

# Application of Nitrogen and Silicon Rates on Morphological and Chemical Lodging Related Characteristics in Rice (*Oryza sativa* L.) at North of Iran

Dastan Salman (Corresponding author)

Department of Agronomy, Science and Research Branch, Islamic Azad University, Tehran, Iran

Tel: 98-911-155-2587 E-mail: [sdastan@srbiau.ac.ir](mailto:sdastan@srbiau.ac.ir)

Siavoshi Morteza

Ph.D. Student of Botany Department at Fergusson College, Pune, India

E-mail: [Morteza\\_siavoshi@yahoo.com](mailto:Morteza_siavoshi@yahoo.com)

Zakavi Dariush

Department of Agronomy, Qaemshahr Branch, Islamic Azad University, Qaemshahr, Iran

Ghanbari Malidarreh Abbas

Department of Agriculture, Jouybar Branch, Islamic Azad University, Jouybar, Iran

Yadi Reza

Department of Agriculture, Boushehr Center, Payam Nour University, Boushehr, Iran

Ghorbannia Delavar Ehsan

Department of Agronomy, Qaemshahr Branch, Islamic Azad University, Qaemshahr, Iran

Nasiri Ali Reza

Department of Agronomy, Science and Research Branch, Islamic Azad University, Tehran, Iran

Received: December 6, 2011 Accepted: December 26, 2011 Online Published: April 17, 2012

doi:10.5539/jas.v4n6p12

URL: <http://dx.doi.org/10.5539/jas.v4n6p12>

## Abstract

Rice-based irrigated lowlands are the major cropping system in north of Iran. This experiment was carried out in split plot in basis of randomized complete block design with three replications at north of Iran in 2010. Main plot was nitrogen rates including (0, 50, 100 and 150 kg N ha<sup>-1</sup>) applied as urea and sub plot was silicon rates (0, 300 and 600 kg ha<sup>-1</sup>) applied as calcium silicate. Results showed that minimum of the plant height, flag leaf length, fourth inter-node bending moment and grain yield (4350 kg ha<sup>-1</sup>) were obtained at N<sub>0</sub>, as well as the maximum of the plant height, panicle length, flag leaf length, third inter-node length were observed at N<sub>100</sub> and N<sub>150</sub>, respectively. But the highest of bending moment obtained for fourth inter-node and maximum grain yield (6063 kg ha<sup>-1</sup>) was observed in N<sub>150</sub>. Treatment Si<sub>600</sub> had increased significantly over control in plant height, stem length, panicle length, third inter-node length, third inter-node bending moment, cellulose, hemi-cellulose and lignin in relation to 7.76, 9.91, 30.18, 31.03, 18.71, 7.60, 34.50 and 26.26 %, respectively. Therefore treatment with N<sub>150</sub> and Si<sub>600</sub> had shown best results for agronomical indices and grain yield.

**Keywords:** Bending moment, Cellulose, Lignin, Nitrogen, Rice, Silicon

## 1. Introduction

Rice is one of the most important crops in developing countries and a main food stuff for about 35% of the whole world population (Becker and Asch, 2005). Rice plants require large amounts of mineral nutrients including N for their growth, development and grain production (Ma, 2004). Rice continuous cultivation in the north of Iran has recently decreased rice production and farmers for increasing yield used nitrogen application resulting in cost increasing and production decreasing due to highland sensitive to disease especially blast and lodging, where disease and lodging have caused major yield losses. Rice production in much of the world increasingly focuses on optimizing grain yield, reducing production costs, and minimizing pollution risks to the environment (Koutroubas and Ntanos, 2003). Nitrogen nutrition is critical in yield realization of irrigated rice ecosystems. Nitrogen is clearly the most limiting element; we proposed a set of basic guidelines for improved nutrient management, which after further efforts of all stakeholders involved, could contribute to increased system productivity (Haefel *et al.*, 2006). Nitrogen fertilization increased the number of stems and panicles per square meter and the total number of spikelets, reflecting on grain productivity. Excessive tillering caused by inadequate nitrogen fertilization reduced the percentage of fertile tiller, filled spikelet percentage and grain mass (Mauad *et al.*, 2003). N application significantly increased grain yield largely through an increased biomass and grain number (Belder *et al.*, 2005). Nitrogen rates of 138 and 0 kg ha<sup>-1</sup> produced maximum and minimum grain yield, biological yield and straw yield, respectively. Si at 500 and 0 kg ha<sup>-1</sup> produced maximum and minimum biological yield with 11874 and 10538 kg ha<sup>-1</sup>, and straw yield, respectively (Ghanbari-Malidarreh *et al.*, 2008).

Silicon is one of the most abundant elements in Earth's crust and plants ash (Jones and Handreck, 1976). It is a necessary element for rice because of its positive effects on rice planting (Mengel and Kirkby, 1987). Silicon uptake is activated in rice and wheat, so it's not affected by the rate of transpiration and this element is located in leaf, sclerenchyma, vascular tissues and vascular sheaths, old leaves have more silicon than the young leaves (Tanaka and Park, 1996). Silicon caused to be vertical in leaves (Elwad and Green, 1979), increase resistance to fungal diseases (Datnoff *et al.*, 1997) and caused to increase filled spikelets percentage and grain yield (Datnoff *et al.*, 2001). Silicon caused to increase total number of spikelets per panicle, filled spikelets percentage, 1000-seed weight, grain yield and to decrease lodging (Chaoming *et al.*, 1999). Silicon increases vegetative growth, dry matter and decreases transpiration and affects on qualitative and grain yield (Agarie *et al.*, 1993). Silicon is necessary for grain yield stability in rice (Mauad *et al.*, 2003). Silicon application showed direct growth in leaves, stems and plants sheaths specially in rice consequently silicon application improved light contributing inside of canopy (Savant *et al.*, 1997). Silicon uptake is different in varieties and parts of plants (Windslow *et al.*, 1997). Optimal silicon application increases tolerance of plants to salinity and drought (Bocharnikova and Matichenkov, 2008). Silicon improved plant height, inter-node length, fresh weight, bending moment, breaking resistance, lodging index, and increases tolerance of lodging in rice (Fallah, 2008). So according to silicon and potassium importance on growth and yield an experiment was carried out intitled: "Application of Nitrogen and Silicon Rates on Morphological and Chemical Lodging Related Characteristics in rice (*Oryza sativa* L.)."

## 2. Materials and Methods

The field experiment was conducted at Neka region in the north of Iran (Latitude 36° 46' N, Longitude 53° 13' E and altitude 4 m above sea level) in 2010. The minimum and maximum daily temperatures were obtained from the Dashte-Naz airport at Sari near to farm (Table 1). The soil was a loamy, with a sand, silt, and clay composition of 39, 39, and 22%, respectively. The soil chemical analysis indicates (Table 2). The experiment was carried out as split-plot in randomized complete block design with four replications. The rice cultivar was Tarom Hashemi that is one of medium grain yield, early-maturing, tall and sensitive cultivar to blast. Main plots were nitrogen rates in four levels including (0, 50, 100 and 150 kg ha<sup>-1</sup> N) applied as urea and sub plots were three silicon rates (0, 300 and 600 kg ha<sup>-1</sup>) applied as calcium silicate (total silicon oxide (SiO<sub>2</sub>)=62%), pH in water = 7.1 to 7.4, solubility in water negligible, 91% calcium silicate. Seeds were soaked for 12 to 24 h and emergence date was considered to be five days after sowing, when 90% of the seedlings showed coleoptile. Seeds spread with hands into an area of 10 m<sup>2</sup> (2 × 5). Sowing arrangement was 20 × 20 cm<sup>2</sup>. The water depth was controlled at 3 to 5 cm. Nitrogen, phosphorous and potassium fertilizers were used at the rates of N 150 kg ha<sup>-1</sup> urea, P<sub>2</sub>O<sub>5</sub> 100 kg ha<sup>-1</sup> triple superphosphate and K<sub>2</sub>O 100 kg ha<sup>-1</sup> potassium sulphate. Basal fertilizers were applied in all plots 1 day before transplanting. Nitrogen was applied by designing map arrangement. Nitrogen was applied three times (first at planting time, second at tillering time and third panicle immitation, using 33.3%, 33.3% and 33.3% in each stage in plot. Calcium silicate was used in the field 10 days before sowing. Phosphate and potassium fertilizers weren't used during of growth stages. Weeding was made 22 days after sowing by hand. 10 hills were randomly collected at harvesting time from each plot to measure grain yield and morphological

characteristics. 12 samples were used for measuring of plant height, stem length and panicle length. Grain dry weight from panicle in each plot was measured as final grain yield ( $\text{g m}^{-2}$ ). Lodging characteristic was observed when the flowering of the plant just started. Stem characters related to lodging were determined at 10 days after flowering. 12 samples were measured in each plot for lodging characteristics. Stem length (length between plant base and panicle neck node), and the lengths of the third inter-node ( $N_3$ ), and fourth inter-node ( $N_4$ ) from the top were measured. Bending moment (BM) at  $N_3$  or  $N_4$  inter-node was calculated using the following formula (Islam *et al.*, 2007).

$$\text{BMN}_3 = \text{Length from the lowest node of } N_3 \text{ to the top of panicle} \times \text{weight of this portion}$$

$$\text{BMN}_4 = \text{Length from the lowest node of } N_4 \text{ to the top of panicle} \times \text{weight of this portion}$$

The data were analyzed with SAS software. Mean comparison calculated by method of Duncan's multiple range tests at the 0.05 significance level.

### 3. Results and Discussion

Stem length had significant effect under nitrogen treatment in 5 % probability level and under silicon treatment 1 % probability level (Table 3). Maximum stem length (137.1 cm) was observed for 100  $\text{kg h}^{-1}$  nitrogen and minimum of that (122.7 cm) was for control (no nitrogen application). Stem length decreased 9.1 % by silicon application. Maximum stem length (135.3 cm) was obtained for control (no silicon application) and minimum of that (123.1 cm) was for 600  $\text{kg h}^{-1}$  silicon application (Table 4). Saadati and Fallah (1995) stated stem length had significant effect in tillering time by nitrogen contributing treatments in 1 % probability level.

Panicle length had significant effect under nitrogen treatment in 5 % probability level and under silicon treatment 1 % probability level (Table 3). Maximum panicle length (34.9 cm) was observed for 100  $\text{kg h}^{-1}$  nitrogen and minimum of that (28.2 cm) was for control (no nitrogen application). Panicle length decreased 30.18 % by silicon application. Maximum panicle length (35.8 cm) was obtained for control (no silicon application) and minimum of that (27.5 cm) was for 600  $\text{kg h}^{-1}$  silicon application (Table 4). Panicle length affects in grain yield by more transport of photosynthesis material (Dobermann *et al.*, 2002). Saadati and Fallah (1995) stated panicle length had significant effect in tillering time by nitrogen contributing treatments in 1 % probability level. Mobasser (2004) found that panicle length had significant effect by interaction year  $\times$  nitrogen amounts  $\times$  nitrogen contributing in 5 % probability level.

Plant height had significant effect under nitrogen treatment in 5 % probability level and under silicon treatment 1 % probability level (Table 3). Minimum plant height (154.6 cm) was noted for control (no nitrogen application) and maximum of that (168.7 cm) was for 100  $\text{kg h}^{-1}$  nitrogen. Plant height decreased 7.2 % by silicon application. Maximum plant height (168 cm) was obtained for control (no silicon application) and minimum of that (155.9 cm) was for 600  $\text{kg h}^{-1}$  silicon application (Table 4). Absorbed silicon is located on leaf area in rice and by this, decreased cuticle transpiration and it decreases plant elongation (Datnoff *et al.*, 2001). Silicon improved plant height, inter-node length and fresh weight in rice (Fallah, 2008). Yoshida *et al.* (1962) stated that plant height increased by increase of sodium silicate levels because of silicon effect on straight stature of leaves. Agarie *et al.* (1993) showed silicate fertilizers increased vegetative growth, dry matter and grain yield. Saadati and Fallah (1995) stated plant height had significant effect in tillering time by nitrogen contributing treatments in 1 % probability level.

Flag leaf length had significant effect under nitrogen treatment in 5 % probability level (Table 3). Maximum flag leaf length (37.00 cm) was observed for 150  $\text{kg h}^{-1}$  nitrogen and minimum of that (29.9 cm) was for control (no nitrogen application) (Table 4). Sedghi *et al.* (2007) reported that silicon had no significant effect on flag leaf length and this result supported our experiment. Pantuwan *et al.* (2002) stated that grain yield had a positive correlation and significant with flag leaf length.

3<sup>rd</sup> inter-node length had significant effect under nitrogen and silicon treatments in 1 % probability level (Table 3). Maximum 3<sup>rd</sup> inter-node length (36.7 cm) was observed for 150  $\text{kg h}^{-1}$  nitrogen and minimum of that (27.1 cm) was for control (no nitrogen application). 3<sup>rd</sup> inter-node length decreased 23.7 % by silicon application. Maximum 3<sup>rd</sup> inter-node length (38 cm) was obtained for control (no silicon application) and minimum of that (29 cm) was for 600  $\text{kg h}^{-1}$  silicon application (Table 4). Silicon improved inter-node length in rice (Fallah, 2008).

4<sup>th</sup> inter-node length had significant effect under silicon treatment in 1 % probability level and under interaction nitrogen  $\times$  silicon in 5 % probability level (Table 3). 4<sup>th</sup> inter-node length decreased 10.1 % by silicon application. Maximum 4<sup>th</sup> inter-node length (27.7 cm) was obtained for control (no silicon application) and minimum of that (24.9 cm) was for 600  $\text{kg h}^{-1}$  silicon application (Table 4). Minimum 4<sup>th</sup> inter-node length (23.3

cm) was obtained under interaction control ( $0 \text{ kg h}^{-1}$  nitrogen)  $\times$  silicon ( $600 \text{ kg h}^{-1}$ ) and maximum of that (29 cm) was for interaction  $100 \text{ kg h}^{-1}$  nitrogen  $\times$  control ( $0 \text{ kg h}^{-1}$  silicon) (Figure 1). Yoshida (1981) stated that inter-node length decreased by less than  $40 \text{ kg h}^{-1}$  nitrogen application. 3<sup>rd</sup> and 4<sup>th</sup> inter-nodes length are important for morphological characteristics related to lodging, because the most lodging were happened in this two areas, on the other hand 3<sup>rd</sup> and 4<sup>th</sup> inter-nodes length have positive correlation with lodging index (Islam *et al.*, 2007).

Bending moment of 3<sup>rd</sup> inter-node had significant effect under silicon treatment in 5 % probability level (Table 3). Silicon application had decreasing trend in bending moment of 3<sup>rd</sup> inter-node because of decrease in stem length, panicle length, plant height, 3<sup>rd</sup> and 4<sup>th</sup> inter-nodes length. Maximum bending moment of 3<sup>rd</sup> inter-node (2588 g cm) was obtained for control (no silicon application) and minimum of that (2180 g cm) was for  $600 \text{ kg h}^{-1}$  silicon application (Table 4).

Bending moment of 4<sup>th</sup> inter-node had significant effect under nitrogen treatment in 5 % probability level (Table 3). Maximum bending moment of 4<sup>th</sup> inter-node (4585 g cm) was obtained for control (no nitrogen application) and minimum of that (3652 g cm) was for  $100 \text{ kg h}^{-1}$  nitrogen application. Maximum and minimum of plant height and stem length were observed by  $100 \text{ kg h}^{-1}$  nitrogen and control (no nitrogen application) respectively, so most bending moment was also for these treatments (Table 4). Silicon contents in rice stem had a direct relation with lodging resistance (Ma and Yamaji, 2006). Mobasser *et al.* (2008) found that bending moment of 4<sup>th</sup> inter-node decreased by  $500 \text{ kg h}^{-1}$  silicon, but it didn't support our results.

Cellulose had significant effect under silicon treatment in 1 % probability level (Table 5). Cellulose increased 7.6 % by silicon application. Maximum cellulose (46.7 %) was noted for  $600 \text{ kg h}^{-1}$  silicon application and minimum of that (43.4 %) was for control ( $0 \text{ kg h}^{-1}$  silicon application) (Table 6).

Hemicellulose had significant effect under nitrogen treatment in 5 % probability level and under silicon treatment 1 % probability level (Table 5). Maximum hemicellulose (15.1 %) was noted for control ( $0 \text{ kg h}^{-1}$  nitrogen application) and minimum of that (12.8 %) was for  $150 \text{ kg h}^{-1}$  nitrogen application (Table 6). Hemicellulose increased 34.5 % by silicon application. Maximum hemicellulose (15.2 %) was obtained for  $600 \text{ kg h}^{-1}$  silicon application and minimum of that (11.3 %) was for control ( $0 \text{ kg h}^{-1}$  silicon application) (Table 6).

Lignin had significant effect under silicon treatment in 1 % probability level (Table 5). Lignin increased 26.3 % by silicon application. Maximum lignin (12.5 %) was obtained for  $600 \text{ kg h}^{-1}$  silicon application and minimum of that (9.9 %) was for control ( $0 \text{ kg h}^{-1}$  silicon application) (Table 6).

Grain yield had significant effect under nitrogen treatment in 5 % probability level (Table 5). Maximum grain yield ( $6063 \text{ kg h}^{-1}$ ) was observed for  $150 \text{ kg h}^{-1}$  nitrogen application and minimum of that ( $4350 \text{ kg h}^{-1}$ ) was for control ( $0 \text{ kg h}^{-1}$  nitrogen application) (Table 6). Pantuwan *et al.* (2002) reported that grain yield had positive correlation with flag leaf length. Chaoming *et al.* (1999) stated that silicon application increased grain yield by increase of spikelet number, filled spikelet percentage and 1000-seed weight. Mauod *et al.* (2003); Ma and Takashi, (1990); Mobasser *et al.* (2008) reported that grain yield increased by silicon application. Maximum grain yield was obtained by  $69 \text{ kg h}^{-1}$  nitrogen and nitrogen contributing in three times (transplanting time, panicle initiation and heading time) (Mobasser *et al.*, 2005). Grain yield increased by  $120 \text{ kg h}^{-1}$  nitrogen contributing in three times (transplanting time, tillering time and panicle initiation) (Singh *et al.*, 2002).

Straw yield had significant effect under silicon treatment in 5 % probability level (Table 5). Maximum straw yield ( $9846 \text{ kg h}^{-1}$ ) was observed for  $300 \text{ kg h}^{-1}$  silicon application and minimum of that ( $8558 \text{ kg h}^{-1}$ ) was for control ( $0 \text{ kg h}^{-1}$  silicon application) (Table 6). Agarie *et al.* (1993) showed that silicate fertilizers increased dry matters by effect on vegetation growth consequently increase grain yield. Matsuo *et al.* (1995) stated that silicon increased vegetation growth and dry matter. Sedghi *et al.* (2007) reported that grain yield increased by silicon application.

#### 4. Conclusions

According to results of this study, plant height, stem length, panicle length and third inter-node length were increased by increasing the nitrogen fertilizer. With increase of nitrogen, the fourth inter-node length had increased and it caused more lodging. Application of silicon increased lodging-related traits such as plant height, panicle length, third inter-node length and stem length, but the fourth inter-node length was reduced which is so important to breaking resistant. So there was no significant difference in the bending moment of fourth inter-node, although the bending moment of the third inter-node was significant and the use of silicon was increased the bending moment and it seems that use of silicon can be distributed between the third and fourth inter-node and had increased resistance to lodging.

## References

- Agarie, S., Uchida, H., Agata, W., Kubota, F., & Kaufman, B. (1993). Effect of silicon on growth, dry matter production and photosynthesis in rice. *Crop Pro and Improve Tech.*, 34, 225-234.
- Becker, M., & Asch., F. (2005). Iron toxicity in rice condition and management concepts. *J. Plant Nutr. Soil Sci.*, 168, 558-573.
- Belder, P., Spiertz, J. H. J., Bouman, B. A. M., & Toung., T. P. (2005). Nitrogen economy and water productivity of lowland rice under water irrigation. *Field Crop Res.*, 93, 169-185.
- Bocharnikova, E. A., & Matichenkov., V. (2008). Using Si fertilizers for reducing irrigation water application rate. *Silicon in Agriculture Conference*, Wild Coast Sun, South Africa, 26-31 October.
- Chaoming, Z., Jianfei, L., & Liping, Ch. (1999). Yield effects on the application of silicon fertilizer early hybrid rice. *Journal Article*, 2, 79-80.
- Datnoff, L. E., Dren, C. W., & Snyder, G. H. (1997). Silicon fertilizer for disease management of rice in Florida. *Crop Production*, 16(6), 525-531.
- Datnoff, L. E., Snyder, G. H., & Korndorfer, G. H. (2001). Silicon in Agriculture, *Studies in Plant Science*. Amsterdam: Elsevier, 403.
- Dobermann, A. C. D., Witt, D., Dawe, S., Abdulrachman, S., Gines, H. C., Agarajan, R., ... G. C. Simbahun. (2002). Site-specific nutrient management for intensive rice cropping system in Asia. *Field Crop Res.*, 74, 37-66.
- Elawad, S. H., & Green, V. E. (1979). Silicon and rice plant environment, a review of recent research. *Riv. Riso*, 28, 235-253.
- Fallah, A. (2008). Studies effect of silicon on lodging parameters in rice plant under hydroponics culture in a greenhouse experiment. *Silicon in Agriculture Conference*, Wild Coast Sun, South Africa, 26-31 October.
- Ghanbari-Malidarreh, A., Kashani, A., Nourmohammadi, Gh., Mobasser, H. R., Alavi, V., & Fallah, A. (2008). Effect of silicon application to nitrogen rate and splitting on agronomical characteristics of rice (*Oryza sativa* L.). *Silicon in Agriculture Conference*. Wild Coast Sun, South Africa, 26-31 October.
- Haefel, S. M., Naklang, K., Harnpichitvitaya, D., Jearakongman, S., Skulkhu, E., Romyen, P., Tabtim, S., & Suriya-Arunroj, S. (2006). Factor affecting rice yield and fertilizer response in rain fed lowlands of northeast Thailand. *Field Crop Res.*, 98, 39- 51.
- Islam, M. S., Peng, Sh., Visperas, R. M., & Ereful., N. (2007). Lodging-related morphological traits of hybrid rice in a tropical irrigated ecosystem. *Field Crops Res.*, 104 (2), 240-248.
- Jones, L. H., & Handreck., K. A. (1976). Silica in soils and plants. *Agron. J.*, 19, 107- 109.
- Koutroubas, S. D. & Ntanos., D. A. (2003). Genotype differences for grain yield and nitrogen utilization in indica and japonica rice under Mediterranean conditions. *Field Crop Res.*, 83, 251-260.
- Ma, J. F. (2004). Role of silicon in enhancing the resistance of plants to biotic and abiotic stresses. *Soil Sci. Plant Nutr.*, 50, 11-18.
- Ma, J. F., & Takahashi, E. (1990). Effect of silicic acid on phosphorus uptake by rice plant. *Soil. Sci. Plant. Nutr.*, 35, 227- 234.
- Ma, J. F., & Yamaji, N. (2006). Silicon uptake and accumulation in higher plants. *Trends Plant Sci.*, 11, 392-397.
- Matsuo, T., Kumazawa, K., Ishii, R., Ishihara, K., & Hirata, J. (1995). *Science of the rice plant* (No. 2, pp. 1240). Food and Agriculture Policy Research Center, Tokoyo, Japan.
- Mauad, M., Crusciol, C. A. C., Grassi Filho, H., & Correa., J. C. (2003). Nitrogen and silicon fertilization of upland rice. *Scientia Agricola*, 60, 761-765.
- Mengel, K., & Kirkby, E. A. (1987). *Principles of Plant Nutrition 4<sup>th</sup> Edition International Potash Ins.* (pp. 687) Bern, Switzerland.
- Mobasser, H. R. (2004). *Effect of amounts and contributing nitrogen on physiological characteristics in rice tarom hashemi cultivar*. Ph.D Thesis. (p.180). Sciences and researches Islamic Azad University, Tehran.
- Mobasser, H. R., Nourmohammadi, Gh., Fallah, V., Darvish, F., & Majidi, V. (2005). Effect of amounts and contributing nitrogen on grain yield in rice tarom hashemi cultivar. *Agriculture Science Magazine*, 11(3), 109-130.

Mobasser, H. R., Ghanbari-Malidareh, A., & Sedghi, A. H. (2008). Effect of silicon application to nitrogen rate and splitting on agronomical characteristics of rice (*Oryza sativa* L.). *Silicon in Agriculture Conference*, Wild Coast Sun, South Africa, 26-31 October.

Pantuwan, G., S. Fukai, M., Cooper, Rajatasereekul, S., & O'Toole, J. C. (2002). Yield response of rice (*Oryza sativa* L.) to drought under rainfed types. *Field Crop Res.*, 73, 169–180.

Saadati, N., & Fallah, A. (1995). *Consider of effective factors in rice ratoon grain yield tarom cultivar*. National Rice Research Institute, Amol.

Savant, N. K., Snyder, G. H., & Datnoff, L. E. (1997). Silicon management and sustainable rice production. *Adv. Agron.*, 58, 151-199.

Sedghi, A. H. (2007). Investigated effects of silicon rates and nitrogen splitting on rice var. Tarom Hashemi. *M.Sc. Thesis of Agronomy* (pp. 90). Islamic Azad University, Varamin, Iran.

Tanaka, A., & Park, Y. D. (1996). Significant of the absorption and distribution of silica in the growth of rice plants. *Soil Sci. Plant Nutr.*, 12, 25-28.

Windslow, M. D., Okada, K., & Correa-Victoria, F. (1997). Silicon deficiency and the adaptation of tropical rice ecotypes. *Plant Soil.*, 188, 239-248.

Yoshida, S. (1981). *Fundamentals of Rice Crop Science*. International Rice Research Institute, Los Banos, Laguna, Philippines.

Yoshida, S., Ohinishi, Y., & Kitagishi, K. (1962). Chemical forms, mobility and deposition of silicon in the rice plant, *Soil Sci. Plant Nutr.*, 8, 15-21.

Table 1. Weather condition in experiment site in rice growth stages at Neka in 2010

Variable	Jan.	Feb.	March	April	May	June	July	August
Minimum tem.	2.2	4.1	8.2	1.3	14.2	19.5	25	28
Maximum tem.	12.1	14.1	12.1	16.3	23.1	31.7	33	36
Evaporation (mm)	46	45	48	52	96	152	192	212
Precipitation (mm)	55	124	31	108	28	16	18	14

Table 2. Selected soil properties for composite samples at experimental site in 2010

Soil texture	K (ppm)	P (ppm)	N (%)	OM (%)	pH	EC ( $\mu\text{m}/\text{cm}$ )	Depth (cm)
Loamy	285	18.2	0.12	1.6	7.2	0.74	0-30

Table 3. Mean square of nitrogen and silicon rates on lodging related characteristics in rice

Sours Of Variation	DF	Plant height	Stem length	Panicle length	Flag leaf length	Third Inter-node length	Fourth Inter-node length	Third	Fourth	Inter-node number	Third	Fourth
								Inter-node diameter	Inter-node diameter		inter-node bending moment	inter-node bending moment
Replication	2	395.36	297.80	11.96	35.44	52.69	51.38**	1.72*	1.02	0.10	639630.33	942386.78
N rates (A)	3	426.39*	437.53*	97.67*	100.31*	187.83**	2.39	0.11	0.94	0.04	306432.99	1375119.00*
E (A)	6	123.50	129.90	13.05	16.22	15.64	4.08	0.25	0.83	0.03	266497.69	337915.22
Si rates (B)	2	442.72**	444.26**	205.03**	22.65	257.22**	25.26**	0.06	0.14	0.06	609847.00*	409321.19
A×B	6	24.38	18.86	4.72	45.92	16.72	6.06*	0.09	0.14	0.02	214078.96	333757.97
E	16	13.41	13.82	9.51	30.90	9.65	2.42	0.22	0.22	0.03	205495.47	830201.90
C.V. (%)	-	2.26	2.88	9.70	16.23	9.43	5.96	8.74	8.03	3.75	19.46	22.46

\*\* and \* respectively significant in 1% and 5% level.

Table 4. Mean comparison of nitrogen and silicon rates on lodging related characteristics in rice

Treatments	Plant	Stem	Panicle	Flag	Third	Fourth	Third	Fourth	Inter-node	Third	Fourth	
	height (cm)	length (cm)	length (cm)	leaf length (cm)	Inter-node length (cm)	Inter-node length (cm)	Inter-node diameter (mm)	Inter-node diameter (mm)	number	inter-node bending moment (g cm)	inter-node bending moment (g cm)	
<b>Nitrogen rates</b>												
control	154.6 b	122.7 b	28.2 b	29.9 b	27.1 b	25.6 a	5.4 a	6.0 a	4.9 a	2082 a	3652 b	
50 kg ha <sup>-1</sup>	157.1 ab	123.9 b	29.8 b	33.4 ab	31.5 b	25.7 a	5.5 a	6.0 a	4.9 a	2294 a	3922 ab	
100 kg ha <sup>-1</sup>	168.7 a	137.1 a	34.2 a	36.7 a	36.5 a	26.6 a	5.2 a	6.0 a	5.0 a	2467 a	4062 ab	
150 kg ha <sup>-1</sup>	166.4 a	132.7 ab	34.9 a	37.0 a	36.7 a	26.6 a	5.4 a	5.4 a	4.8 a	2474 a	4585 a	
<b>Silicon rates</b>												
control	155.9 c	123.1 c	27.5 c	32.7 a	29.0 c	27.7 a	5.3 a	5.9 a	4.9 a	2180 b	3913 a	
300 kg ha <sup>-1</sup>	161.3 b	129.0 b	32.1 b	35.1 a	31.8 b	25.8 b	5.4 a	5.7 a	4.8 a	2219 ab	3995 a	
600 kg ha <sup>-1</sup>	168.0 a	135.3 a	35.8 a	35.0 a	38.0 a	24.9 b	5.4 a	6.0 a	5.0 a	2588 a	4266 a	

Values within each column followed by same letter are not significantly different at Duncan ( $P \leq 0.05$ ).

Table 5. Mean square of nitrogen and silicon rates on chemical traits and grain yield and straw yield in rice

Sours Of Variation	DF	Cellulose	Hemi-cellulose	Lignin	Grain yield	Straw yield
Replication	2	17.69	3.53	0.25	1352368.44	53156653.69**
N rates (A)	3	90.56	8.33*	5.85	4685057.07*	2090775.81
E (A)	6	9.25	2.19	4.77	653297.19	4260062.14
Si rates (B)	2	34.19**	11.44**	21.58**	57204.78	5156484.78*
A×B	6	1.42	1.44	0.88	66275.07	1925948.56
E	16	4.11	0.82	1.18	65926.67	1369617.42
C.V. (%)	-	4.53	6.44	9.88	4.96	12.75

\*\* and \* respectively significant in 1% and 5% level.

Table 6. Mean comparison of nitrogen and silicon rates on chemical traits and grain yield and straw yield in rice

Treatments	Cellulose	Hemi-cellulose	Lignin	Grain yield (kg ha <sup>-1</sup> )	Straw yield (kg ha <sup>-1</sup> )
<b>Nitrogen rates</b>					
control	45.7 a	15.1 a	9.9 a	4350 c	8820 a
50 kg ha <sup>-1</sup>	43.8 a	14.1 ab	11.0 a	4941 bc	8842 a
100 kg ha <sup>-1</sup>	45.7 a	14.2 ab	11.3 a	5370 ab	9853 a
150 kg ha <sup>-1</sup>	44.0 a	12.8 b	11.8 a	6063 a	9202 a
<b>Silicon rates</b>					
0 kg ha <sup>-1</sup>	43.4 b	11.3 b	9.9 b	5118 a	8558 b
300 kg ha <sup>-1</sup>	44.3 b	13.7 b	10.6 b	5255 a	9864 a
600 kg ha <sup>-1</sup>	46.7 a	15.2 a	12.5 a	5170 a	9116 ab

Values within each column followed by same letter are not significantly different at Duncan ( $P \leq 0.05$ ).

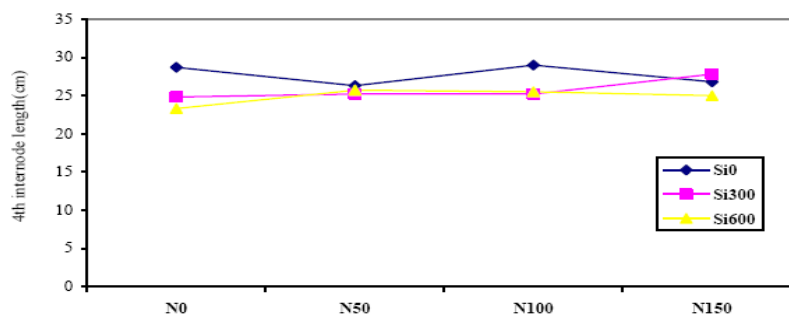


Figure 1. Interaction effects of nitrogen silicon rates on fourth internode length