Silicon Application and Nitrogen on Yield and Yield Components in Rice (*Oryza sativa L.*) in Two Irrigation Systems

Abbas Ghanbari-Malidareh

Abstract**—**Silicon is a beneficial element for plant growth. It helps plants to overcome multiple stresses, alleviates metal toxicity and improves nutrient imbalance. Field experiment was conducted as split-split plot arranged in a randomized complete block design with four replications. Irrigation system include continues flooding and deficit as main plots and nitrogen rates N_0, N_{46}, N_{92}, and N_{138} kg/ha as sub plots and silicon rates Si_0 & Si_{500} kg/ha as sub-subplots. Results indicate that grain yield had not significant difference between irrigation systems. Flooding irrigation had higher biological yield than deficit irrigation whereas, no significant difference in grain and straw yield. Nitrogen application increased grain, biological and straw yield. Silicon application increased grain, biological and straw yield but, decreased harvest index. Flooding irrigation had higher number of total tillers / hill than deficit irrigation, but deficit irrigation had higher number of fertile tillers / hill than flooding irrigation. Silicon increased number of filled spikelet and decreased blank spikelet. With high nitrogen application decreased 1000-grain weight. It can be concluded that if the nitrogen application was high and water supplied was available we could have silicon application until increase grain yield.

Keywords—Grain yield, Irrigation, Nitrogen, Rice, Silicon.

I. INTRODUCTION

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. Rice production in much of the world increasingly focuses on optimizing grain yield, reducing production costs, and minimizing pollution risks to the environment [1]. One of the inputs limiting rice production is N [2]. Nitrogen is essential to the rice plant, with about 75% of leaf N associated with chloroplasts, which are physiologically important in dry matter production through photosynthesis [3]. Rice plants require N during the vegetative stage to promote growth and tillering, which determines the potential number of panicles [4]. Nitrogen contributes to spikelet production during the early panicle formation stage, and contributes to sink size by decreasing the number of degenerated spikelets and increasing hull size during the late panicle formation stage. Nitrogen contributes to carbohydrate accumulation in culms and leaf sheaths during the preheading stage and in grain during the grain-filling stage by being a component of photosynthesis [4]. Information on the seasonal patterns of N uptake and its partitioning within the crop is useful in assessing the amount, timing, and method of N fertilization to prevent the occurrence of N deficiencies, as well as to prevent overfertilization, which contributes to increased lodging, poor grain filling due to mutual shading, and increased severity and incidence of diseases [5], [6]. The development of efficient N management protocols requires recognizing cultivar differences and the critical stages of crop growth where fertilization is necessary to avoid potential yield loss [7]. Increasing the N concentration in rice plants does not always increase grain yield due to diminishing returns, and it is not always optimal from an economic perspective. The excessive use of N poses potential adverse environmental and health concerns [8], and increases incidence of foliar pathogens and plant lodging. Furthermore, the management of the N nutrition of the rice crop is difficult because lowland rice crop culture is conducive to N losses through ammonia volatilization, nitrification denitrification, leaching, and runoff [9], which decreases the availability of N to the rice plant. Grain protein concentration is directly related to the N concentration in the grain [10]. With rice being the most widely consumed cereal in the world [11], it is important that rice breeders consider selecting genotypes with high efficiency in remobilizing N from vegetative parts to the grain or genotypes with high grain protein concentration. Increase grain yield can be attributed to an increase in the number of grains per panicle [12]. Spikelet fertility also has been associated with Si concentration in rice [13].

The lowest productivity of rice obtained in dryland systems is a consequence of a set of biotic and abiotic factors, among which are the occurrence of diseases, inadequate rainfall distribution in the main producing regions and little use of fertilizers and lime [14]. 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 [15] imparting mechanical resistance to the penetration of fungi, decrease in transpiration [15], and improvement of the leaf angle, making leaves more erect, thus reducing self-shading, especially under high nitrogen rates [16]. In terms of yield components, silicon increases the number of spikelets per panicle [12], [17], [18] spikelet fertility [18], and the mass of grains [19]. With regard to the number of panicles, results found in the literature are contradictory: Takahashi (1995) found an increase for this trait, while Ma et al. (1989) and Deren et al. (1994) did not observe significant increases.

Abbas Ghanbari-Malidareh is with the Islamic Azad University, Assistance professor of Department of Agronomy, Jouybar Branch, IRAN (phone: 124-336-3181; fax: 124-336-3190; e-mail: aghanbari@jouybariau.ac.ir).

Increase in yield with adding Si was attributed to a great number of grains per panicle, whereas weight per 1000 seeds and panicle per square meter exhibited less change [12]. Therefore, Si alone could improve grain yields of rice cultivars without further genetic improvements. Silicon helps plants to overcome multiple stresses including biotic and abiotic stresses [20]. For example, Si plays an important role in increasing the resistance of plants to pathogens such as blast on rice [21]. Silicon also alleviates the effects of other abiotic stresses including salt stress, metal toxicity, drought stress, radiation damage, nutrient imbalance, high temperature, and freezing [20], [22], [23]. Rice blast is particularly severe on rice grown in upland ecosystems due to increased susceptibility to blast by plants grown under non-flooded conditions [24], [25]. In the upland ecosystem, rice blast is controlled primarily through the planting of resistant cultivars and through cultural practices, such as the avoidance of excessive nitrogen fertilization and planting early in the season [26], [27]. Fungicides are also employed for the control of rice blast, but they are practical only in more industrialized countries due to their relatively high cost [24], [25]. Cultivars that are partially resistant to blast have also been utilized to control blast in irrigated lowland rice in tropical regions, but they have performed poorly in areas with greater blast severity, such as irrigated lowland rice in temperate regions and upland rice systems [28]. Among the elements deficient in these soils is silicon, which has been shown to be essential for the maximum growth and yield of a number of plant species, including *O. sativa* [29]-[30]. Increased levels of Si in the rice plant are associated with decreasing the levels of grain discoloration at harvest, and Si has been reported to reducing shattering of seeds in rice and to increasing the number and weight of filled grains [24], [29], [31], [32].

The search for new technologies that will enable the expansion of the producing area as well as productivity has featured the use of silicon fertilization in rice crops as a promising alternative. Nitrogen 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. Therefore, this paper aims to evaluate the effect of silicon and nitrogen rates on yield, yield components and grain protein content of rice.

II. MATERIALS AND METHODS

A. Review Stage

The field experiment was conducted in Agricultural Research Center in the north of Iran (36°37' N latitude, 53°11' E longitude) in 2007. The minimum and maximum daily temperatures were obtained from the Dashte-Naz airport at Sari near to farm. The soil was a loamy, with a sand, silt, and clay composition of 39, 39, and 22%, respectively. The soil chemical analysis indicates: pH at 7.68 and estimated the following nutrients in their available form: 0.14 (%) N, 33.8 g kg^{-1} P, 455 g kg^{-1} K, 3.0 g kg^{-1} Zn, O.M. = 2.46 %, O.C. = 1.43, S.P. = 58, E.C. = 0.5.

TABLE I

CLIMATIC DATA INCLUDE MEAN OF HUMIDITY, TEMPERATURE, RAINFALL AND EVAPORATION OF EXPERIMENTAL FARM.

Variable		Evaporation (mm)	Humidity (%)	Temperature (°C)	Rainfall (mm)
Months	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	0.1

The experimental design consisted of a completely randomized design, 2 × 4 × 2 split-split plot scheme, with four replicates. Factors experiment consisted of two irrigation systems, four nitrogen rates and two silicon rates. The rice cultivar was Mahalli Tarom that one medium-grain, early-maturing, tall and blast to sensitive cultivar. Irrigation system at two levels continues flooding irrigation and deficit irrigation systems as main plots and nitrogen rates in four levels N_0, N_{46}, N_{92}, and N_{138} kg N ha^{-1}, as sub plots and silicon rates in two levels Si_0 and Si_{500} kg/ha as sub-subplots corresponded to the application of 0, 100, 200 and 300 and 500 kg as urea (46% N) and Si kg^{-1}, equivalent to 0 and 800 kg SiO_2 ha^{-1}, utilizing as calcium silicate total silicon oxide (SiO_2)=62%, respectively; pH in water = 7.0 to 7.5; 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 hand-broadcast into an area of 10 m^2 (2 × 5). Density was seeding 400 seeds m^{-2}. The water depth was controlled at 2 to 3 cm. Temperature was controlled between the ranges of 20 and 25°C during day and 18 and 23°C during night. Sowing was performed on 26 April 2007, using 90% viable seeds. Fertilization at sowing consisted of 4 kg N for pot, plus 2 kg P (Triple super phosphate, 46% P_2O_5) and 3 kg

(Potassium sulfate, 46% K_2O). In plots, nitrogen topdressing was carried out 20 days after emergence, using 2 kg N in 10 m^2. Each unit consisted of a plot with internal dimensions of 2 × 5 m, containing 10 sowing rows 5 cm in length and spaced 20 cm apart. Rice density was transplanted at the rate of 50 plant m^{-2} on 26 may 2007. Silicate was incorporated into the soil 10 days before sowing. No phosphate and potassium fertilization used during the experiment. Nitrogen fertilization at sowing base on N treatments: Nitrogen topdressing was carried out 1, 32 and 54 days after transplanting, using 33.3%, 33.3% and 33.3% in each stage in plot. No foliar diseases occurred during the experiment. Weeding was made 22 days after emergence by hand. Permanent flood water was maintained at a 5-10-cm depth starting at fertilization following plant thinning. The tillers were counted. An area of 1 m^2 at the center of each plot was measured as an inner-plot. Prior to harvest, 10 hills were randomly collected from each of the inner-plots to measure shoot dry weights and yield components. The shoots and panicles of each of these plants were bagged individually and dried at 70°C for 1 wk. All the panicles from an individual plant were measured and averaged. Yield components were analyzed based on the measurements from these plants to determine the spikelets per panicle, fertility (i.e., percentage of filled spikelets per panicle), seed weight per panicle, seed weight per plant, kernel weight, and harvest index (i.e., seed weight per plant/total aboveground biomass per plant). Data were averaged over the 10 subsamples. Grain yields were estimated on a unit area basis. Plants were harvested in 16 Aug. 2007. One of the sowing rows was utilized to determine plant height, number of stalks and panicles per square meter, percentage of fertile stalks, numbers of filled and blank spikelets per panicle, spikelet fertility, mass of 1000 grains and productivity. All the plots were harvested in one week when most panicles had matured. Panicles were cut from the unsampled plants in each inner-plot. The numbers of panicles in each inner-plot were counted and recorded as panicle density (panicles m^{-2}), and oven-dried. Seed dry weights from panicles in each inner-plot were measured as final grain yield (g m^{-2}). Plants were carefully separated, counted, and recorded as plant stand (plants m^{-2}). Each plot was 5 m long and consisted of 10 rows, which were spaced 20 m apart the plant samples were subdivided into stems (culms and leaf sheaths), leaf blades, and panicles. All samples were dried at 70°C and dry masses were obtained after 48 h or until a constant mass was obtained. Dried and ground samples were sealed in plastic vials and stored at 4°C until analyzed for total N concentration. Silicon content of tissue samples was determined by first digesting 1 g of dried tissue, changed by Yoshida, (1975) [33], [34]. Results obtained from analysis expressed in absorbance units (mV), were converted to percentages of Sio_2 per kg of plant tissue [32], [34]. Harvest date was defined here as the date when about 80% of grain in the panicles was straw-colored and the grain in the lower portions of the panicle were in the hard-dough stage [26]. The data were analyzed using with SAS (version 6.12) and the procedures were described by SAS. The measurements of treatments were compared and grouped using Duncan's multiple range tests at the 0.05 significance level.

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III. RESULTS AND DISCUSSION

A. Yield

The irrigation system influenced dry matter yield. The flooding irrigation produced 14% more biological yield than the deficit irrigation, the most available water in the soil, the greatest dry matter yield. Effect of Silicon application on biological yield was detected. Whereas, grain yield had not significant difference between irrigation systems but, had significant differences nitrogen and silicon rates (Table 2). Flooding and deficit irrigation systems had the maximum and the minimum biological yields with 15723 and 13578 Kg/ha, and straw yields with 10485 and 8372 Kg/ha, respectively. Grain yield in flooding irrigation was 31 kg/ha higher than that of deficit system, which is not much regarding the much of water spent. Flooding irrigation system had the minimum harvest index (33) and deficit irrigation had maximum harvest index (38). N_{138} and N_0 had the maximum and the minimum grain yield (6128 and 4306 Kg/ha), biological yield (16751 and 12681 Kg/ha) and straw yields (10622 and 8374 Kg/ha), respectively. Harvest index was the minimum (34) in N_0 and was the maximum (36.6) in N_{138}. Significant difference was observed in biological and straw yields between the two silicon rates. Si_0 and Si_{500} had the maximum and the minimum biological yield with 15189 and 13991 Kg/ha, and straw yields with 9834 and 8901 Kg/ha, respectively. Si_{500} and Si_0 had the minimum (36) had the maximum harvest index (35), respectively (Table 3). It can be concluded that if the nitrogen rates is increase and if the needed water is supplied then we will have an increase in the grain yield. Therefore, there is not a possible reason for response dry matter to irrigation systems to detect visual differences because grain yield has not difference. Consequently, grain yield was increased by as much as 5% by Si applied at 500 kg/ha. There are two possible reasons for response grain yield to Si application in the soil with less available water (deficit irrigation). On one hand, rice is very accumulation species to deficit irrigation in Iran. On the other hand, it was possible to detect visual differences in rice submitted to the silicon application. Therefore, these results suggests that the water deficit treatment was sufficient to express the role Si plays on soil water deficit tolerance, agree results reported Agarie et al., (1998) and Ma et al., (2001) [40], [41].

Therefore, due to the indifference result of the two systems for the grains yield, we have an increase in the biomass amount and if the nitrogen feeding is not controlled then we will have economic breakdown and it makes the harvesting very difficult and causes the grains to fall. In the flooding irrigation because we have water abundant the minerals will be leaching, the water would be lost due to evaporation and transpiration and the root will not be developed. These results corroborates those obtained by Korndorfer et al., (2001) in a field work conducted, which a 17% increase in *B. decumbens* dry matter yield as observed with the surface application of 2,000 kg ha^{-1} calcium silicate [42]. When the results of grain yield are analyzed (Table 2), the highest yield occurred in the rate of 138 kg of N ha^{-1}. The application of high N rates reflects in yield improvement. High nitrogen rates stimulate tillering and the formation of new leaves, causing shading, a condition that favor diseases, lodging and reductions in productivity [43], [44]. Lodging or diseases were observed in N_{138}. The grain yield response to Silicon application can be related to the fact that silicon application may control the biotic and abiotic stresses. In other words, the fact that types of attack by pests or diseases during the experimental period occurred, that could affect the vegetative development of the rice, inhibited the positive response of Silicon. Therefore, the reduction in productivity with increasing nitrogen fertilization level probably resulted from the sum of several factors, particularly the increase in number of stalks (Table 4) and greater leaf development, which created shading conditions, diminishing the leaf area for active photosynthesis.

TABLE II
ANALYSIS OF VARIANCE (MEAN SQUARE) GRAIN YIELD (G.Y.), YIELD STRAW (S.Y.), BIOLOGICAL YIELD (B.Y.) AND HARVEST INDEX (HI) OF RICE IN IRRIGATION, NITROGEN AND SILICON LEVELS IN RICE

ANOVA	df	Grain yield	Biological yield	Straw yield	Harvest index
Rep.	3	0.25	18.96	16.31	148.5
Irri.(A)	1	0.01	41.12*	40.18	453.8
E (a)	3	0.59	3.80	4.04	90.4
N (B)	3	3.48**	23.32**	8.84**	6.4
A×B	3	0.02	0.65	0.52	15.1
E (b)	18	0.10	1.07	5.94	13.2
Si (C)	1	0.41**	9.46**	0.04**	15.7*
A×C	1	0.00	0.06	0.78	2.3
B×C	3	0.01	0.73	0.34*	6.4
A×B×C	3	0.00	0.35	0.25	5.0
E (c)	24	0.01	0.25	0.07	3.5
C.V.(%)	-	3	5	7	6

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

TABLE III
MEANS OF GRAIN YIELD, YIELD STRAW, BIOLOGICAL YIELD AND HARVEST INDEX OF RICE IN IRRIGATION, NITROGEN AND SILICON LEVELS IN RICE.

Treatments	Grain yield	Biological yield	Straw yield	Harvest index
	Kg/ha	Kg/ha	Kg/ha	%
I1	5238.3 a	15723.7 a	10485.3 a	33.3 a
I2	5206.7 a	13578.7 b	8372.0 a	38.3 a
N0	4306.7 d	12681.3 c	8374.7 c	34.0 a
N46	4951.7 c	13862.3 bc	8910.7b c	35.7 a
N92	5501.7 b	15308.3 ab	9806.7 ab	35.9 a
N138	6128.3 a	16751.0 a	10622.7 a	36.6 a
Si0	5090.0 b	13991.3 b	8901.3 b	36.4 a
Si500	5355.0 a	15189.7 a	9834.7 a	35.3 b

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

B. Yield components

Only nitrogen rates affected plant height ($P \leq 0.05$). An increase in plant height was observed as nitrogen rate increased. This result is agreement with findings obtained by Arf (1993), who observed increasing plant height with increasing nitrogen fertilization level [45]. Deficit irrigation increases plant height because there is competition among high tillers number. Whereas dry matter production was low, silicon application increases plant height because leaves and stem become more erect, thus reducing self-shading and increasing photosynthesis rate, especially under conditions of high population densities and high doses of nitrogen [16].

Number of stalk (Total tillers /hill) was decreased with flooding irrigation because increase of water height and induce decreasing the formation the smaller number of stalks of vegetative, vegetative bud, and increase vegetative phase but increase the percentage of fertile tillers because there is not under drought stress (Table 5). The number of stalks was associated to nitrogen rates ($P \leq 0.01$) (Table 4). As all experimental units were maintained with 50 plants/m^2 the observed increase in the number of stalks as a response to nitrogen fertilization were related to the cultivar stimulation to produce tillers, which is related to the greater nitrogen availability to plants. The increase in number of stalks, provided by the increasing nitrogen rates, contributed to increase the number of leaves, which could have caused shading, decreasing the area of active photosynthesis and diminishing the production of carbohydrates. This would not have been sufficient to ensure panicle primordium differentiation, panicle growth and stalk elongation. As a consequence, some stalks produced panicles, and others did not. The number of stalks does not constitute a yield component; neither does the percentage of fertile tillers. This variable expresses the percentage of stalks that actually produced a panicle, which increased with increasing rate of N [14]. The reduction in fertile tillers could be related to the greatest number of stalks produced as nitrogen fertilization increased, which could have caused a smaller number of vegetative buds to become reproductive. High nitrogen rates induce the formation of large number of stalks and leaves, creating unfavorable conditions to yielding, such as shading and lodging [44]. This behavior could be related to the fact that at the vegetative stage there was greater amount of nitrogen available for the plant, which increased tillering and number of panicles (Table 5).

Silicon would have little effect on the vegetative stage, at which this component is defined [17] and probably influence nitrogen content of vegetative organs. Percentage of fertile tillers was decreased with increasing rate of silicon that probably happened because Si contents in the plant were at a sufficient level for N content of plant to control thus reducing self-shading and increasing photosynthesis rate, especially under conditions of high doses of nitrogen [16]. Results found for silicon agree with those of [12], [17], [46], who also did not find significant differences for number of panicles, but contradict those obtained by Barbosa Filho (1987) and Takahashi (1995) [18], [47]. Since no organic molecule is known to be associated to silicon in plants [48], no statement can be made about the influence this element has on defining this component.

TABLE IV

ANALYSIS OF VARIANCE OF TILLER NUMBER, FERTILE AND STERILE TILLER NUMBER IN HILL, PANICLE NUMBER IN M^2 AND PLANT HEIGHT IN IRRIGATION, NITROGEN AND SILICON LEVELS IN RICE.

ANOVA	df	Tillers No / hill	Fertile tillers No / hill	Sterile tillers No / hill	Panicle No /m^2	Plant height cm
Rep.	3	8.34	6.37	0.14	89897 *	472.73
Irri.(A)	1	34.51 *	20.25 *	1.89	5413	36.00
E (a)	3	2.34	1.29	2.26	4885	152.25
N(B)	3	87.34 **	47.62 **	8.47 **	53665 **	319.23*
A×B	3	1.76	1.29	0.59	1264	79.42
E (b)	18	2.48	1.38	1.45	8941	85.98
Si(C)	1	1.26	2.25	0.14	2870	76.56
A×C	1	0.01	0.25	0.39	21	56.25
B×C	3	1.43	0.12	0.93	1140	114.73
A×B×C	3	0.18	0.20	0.43	1896	95.33
E (c)	24	1.47	0.60	0.49	3171	69.50
C.V.(%)	-	10.2	7.2	9.0	14.4	5.6

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

TABLE V

MEANS OF TILLER NUMBER, FERTILE AND STERILE TILLER NUMBER IN HILL, PANICLE NUMBER IN M^2 AND PLANT HEIGHT IN IRRIGATION, NITROGEN AND SILICON LEVELS IN RICE.

Treatments	Tillers No / hill	Fertile tillers No / hill	Sterile tillers No / hill	Panicle No / m^2	Plant height cm
Flooding	11.16 b	10.31 b	0.844 a	400.62 a	147.84 a
Deficit	12.63 a	11.44 a	1.190 a	382.23 a	149.34 a
N0	9.63 c	9.19 c	0.44 bc	341.95 b	142.69 b
N46	10.69 c	9.75 c	0.94 b	340.70 b	148.19 ab
N92	12.25 b	11.63 b	0.63 bc	438.15 a	150.19 a
N138	15.00 a	12.94 a	2.06 a	444.89 a	153.31 a
Si0	12.10 a	11.06 a	0.97 a	398.12 a	147.50 a
Si500	11.75 a	10.69 a	1.06 a	384.73 a	149.69 a

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

Nitrogen rates influence of panicles number/m^2. Nitrogen fertilization induced an increase of this variable, and the result is associated to a greater availability of nitrogen. This behavior is a consequence of the participation of N in structural functions of the plant, such as cell multiplication and differentiation, genetic inheritance and formation of tissues [49]. The number of panicles is defined during the period from ten days after transplanting to 15 days before the booting stage is visible, since it occurs as a direct function of the number of stalks depending, therefore, on genetic and environmental factors. Nitrogen rates increased tillers number and occurred with panicle number. These results agree with those reported by Arf (1993) [45], [47].

No significant difference between irrigation systems in total spikelets number / hill but there is difference in ear ($P \leq 0.05$). Flooding irrigation was higher than deficit irrigation. Whereas, deficit irrigation had high total and fertile tillers number. Silicon application influence number of spikelets per panicle ($P \leq 0.05$) also this agrees with results of Deren et al. (1994) and Barbosa Filho (1987), who verified a positive response to the application of this element. However, in opposition to results Carvalho (2000) and Mauad et al. (2003) did not observe any influence of silicon fertilization on this yield component. We measured spikelets per hill that there is not significant difference between two silicon treatments. However, tiller number and dry matter accumulation is the most important in spikelet formation in ear and hill and probably there is a correlation between two traits. Therefore, the total number of spikelets is determined during the reproductive stage [50]. The definition of this component begins with the differentiation of the vegetative into a reproductive bud, giving origin to the panicle primordium, and ends at booting stage [50]. Nitrogen fertilization induced an increase of this variable, and the result is associated to a greater availability of nitrogen, since N is related to the formation of tissues [49]. Therefore, nitrogen influence number of spikelets per panicle and N138 had the most spikelets per panicle and hill. When levels of nitrogen had increased obtain an increase in the number of spikelets per panicle. This result agrees with reports of Barbosa Filho (1987), but goes against those of Arf (1993), who did not obtain an increase as the levels of nitrogen increased. That probably happened because N contents in the soil were at a sufficient level for spikelets on panicle branches to differentiate particularly characterized by their poor response to nitrogen fertilization [14].

The number of blank spikelets also differed for nitrogen rates; higher values were recorded for the rate of 138 kg of N ha^{-1}(Table 7). The tendency of reduction observed in the rate of 92 kg of N ha^{-1} was probably caused by limiting sink and relation between sink and source for yielding higher production of photoassimilates. Nitrogen fertilization did modify spikelet fertility. Greater tillering caused shading, reducing the area of active photosynthesis, therefore reducing the production of assimilates, that otherwise would be directed to grain filling, and increasing the number of blank spikelets, consequently reducing spikelet fertility [14]. Significant differences were found for effect of silicon application on filled spikelets ($P>0.05$), agree with reports by Barbosa Filho (1987). In the condition, leaves become more erect, thus reducing self-shading and increasing photosynthesis rate, especially under conditions of high population densities and high doses of nitrogen [16]. The reproductive stage is the most affected by the absence of silicon, with a reduction of up to 40% in the number of blank spikelets, and 10% in the total number of spikelets per panicle [17]. In addition, in the case of rice, silicon is controlled disease and lodging especially during period grain filling. That caused plants to have enough carbohydrates to fill up all spikelets produced as the nitrogen fertilization level increased, contributing to increase the number of blank spikelets and to decrease fertility, lowering productivity. Spikelets fertility expresses the percentage of spikelets that turned into grain. This yield component is dependent upon pollen grain meiosis, anthesis, pollination, fertilization and carbohydrate translocation, and is influenced by prevalent environmental conditions, especially around 10 days before and after flowering, as well as by excessive rates of nitrogen fertilizers [50].

TABLE VI

ANALYSIS OF VARIANCE SPIKELET NUMBER IN EAR AND HILL, FILLED SPIKELET NUMBER IN EAR AND HILL, BLANK SPIKELET NUMBER IN EAR AND HILL AND 1000 GRAIN WEIGHT IN IRRIGATION, NITROGEN AND SILICON LEVELS OF RICE.

ANOVA	Df	Spikelets No./ hill	Spikelets No /ear	Filled Spikelets No./ hill	Filled spikelets No/ear	Blank spikelets No/ hill	Blank spikelets No/ear	1000-grain weight
Rep.	3	116594	777.29	47224	1026.6	18283	91.2	11.0
Irri.(A)	1	62875	4419*	44205	961.0*	1640	382.3*	4.0 *
E (a)	3	94192	627.95	80724	54.9	790	39.5	0.3
N (B)	3	1008006 **	6720.0**	482471 **	10488.5**	103660 **	5183.0**	0.9
A×B	3	16260	108.40	3488	75.8	6250	312.5	1.9
E (b)	18	16710	111.40	10711	232.8	5553	277.7	2.2
Si (C)	1	10	852.5*	3422	174.4*	3813	190.7*	0.2
A×C	1	390	2.60	39	0.8	676	33.8	0.1
B×C	3	1434	9.56	1361	29.6	970	458.6*	0.5
A×B×C	3	15855	105.70	10329	24.5	1000	50.0	1.4
E (c)	24	13178	87.85	12194	265.1	564	28.2	2.1
C.V. (%)	-	12.4	18.3	14.4	18.9	15.2	17.9	6.5

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

TABLE VII

MEANS OF SPIKELET NUMBER IN EAR AND HILL, FILLED SPIKELET NUMBER IN EAR AND HILL, BLANK SPIKELET NUMBER IN EAR AND HILL AND 1000-GRAIN WEIGHT IN IRRIGATION, NITROGEN AND SILICON LEVELS IN RICE.

Treatment	Spikelets No./ hill	Spikelets No. /ear	Filled Spikelets No./ hill	Filled spikelets No / ear	Blank spikelets No./ hill	Blank spikelets No. / ear	1000-grain weight (g)
Flooding	a 955	92.7 a	a 793	76.9 a	a 161	15.6 a	22.68 a
Deficit	a 893	78.1 b	a 741	64.8 b	a 151	13.2 b	22.14 a
N0	c 640	69.7 d	d 563	61.3 c	c 77	8.4 d	22.57 a
N46	b 867	89.1 b	c 721	73.9 ab	b 146	15.1 b	22.55 a
N92	b 741	81.1 c	b 807	69.4 b	b 134	11.5 c	22.47 a
N138	a 1248	96.5 a	a 979	75.7 a	a 268	20.7 a	22.05 a
Si0	a 925	83.6 b	a 760	68.7 b	a 164	14.8 a	22.47 a
Si500	a 924	86.4 a	a 775	72.5 a	b 149	13.9 b	22.35 a

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

Silicon seems to play a role on spikelet fertility, but no mechanism or action site through which silicon would act on this yield component is known [17]. Only, Effect of silicon rates on spikelet fertility in ear was observed in the present study but there is not in hill.

The number of blank spikelets was influenced by the N×Si interaction. As it was observed at the nitrogen rates, increasing levels of silicon fertilization change the number of blank spikelets. Notwithstanding, N rates was affected by the application of Si, resulting in a decrease in the number of blank spikelets, only in the lowest (N_0) did not affected. Such effect can be explained by improvement in plant architecture (Deren et al., 1994), which results in smaller opening of the leaf angle verified visually in the present work. Also silicon application decreased lodging and ear blast (data did not see). 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 [16]. However, at the rate of 138 kg N ha^{-1}, number of blank spikelets was decreased with increasing of silicon fertilization (Table 8).

Grain thousand weights (GTW) were increased significantly with increasing irrigation ($P \leq 0.05$). 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. 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 the maximum and minimum grain thousand weights with 22.57 and 22.05 g, respectively, it was not significantly at P=0.05.

Nitrogen increased spikelets number at high nitrogen. Whereas 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., (2003); Arf (1993), who verified a reduction in the mass of 100 grains for cultivar Rio Paranaíba in the order of 0.0011g per kg of applied nitrogen. However, they diverge from results of Stone et al. (1999) [51], who did not observe differences for the mass of 1,000 grains as nitrogen rates increased. In silicon treatment, grain thousand weights was Si_0 more than Si_{500} although, it was not significantly at P=0.05. Silicon fertilizer application decreased blank spikelets number in rice and 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. Fallah et al., (2004) missing indicated that silicon significantly increases percent spikelet filling, resulting in improved grain yield. Silicon deposition was on rice grain hulls [52]. The increase in grain mass would be the greatest deposition of silicon on the paleae and lemmas, as reported by Balastra et al (1989). Thus, grain thousand weights each cultivar is constant trait but, in environment conditions and stress could be decrease or increase. Mauad, et al., (2003) indicated the grain mass is a quite stable variety trait, and depends on hull size, determined during the two weeks that precede anthesis, and on caryopsis development after flowering.

TABLE VIII
MEANS OF N×SI INTERACTION ON SPIKELET NUMBER, FILLED SPIKELET NUMBER IN EAR AND FERTILE SPIKELET PERCENTAGE IN IRRIGATION, NITROGEN AND SILICON LEVELS IN RICE.

Treat.	Spikelets Number /ear	Filled spikelets No. /ear	Blank spikelets No. /ear	Fertile spikelets /ear %
N0Si0	68 c	59 d	8.1 d	86.0 a
N0Si500	72 c	63 c	8.7 d	87.5 a
N46Si0	87 ab	71 b	16.2 b	81.6 b
N46Si500	98 a	77 a	13.7 bc	78.6 b
N92Si0	80 b	68 bc	12.0b c	85.0 a
N92Si500	82 b	71 b	11.0b c	86.6 a
N138Si0	95 ab	74 ab	21.1 a	77.9 b
N138Si500	98 a	77 a	20.4 a	78.6 b

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

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 [15]. When a given plant organ is developing, transpiration tends to become more intense, and consequently silicon deposition tends to be higher. This result contradicts findings by Balastra et al. (1989) and Deren et al. (1994), who also observed increasing grain mass with increasing levels of silicon fertilization. Mauad, et al. (2003) showed that probably because increase silicon rate the greatest number of spikelets produced. Therefore, it depends on carbohydrate translocation, in the first seven days, to fill the hull in the direction of its length, and in the seven days that follow, to increase in width and thickness [50].

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