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Effect of silicon addition to different fertilizer on yield of rice (*Oryza sativa* L.) plants. II- Micronutrient status by Different Rice Parts

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ABSTRACT

Although silicon is not recognized as a nutrient it may benefit rice plants and may alleviate the Mn toxicity in some plant species.

Two experiments were conducted during two successive seasons to study the effect of silicon addition to fertilizer on the yield and micronutrient status by different rice parts. The important results can be summarized in the following.

- Silica addition significantly improved dry matter of roots, shoots and grain yield.
- The highest values of dry matter of roots, shoots and grain were obtained by using the NPK + Si treatment followed by NP + Si, NK + Si and N + Si in decreasing order.
- Silicon addition to the different fertilizer treatments significantly increased the content of Mn and Fe in the roots, while they significantly decreased in the shoots and grains of rice plant.
- Manganese and Fe uptake by the roots significantly increased by Si addition, while they significantly decreased in the shoots and grains of rice plant.
- Data also show that the highest Mn and Fe content and uptake values in the different parts of rice plants were obtained by using NPK + Si treatment followed by NP +Si, NK + Si and N + Si in decreasing order.
- As Si was added to the nutrient solution, the concentration of Mn and Fe in leaves decreased and in roots increased thus alleviating the toxic effects of Mn and Fe on the plants.

Key words: Micronutrient , significantly , Si , uptake , yield , decreased, toxic.

Introduction

Silicon (Si) is beneficial element for plant growth and development (Ma and Yamaji, 2015). The beneficial effects of Si are characterized by enhancing the tolerance of plants to varous abiotic and biotic stresses (Ma 2004; Ma and Yamaji, 2006). High accumulation of Si in rice has been demonstrated to be necessary for healthy growth and high and stable production (Ahmed et al., 2013). One of them is the alleviation of Mn toxicity, which is one of the major factors limiting plant growth (Pontigo *et al*., 2015). Si was added to the nutrient solution, the concentration of Mn in leaves decreased and in roots increased thus alleviating the toxic effects of Mn on the plants (Luiz *et al*., 2010). The mechanisms for the Si-decreased Mn toxicity seem to differ with plant species. In rice, a typical Si-accumulating plant, Si alleviated Mn toxicity by decreasing Mn accumulation in the shoots (Li *et al*., 2012). Manganese deficiency occurs in plants grown in alkaline soils and toxicity occurs on very acid and poorly drained soils. A deficiency of Si causes an increased uptake of Manganese in rice, barley, rye and ryegrass causing toxicities. Si fertilization relieves this toxicity (El-Jaoual and Cox, 1998). Recently, (Li *et al*., 2012) found that although Si enhanced Mn tolerance in both Mn-sensitive and tolerant rice cultivars, the effect of Si on Mn accumulation differed between cultivars. In a Mn-sensitive rice cultivars, Si increased Mn in the roots, but did not affect Mn in the shoots. By contrast, Si decreased Mn of both the roots and shoots in a Mn-tolerant rice cultivar (Li *et al*., 2012). In cucumber, Si increased the binding capacity of the cell wall to Mn, thereby lowering Mn concentration within the symplast (Rogalla and Romheld, 2002) and decreasing the free leaf apoplastic Mn^{2+} as a catalyst for the Fenton reaction (Dragisic Maksimovic *et al*., 2012). Iron is classified as a trace element, or micro-nutrient, because it is only needed in small amounts. Too much iron can be toxic to plants, producing stunted growth of roots and tops, dark green foliage, or dark

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brown to purple leaves on some plants. Iron toxicity is a particular problem in rice paddies that show the symptom of brown leaves, called "bronzing". Silicon deficiency also causes an increased uptake of Iron (Fe) in rice while adding Fe oxides to soil will reduce the plant availability of Si (Lewin and Reimann, 1969). The presence of sufficient PAS at the root surface may increase the oxidative power to precipitate toxic levels of Fe as for Mn (Perry and Keeling-Tucker, 1998). Also, Matichenkov and Calvert, (2002) reported that silicon reduced aluminum (AL), Iron (Fe), Manganese (Mn) and heavy metal mobility.

A negative correlation was observed between the apoplastic guaical peroxidase (POD) activity and Si concentration (Iwasaki and Matsumura 1999).

Silicon was also effective in alleviating Fe excess toxicity in rice through enhancing the oxidative power of rice roots, resulting in enhanced oxidation of Fe from ferrous iron to insoluble ferric iron Ma and Yamaji (2006) and Liang *et al*., (2007). Siam and Abd El-Moez*,* (2017) observed that the Si added to the nutrient increased the dry matter of roots, shoots and grain yield of rice plant, also Merwad *et al*., 2016) observed that Si increases plant growth by improving the mechanical strength of stems and leaves on light absorption and photosynthetic capacity of the plant is increased.

Generally silicon was reported to reduce the hazard effects of various a biotic and biotic stresses including salt stress, metal toxicity, drought stress, radiation damage, various pests and diseases caused by both fungi and bacteria, nutrients imbalance, high temperature and freezing Ma, (2004).

The purpose of this research work was to study ameliorative effect of Si on yield and mineral status by different parts of rice.

Materials and Methods:

Two pot experiments were conducted during two successive seasons to study the effect of silicon addition on the yield and micro nutrients by different rice parts. Soil samples at a depth from (0-30 cm) from the surface layer of clay loam soil has a 26.7% sand, 39.6% silt and 33.7% clay, pots contain air dried soil were arranged in a complete randomize design.

Saturation capacity 27.08, pH 8.0, Ece 2.53 mmohs/cm, $CaCO_3$ 4.0% organic matter 1.6%. All the mentioned determinations wre conducted according to Jackson (1982).

The experiment included of four fertilizer treatments: a) Nitrogen alone (0.8 gm/pot (Urea), b) Nitrogen + Phosphorus (0.8 gm/Pot (Urea + 0.8 gm/pot superphosphate), c) Nitrogen + Potassium (0.8 gm/pot Urea + 0.8 gm/pot Potassium Sulphate) and d) Nitrogen + Phosphorus + Potassium (0.8 gm/pot Urea + 0.8 gm/pot Supperphosphate + 0.8 gm/pot Potassium Sulphate).

Silicon was added to four pots at a rate of 1.87 gm Si/pot in the form of sodium meta silicate (Na2 SiO3.5H2O) with irrigation water. The plants of the four other pots of each treatment were not supplied with silicon. Throughout the growth period which lasted 140 days, the pots received sufficient distilled water for flooding.

Total silica, magnesium and iron were determined and chemically analyzed for Fe and Mn (determination was carried out as described by Cottenie *et al*., (1982) and Silica was determined according to Wolf (1982) in the different parts of the rice plant (roots, shoots, and grains).

Statistical analysis performed analysis were performed using the least significant difference (L.S.D.) method at 1% and 5% according to Stell and Torrie (1980).

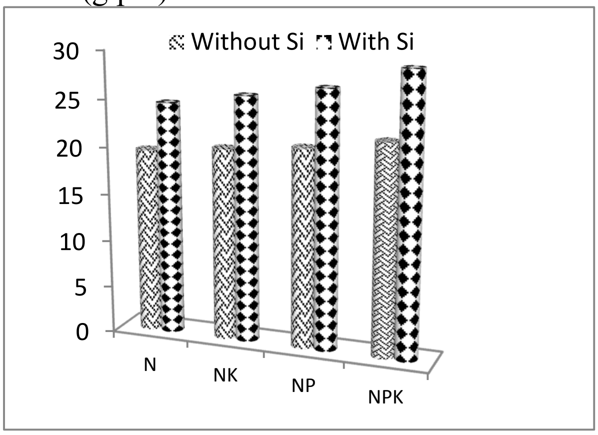
Results and Discussion:

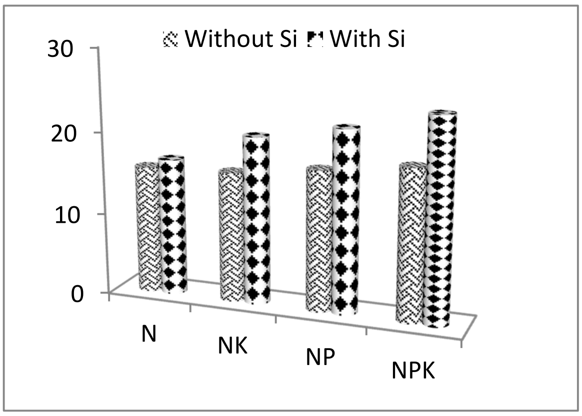
Yield Parameters:

Data presented in Fig. (1) indicated that silicon application significantly improved dry matter of roots, shoots and grain yield of rice plants Fig. (1). However, NPK + Si treatment gave higher roots, shoots and grains followed by NP + Si, NK + Si and N + Si in decreasing order. Many studies have suggested the positive effects of silicon it reduces micronutrients and metal toxicity event Britez *et al*., (2002). The increment effect of dry weight roots, straw and grain yield by (29.48, 48.86 and 41.61 g/pot), respectively at first season. Results in agreement with Zhu *et al*., (2004) found that Silicon promotes the growth of various higher plants and its uptake and role as an alleviator of biotic and abiotic stress was reported by Currie and Perry (2007).

Roots

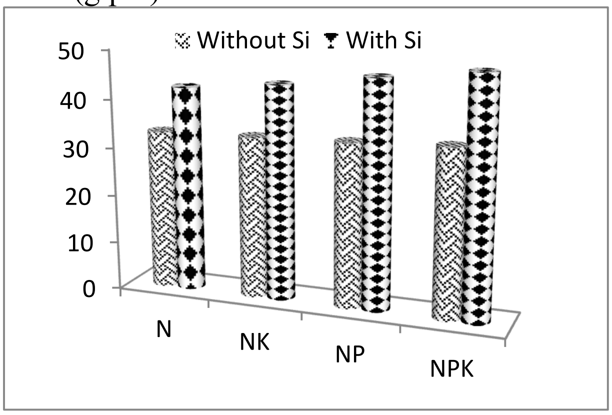
D.W. (g/pot)

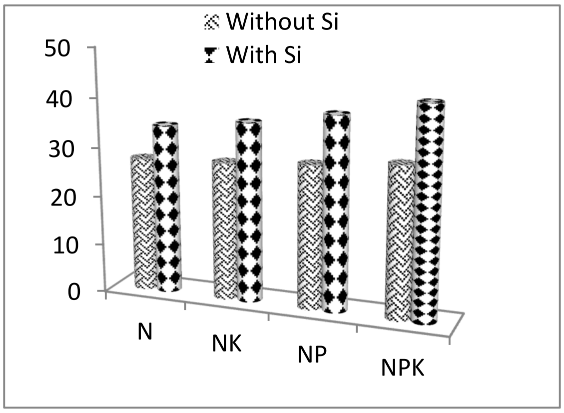




Shoots

D.W.(g/pot)



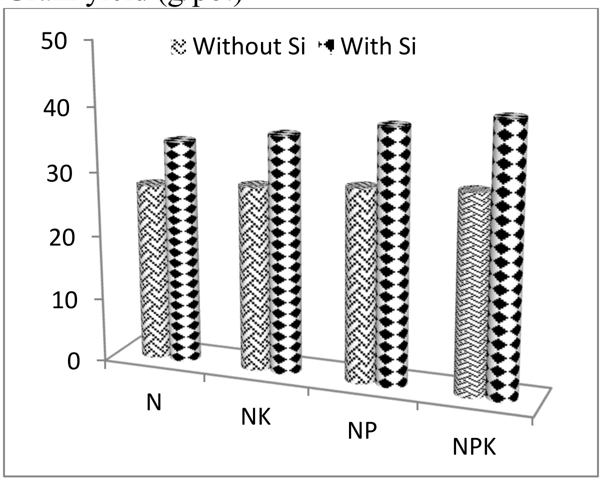


Fertilizer treatments
First season

Fertilizer treatments
Second season

Grain Yield

Grain yield (g/pot)



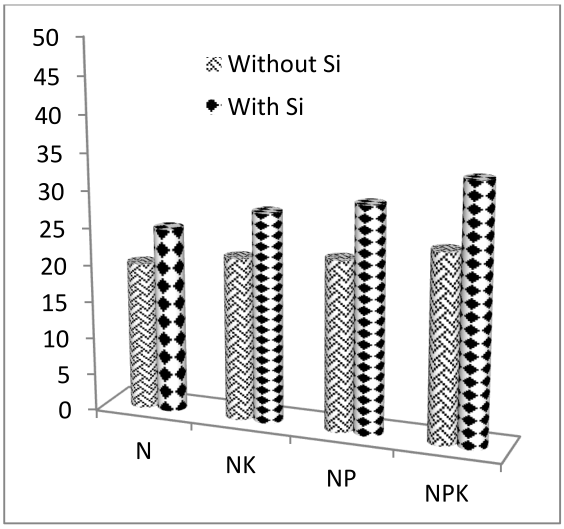


Fig. (1): Effect of silicon application on dry weight production (gm/pot) of different parts of rice plant.

and Luiz *et al*., (2010) how stated that Si added to the nutrient solution increased the dry matter yield of roots, sheaths and leaf blades and also decreased the angle of leaf blade insertion into the sheath and the foliar are in the rice plant. The positive effect of Si on increasing yield of rice plants may be due to the Si effects of Si are mainly associated with its deposition in plant tissues enhancing their strength and rigidity, Epstein *et al*., (1999) Hanfy Ahemd (2008). Furthermore Liang *et al*., (2003) and Merwad *et al*., (2016) observed that Si increases plant growth by improving the mechanical strength of stems and leaves on light absorption and photosynthetic capacity of the plant is increased.

Effect on micronutrients:

Manganese:

Table (1) and Fig. (2) show the effect of Si application on Mn content and uptake by the different parts of rice plants. Data reveal that Mn content and uptake by roots of rice plant were significantly increased by Si addition. These results were true for all fertilizer treatments and in both growing seasons. On the other hand, data show that Si addition to rice plant decreased Mn content and uptake by the shoots, and grains of the planted rice. The decreasing effect of Si on Mn content and uptake by shoots and grains rice plants may be attributed to the Si remaining in the root cells during pretreatment (Jing *et al*., 2017).

Table 1: Effect of silicon application on Mn content and uptake by different parts of rice plants grown for two seasons.

Fertilizer treatments	1st Season						2nd Season					
	Roots		Shoots		Grains		Roots		Shoots		Grains	
	-Si	+Si	-Si	+Si	-Si	+Si	-Si	+Si	-Si	+Si	-Si	+Si
	Mn content (ppm)											
N	225.00	315.25	115.00	61.00	78.00	45.00	230.00	340.00	123.00	70.00	88.00	50.00
NK	234.00	320.50	117.00	65.00	79.00	48.00	250.00	357.00	129.00	76.00	9100	55.00
NP	257.00	386.00	135.00	68.00	80.00	51.75	280.25	410.00	140.00	82.00	96.00	61.00
NPK	260.25	448.50	138.75	85.00	84.50	56.00	300.00	535.00	148.00	90.00	98.00	63.00
L.S.D. at Level												
5%	12.24		6.24		5.54		10.65		4.64		4.48	
1%	16.66		8.49		7.54		14.49		6.31		6.10	
	Mn uptake (mg / pot)											
N	4.40	7.75	3.79	2.59	2.15	1.56	3.57	6.68	3.37	2.41	1.76	1.25
NK	4.75	8.28	3.90	2.87	2.27	1.77	3.94	7.23	3.61	2.76	2.00	1.56
NP	5.40	10.45	4.56	3.18	2.39	2.03	4.76	9.02	4.08	3.20	2.22	1.86
NPK	5.79	13.22	4.80	4.15	2.60	2.33	5.48	13.03	4.54	3.82	2.50	2.19
L.S.D. at Level												
5%	0.42		0.28		0.28		0.32		0.21		0.13	
1%	0.58		0.39		0.38		0.44		0.29		0.18	

- Si Without silicon addition. + Si With silicon addition.

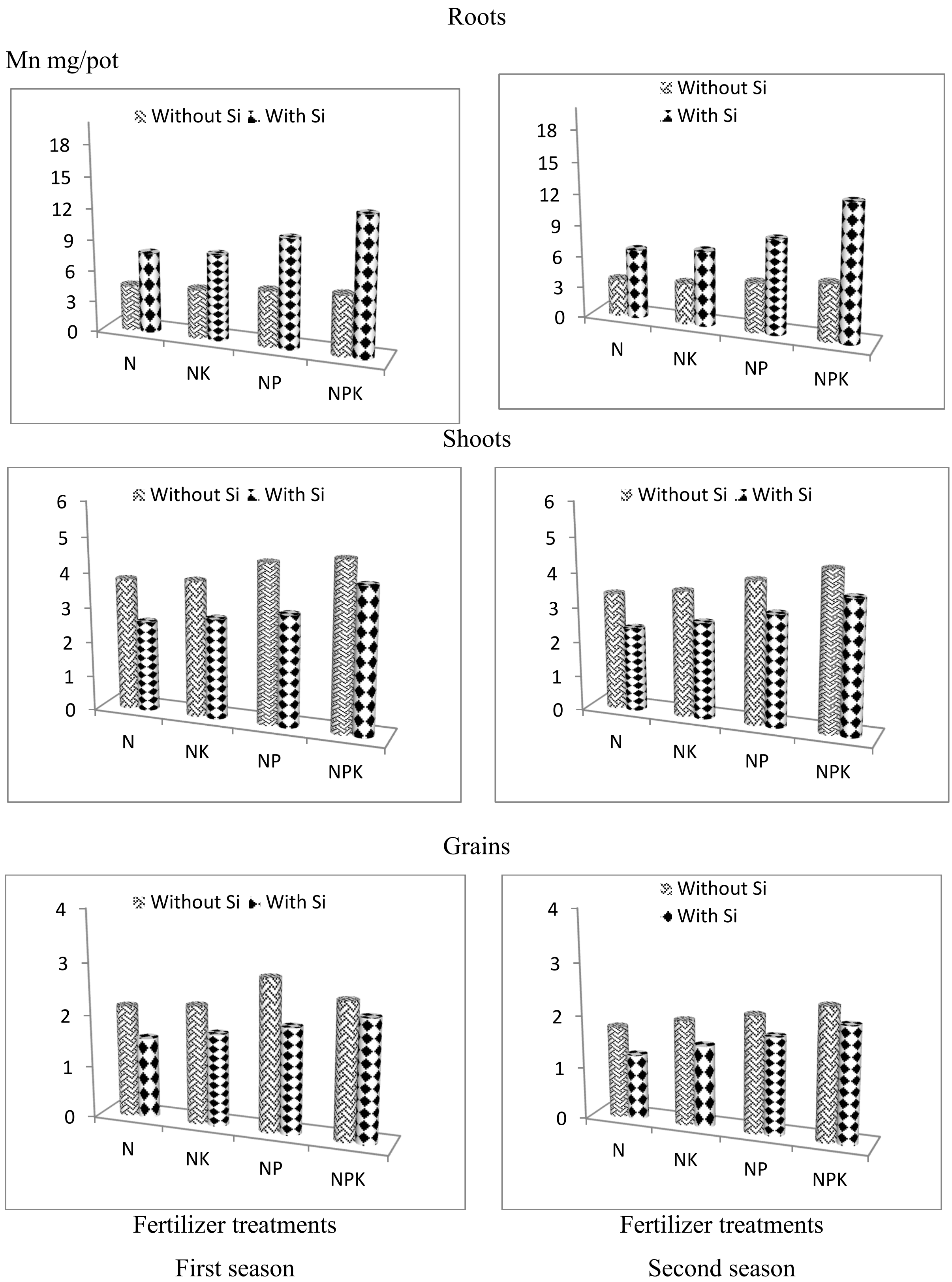


Fig.2: Effect of silicon application on Mn uptake (mg/pot) by different parts of rice plant

Maximum Mm content in root 448.50 (ppm) and uptake 13.22 (mg/pot) in root at first season was reported when NPK combined with Si addition. The increasing effect of Si on Mn uptake by roots rice plant may be due to the promotion effect of Si on the oxidation power of the roots and thus decrease the solubility of Mn and Fe and resulting in a depression of the uptake by rice also, in rice, Si reduced Mn uptake by promoting the Mn oxidizing power of the roots which led to a homogenous distribution of Mn in the leaf blade Liang *et al*., (2007). Also Si improve the oxidizing power of the roots and its known that Si increases the volume and gives rigidity to the aerenchyma which is an air channel present in the rice roots, and other plants, involved in the exchange of oxygen and other gases within the plant. These results agreement with those obtained by Horst *et al*., (1999) found that Si led to a lower Mn concentration in cowpea and suggested that Si modifies the cation binding properties of the cell wall, by contrast, Si caused a localized accumulation of Mn around the base of trichomes in pumpkin (Iwasaki and Matsumura 1999). Moreover several possible mechanisms have been proposed including the precipitation of Mn on the root surface due to Si-increased oxidation, enhanced internal tolerance to Mn (Horiguchi, 1988) and inhibited root-to-shoot translocation of Mn (Li *et al*., 2012). However,the evidence supporting these possible mechanisms is not convincing enough.

Fuehrs *et al*. (2009) and Iwasaki *et al*., (2002a,b) further studies have indicated that there was a negative correlation between the Si concentration and the expression of Mn toxicity and the maintenance of a reduced state of the apoplast by soluble Si was also involved in the Si-enhanced Mn tolerance in cowpea. Slicon is able to suppress of Mn toxicity either by reducing the soluble apoplastic concentration of Mn in the cell wall or with an apoplastic Mn detoxification, also, Iwaski *et al*. (2002a) shown that release Si can cause Mn oxidation in the dposited form via relation with apoplast phenolic substances which results in improving the tolerance of leaves to Mn.

Data also reveal that the highest values of Mn content and uptake by the roots, shoots and grains were obtained by using NPK + Si followed by NP + Si, NK + Si and N+Si in a decreasing order. These result are in good agreement with those obtained by Osuna-Canizalez *et al.* (1991) and Ma and Takahashi (1991) who reported that Mn contents of the roots increased by the Si supply, whereas those of the tops decreased. Moreover, Jing *et al*., (2016) indicated thatSi-decreased Mn accumulation in rice is a consequence of both reduced root-to-shoot translocation of Mn, probably by formation of Mn-Si complex in the root cells cytosol, and decreased Mn uptake due to down-regulation Mn transporter of O_5 Nramp S gene in rice and Matichenkov and Bocharnikova, (2001) found that silicates soil amendments provide effective and efficient means to correct a toxicity issues and from stable silicon-based complexes with potentially plant toxic forms of iron, manganese, and aluminium ions thereby reducing their bioavailability and phytotoxicity in the soil as well as in plant.

Generally, addition of Si helped block the transport of Mn and Fe form roots to the shoots, providing a more homogeneous distribution of Mn and Fe among the plant parts (Luiz *et al*., 2010). Also, Iwasaki *et al*., (2002a) found that Si reduces the concentration of Mn and Fe by increasing its adsorption by the cell wall and also by the action of the soluble Si, which reduces the concentration of Mn and Fe in the environment.

Iron:

Table (2) and Fig. (3) show that Si application significantly increased Fe content and uptake by roots of rice plants grown for two seasons and fertilized with different treatments (N, NK, NP, NPK). These results agreement with those obtained by Pierce *et al*., (2010). The increases of Fe content and uptake by roots as affected by Si application can be explained by the finding of Jones *et al*., (2009) who stated that addition of silicon to the soil increases the oxidation power of rice which renders Fe insoluble and deposited it in the roots. Also Matichenkov and Calvert, (2002) who stated that addition Si reduced Aluminium (Al, iron, Fe, Manganese Mn) and heavy metal mobility. Also, Sadgrove (2006) who stated that added Si increased amount of Si decreased the iron content of the rice plant. Silicon was also effective in alleviating Fe excess toxicity in rice through enhancing the oxidative power of rice roots, resulting in enhanced oxidation of Fe from ferrous iron to insoluble ferrice iron. Once the silicon is absorbed by the plant it actively contributes to a balanced state of nutrient availability through uptake processes Matichenkov and Bochranikova (2001); Ma and Yamaji, (2006).

Data presented in Table (2) and illustrated in Fig. (3) reveal that Si addition as sodium meta silicate significantly reduced Fe content and uptake by shoots and grains of rice plants. Also, Flavia *et al*., (2017) who stated that the presence of P and Si in the soil created a synergistic effect on soil Al, Fe and Mn through significantly reduced the Mn and Fe content straw and grain respectively. The low results were reached through the use of silica in addition to NPK in Mn content and uptake in straw and grain yield of rice (305.00 ppm and 14.90 mg/pot) for straw and grain (258.00 ppm and 10.74 mg/pot) at first season, whereas application NPK fertilizer without Si were (460.00 ppm and 15.91

mg/pot) for shoot and grain (400.00 ppm and 12.30 mg/pot), similar results at the second season took the same. In this connection Neumann and Zur Nieden (2001) reported that excess of Fe uptake was indirectly prevented by Si application for upland plants, excess Fe stress is not a problem. Jing *et al.* (2016) who stated that most Fe is retained in the roots due to Si enhanced oxidation of ferrous (Fe) to ferric Fe, suppressing its uptake to the root cells.

These results, obtained in the two seasons are in good agreement with those obtained by Hinman Lindstrom (1996) and Kabata-Pendias (2001) reported the existence of several interferences between Si and other ions such as P, Al, Ca and Fe occurring in soil that modify its behavior. Also, data revealed that the highest Fe content (2470 ppm) in roots and Fe uptake (72.82 mg/pot) at first season. Similar results took the same trend at second season. Data also show that the highest Fe content and uptake values in the different parts of rice plants were obtained by using NPK + Si treatment followed by NP +Si, NK + Si and N + Si in decreasing order.

From the abovementioned results affirm the similarity in trend of both of Fe and Mn (Table 1,2 and Figs. 2&3) whose content and uptake significantly increased in the roots and significantly decreased in the shoots and grains of rice plants. The retardation in the uptake of Fe and Mn can be explained by increasing the oxidation power of rice roots by Si addition and the oxidation of Fe2+ to Fe3+ and Mn2+ to Mn3 +, and thereby the both element inos became insoluble and deposited on the surface of the roots Lux *et al*., (2003).

Finally, the larger beneficial effect of Si on plant growth under P deficiency stress may be attributed to the enhanced availability of internal P through the decrease of excess Fe and Mn uptake. This is supported by fact that Si supply increased the rate of P translocation to the panicles in rice Nagaoka (1998) Moreover, the role of Si in the alleviation of iron soybean and cucumber plant growth is revealed by reducing the iron choruses and impact of iron distribution (Gonzalo *et al*., 2013).

Table 2: Effect of silicon application on Fe content and uptake by different parts of rice plants grown for two seasons.

Fertilizer treatments	1st Season						2nd Season					
	Roots		Shoots		Grains		Roots		Shoots		Grains	
	-Si	+Si	-Si	+Si	-Si	+Si	-Si	+Si	-Si	+Si	-Si	+Si
	Fe content ppm											
N	910.00	1932.75	400.00	274.75	335.00	230.00	1250.00	2500.00	470.00	320.00	430.00	280.00
NK	963.50	2001.50	413.00	285.25	360.00	240.00	1350.00	2700.00	485.00	334.75	449.00	288.50
NP	1034.00	2237.75	440.00	294.75	376.00	250.00	1448.00	2995.00	500.00	348.00	459.00	297.25
NPK	1107.00	2470.00	460.00	305.00	400.00	258.00	1600.00	3200.00	520.00	352.00	477.50	310.00
L.S.D. at Level												
5%	88.89		17.26		20.59		39.61		19.11		18.21	
1%	120.98		23.49		28.02		53.91		26.00		24.79	
	Fe uptake mg / pot											
N	17.80	47.51	13.18	11.65	9.23	7.97	19.38	49.13	12.87	11.02	8.60	7.00
NK	19.57	51.68	13.76	12.59	10.34	8.83	21.26	54.68	13.58	12.16	9.88	8.16
NP	21.71	60.60	14.87	13.76	11.25	9.83	24.62	65.89	14.57	13.59	10.60	9.07
NPK	24.64	72.82	15.91	14.90	12.30	10.74	29.20	77.92	15.94	14.95	12.18	10.77
L.S.D. at Level												
5%	1.69		0.96		1.23		1.71		0.93		0.59	
1%	2.30		1.30		1.67		2.33		1.27		0.80 '	

- Si Without silicon addition. + Si With silicon addition.

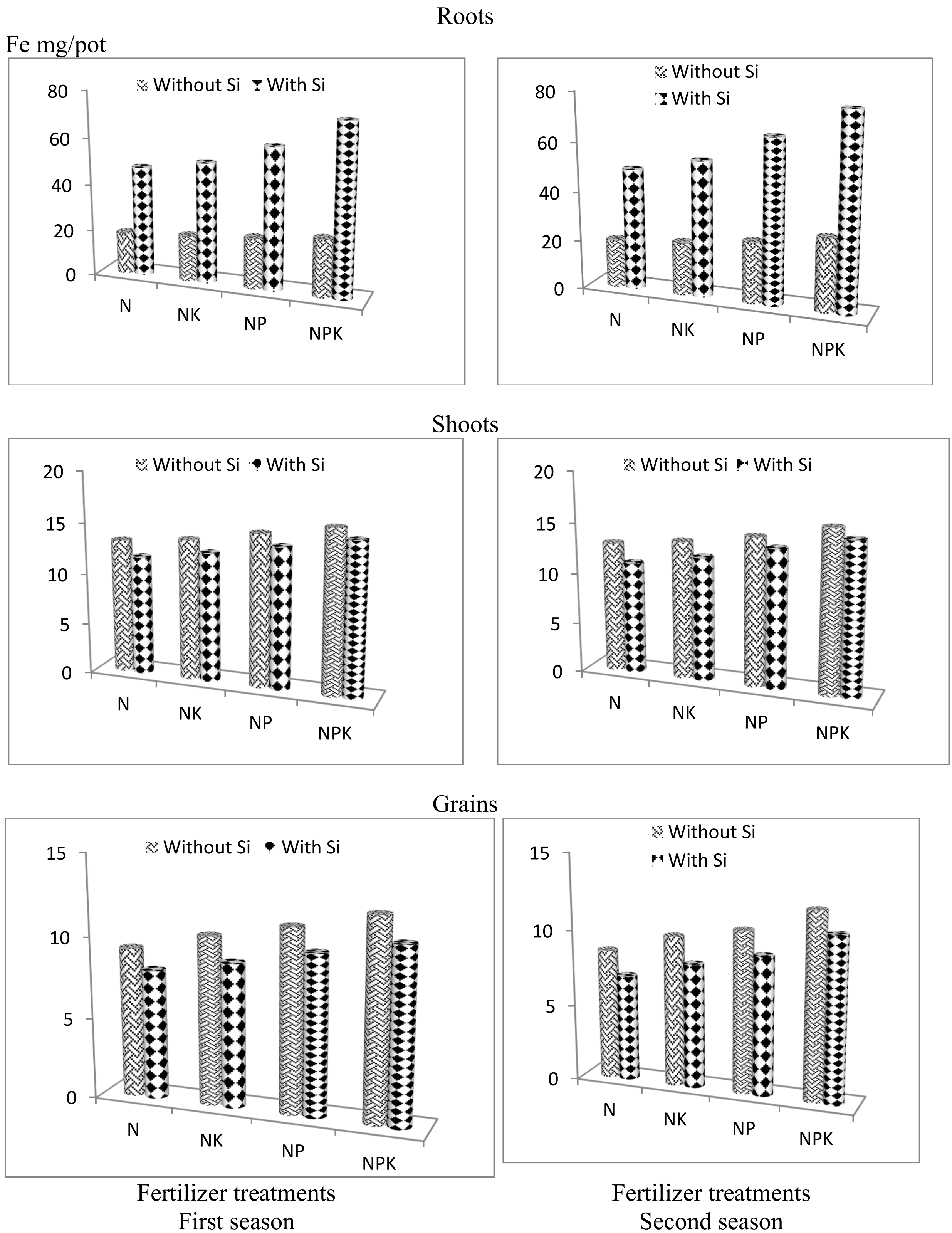


Fig. 3: Effect of silicon application on Fe uptake (mg/pot) by different parts of rice plant

Finally in areas where excess Mn is a problem, studies to establish rates and sources in order to increase the Si availability to rice plants must be implemented to supplement information for fertilizer recommendations for this crop and Jing *et al*., (2016). How stated that Si provides a more homogeneous distribution of Mn and Fe among roots shoots and grains in the rice plant. The addition of Si to the solution increased the content of Mn in roots and decreased in leaves and sheaths showing lower translocation of Mn to leaves which indicates that Si reduces the toxicity caused by Mn, what may be an alternative to alleviate such adversity. Also our results indicate that the Si-decreased Mn accumulation in rice is a consequence of both reduced root to-shoot translocation of Mn and Fe, probably by formation of Mn-Si or Fe-Si complex in the root cytosol, and decreased Mn or Fe uptake attributed to the down-regulation of OsNramp 5 gene in rice is a major transporter for Mn and Fe uptake in rice (Sasaki *et al*., 2012).

Conclusion

Generally, addition of Si has a positive effect on, yield and micronutrients of rice. The highest values of Si content and uptake by the different parts of rice plant were obtained when the NPK + Si treatment was used.

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