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Effect of Silicon Application and Nitrogen Rates on N and Si Content and Yield of Rice (*Oryza sativa L.*) In Two Water Systems in North of Iran

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Abstract: Silicon (Si) is the major element in soil, which has been essential for the maximum growth especially, under high nitrogen rates which, lodging and disease is limiting of yield a number of plant species, including rice. Field experiment was selected as split-splitplot arranged in a randomized complete block design with four replications. Irrigation system at two levels (continues flooding and deficit irrigation systems) as main plots and nitrogen rates in four levels (N_0, N_{46}, N_{92} and N_{138} kg ha^{-1}) as sub plots and silicon rates in two levels (Si_0 and Si_{500} kg ha^{-1}) as sub-subplots. Results indicate that grain yield had not significant difference between irrigation systems. In straw, Si content of continues flooding was more than deficit irrigation. Si content of N_{138} and N_{92} was minimum and maximum in the straw and grain, respectively. Grain yield was increased by as much as 5% by Si applied at 500 kg ha^{-1}. Nitrogen fertilizer application increased the straw and grain nitrogen content but, decreased the straw and grain silicon content in N_{138}. Si content in the straw and grain was more than nitrogen. Si fertilizer application decreased the straw and grain nitrogen. Si_0 and Si_{500} (kg ha^{-1}) had maximum and minimum grain nitrogen with 1.93% and 1.91% and straw nitrogen with 1.02 and 0.92, respectively. Thus, Si and N application attributed to selective uptake and transport of nitrogen to grain or straw by plant. N and Si content had negative correlation.

Key words: Silicon · Nitrogen · Rice · Harvest index (HI) · Grain yield

INTRODUCTION

Iran is a rice-producing country and rice is a staple food in the diet of the population; with 700 000 ha planted annually under irrigated conditions. Total agronomical produced area have been 13 million hectares, with 50% irrigated areas in 2007. Rice production is one of the most agricultural products in the north of Iran (Mazandaran and Gilan) with 2500 thousands ton grain production and the medium yield is 6005 kg ha^{-1}. Rice continuous cultivation in the north of Iran has recently decreased rice production and farmers for increasing yield used nitrogen application resulting in coast increasing and production decreasing duo to highland sensitive to disease especially blast and lodging, where disease and lodging have caused major yield losses.

Silicon (Si) is the second most abundant constituent 28% of the total soil weight in the earth's crust [1], which is only lower than oxygen that is 47%. Si is required as a nutrient for normal growth in wetland species of the families Gramineae, Equisetaceae and some Cyperaceae, but in dicotyledons and other grasses, its role remains elusive [2]. Silicon is not considered within the group of nutrients that are essential or functional for plant growth, but its absorption brings several benefits, especially for rice, such as the increase of cell wall thickness below the cuticle [3]. imparting mechanical resistance to the penetration of fungi, decrease in transpiration [3] and improvement of the leaf angle, making leaves more erect, thus reducing self-shading, especially under high nitrogen rates [4]. Silicon has been shown to be essential for maximum growth and yield of a number of plant

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species, including *Oryza sativa* [1]. Increased levels of Si in the rice plant are associated with decreased levels of grain discoloration at harvest and Si has been reported to reduce shattering of the grains in rice and to increase the number and weight of filled grains [5].

Great variation is evident among different plant species rooting in soil and rice is known to be the most effective Si-accumulating species [2]. While rice has a general high ability to absorb and accumulate Si, Si deposition in rice varies greatly among different organs of the plant [6]. Silicon accumulation into various plant organs varies among rice genotypes [7- 8]. Silicon content in different organs of a rice plant generally ranged from high to low, in descending rank in the hull, leaf, leaf sheath, culm and root [9]. Numerous experiments have shown that Si deposition in the plant tissues could improve yield, biotic stress and abiotic stress of rice plants [1, 5, 10]. It is conceivable that development of rice varieties with high Si deposition would be a better strategy than amending the soil with Si [5, 11]. Diallel analysis showed that genotype differences on Si content in rice were controlled by polygenes [7]. While Si content in a given rice genotype might change with variation of Si fertilization and/or Si in soil, the relative ranking of Si content among different rice genotypes remained fairly stable across different environments and locations [11]. Silicon helps plants to overcome multiple stresses including biotic and abiotic stresses [12]. For example, Si plays an important role in increasing the resistance of plants to pathogens such as blast on rice [13]. Silicon also alleviates the effects of other abiotic stresses including salt stress, metal toxicity, drought stress, radiation damage, nutrient imbalance, high temperature and freezing [10,12,14]. These beneficial effects are mostly expressed through Si deposition in the leaves, stems and hulls, although other mechanisms have also been proposed [12]. Therefore, the Si effect is characterized by a larger effect associated with a greater Si accumulation in the shoots. However, Si accumulation in the shoots varies considerably among plant species, ranging from 0.1 to 10% Si in the dry weight [14]. The difference in Si accumulation has been attributed to the ability of the roots to take up Si [2]. Three different modes of Si content have been proposed for plants having different degrees of Si accumulation, that is, active, passive and rejective content [2, 15].

Nitrogen (N) is essential for plant growth and development and is often a limiting factor for high productivities. However, when applied in excess it may limit yield because of lodging, especially for cultivars of the traditional and intermediate groups and promote shading and disease problems. These effects could be minimized by the use of silicon [16-17].

Si in plants can be linked to a reduction in lodging, as previously observed for plants and also because it is responsible for regulating transpiration, which is the likely reason for the resistance shown by this plant to water deficits which occur in the Mazandaran, in addition to protecting the leaves against pest and disease attacks. Therefore, this paper aims to evaluate the effects of irrigation, silicon and nitrogen rates on silicon and nitrogen accumulation on rice and their interaction with grain yield under field conditions.

MATERIALS AND METHODS

Study Site, Experimental Design and Treatments: A field experiment was done at Dashte-Naz research station, located in Mazandaran, the north of Iran (53°11'E, 36°37'N 10 m altitude) in 2007. Climatic data collected during growing seasons of the experiment, are show that at Table 1. The area rainfall received in average 800 mm yr^{-1} that about 80% of it occurred from September to April. Mean maximum and minimum temperatures were 35 and 18°C during rice cropping (April to August). The experiment was established in a soil type loamy (L) with pH 7.68, cation exchange capacity (CEC) 3.11, soil organic matter content 2.46%, N 0.14 ppm, P 33.8 ppm, K 455 ppm. Silicon was determined to be present approximately 14 ppm plant-available Si. The previous crop was kalam, which was harvested on 20 April in 2007. Lettuce straw was baled and removed after harvest. The experimental design was split-splitplots arranged in a Completely Randomized Block Design (CRBD) with four replications and three treatments (irrigation system, nitrogen and silicon), two irrigation systems

Table1: Climatic data include mean of humidity, temperature, rainfall and evaporation of experimental farm

	Variable			
Months	Evaporation (mm)	Humidity (%)	Temperature (°C)	Rainfall (mm)
April	55.5	82	12.8	52.6
May	93.7	77	17.7	16.6
Jun	166.6	65	25.6	13.5
Jul	136.3	76	25.5	31.7
Aug	199.7	68	28.0	0.1

(I_1= continuous flooding irrigation and I = $_2$ deficit irrigation) as main plots, four levels fertilizer nitrogen (N_0, N_{46}, N_{92} and N_{138} kg ha^{-1}) as urea (46% N) in subplots and two levels of silicon fertilizer (Si_0 and Si_{500} kg ha^{-1}) as calcium silicate in sub-subplots. The experiment was conducted under controlled conditions from April to Aug. Seedbed preparation included ploughing, disk harrowing and cultivation. N, P_2O_5 and K_2o were at 10, 5 and 12 kg 10 m^2, respectively. The row spacing was 2 cm and the seeds were sown. The rice cultivar was *Oryza sativa* L. var. Mahalli Tarom (blast susceptible). Rice was sown of at the seeding rate of 60 kg ha^{-1} with 0.5 cm depth on 25, April. Before seeding, the land was plowed twice with about 20 cm depth and leveled.

Planting date was on 30 April. Nitrogen was incorporated into the soil 1-day after transplanting. In the recommended splits, N was applied at transplanting 33%, panicle initiation 33% (42 DAT (Days after transplanting)) and full panicle 33% (55 DAT) in 1, 42 and 55 days after transplanting (DAT). Phosphorus and potassium were not preplan incorporated. Silicon fertilizer, in the form of wollastonite ($CaSiO_3$), was broadcast according to rate by hand and was incorporated into the soil prior to planting. Wollastonite, used as a source of calcium silicate ($CaSiO_3$) is composed of 60% Si and 20.1% calcium, was applied approximately 5 days before transplanting at 0 and 833 kg ha^{-1}, corresponding to 0 and 500 kg of elemental Si per hectare. After removing crop residues, the main land was plowed, puddled and leveled for rice transplanting on 29 April 2007. During the rice season, along with rainfall, irrigation was provided using canal water.

All plots were kept flooded for 1 wk after transplanting; Propanil and Bentazone were applied at labeled rates for control of weeds. Weeds were controlled as required a 20 days after transplanting, each plot was controlled to weeds (Hand-weeding was done). Thereafter, rice was irrigated at two systems. Although the soil did not remain flooded for more than 8 to 10 h after irrigation, anaerobic conditions prevailed for >75% of the rice growth period. 4-wk-old rice seedlings were transplanted at 20- by 10-cm (10 rows per subplot) spacing in 10 m^2 (2to 5) plots on 26 May. Treatments were separated by a 1 m buffer zone. Whole plots were 2 × 16 m and were subdivided into four 2 × 8 m subplots. In all plots, rice crop was transplanted with a farmer's equipment (10-row sowing hand). Spacing between plots in each block was 1 m and spacing between blocks was 2 m. No modifications were made to the plots to allow for drainage and plants were kept under flooded conditions until the end of the experiments. Rice crop was harvested by hand at ground level at maturity on 16 Aug. 2007.

Yield Measurements: Samples were harvested in a randomly selected 8 hill of each plot at harvest growth stages. Grains were separated from straw using a plot thresher, dried in a batch grain dryer and weighed. Grain moisture was determined immediately after weighing and samples were dried in an oven at 65°C for 48 h. Grain and straw yields were determined by harvesting by hand, approximately 1-2 cm above the soil surface from an area 3 m^2 (1×3) located at the center of each plot. Grain yield was calculated on a 12% water basis; the standard moisture content for harvesting for rice. HI was calculated on: grain yield/biological yield× 100.

Plant Sampling and Quality Analysis: Grain and straw samples were dried in the oven for 72 h at 70°C and prepared for chemical analysis finely ground to pass through a 0.5-mm sieve. Nitrogen content in grain and straw was determined by digesting the samples in sulfuric acid (H_2SO_4), followed by analysis for total N by a micro-kjeldahl method [4]. Additionally, Plant dry weight was determined after harvest rice roughly 500 g of straw tissue (leaf, sheath and stem) and grain (grain with hull) were collected from each replication. Dried tissue was ground to pass through a 40-mesh screen using a Thomas-Wiley mill (Thomas Scientific, Swedesboro, NJ). Silicon content of tissue samples was determined by first digesting 1 g of dried tissue, changed by Yoshida [3]. Results obtained from analysis expressed in absorbance units (mV), were converted to percentages of SiO_2 per kg of plant tissue [8].

Data Statistical Analyses: All data collected were analyzed by analysis of variance (ANOVA) using SAS program was used to conduct the analyses of variance and the regression analysis, respectively. Analysis of variance was performed on yield parameters to determine effects of irrigation, N and Si. Treatment means differences were separated by Duncan's Multiple Range Test (DMRT) at the 0.05 probability level. Tests for linear correlation were performed between means for content of Si and N in plant tissue straw (leaf, sheath and stem) and grain (hull and grain).

RESULTS AND DISCUSSION

Climate Condition: we see that during the growing season the temperature and evaporation of the water are increasing, while the raining is decreasing which results in a decrease in the soil moisture and increase in the plant need for water. The usable water for the plants comes from the soil moisture which has been gathered during the raining time of the winter and the plant face water shortage which needs watering. In the region the general system of irrigation was continuous flooding, but due to increasing tendency to cultivate rice in the land and high yielding kinds of rice the need for a high content of water merits attention (Table 1).

Grain Yield: There weren't any significant difference between the two systems and flooding irrigation was higher than (329 kg ha^{-1}) deficit irrigation. Hence, flooding irrigation increased production dry matter, which is not much regarding the content of water spent [17-18]. There was significant difference in grain yield among the nitrogen rates at the 0.01 probability level. N_0 and N_{138} with 4306 and 6128 kg ha^{-1} were the lowest and highest, respectively [18-19]. It can be concluded that if the amount of nitrogen is increase we will have an increase in the grains yield. Therefore, due to the indifference result of the two systems for the grains yield, we have an increase in the biomass content and if the nitrogen feeding is not controlled then we will have economic breakdown and it makes the harvesting very difficult and causes the grain to fall. Because, in the flooding irrigation we have water abundant and the minerals will be leaching, the water would be lost due to evaporation and transpiration and the root will not be developed [18-20]. Grain yield was significant difference higher under silicon application than under check. Silicon application decrease lodging and disease [20]. Grain yield across all nitrogen rates were higher under flooding irrigation than under deficit irrigation. Grain yield across irrigation systems were lower under check than under silicon application (Table 2,3). Fallah *et al.* [21] indicate that silicon significant increases in harvest index and percent spikelet filling, resulting in improved grain yield [21] Application of nitrogen fertilizers is an important practice for increasing yield [22].

Table 2: Analysis of variance (mean square) of data for grain yield, GTW, HI, N and silicon (Sio_2) content in rice

S.O.V.	D.F.	GTW	Grain yield	HI	Sio_2 Grain	Sio_2 Straw	N Grain	N Straw
Rep	3	457.11	0.25	148.50	0.02	0.05	0.01	0.00
Irrigation	1	*666.40	0.01	453.89	0.02	0.06	0.02	0.01*
E (a)	3	370.00	0.59	90.44	0.03	0.05	0.01	0.00
Nitrogen	3	948.00	3.48 **	6.48	0.42	0.49 *	0.62 **	0.37 **
A×B	3	971.10	0.02	15.10	0.01	0.01	0.02	0.03
E (b)	18	205.20	0.10	13.21	0.02	0.02	0.02	0.02
Silicon	1	258.00	0.41**	15.76 *	0.01	0.1*	0.01	0.17 *
A×C	1	065.00	0.00	2.38	0.01	0.01	0.01	0.03
B×C	3	540.00	0.01	6.46	0.03	0.09**	0.03	0.13
A×B×C	3	438.10	0.00	5.07	0.1*	0.1**	0.09 *	0.04 *
E (c)	24	132.20	0.01	3.52	0.03	0.02	0.03	0.03
C.V. %	-	6.5	3.0	6.0	14.0	5.0	8.7	0.18

* and **: significant at the 5% and 1% levels, respectively

Table 3: means of grain yield, GTW, HI, Silicon (Sio_2) and N content in rice the grain and straw

Treatments	GTW (g)	Grain yield (Kg ha^{-1})	HI	Sio_2 Grain	Sio_2 Straw	N Grain	N Straw
I1	22.68 a	5238.33 a	33.31 a	3.10 a	17.90 a	1.90 a	0.99 a
I2	22.14 b	5206.67 a	38.34 a	3.10 a	18.10 a	1.93 a	0.96 b
N0	22.57 a	4306.67 a	33.96 a	3.10 ab	17.90 b	1.69 d	0.78 c
N46	22.55 a	4951.67 b	35.72 a	3.10 ab	18.00 b	1.83 c	0.93 b
N92	22.47 a	5501.67 c	35.94 a	3.20 a	18.50 a	2.02 b	1.06 a
N138	22.05 a	6128.33 d	36.58 a	2.90 b	17.50 c	2.13 a	1.11 a
Si0	22.47 a	5090.00 a	36.38 a	3.10 a	17.70 a	1.93 a	1.02 a
Si500	22.35 a	5355.00 b	35.25 a	3.00 a	18.30 b	1.91 a	0.92 b

Within each treatment, means followed by different letter in a column are significantly different at the 0.05 probability level

Table 4: Means of interaction effect I×N, I×Si and N×Si, grain yield, HI, Silicon (Sio$_2$) and N content in rice

Treatments		Grain yield (Kg ha^{-1})	HI	Sio$_2$ Grain	Sio$_2$ Straw	N Grain	N Straw
I1	N0	4385.00 ef	31.11 c	3.0 ab	17.6 d	1.67 d	0.74 e
	N46	4953.33 de	32.93 bc	3.1 ab	17.8 cd	1.81 cd	0.95bcd
	N92	5451.67 cd	33.74 bc	3.2 ab	18.6 a	1.99 ab	1.13 a
	N138	6160.00 a	35.00 ab	3.0 ab	17.8 cd	2.14 a	1.13 a
I2	N0	4228.33 f	37.52 a	3.3 a	18.3 ab	1.70 cd	0.81 de
	N46	4948.33 de	39.02 a	3.2 ab	18.1 bc	1.86 bc	0.92 cd
	N92	5551.67 bc	38.39 a	3.1 ab	18.5 a	2.05 a	1.00abc
	N138	6098.33 ab	38.35 a	2.9 b	17.2 e	2.13 a	1.1 ab
I1	Si0	5116.67 b	33.60 c	3.0 b	17.5 c	1.93 a	1.06 a
	Si500	5358.33 a	33.04 c	3.1 ab	18.4 a	1.88 ab	0.91 b
I2	Si0	5061.67 b	38.95 a	3.2 a	18.0 b	1.94 a	0.99 ab
	Si500	5351.67 a	37.79 b	3.0 b	18.1 bc	1.93 a	0.93 ab
N0	Si0	4135.00 h	33.84 b	3.2 a	17.6 d	1.71 cd	0.86bcd
	Si500	4480.00 g	34.08 b	3.1 ab	18.2 b	1.66 d	0.7 cde
N46	Si0	4856.67 f	36.18 ab	3.1 ab	18.3 b	1.79 bcd	1.05abc
	Si500	5046.67 e	35.29 b	3.1 ab	17.6 d	1.88 bc	0.82 cde
N92	Si0	5355.00 d	35.69 b	3.2 a	17.0 e	2.09 a	0.98bcd
	Si500	5648.33 c	36.18 ab	3.1 ab	20.1 a	1.96 ab	1.15 ab
N138	Si0	6011.67 b	38.04 a	2.9 c	18.0 c	2.14 a	1.21 a
	Si500	6246.67 a	35.29 b	2.9 c	17.0 e	2.13 a	1.02abc

Within each treatment, means followed by different letter in a column are significantly different at the 0.05 probability level

Table 5: Means of interaction effect I×N× Si grain yield, HI, Silicon (Sio$_2$) and N content in the grain and straw.

Treatments			Grain yield (Kg ha^{-1})	HI (%)	Sio$_2$ grain (%)	Sio$_2$ straw (%)	N grain (%)	N straw (%)
I1	N0	Si0	4230.00 jk	30.62 d	3.1 abc	17.4 de	1.73 cd	0.82 def
		Si500	4541.67 i	31.59 cd	2.8 c	17.7 cde	1.62 d	0.66 f
	N46	Si0	4891.67 gh	33.10 cd	2.8 c	17.6 cde	1.68 cd	1.04 abcd
		Si500	5016.67 gh	32.78 cd	3.4 ab	18.1 c	1.94 abc	0.85 cdef
	N92	Si0	5290.00 ef	33.25 cd	3.2 abc	18.1 c	2.15 a	1.14 ab
		Si500	5613.33 cd	34.21 c	3.3 abc	19.0 b	1.84 bcd	1.11 abc
	N138	Si0	6058.33 ab	36.91 b	3.0 abc	16.9 f	2.15 a	1.23 a
		Si500	6260.00 a	33.32 cd	2.9 bc	18.7 b	2.13 a	1.03 abcd
I2	N0	Si0	4040.00 k	38.02 ab	3.2 abc	17.8 cd	1.7 cd	0.89 bcdef
		Si500	4418.33 ij	37.08 ab	3.3 abc	18.8 b	1.71 cd	0.74 ef
	N46	Si0	4820.00 h	39.95 a	3.5 a	19.1 b	1.90 abc	1.05 abcd
		Si500	5075.00 fg	38.16 ab	2.8 c	17.2 ef	1.81 bcd	0.78 def
	N92	Si0	5420.00 de	38.44 ab	3.2 abc	15.9 g	2.03 ab	0.82 def
		Si500	5683.33 c	38.35 ab	2.9 bc	21.2 a	2.07ab	1.18 ab
	N138	Si0	5965.00 b	39.26 ab	2.9 bc	19.2 b	2.12 a	1.18 ab
		Si500	6231.67 a	37.51 ab	3.0 abc	15.3	2.13 a	1.02 abcde

Within each treatment, means followed by different letter in a column are significantly different at the 0.05 probability level.

Harvest index: There was significant difference in HI between silicon application rates at the 0.01 probability level. The HI was significant difference higher under silicon application than under check. The HI differential between silicon application rates was again linked to higher production of grain yield. The HI was not significantly affected by irrigation, but the values are consisted with the finding of a lower HI for flooding irrigation. The HI differential duo to irrigation systems is reflected in a higher dry matter production and a higher grain yield under flooding irrigation compared deficit irrigation. There was not significant difference in HI among nitrogen rates, but higher nitrogen application increased HI. N_0 (34%) and N_{138} (37%) had the lowest and highest indexes, respectively. The result showed that the HI for the continuous flooding was lower, which was not cost-effective due to content of water spent [19]. Although, the flooding irrigation has produce biological and straw yield it was not significant in grain yield [20] (Table 2,3). Fallah *et al.* [21] indicate that silicon significantly increases in harvest index and percent spikelet filling, resulting in improved grain yield.

Nitrogen and Silicon Content in Grain and Straw of Rice: Among treatments, nitrogen content was more in the grain than the straw. Maximum and minimum of straw nitrogen content were 1.63 and 0.58% in $I_2N_{138}Si_{500}$ and $I_1N_0Si_0$, respectively. The content of the grain nitrogen was 2.59 and 1.56% in $I_1N_{138}Si_{500}$ and $I_1N_0Si_{500}$, respectively. Silicon content was more than nitrogen content in the grain and straw [23]. Silicon content was more in the straw than the grain [9]. Maximum and minimum of straw silicon were 22.26 and 14.42% $I_2N_{92}Si_{500}$ and $I_2N_{138}Si_{500}$ and the grain silicon content was 4.08 and 2.23% in $I_1N_{46}Si_{500}$ and $I_2N_{46}Si_{500}$, respectively. Nitrogen content of the grain (1.93) was about twice of the straw (0.97) and silicon content of the straw (17.99) was about 6-fold in comparison to the grain (3.10) (Table 3). These results are agreement with previous findings [4, 6-8].

Nitrogen Content of the Rice Grain: Flooding irrigation reduced the grain nitrogen content and it was vice versa in deficit irrigation in the N straw. Deficit irrigation in comparison to flooding irrigation increased 2.6 percents nitrogen content of the grain. Analysis of variance shows that nitrogen content of the grain to be affected by nitrogen rates at the 1% probability level and interaction effect of irrigation × nitrogen × silicon at the 5% probability level (Tabel 2). The grain nitrogen content N_0 and N_{138} with 1.668 and 2.131% were the lowest and highest, respectively. Interaction effect of irrigation × nitrogen was 2.138% (max) in the I_1N_{138} and 1.672% (min) in the I_1N_0. Interaction effect of nitrogen × silicon, $N_{138}Si_0$ and N_0Si_{500} with 2.135 and 1.662%, were the highest and lowest, respectively (Table 3,4). Silicon application (Si_{500}) reduced the grain nitrogen content down to 2.4%. Silicon application reduced the grain nitrogen content (1.91%) in comparison to the control (1.93) and it was a minus linear relation. The grain nitrogen content had a positive linear relation with nitrogen rates increasing. Interaction effect irrigation × nitrogen on the grain nitrogen content was fewer at all treatment levels at flooding in comparison with deficit irrigation [17, 20]. The accumulation of Si in the straw may be related to a number of factors such as, transpiration, growth duration, growth rate and etc [24], but N content in the most important factor determining Si accumulation in the straw. Ma [22] indicate that Excessive application of nitrogen fertilizers also causes high protein content in brown rice, which affects its quality. Sufficient supply of Si to rice is effective in producing low protein rice [22, 24].

Nitrogen Content of the Rice Straw: Flooding irrigation increased the straw nitrogen content and it was vice versa in deficit irrigation in the N grain. Flooding irrigation in comparison to deficit irrigation caused to increasing of the straw nitrogen content up to 3%. The straw nitrogen content had been influenced by irrigation, silicon application and interaction effect of nitrogen × silicon, at 5% probability level and by nitrogen content at 1% probability level (Table2). The straw nitrogen content in flooding and deficit irrigations was 0.986 and 0.957%, respectively. The straw nitrogen content N_0 and N_{138} with 0.776% and 1.114% were the lowest and highest, respectively. Maximum of straw nitrogen content was obtained by effect of nitrogen × silicon in $N_{138}Si_0$ (1.205%) and the minimum was in N_0Si_{500} (0.698%). Silicon application reduced the straw nitrogen content as much as 10% (Tabel 3,4). Although interaction effect of irrigation × silicon and irrigation × nitrogen × silicon were not statistically significant, but the treatments were, settled in various levels in multiple range Duncan's test. Interaction effect of irrigation × silicon, N_0si_0 and N_0Si_{500} with 1.059% and 0.986 were maximum and minimum of straw nitrogen content, respectively. Interaction effects of irrigation × nitrogen × silicon, $I_1N_{138}Si_{500}$ and $I_1N_0Si_{500}$ were the highest and the lowest, respectively, which settled with the other treatments, especially $I_1N_0Si_0$ at same statistically level and did not have any significant difference with each other (Table5). The accumulation of N in the straw (shoot, sheath leaf and leaf) may be related to a number of factors such as nitrogen rates, nitrogen splitting, transpiration, growth duration, growth rate and etc, but silicon content in the most important factor determining N accumulation in the straw [19].

Silicon Content of the Rice Grain: The grain silicon content was not affected by irrigation, nitrogen rates and silicon application, but the interaction effect of the factors irrigation × nitrogen × silicon was significant at 5% probability level (Table 2). Maximum and minimum of the grain silicon content were 3.5 % ($I_2N_0Si_0$) and 2.8% ($I_1N_0Si_{500}$), respectively (Table5). That it was at the same statistical level with $I_1N_{46}Si_0$ and $I_2N_{46}Si_{500}$ treatments [6, 8, 9]. These results are agree with Mauad *et al.* [16]. The accumulation of silicon in the grain related to hull, because silicon deposition was on rice grain hulls, the likely explanation for the increase in grain mass would be the greater deposition of this element on the paleae and lemmas [25-26].

Silicon Content of the Rice Straw: Silicon content was influenced by nitrogen rates and silicon application at 5% probability level and by interaction effect of nitrogen × silicon and irrigation × nitrogen × silicon at 1% probability level (Table 2). Maximum and minimum of the straw silicon content obtained for N_{92} (18.5%) and N_{138} (17.5%) and for N_0 (17.9%) and N_{46} (18%), respectively (Table3). Maximum and minimum of the straw silicon content were obtained by 500 (18.3%) and 0 kg ha^{-1} (17.7%) silicon fertilizer, respectively. The highest of the straw silicon content was obtained by the interaction effect of triple factors ($I_2N_0Si_{500}$) (Table 5). The results showed that the Si content in the straw increased with increasing Si application and Si content in the straw increased with increasing N application to N_{92} but, had decrese in N_{138} these results are agree withMa and Takahashi, 1990, who compared only silicon and phosphorus in rice [9] Elawad *et al.* [27], found that application of silicate materials increased the levels of Si, P, Ca and Cu and reduced the levels of N, K, Mg, Fe, Mn and Zn in the leaf [27]. Also, Fallah *et al.* [21] indicate that silicon easily absorbed by the plant as detected in the tissues. Silicon increased dry matter production and silicon oxide accumulation in tissues regardless of nitrogen supply [21]. However, excess N causes lodging, mutual shading, susceptibility to diseases and so on. Silicon deposited on the stems and leaf blades prevents mutual shading, as stated above [22].

Relation of Nitrogen and Silicon Content on Rice: Irrigation systems did not effect on the grain silicon content, but deficit irrigation increased the straw silicon content [3, 15] and decreased the straw N content [19]. Relation between N and Si content is complex in straw and grain of rice. The results from this experiment show that nitrogen content was more in the grain than the straw. Nitrogen content in the straw and grain increased with increasing nitrogen fertilizer application. In straw, increase of nitrogen content was decreased with increasing nitrogen fertilizer application (0.145, 0.188 and 0.11), but at the first, it had increased and then reduced and in the grain, increase of nitrogen content was decreased with increasing nitrogen fertilizer application (0.155, 0.132 and 0.051), although increase nitrogen fertilizer application was constant. A higher Si content in the straw than in the grain suggests that Si is linked in shoot and leaf (straw) and for lodging and disease control is important [1, 5, 11, 13, 28]. Si content in the straw increase with increasing silicon application, but in the grain had decreased. Silicon application decrease N content in the straw and grain. Nitrogen fertilizer application, at the first, increased Si content in the straw and grain (N_{92}) and then reduced in N_{138}. Silicon content of the grain and straw was reduced by nitrogen application increasing in N_{138}. Ma [22] found that these functions of Si are especially important in the cultivation systems with dense planting and high N application [22].

Silicon application caused the grain and straw nitrogen content reduction and this effect was more on the straw nitrogen content with increasing of the silicon application. At the final steps, nitrogen content increased and silicon content reduced, thus the lodging and diseases incidence were increased and the yield was reduced [3, 4, 16, 28]. The accumulation of Si in the straw may be related to a number of factors such as, transpiration, growth duration, growth rate and etc. [15].

Application of nitrogen fertilizers is an important practice for increasing yield. However, excess N causes lodging, mutual shading, susceptibility to diseases and so on. Silicon deposited on the stems and leaf blades prevents mutual shading, as stated above. The occurrence of blast disease is significantly inhibited by Si application in the field, especially when N application is heavy [29]. These functions of Si are especially important in the cultivation systems with dense planting and high N application [22]. Excessive application of nitrogen fertilizers also causes high protein content in brown rice, which affects its quality. Sufficient supply of Si to rice is effective in producing low protein rice [22, 24] Elawad *et al.* [27], found that application of silicate materials increased the levels of Si, P, Ca and Cu and reduced the levels of N, K, Mg, Fe, Mn and Zn in the leaf [27-29].

Grain Thousand Weights: Grain thousand weights (GTW) increased significantly with increasing irrigation (P=0.05) (Table2). Grain thousand weights in plants growth in flooding reached 22.68 g; much higher than the 22.14 in plants growth with deficit irrigation because the main reason may be increase of active photosynthesis, grain filling period and delay ripening in flooding irrigation. Silicon deposition was on rice grain hulls.

This greater deposition is attributed to intense panicle transpiration during the grain filling stage, since the process of transportation and deposition of silicon in plant tissues depends upon the transpiration rates that occur in different plant organs [3]. In nitrogen rates, grain thousand weights in rice were decreased by nitrogen at all levels related to N_0. N_0 and N_{138} had maximum and minimum grain thousand weights with 22.57 and 22.05 g, respectively, it was not significantly at P=0.05 (Table 2). Nitrogen increased spikelet number at high nitrogen. That caused plants not to have enough carbohydrates to fill up all spikelets produced as the nitrogen fertilization level increased. These results are similar to those obtained by Mauad, *et al.* [16]. In silicon treatment, grain thousand weights was Si_0 more than Si_{500}, although, it was not significantly at P=0.05 (Table 2). Silicon fertilizer application decrease blank spikelet number in rice (data not show). That caused plants not to have enough carbohydrates to fill up all spikelets produced as the silicon fertilization level increased, contributing to decrease the number of blank spikelets and to increase fertility. The increase in grain mass would be the greater deposition of silicon on the paleae and lemmas, as reported by Balastra *et al.* [25]. Thus, grain thousand weights each cultivar is constant trait but, in environment conditions and stress could be decrease or increase. This result contradicts findings by Balastra *et al.* [25] and *Deren et al.* [21] who also observed increasing grain mass with increasing levels of silicon fertilization. Fallah *et al.* [21] indicate that silicon significantly increases percent spikelet filling, resulting in improved grain yield.

CONCLUSION

In the north of Iran, regarding the high content of rainfall during the winter and autumn and due to warm seasons of spring and summer and the evaporation and transpiration of the water we are faced with water shortages. The rice plant need for water will increase during the summer. The rice plant in flooding irrigation will have a rapid increase in its growth, therefore the content of nitrogen will have an important role on the growth in a way that if the content is higher it causes the plant to grow rapidly and as a result the biomass will increase and the grain yield and harvest index will be lower. Due to insignificant difference between the two systems of irrigation for the grain yield and regarding the risks of nitrogen conduct it is advised to use deficit irrigation which will not cause a crop reduction by using a lot of nitrogen [19, 20]. Rice is a strategic product in the north part of Iran and we may face a drought and water shortage nearly soon therefore we should conserve our water resources to produce more. Regarding the present study, we will reduce the plant corruption during the severe time of water shortage greatly. Therefore the recommended system for low yielding kind is the deficit system. While it should be noted that in flooding system the pests and herbs will be controlled, we can remove this problem by transplanting the seedlings thickly (10×10) and by using pesticides and herbicides at a proper time. If the flooding system has been chosen, we must control the content of nitrogen to be spread in the land otherwise we will have risks in production but in deficit irrigation system, the consumption of nitrogen is controlled due to having a balance in absorbing and growing of the plant and the pests and weeds will be reduced and it is very cost effective [20]. Based on the results, there was a positive relation between nitrogen and silicon in the rice plant. Silicon must be consumed to prevent the undesired effects of high nitrogen usage; otherwise, high level of nitrogen usage will cause the grain yield reduction.

These results suggest that increase of nitrogen fertilizer application decreased Si content and also, silicon fertilizer application decreased N content. However, that is negative correlation between N and Si content. Generally, the results showed that the N content in the straw decreased with increasing Si application and Si content in the straw increased with increasing Si application also, Si content in the straw increased with increasing N application and N content in the straw increased with increasing N application [5, 15-16].

Generally, although silicon fertilizer application result in decrease of N uptake but, increase of nitrogen result in increase grain yield because there is direct and positive relation between N fertilizer application and grain yield while silicon deficiency and high N result in lodging and disease, low yield. Leaves become more erect, thus reducing self-shading and increasing photosynthesis rate, especially under conditions of high population densities and high doses of nitrogen [4], as observed. The combination between high nitrogen rates and the absence and/or low silicon rates tend to turn leaves more decumbent, as a result of greater leaf opening angles [4]. High silicon and increasing N fertilizer application result in decrease of high N uptake, lodging, disease and high grain yield.

REFERENCES

1. Epstein, E., 1994. The anomaly of silicon in plant biology. Proc. Natl. Acad. Sci., 91: 11-17.
2. Takahashi, E., J.F. Ma and Y. Miyake, 1990. The possibility of silicon as an essential element for higher plants. Comments Agric. Food Chem., 2: 99-122.
3. Yoshida, S., Y. Ohnishi and K. Kitagishi, 1962. Chemical forms, mobility and deposition of silicon in the rice plant. Jpn. J. Soil Sci. Plant Nutr., 8: 107-111.
4. Yoshida, S., S.A. Naveser, E.A. Ramirez, 1969. Effects of silica and nitrogen supply on some leaf characters of rice plant. Plant and Soil, 31: 48-56.
5. Savant, N.K., G.H. Snyder and L.E. Datnoff, 1997. Silicon management and sustainable rice production. Adv. Agron., 58: 151-199.
6. Alina, K., 1984. Trace elements in soils and plants. CRC Press.
7. Majumder, N.D., S.C. Rakshit and D.N. Borthakur, 1985. Genetics of silica content in selected genotypes of rice. Plant Soil, 88: 449-453.
8. Winslow, M.D., K. Okada and F. Correa-Victoria, 1997. Silicon deficiency and the adaptation of tropical rice ecotypes. Plant Soil, 188: 239-248.
9. Zhu, H.J., 1985. Rice soil. Agricultural Publishing Press.
10. Epstein, E., 1999. Silicon. Annu. Rev. Plant Physiol. Plant. Mol. Biol., 50: 641-664.
11. Deren, C.W., 2001. Plant genotype, silicon concentration and silicon-related responses. In L.E. Datnoff *et al.*, (ed.) Silicon in agriculture. W.B. Saunders, Philadelphia, PA., pp: 149-158.
12. Ma, J.F., 2004. Role of silicon in enhancing the resistance of plants to biotic and abiotic stresses. Soil Science Plant Nutr., 50: 11-18.
13. Datnoff, L.E., C.W. Deren and G.H. Snyder, 1997. Silicon fertilization for disease management of rice in Florida. Crop Protection, 16: 525-531.
14. Ma, J.F. and E. Takahashi, 2002. Soil, fertilizer and plant silicon research in Japan. Elsevier Science Press.
15. Mitani, N. and J.F. Ma, 2005. Uptake system of silicon in different plant species. J. Exp. Botany, 56: 1255-1261.
16. Mauad, M., C.A.C. Crusciol, H. Grassi Filho and J.C. Correa, 2003. Nitrogen and silicon fertilization of upland rice. Scientia Agricola, 60: 761-765.
17. Surek, H., H. Aydin, R. Cakir, H. Karaata, M. Negis and H. Kusku, 1996. Rice yield under sprinkler irrigation. International Rice Research Notes, 21: 2-3.
18. Westcott, M.P. and K.W. Vines, 1986. A comparison of sprinkler and flood irrigation for rice. Agronomy J., 82: 667-683.
19. Tripathi, B.P., J.K. Ladha, J. Timsina and S.R. Pascua, 1997. Nitrogen dynamics and balance in intensified rainfed lowland rice-based cropping systems. Soil Sci. Soc. Am. J., 61: 812-821.
20. Turner, F.T. and G.N. McCauley, 1983. In: I.D. Teare and M.M. Peet (eds.). Crop-Water Relations. John Wiley and Sons, New York, Rice, pp: 307-380.
21. Fallah, A., R.M. Visperas and A.A. Alejar, 2004. The interactive effect of silicon and nitrogen on growth and spikelet filling in rice (*Oryza sativa* L.) Philipp. Agric. Scientist, 87: 174-176.
22. Ma, J.F., 2005. Silicon requirement for rice. Proceeding of Third Silicon in Agriculture Conference, pp: 46-57.
23. De Detta, S.K., 1989. Rice. In: Plucknett, D.L., Sprague, H.B. {eds} Detecting Mineral Nutrient Deficiencies in Tropical and Temperature Crop. Westview Press Inc.
24. Morimiya, Y., 1996. Role of Si in production of low protein rice and diagnosis parameters. Jpn. Soil Sci. Plant Nutr., 67: 696-700.
25. Balastra, M.L.F., C.M. Perez, B.O. Juliano, P. Villreal, 1989. Effects of sílica level on some proprieties of Oriza sativa straw and hult. Canadian Journal of Botany, 67: 2356-2363.
26. Ma, J.F. and E. Takahashi, 1990. Effect of silicon on the growth and phosphorus uptake of rice. Plant and Soil, 126: 115-119.
27. Elawad, S.H., J.J. Street and G.H. Gascho, 1982. Response of sugarcane to silicate source and rate. II. Leaf freckling and nutrient content. Agronomy Journal, 74: 484-487.
28. Deren, C.W., L.E. Datnoff, G.H. Snyder, F.G. Martin, 1994. Silicon concentration, disease response and yield components of rice genotypes grown on flooded organic histosols. Crop Science, 34: 733-737.
29. Ohyama, N., 1985. Amelioration of could weather damage of rice by silicate fertilizer application. Agric. Hort., 60:1385-1389.