facts lead to the concept of the maintenance of multifactor balance in rice soil management if high yields were to be obtained. Similar results also reported by Mongia and Chhabra (2001).

#### **Relationship of silicon and other nutrients content in rice grain**

The district wise correlation study between silicon content in grain with other important nutrient contents in rice revealed that the rice grain silicon gave significant correlation with all other nutrient content (Table 9). In case of Ahmedabad district, coefficient of correlation between the N and Zn contents in rice grain with silicon content showed highly significant positive ( $r = 0.551^{**}$  and  $r = 0.474^{**}$ , respectively); and K and S content showed significant positive ( $r = 0.187^*$  and  $r = 0.198^*$ , respectively) relationship. Whereas, P, Na, Fe and Cu content in grain showed negative relationship but the results were non-significant when they all were correlated with content of silicon in grain.

In Kheda district, the grain N content showed the reverse correlation than Ahmedabad district that N and Fe showed the highly significant ( $r = -0.339^{**}$ ) and significant ( $r = -0.192$ ), negative correlation, respectively when correlated with silicon content in grain and other nutrients content showed the non-significant results. The relationship between silicon content in grain with other nutrients in

Anand district was somewhat different than other districts as N and Na showed highly positive ( $r = 0.237^{**}$  and  $r = 0.280^{**}$ ) correlation, while Mn content gave significant positive ( $r = 0.179^{*}$ ) relationship. Only S content in grain resulted significantly negatively correlated ( $r = -0.238^{*}$ ) with silicon content in grain.

In Panchmahal district, N, P and K content in grain ( $r = 0.343^{**}$ ,  $0.419^{**}$  and  $0.288^{**}$ , respectively) showed highly positive significant relationship with silicon content in grain, whereas, other nutrients content showed non-significant association with silicon. In case of Dahod district, the value of correlation coefficient ( $r$ ) rather lesser than other districts as N, Mn, Zn and Cu content showed highly significant positive correlation ( $r = 0.378^{**}$ ,  $0.506^{**}$ ,  $0.275^{**}$  and  $0.261^{**}$ , respectively). Whereas, Fe content in grain had highly negative significant relationship ( $r = -0.676^{**}$ ) with silicon content in grain. The Mn content in grain ( $r = 0.248^{**}$ ) was highly significant positively correlated in Vadodara district, while in context N, Fe and Zn ( $r = -0.182^{*}$ ,  $-0.221^{*}$  and  $-0.199^{*}$ , respectively) were gave significantly negative relationship with silicon. Dean and Rubins, (1947) all in one line reported that ability of silicate ion to displace the phosphate ion from the adsorbed conditions in the soil thus increasing the availability of phosphorus. But in contrast, application of silicate was reported to decrease the phosphorus fixing capacity of some highly weathered volcanic ash soils (Iwata and Baba 1962). He reported that rate of silicon release from clay mineral was enhanced immediately after application of P.

### **Relationship of silicon and other nutrients content in rice straw**

The district wise correlation coefficient between silicon content in straw with other important nutrient contents in rice also worked out and given in Table 10. The results indicated that silicon content in rice straw had significant correlation with all other nutrient content (Table

10). The total P, Fe and Mn content in rice straw showed highly significant positive association ( $r = 0.317^{**}$ ,  $0.272^{**}$  and  $0.399^{**}$ , respectively) and N, K, S and Zn showed highly significant negative ( $r = -0.290^{**}$ ,  $-0.318^{**}$ ,  $-0.383^{**}$  and  $-0.444^{**}$ , respectively) impact in Ahmedabad district. While, Na showed the significant negative ( $r = -0.179$ ) impact, when they were correlated with silicon content in straw.

In Kheda district, the N, Na and Cu showed the reverse correlation than Ahmedabad district. as N and Na showed the highly positive significant ( $r = 0.430^{**}$  and  $0.419^{**}$ , respectively) relationship and Cu showed the significant ( $r = 0.210^{*}$ ), positive correlation with Si content in straw. The total S content in straw gave highly significant negative correlation ( $r = 0.329^{**}$ ) with silicon and other nutrient content showed the non-significant results. Silicon in rice straw in Anand district showed highly positive ( $r = 0.255^{**}$ ) correlation, while K and Na gave significant positive ( $r = 0.229^{*}$  and  $0.219^{*}$ ) relationship with S content in straw. The Fe content in straw only had highly significant negative correlation ( $r = -0.361^{**}$ ) with silicon content in straw.

In Panchmahal district, silicon content showed mostly negative correlation with P, Fe and Cu ( $r = -0.245^{**}$ ,  $-0.340^{**}$  and  $-0.262^{**}$ , respectively) content in straw. Whereas, Mn and Zn content had the significant negative relationship ( $r = -0.182^{*}$  and  $-0.184^{*}$ , respectively) with silicon content. In case of Dahod district, the Fe and Mn content in straw indicated highly significant negative relationship ( $r = -0.310^{**}$  and  $-0.623^{**}$ , respectively). While other nutrients content showed non-significant relationship with silicon. In Vadodara districts, correlation coefficient between N, K, S and Mn content ( $r = -0.528^{**}$ ,  $-0.250^{**}$ ,  $-0.626^{**}$  and  $-0.257^{**}$ , respectively) and silicon content gave significantly negative relationship and it was non-significant with other nutrient contents in straw. Slag might neutralise the soil acidity with the formation of silicic acid and could thus

diminish the solubility of such elements as Mn, Fe and Al (Okuda and Takahashi, 1962; Ayers, 1966). Therefore formation of silicic acid somehow in soils could be the reason for negative results of Si with Fe and Mn contents of soils of middle Gujarat.

The silicon content of rice grain collected from the region ranged from 1.20 to 5.99 per cent and the rice straw Si content ranged from 3.52 to 9.80 per cent of different districts of middle Gujarat region. The total uptake of Si by rice was 88, 114, 87, 91, 73 and 102 kg ha<sup>-1</sup> and the uptake of Si was nearly 2 to 45 times more as compared to N, P, K and S uptake by rice. The ratio of silicon and other nutrient contents in rice grain and straw indicated that amongst N, P, K, S and Na, the higher ratio was observed in Si: P indicating lower content of P in comparison with silicon.

### Future Thrust

Extensive survey of intensively cultivated rice ecosystem must be conducted to identify soil, water and plant silicon status. Identification of efficient Si accumulating paddy cultivars is desired. Standardization of cheap silicon fertilizer sources is very important as per Indian scenario for sustaining the agricultural productivity.

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