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Fertilization of N and Si to Sustain Grain Yield and Growth Characteristics of Rice after Winter Greenhouse Water-melon Cropping

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ABSTRACT : In Korea, silicate fertilization (SF) is being practiced every four years to enhance rice production. However, the relationship between nitrogen (N) and SF in view of growth characteristics and grain yield of rice has not been examined after watermelon cropping in plastic film house. This study was carried out to identify useful critical N and Si fertilizer levels to sustain grain yield and to improve N use efficiency for rice. The watermelon-rice cropping system has maintained for three seasons in each year from 1998 to 2001 by farmer before this experiment. Experiments on N and Si fertilization levels were evaluated with Hwayoungbyeo (*Oryza sativa* L.) in 2002 and 2003 at Uiryeong, Korea. The goal of this experiment was to find out the optimum N and Si levels to sustain rice yield by reducing excessive N fertilizer in watermelon-rice cropping system. Nitrogen fertilization (NF) levels were three (0, 57, 114 kg ha^{-1}; 0, 50, 100% of conventional NF amount) and five (0, 25, 50, 75, 100%) in 2002 and 2003, respectively, and combined with three SF levels (70, 130, 180 mg kg^{-1}; 100, 150, 200% which were adjusted with Si fertilizer in soil) were evaluated for the improvement of N and Si fertilization level in both years. Rice yielded 3.98-5.95 and 2.84-4.02 t/ha in 2002 and 2003, respectively. Our results showed the combinations of 50% and 100% of N with 200% level of Si produced the highest grain yield in both years, respectably. The grain yield was greatly improved in plot of N25% level when compared to conventional NF (N100%) in 2003. In conclusion, NF amount could be reduced about 50% compared to recommended level by specific fertilization of N and Si combination levels for rice growing and grain yield after cultivation watermelon in paddy field.

Keywords: rice, silicate, nitrogen, fertilizer, cropping system, greenhouse

In Korea, the area of cropping vegetable in plastic film house was 3,727 ha in 1970, however, it has been increasing annually and reached 90,672 ha in 2000 (Ministry of Agriculture and Forestry, 2001). In general, most farmers do not prefer the cultivating rice after cropping vegetables in plastic film house because of difficulties in removing, transporting and reinstalling the plastic film house, but rice cultivation after vegetable cropping has many beneficial effects for vegetable crop such as elimination of accumulated salts and maintaining anaerobic soil condition during rice cultivation which will eliminate soil sickness (Park *et al.*, 2004). However, farmers apply fertilizers by conventional fertilization level which may cause lodging and reduce rice yield owing to recommend the fertilization by soil testing for rice after cultivating vegetable under plastic film house. Systematic fertilization model is essential for reducing production cost and increasing grain yield for rice after vegetable cropping in paddy field. Especially, Si for rice is one of the most useful elements for stable rice production by improving lodging resistance, insect-pest resistance and grain yield. Therefore, Si application could be called as Si fertilization. Si fertilization is recommended for improving grain yield and grain quality for rice of single or rice-wheat and rice-barley cropping systems (NAIST, 1983; Kang *et al.*, 1997). In addition, Si fertilizer can remarkably reduce insect- and pest diseases (Datnoff *et al.*, 1991; Deren *et al.*, 1994; Nam *et al.*, 1995; [b]Cho *et al.*, 2006). Si fertilizer also improves photo reception rate, lodging resistance and water use efficiency by improvement erected leaf blade type (Takahashi *et al.*, 1990; Ma and Takahashi, 1991). Korean government has supported Si fertilizers every four years for farmers who cultivate rice (NAIST, 1984). Si is supplied through irrigation water or Si fertilizer and rice absorbs 1-13% of Si which can not increase without fertilization (Juo and Sanchez, 1986; Foy, 1992). Rice absorbs Si mostly from soils by the lateral roots (Ma *et al.*, 2001) and it indicates that Si is mostly absorbed between maximum tillering stage and heading stage having maximum lateral root numbers and length.

The fertilization model has been developed by multiple nutrient factors which used SiO_2/OM (organic matter) in paddy field (Lee, 1986) and modified as "12.74 – 1.52 (OM) + 0.028 (SiO_2 gained by analysis)" (RDA, 1999). The more increase of Si fertilization in rice single or rice-wheat/barley

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cropping systems recommend the more N fertilizer. The amounts of chemical fertilization and compost are increasing year by year for vegetable cultivated in plastic film house, however, there is no N recommendation by soil testing for high compost or fertilized paddy field.

The maximum grain yield might be possible by adjusting 130-180 mg/kg of SiO_2 in the soil (Lee *et al.*, 1987), however, there is no study for integrated evaluation of rice growth characteristics and grain yield in greenhouse vegetable-rice cropping system with combination of N and Si fertilization levels. Therefore, the purpose of this experiment was to find out the suitable combination of N and Si fertilization levels in aspects of growth characteristics and grain yield of rice in greenhouse watermelon-rice cropping system.

MATERIALS AND METHODS

Site details

The data in this paper were obtained from experiments conducted between 2002 and 2003 at Uiryeong (35°25'N, 128°22'E) in southern part of Korea. The soil was a sandy loam (68.0% sand, 27.5% silt and 4.5% clay) with a pH of 5.9 (1:5, soil : water); mean available P_2O_5, 350 mg kg^{-1}; exchangeable potassium, 1.14 $cmol^+$ kg^{-1}; exchangeable Calcium, 2.6 $cmol^+$ kg^{-1}; exchangeable magnasium, 1.1 $cmol^+$ kg^{-1}; available SiO_2, 75 mg kg^{-1}; and 2.3% organic matter. Chemical analyses of soil were followed by NIAST(1988).

Experimental design and treatments

The experiment was conducted by a randomized block design with three replications in 2002 and 2003. The treatments were three levels of N (N0%, N50%, N100%: 0, 57, 114 kg ha^{-1}) and three levels of SiO_2 (Si100%, Si150%, Si200% of recommendation: 75, 130 and 180 mg kg^{-1} with Si fertilizer 0, 520, 790 kg ha^{-1}, respectively). The fertilization amount was followed by RDA (Rural Development Administration of Korea) model:

N-fertilization amount (kg ha^{-1}) = 127.4 - 15.2 [OM] + 0.28 [SiO_2]

Where, OM: organic matter (%) content in top soil

SiO_2: available silicate content (mg kg^{-1})

Si application (kg ha^{-1}) = ((Target uptake - Natural supply) – (Si concentration in soil (mg kg^{-1})) × 3.8

Applied silicate fertilizer, calcium silicate: pH 9.7-10.7, contained 25% of SiO_2, 40% of Al_2O_2, 40% of CaO and 2% of MgO.

The experimental design in 2003 was same with 2002, and N25% and N75% treatments were added to determine critical N level.

Each subplot size was 30 m^2 (5 m × 6 m) and the main plot treatments were three levels of N and Si fertilization rate and followed by the recommendation for rice cultivation in RDA of Korea. Phosphate (P: calcium super phosphate) and potassium (K: potassium chloride) fertilizers were applied at 30 and 21 kg ha^{-1} as basal application, respectively. For the top-dressing, N was applied at 17 and 34 kg ha^{-1} in N50% and N100% plots, respectively, and K was applied with 7 kg ha^{-1} at panicle initiation stage (25 days before heading) by urea and potassium chloride.

Cultural practice, fertilization methods and rice cultivation

Watermelon was cultivated in plastic film house during the seasons of winter (November- February) and spring (March-May or Mid. of June), and plastic film was eliminated during rice cultivation. Compost contained 3.5-4.0% of N and other nutrients was applied 30-40 t ha^{-1} for watermelon cultivation. Watermelon-transplanted rice cropping system has been maintained on the site for 3 and 4 years in 2002 and 2003, respectively.

Field was tilled at dry condition after harvesting watermelon and each plot was separated by levee. Fertilizer was applied on the soil surface followed by rotary tilled by 15 cm-soil depth for well mixing applied fertilizer. After mixing dry soil, water was irrigated at 5cm level. Thirty days old rice was transplanted at 2-3cm depth after two days of water irrigation. Rice cultivar, Hwayeongbyeo was grown for thirty days in the seedbed and it was planted using transplanter by 30 × 15cm distance and 5-6 seedlings per hill at 2-3 cm soil depth.

Herbicide (Nonanme: soil-applied herbicide) was sprayed after seven days of rice transplanting to control the growth of initial growing weeds. Conventional cultivation methods were followed for all other managements.

RESULTS AND DISCUSSION

Changes in rice growth

In 2002, plant height was positively affected by NF and SF level, however, SF was not affected in 0%N level (Fig. 1). In 2003, plant height was not affected by NF amount (Fig. 1) but SF increased plant height in all N treatments with the biggest in Si200% of all Si treatments. The difference in plant height was not observed in N and Si treatments until 30 days after transplanting (DATP), however, it was

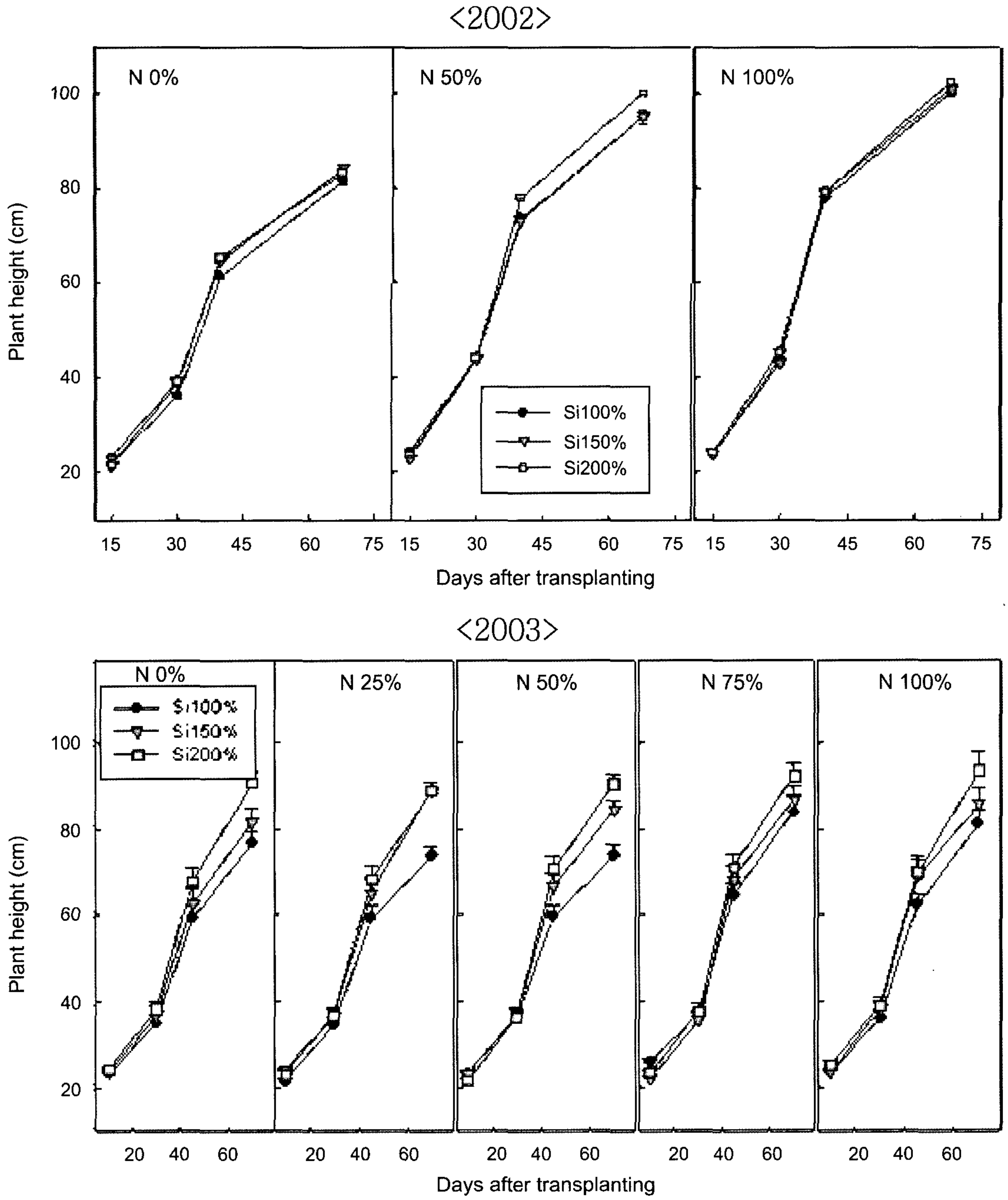

Fig. 1. Changes in plant height of rice plant as affected by N and Si fertilization level in field experiment in 2002 and 2003. Bars indicate the S.E. of the mean.

greatly different with progress of plant growth. The plant height for all treatments was shorter in 2003 than in 2002, because of the uncommonly low temperature in 2003, which might have reduced N uptake by decreased mobilization of organic N.

Changes in tiller number of rice

The increasing pattern of tiller numbers was similar in all N treatments in 2002, with the biggest increase occurring until 30 DAPT (Fig. 2). Tiller number was greatly increased with increasing N level in 2002, and SF was greatly increased tiller numbers in N0% and N50% treatments in all measured stage, however, tiller number was the greatest in Si100% in N100%. In 2003, tiller numbers were the greatest at 45 DATP (Fig. 2), however, NF a little increased plant height but it had little effect compared to 2002. In 2003, tiller number changing pattern was maximized at 45 DATP

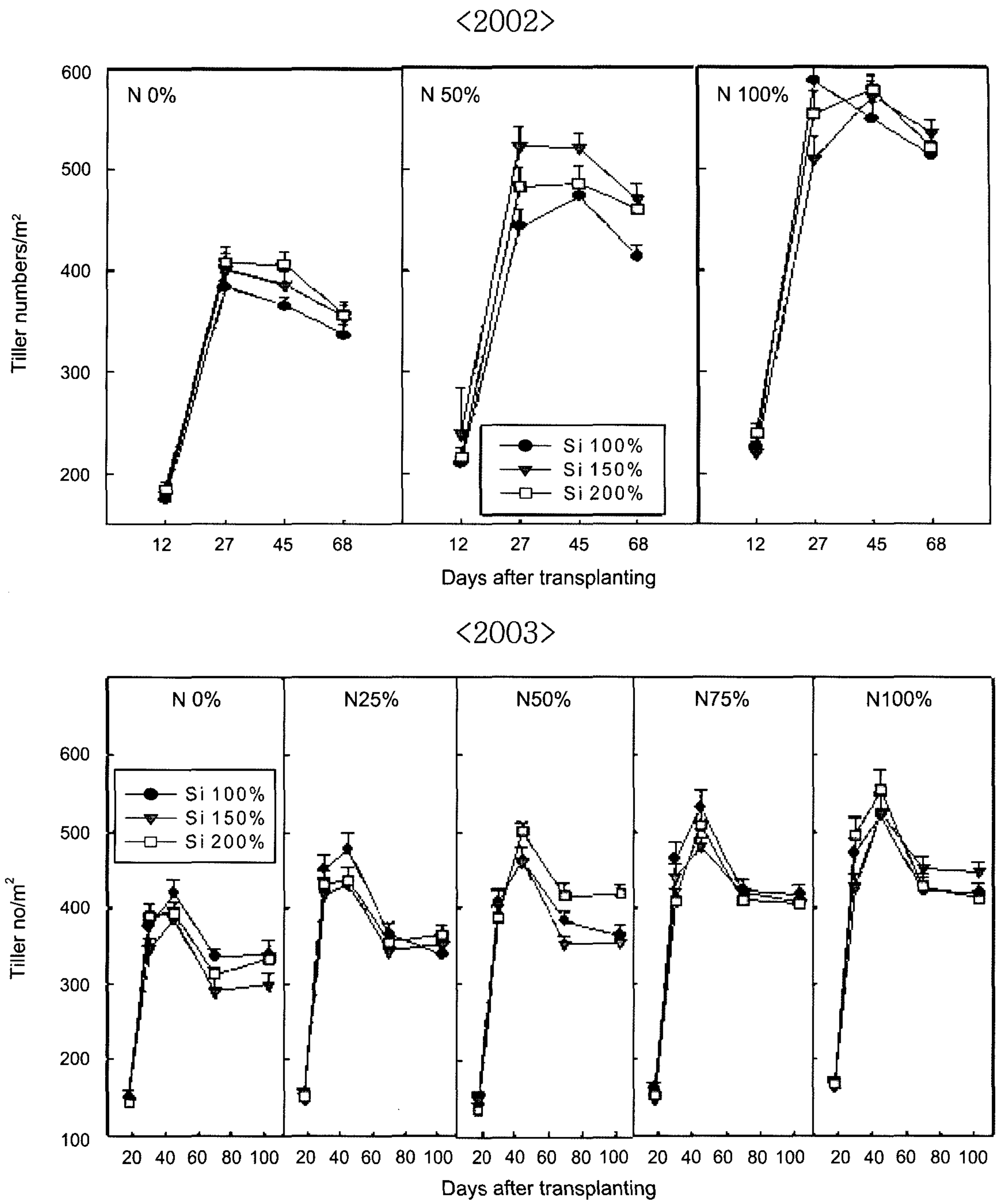

Fig. 2. Changes of tiller numbers m^{-2} as affected by N and Si fertilization level in watermelon-rice multi-cropping systems in 2002 and 2003. Bars indicate the S.E. of the mean.

then it greatly decreased which might be related with reduced photosynthetic activity by uncommon cool temperature. NF level was little effect on tiller numbers in 2003. Tiller numbers of three SF levels at 68 DATP and 100 DATP in 2002 and 2003, respectively, were not related with panicle numbers (Fig. 2 and Table 1, 2). The main reason might be related with unproductive tiller numbers which contribute to improving panicle size and reproductive growth of effective tillers.

Changes of leaf greenness

The greenness of fully grown uppermost leaves was higher in N fertilized plots until 70 DATP in 2002 (Fig. 3). However, leaf greenness was just greater in N100% than N50% after 30 DATP but they were no significance before 30 DATP. In 2002, SF greatly increased the leaf greenness at 18 and 28 DATP, however, it was low at 68 DATP in N0%

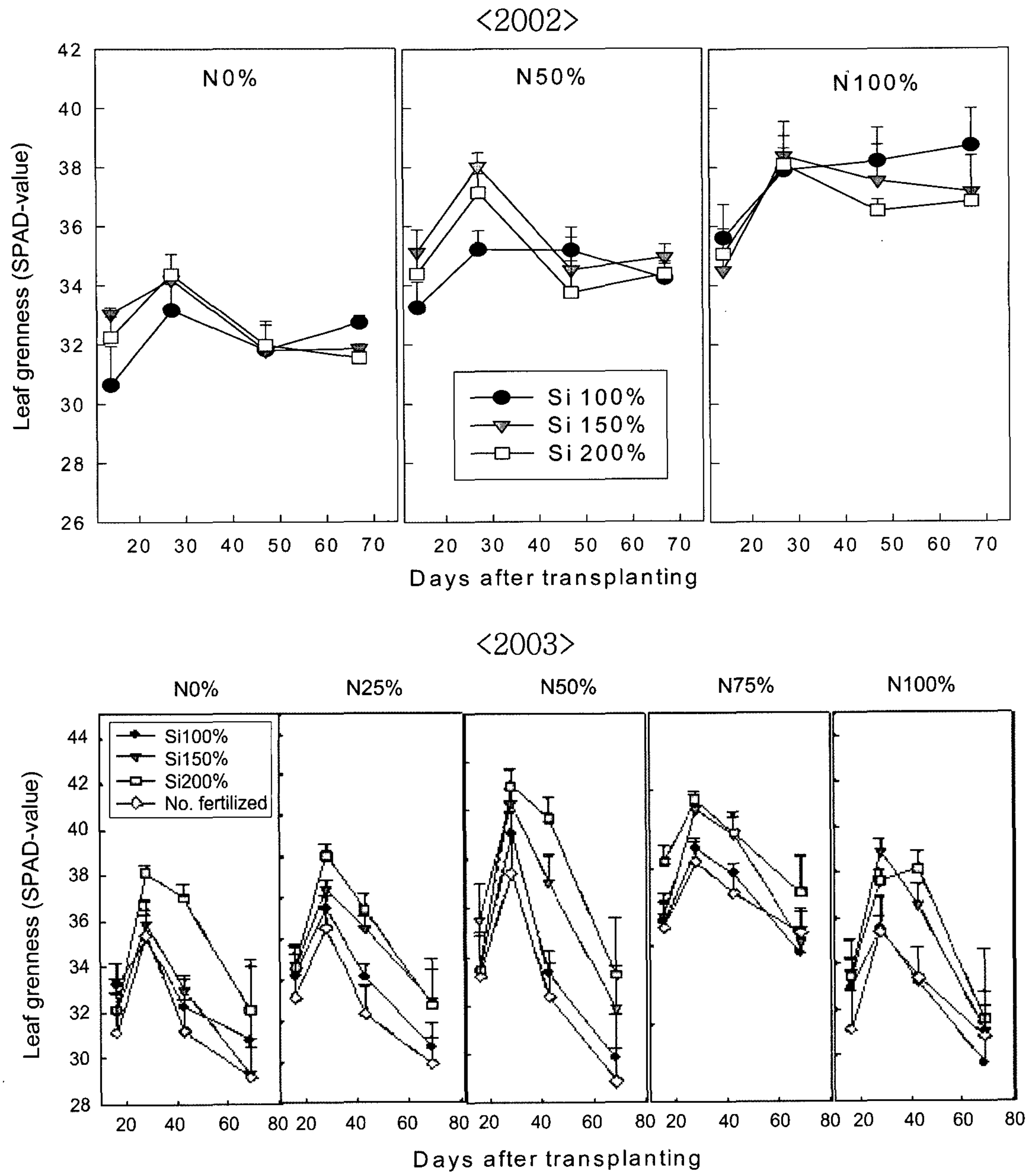

Fig. 3. Changes of SPAD-value as affected by N and Si fertilization level in watermelon-rice multi-cropping systems in 2002 and 2003. Bars indicate the S.E. of the mean.

and N100% plots or similar at 45 DATP in N0% plot. It was similar at 28 DATP in N100% which was top level in the all growth duration. In 2003, the leaf greenness was not greatly affected by NF amount and it was similar between N50% and N75% at 28 and 38 DATP (Fig. 3). In 2003, the leaf greenness was the greatest at Si200% in N0, N25, N50 and N75% during all measured stage and maintained high level in N100%. So, SF greatly effected increasing of leaf greenness in all N treatments. The leaf greenness was maximum level at 30 DATP in all N and Si combination treatments.

Grain yield and yield components of rice

In 2002, NF and SF derived increase of panicle number (Table 1). The number of panicles was the greatest in maximum fertilized N and Si plot. Consequently, increased panicle numbers more increased grain yield despite of decreasing ripened grain ratio. This was similar to previous report (Kang *et al.*, 1997). In 2003, NF a little increased panicle numbers, however, SF greatly increased panicle numbers in N50, N75, and N100% plots (Table 2).

In 2002, NF increased the number of spikelets per panicle, however, SF affected little in all N treatments except N100% (Table 1). In 2003, NF increased spikelet numbers in N50 and N100% but it was little effect on other N treatment (Table 2), however, SF increased spikelet numbers in N25 and N50% in Si150 and Si200% treatment in 2003.

In 2002, NF increased ripened grain ratio (%) in all N treatments (Table 1) but Si200% was only effective in N50%,

Table 1. Yield and yield components of rice as affected by N and Si fertilization level in watermelon-rice cropping systems in 2002.

N application	Si (%)	Panicles (no. m^{-2})	Spikelets panicle^{-1}	Ripened grain (%)	1,000-grain weight (g)	Rice yield (t ha^{-1})
	100	306	81.5	86.2	24.9	3.98bc†
0	150	306	81.1	86.0	25.4	4.23b
	200	321	81.8	77.9	24.6	4.69a
Average		311	81.5	83.4	25.0	4.30
	100	369	87.1	86.1	25.4	4.72c
50	150	349	88.8	94.4	25.1	5.08b
	200	338	84.6	96.1	24.6	5.95a
Average		352	86.8	92.2	25.0	5.25
	100	385	91.1	89.0	25.3	4.98b
100	150	362	91.8	88.0	24.8	4.70bc
	200	400	92.7	81.2	24.5	5.50a
Average		382	91.9	96.1	24.9	5.06

†Values followed by the same letter in the same column do not differ significantly (*P*>0.05).

Table 2. Yield and yield components of rice as affected by N and Si fertilization level in watermelon-rice cropping systems in 2003.

N application	Si (%)	Panicles (no./m^2)	Spikelets panicle^{-1}	Ripened grain (%)	1,000-grain weight (g)	Rice yield (t ha^{-1})
	100	580	54.9	87.8	24.3	2.84b†
0	150	453	58.8	84.3	24.7	3.09a
	200	520	53.0	86.0	25.4	2.87b
Average		518	55.6	86.1	24.8	2.94
	100	550	53.9	83.8	24.8	3.57c
25	150	500	61.1	83.8	24.7	3.71ab
	200	517	63.8	81.5	25.2	3.90a
Average		522	59.6	83.0	24.9	3.89
	100	537	54.3	80.3	24.1	3.07b
50	150	593	57.1	77.9	24.2	2.67c
	200	570	56.6	78.6	24.0	3.57a
Average		567	56.0	79.0	24.1	3.10
	100	577	59.1	69.1	22.2	3.49c
75	150	597	52.1	81.0	24.3	4.02a
	200	603	56.5	71.6	23.8	3.81b
Average		592	55.9	73.9	23.5	3.77
	100	583	64.6	75.4	24.0	3.49c
100	150	590	55.0	73.2	23.7	3.98ab
	200	620	63.0	67.6	24.9	4.19a
Average		598	60.9	72.1	24.2	3.89

†Values followed by the same letter in the same column do not differ significantly (P>0.05).

and consequently, grain yield was high despite of decrease in panicle numbers, spikelet numbers and grain weight. In 2003, NF negatively effects on ripened grain ratio (Table 2) and SF was only effective in N75% plot but no effect or lower than Si0% treatment in other N levels.

In 2002, NF was not affected on 1000 grains weight in all N treatments but SF negatively affects on all N treatment except a little high in N0% with Si100% (Table 1). In 2003, NF had no effect on grain weight but SF positively effected grain weight in all N treatments except N50% (Table 2).

In 2002, grain yield was higher in N50% than N100% which was mostly affected by increased grain ratio by SF (Table 1). SF was increased grain yield in all N treatments and this result was similar to the result of increased grain yield of rice cultivated in Si contained solution cultivation (Kang and Stutte, 1982). However, Si 150% was not effective for grain yield in N100% by the lower panicle numbers. In 2003, NF was not significantly increased grain yield but it was the greatest in N25 and N100%. However, SF was increased grain yield in all N treatments except N50% with Si100% (Table 2). This result was not correlated with 2002 and the main reason was uncommon weather condition such as low temperature at initial tillering stage and increased rainy days than duration of 2002.

The fertilization model (RDA, 1999) was not matched in this greenhouse watermelon-rice cropping system which reason might be NF model focused on soil OM which could not evaluate the exact amount of available soil N. Determination of soil OM should be pass the 100-mesh which might be not evaluate the exact amount of available N for rice because OM degradation depends on soil moisture level, soil temperature and et cetra. Additionally, inputting of compost mostly contained 3.5-4.0% N for watermelon cultivation and its uptake was little part by watermelon, so this compost N might be released during rice cropping and it is greatly different to the conventional rice single or rice-wheat/barley cropping system.

CONCLUSION

SF increased growth characteristics of rice, especially in low N level and the main reason might be improved photosynthesis and fluorescent factors ([a]Cho *et al.*, 2006). However, growth characteristics were limited at conventional NF level and Si limited over growth of rice on high N level, which results might be possible for buffer effect of SF on rice growth in common or uncommon environmental conditions. In addition, NF could be saved about 50% in Si fertilizer treatments (Si150%, 130 mg kg^{-1}; Si200%, 180 mg kg^{-1}) without any kind of grain yield loss. However, if available, Si200% (180 mg kg^{-1}) is recommended than Si150%.

In conclusion, SF could save about 50% of NF amount in normal season and 75% of NF amount in uncommon cold season at tillering by recommended fertilization model, so fertilization level should not be decided by soil OM in compost input watermelon-rice cropping system but soil total N should be included in the equation model as a main parameter for potentiality supplying N to rice.

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