Studies on the Responses of Rice to Silicon Nutrition at Different Growth Stages under Water Culture Condition

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Abstract : A water culture pot experiment was conducted under natural sun light condition to study the effects of silicon (Si) on plant growth, characteristics of dry matter production, nutrients uptake and their differences in two rice varieties akenohoshi and koganemasari during vegetative stage (SI), reproductive stage (SII) and ripening stage (SIII). There were four silicon treatment groups viz. I .−−−Si (control), II. −+−Si, III. +−+Si and IV. +++Si where '+' and '−' signs indicated presence and absence of Si and three signs in each group denoted stages SI, SII and SIII respectively.

Plant height, tiller number, root weight, culm and panicle lengths were less affected by Si application but most of these characters in both the varieties were better in Si added treatment and akenohoshi responded well to Si nutrition. Leaf drooping was the least in continuous Si supplied (+++Si) plants while the highest drooping was observed in −−−Si. Koganemasari was found to be more prone to drooping in control plants than akenohoshi. Shoot dry matter (leaf blade+leaf sheath & culm) produced by +Si and +++Si of stages SI and SIII in akenohoshi and koganemasari were increased 23 and 15% and 23 and 11% over control respectively. The highest panicle weight and panicle weight to shoot weight ratio of akenohoshi at maturity were 52 g pot^{-1} (16% higher over control) and 0.91 respectively produced by −+−Si. But very little difference was found in panicle weight of koganemasari among different Si treatments. Higher ripening % of grains both in primary and secondary rachis branches and higher 1000 grain weight were obtained when Si was applied only during reproductive stage (−+−Si) in akenohoshi and the highest grain yield (50.3 g pot^{-1}) was also obtained from the same treatment. Although Si application in koganemasari improved ripening % and 1000 grain weight except +++Si, little variation was seen in grain yield among treatments. The lowest grain yield in koganemasari was obtained in +++Si due to less number of total panicle, productive panicle, total spikelets and lower ripening % but the reason was not clear as there were no signs of abnormality seen during growth phases. Crop growth rate (CGR) during SI and SIII were increased 19 and 22% over control in +Si and −+−Si of akenohoshi respectively while for the same stage and treatments CGR of koganemasari were increased 17 and 11% over control respectively. Omission of Si during stage SII resulted reduced leaf area and dry matter production in both the varieties and as a result CGR was much affected.

Tissue analyses showed that percent of total uptake of Si during stages SI, SII and SIII in continuous Si applied plants were 24, 35, 41 and 21, 42, 37% respectively in akenohoshi and koganemasari. Sixty four and 49% Si of leaf blade of akenohoshi and koganemasari respectively were absorbed during vegetative stage (SI). Distribution % of Si in leaf sheath+culm and leaf blade during stages SII and SIII varied between the varieties. Twenty three and 31% Si of akenohoshi and koganemasari respectively during stage SII were distributed in leaf sheath+culm while in stage SIII, 7 and 16% Si were distributed in leaf blade. Sillicon application during reproductive stage in akenohoshi showed positive effects on most of the plant characters and beneficial effects were exerted on grain ripening %, individual grain weight and ultimately produced higher grain yield but Si application in koganemasari showed positive effects on some of its characters which could resulted very little influence on grain yield. In conclusion it could be said from the results that Si has beneficial effects in rice particularly when applied during reproductive stage and it differ from variety to variety.

Key words : Growth stages, Rice plant, Silicon nutrition, Water culture.

Introduction

Rice (*Oryza sativa* L.) is typically a siliciphylous plant. Rice grown in soils generally contents 4~20% SiO_2 of its dry weight[3]. Plant species differ in silicon (Si) absorption. Even when much abundance of Si is found in the viscinity of some plants, they do not absorb much Si because of their physiological characteristics while others absorb a lot like rice, sugarcane, wheat etc. Because of its higher contents in rice, scientists tried to have a thorough knowledge about the silicon nutrition in rice. The discovery of the beneficial effects of Si on the growth of rice dates back to as early as 1926 when Sommer[15] presented evidences indicating that Si is essential for rice growth. However, because of its much abundance in soil, its study did not attracted much attention until about 1950's when Japanese scientists found that application of silicate slags to degraded paddy soils increased grain yield of rice[1,2]. Okuda and Takahashi[13], Takahashi and Hino[18] found that Si absorbed in rice plant in the form of monosilicic acid. It is deposited in the leaf blade and stem after being transported by transpiration stream, forming cuticle-silica double layers mainly in the leaf blade[21,22]. Ma[5] reported that Si deposited in leaf blade promoted photosynthesis by reducing water stress, improving light transmission and light receiving forms and Si deposited in the husk increase percent of filled spikelets by reducing excessive water loss. Takahashi[17] described the beneficial effects of Si in the paddy fields as it prevent lodging, reduce fungal and insects attacks and improve plant stature so that light penetration in the community become more and mutual shading became less. Okuda and Takahashi[13] precisely cultured rice plants using solution culture and found that both dry weights of shoot and grain yield increased by the addition of silicic acid. This facts suggeted that Si may have physiological functions. A good number of research works so far have been done, published and reviewed by different workers on Si nutrition in rice and its effects on growth and yield[4,7,14,16] but results on silicon essentiality remained a subjects of debate as they varied from researcher to researcher. However, almost all results showed that Si has atleast beneficial effects on rice. In the present study attempt has been made to find out the effects of Si on growth, dry matter production, yield and yield components and Si uptake pattern and distribution in two rice cultivars viz. akenohoshi- a hybrid high yielding rice variety of japonica×indica and koganemasari- a conventional japonica variety at diffferent growth stages under water culture condition.

Materials and methods

The experiment was conducted during May to September, 1992, at the Faculty of Agriculture, Kochi University, Kochi Prefecture, Japan. Two varieties akenohoshi and koganemasari were used in this experiment, the former was a hybrid high yielding variety of japonica×indica and the latter was a conventional japonica type. For the convenience of treatment application, the growth period has been divided into three stages viz. vegetative stage (SI), reproductive stage (SII) and ripening stage (SIII). Vegetative stage refers to the period from transplanting to panicle initiation, reproductive stage from panicle initiation to heading and ripening stage from heading to maturity. There were four Si treatment groups viz. I. −−−Si, II. −+−Si, III. +−+Si and IV. +++Si where the signs '+' and '−'denoted presence and absence of Si and three signs in each group denoted three stages SI, SII and SIII respectively. The schedule of treatment groups and −Si and +Si addition and withdrawal period during growth stages have been shown in Table 1. There were altogether 48 pots of individual pot size 1/5000a. Twenty days old seedlings (3~3.5 leaf stage) were transplanted (three seedlings pot^{-1}) on 15th May, 1992, in deionized water

Table 1. Schedule of treatment groups and addition and withdrawal of +Si and −Si solution at different growth stages

Variety	Treatment groups	Stage		
		SI 92.5.19~92.7.3	SII 92.7.3~92.8.8	SIII 92.8.8~92.9.11
Akenohoshi	I. −−−Si	−	−	−
	II. −+−Si	−	+	−
	III. +−+Si	+	−	+
	IV. +++Si	+	+	+
		92.5.19~92.7.3	92.7.3~92.8.16	92.8.16~92.9.11
Koganemasari[a]	I. −−−Si	−	−	−
	II. −+−Si	−	+	−
	III. +−+Si	+	−	+
	IV. +++Si	+	+	+

[a] Koganemasari received +Si and −Si application at stage SIII about one week later because of its delayed heading than the akenohoshi.

placing plastic sieve on the mouth of the pots. Nutrient solutions including −Si and +Si treatments application were started from 19th May. Nutrients added during the experiment were shown in Table 2. The source of Si was sodium silicate (Na_2SiO_3). pH was

Table 2. Different nutrients composition of the solution used in the pot experiment

Name of nutrients	Chemical formula	Strength (ppm)	Name of nutrients	Chemical formula	Strength (ppm)
N	$(NH_4)_2SO_4$	20	Fe	$C_{10}H_{12}N_2O_3NaFe\cdot 3H_2O$	2
P	$NaH_2PO_4\cdot 2H_2O$	10	Mn	$MnCl_2\cdot 4H_2O$	0.5
K	KCl	20	B	H_2BO_3	0.2
Ca	$CaCl_2\cdot 2H_2O$	10	Zn	$ZnCl_2$	0.05
Mg	$MgCl_2\cdot 6H_2O$	10	Mo	$Na_2MoO_4\cdot 4H_2O$	0.02
Si	Na_2SiO_3	20/30[a]	Cu	$CuSO_4\cdot 5H_2O$	0.02

[a] Si strength was changed to 30 ppm from 20ppm after 30 days of beginning of treatment.

maintained at 5.5. From the beginning to the end of the experiment, deionize water was used for the culture medium and the pots were always kept away from rain water contamination. During first 30 days of transplanting, 20 ppm Si was added to the Si receiving pots but it was then rescheduled to 30 ppm and the solution was renewed at every 5th day.

Growth measurement of plant height and tiller counting were started from 25th May and 2nd June respectively with an interval of about one week. Leaf drooping measurement was started from 24th June with an interval of about one week.

Samplings for stages SI, SII and SIII of akenohoshi and koganemasari were done at 45, 80∼81, 120 and 40, 87∼90, 122 days after treatment beginning respectively. At each sampling plant height, tiller number/panicle number and or culm and panicle length were recorded and leaf area was measured by a leaf area meter (Automatic area meter, AAM-7, Hayashi Denko Co. Japan) after cutting the leaf blades. All other plant parts like leaf sheath+culm, dead leaf, root and or panicles were separated and washed well first by tap water then by deionized water and then dried in oven at 95℃ for two hours and subsequently at 65℃ for 48 hours. Dry matter weights of each plant parts were recorded from these dried samples. Chemical analyses were done using the dried samples after grinding them.

Yield and yield components data were recorded at harvest. Spikelets in primary and secondary rachis branches were separated from the panicles and were counted and then percent filled spikelets was measured by a salt solution of specific gravity 1.06. Ripened grains of primary and secondary rachis branches were separately counted after drying and ripening % were calculated and weighing the ripened grain, per pot yield was determined.

Plant parts of different samplings were grounded and used for chemical analyses for Si. Silicon contents were determined by colorimetric molybdenum blue method after plant samples were melted with Na_2CO_3[12]. Si uptake and distrbution data were calculated from

Si contents of plant parts and dry weights of individual plant parts.

Results and discussion

(1) Effects of Si on morphological characters :

Periodical growth measurement of plant height showed that Si affected plant height more in koganemasari than akenohoshi. It was also observed that Si receiving plants maintained higher plant height than control. However, −+−Si treatment of akenohoshi and +++Si of koganemasari had the highest plant height (Fig.1.). Increase in plant height due to Si application also had been reported by different researchers[7,10,11,12,13].

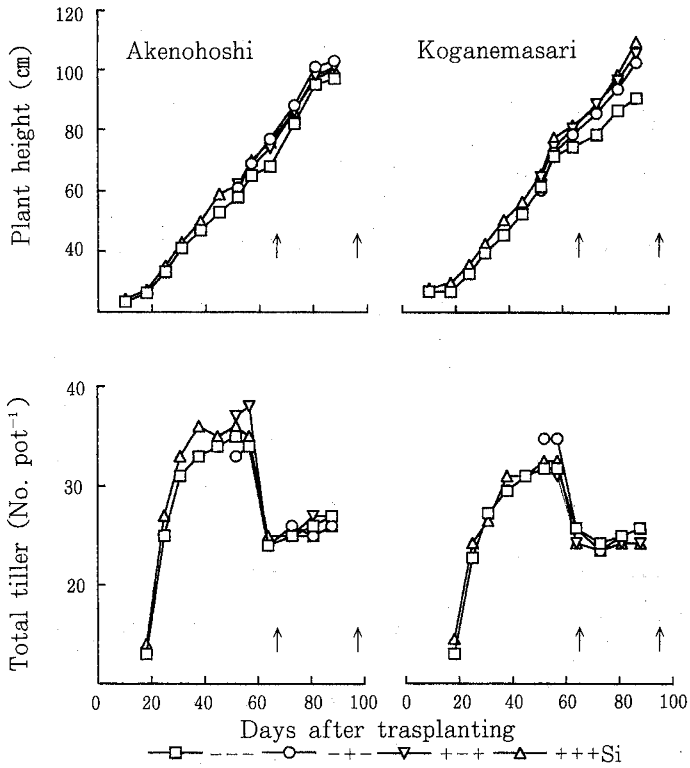

Fig.1. Effects of silicon on plant height and tiller production of rice (var. Akenohoshi and Koganemasari) under water culture condition. Arrows indicate date of change of Si treatments.

Tiller growth in both varieties due to Si application did not follow any definite pattern. It was observed that during SI Si receiving plants produced higher number of tillers but with advanced to age it was reduced. Total tiller production was maximum in +++Si of koganemasari (Fig.1.). Total tillers were reduced in both the cultivars in Si treated plants, however, total productive panicles were remained higher in Si receiving plants except +++Si of koganemasari (Table 3.).

Leaf drooping (LD) were measured in 11th to 15th leaf of both the varieties but 11th, 13th and 15th leaf in both the varieties indicated that LD percentage increased with the advancement of plant as well as leaf age. But it was less in Si receiving plants than in control irrespective of application stages. However, among the leaves higher variation in LD percentages were obtained in the 11th and 13th leaf of akenohoshi and those in koganemasari were 11th, 13th and 15th leaf (Fig.2.). In both the varieties the least

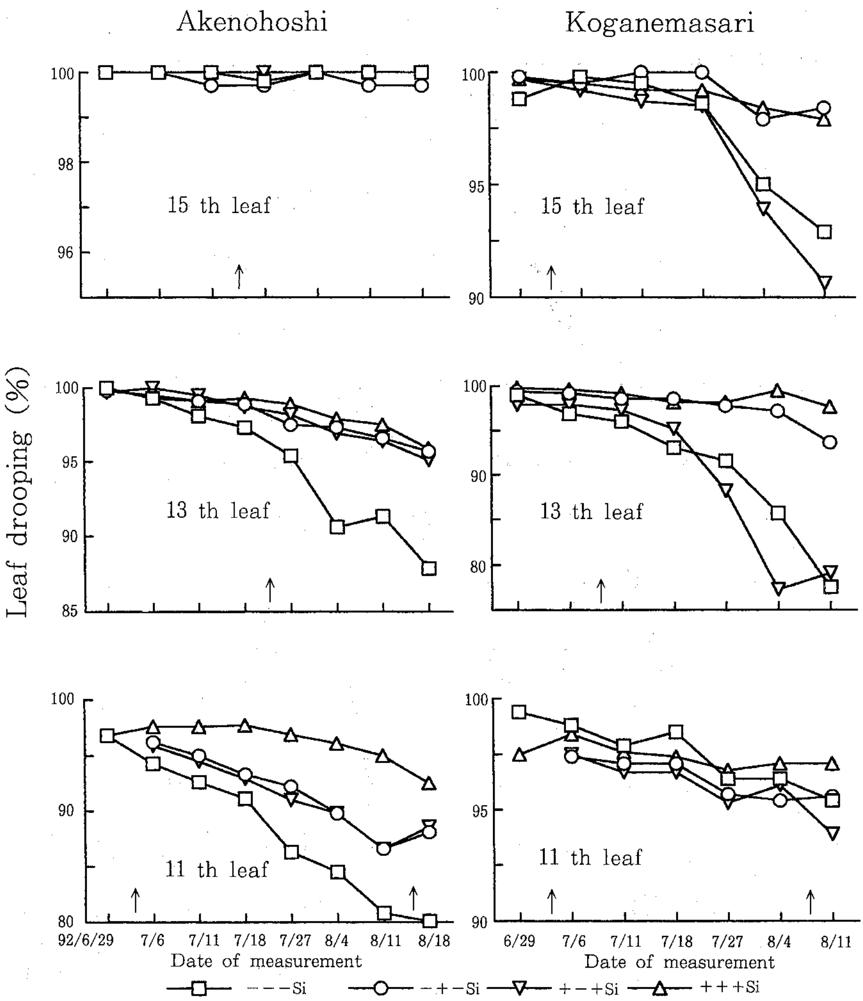

Fig.2. Effects of Si on leaf drooping of rice (var. Akenohoshi and Koganemasari). Arrows indicate date of change of Si treatment.

drooping was in +++Si and the highest was in −−−Si (control). Between varieties, koganemasari was found to be more prone to drooping than akenohoshi. Muller[8] reported that inadequate amount of silica absorption cause the typical droopy leaves in rice while increased absorption made more erect leaves. Yoshida et al.[21] stated that Si deposited in the cell walls of epidermal layers of leaf blades and caused an increment in the mechanical resistance. This deposition also increased the rigidity of leaf blades and alter the leaf angle. Thus this mechanical strength help to keep the leaf blades erect and ultimately reduced drooping percent. Yoshida[20] also reported that in general N tended to make leaf more droopy while Si kept them erect. The present results also in agreement with the reported statement.

Leaf area (LA) during stage SI in akenohoshi had 10% higher over control where in koganemasari it was lower than the control. Silicon withdrawal during SII caused decrease in LA in both varieties. But Si application during stage SIII in akenohoshi had the highest about 50% more LA over control whereas in koganemasari continuous Si application produced 12% more LA over control (Fig.3.). These results indicated that Si affected LA of akenohoshi more than koganemasari. Okamoto[11] found that number of leaves and leaf size increased in Si supplied rice plants. In the present experiment, leaf area of Si supplied

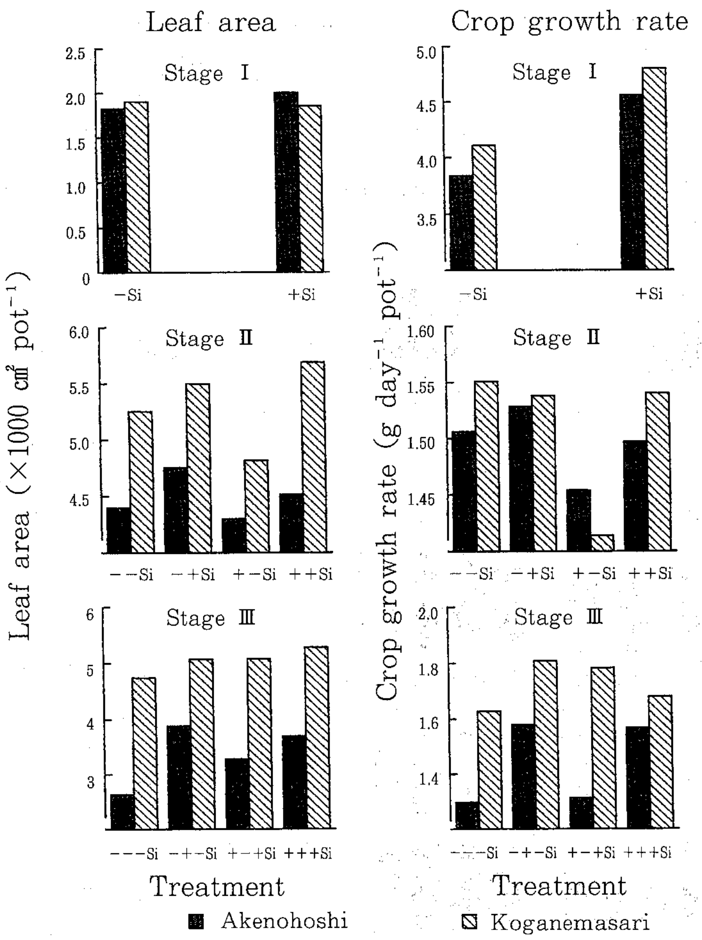

Fig.3. Effects of Si on leaf area and crop growth rate of rice (var. Akenohoshi and Koganemasari) during different growth stages.

plants of both the varieties might be higher due to the same reason.

(2) Effects of Si on dry matter production :

Dry matter production (DM) of different plant parts (oven dry basis) during growth stages and panicle to shoot weight (leaf blades and leaf sheath+culm) ratios have been presented in Fig.4. Shoot weights varied between varieties and among stages due to Si application. It was 23 and 15% higher over control in akenohoshi and koganemasari respectively during SI. During SII cumulative shoot weights varied very little among Si treatments except −+Si in akenohoshi and +−Si in koganemasari. Increase in cumulative shoot weights over control at harvest were 10∼23% and 11∼14% in different Si treatments in akenohoshi and koganemasari respectively. The highest 23% increased in +++Si of akenohoshi.

Panicle weight at maturity of akenohoshi was the highest 52 g pot^{-1} obtained from the treatment −+−Si which was 16% higher over control. Panicle weights of different Si treatments in koganemasari differed a little among them (Fig.4.). The highest panicle to shoot weight ratio (0.91) was obtained from −+−Si of akenohoshi and the lowest (0.49) from the −+−Si of koganemasari. Higher panicle weight and panicle to shoot weight

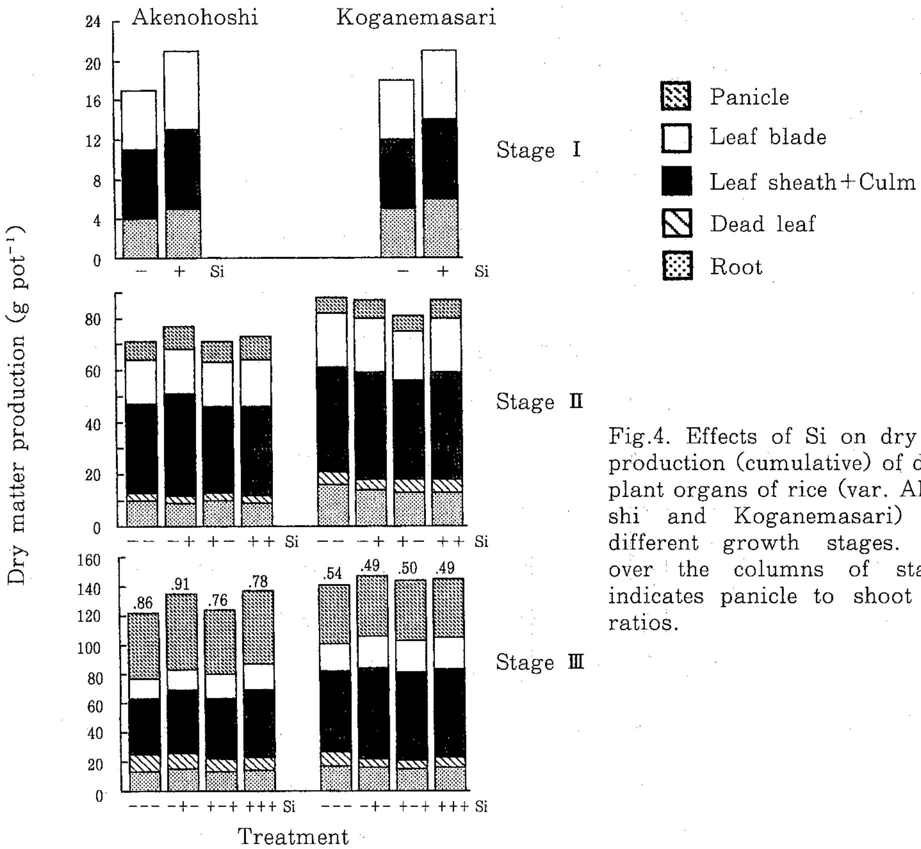

Fig.4. Effects of Si on dry matter production (cumulative) of different plant organs of rice (var. Akenohoshi and Koganemasari) during different growth stages. Values over the columns of stage III indicates panicle to shoot weight ratios.

ratio were produced by the treatment −+−Si and the lower by +−+Si of akenohoshi indicated that addition and withdrawal of Si during the reproductive stage affected ripening percent and individual grain weight positively and negatively respectively. The reproductive stage refers to the period from panicle initiation to heading which is characterized by culm elongation, decrease in the tiller number, emergance of flag leaf, booting, heading and flowering. As a results this stage is most important for the determination of panicle number, spikelets number and fertility of the panicles[6]. In the present experiment Si application during SII favoured the above characters while withdrawal reduced them in akenohoshi. Effects of Si application in koganemasari in respect of panicle weight and panicle to shoot weight ratio did not differ much but addition of Si during SII in akenohoshi was found to be beneficial for panicle development and maturity and ultimately the panicle weight was increased.

Root dry matter production was not much influenced by Si treatment in both the varieties (Fig.4.). Dead leaf dry weight indicated that in later growth stages less dead leaf was obtained from different Si treatments over control indicating Si prevented leaf mortality.

(3) Effects of Si on crop growth rate (CGR) :

CGR of both the varieties during SII were much affected by the withdrawal of Si (+−Si) which resulted lower LA and dry matter production and subsequently CGR was reduced. CGR during SI and SIII of akenohoshi were 0.46 g $d^{-1}pot^{-1}$ and 1.58 g $d^{-1}pot^{-1}$ and those of koganemasari were 0.48 g $d^{-1}pot^{-1}$ and 1.81 g $d^{-1}pot^{-1}$ respectively in +Si and −+−Si (Fig.3.). They were 19 & 22% and 17 & 11% higher over control respectively in akenohoshi and koganemasari. Results indicated that silicon affected CGR of akenohoshi more than koganemasari.

(4) Effects of Si on yield and yield components :

Yield and yield components like productive panicles, spikelets per pot, ripening % of primary and secondary rachis branched grains, 1000 grain weight and grain yield per pot were increased in akenohoshi due to application of Si (Table 3.). The highest average

Table 3. Yield and yield components[a] as affected by +Si application at different growth stages under water culture condition

Variety	Treatment groups	Total panicles (No./pot)	Productive panicles (No./pot)	Total spikelets (No./pot)	%Ripened grain in[b] P.R.B	S.R.B	1000grain weight (g)	Grain yield (g/pot)
Akenohoshi	I. −−−SI	33	18	1850	78.3	76.5	21.9	31.3
	II. −+−Si	31	21	2142	90.0	88.6	25.2	50.3
	III. +−+Si	30	22	2256	86.5	78.2	22.8	42.1
	IV. +++Si	31	22	2322	89.3	77.3	23.4	44.6
Koganemasari	I. −−−SI	36	25	1718	92.8	85.5	22.5	35.1
	II. −+−Si	33	27	1706	95.6	93.3	23.3	38.2
	III. +−+Si	33	28	1809	92.9	86.3	23.8	39.7
	IV. +++Si	28	24	1629	82.0	84.8	21.4	29.9

[a] All data are average of three pots. [b] P.R.B and S.R.B indicate primary and secondary rachis branches respectively.

ripened grain in akenohoshi was 89% in −+−Si which also produced the highest yield 50.3 g pot^{-1} followed by +++Si. Higher grain yield was obtained due to both higher ripening % and individual grain weight as a result of Si application. Nishihara et al.[9] reported that Si deficient rice plants produced less number of spikelets per panicle, lower 1000 grain weight and percent fully ripened grain and also lower matured grains than the Si supplied plants. Ma et al.[6] reported that addition of Si during reproductive period produced 2.5 times higher ripened grains in cultivar akebono. Results of akenohoshi of this experiment showed that it produced about 16% higher ripened grain over control. On the otherhand, yield and yield components of koganemasari such as productive panicles, percent ripened grains, 1000 grain weight and grain yield were slightly affected by Si application especially in −+−Si and +−+Si (Table 3.). All the above characters in +++Si of koganemasari was reduced however, the reasons were not clearly understood as there were no symptoms of abnormality during the whole growth period were noticed.

(5) Effects of Si on silicon uptake and distribution in plant parts :

Silicon uptake in plant parts of akenohoshi and koganemasari were increased due to Si application (Fig.5.). Total uptake in both the varieties during SI were in the order of leaf blade (LB)>leaf sheath+culm (LS+C)>root (R). Without considering dead leaf, total

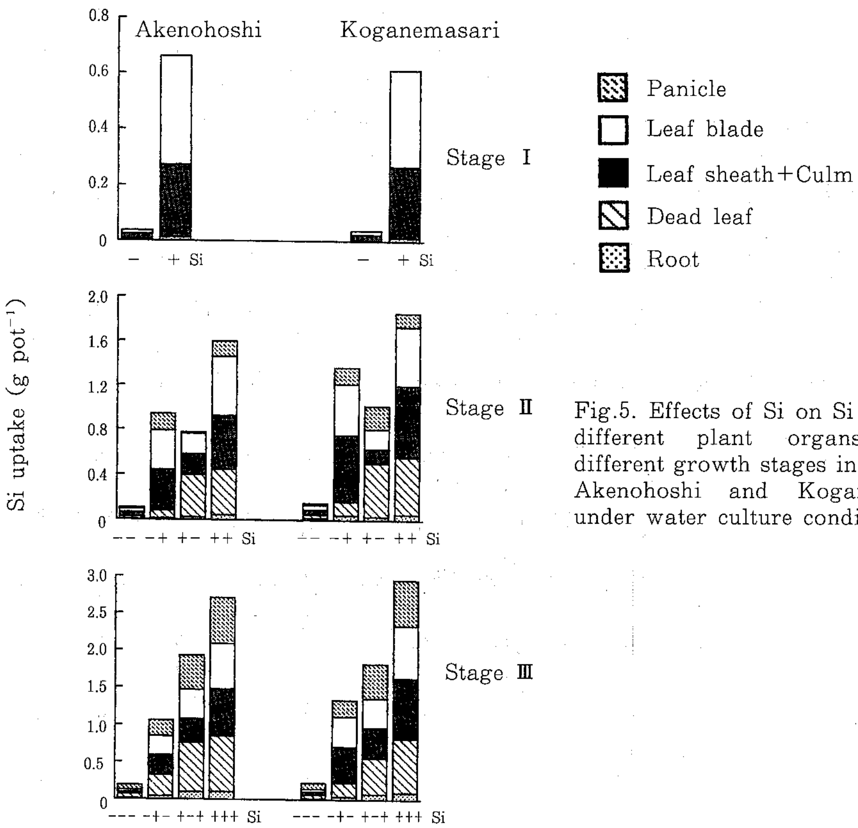

Fig.5. Effects of Si on Si uptake in different plant organs during different growth stages in rice (var. Akenohoshi and Koganemasari) under water culture condition.

uptake in continuous Si supplied plants during SII and SIII of akenohoshi was in the order of LB>LS+C>P (panicle)>R and P>LS+C>LB>R respectively and in koganemasari it was LS+C>LB>P>R in both stages. The uptake order differences between stages in akenohoshi were due to dry matter production and content differences by the respective plant organs. Again among the treatment groups, total uptake in both the varieties were in the order of +Si>−Si, ++Si> −+Si,+−Si>−−Si and +++Si>+−+Si>−+−Si >−−−Si respectively in stages SI, SII and SIII.

Total Si uptake in plant organs and their uptake percentages during stages SII and SIII and distribution in plant organs during stages were determined by deduction of SI from SII, SII from SIII of the continuous +Si treatment. The uptake percentage of Si during SI, SII, and SIII were 24, 35, 41 and 21, 42 and 37 respectively in akenohoshi and koganemasari (Table 4.). Among the total Si absorbed in panicle, 78 and 80% were absorbed during SIII and among total leaf blade Si, 64 and 49% were absorbed during SI respectively of akenohoshi and koganemasari. Distribution percent in plant parts calculated from continuous supplied Si plants showed that Si uptake during SIII were mostly distributed in panicle which was about 45% in both the varieties (Table 5.). But Si distribution in leaf blade during this stage was more than double in koganemasari than akenohoshi. Silicon uptake during SII was mostly distributed in dead leaf and distribution percentages of Si in LS+C were 23 and 31% in akenohoshi and koganemasari respectively. Silicon uptake and distribution results indicated that of the total Si uptake in panicle, about 80% of both the varieties were absorbed during SIII and of the total Si uptake in plant body during SIII,

Table 4. Total silicon uptake in rice plant and its % share by plant organs during different growth stages

Variety	Plant parts	Total silicon uptake[a] (mg pot^{-1})	% uptake by stages[b] S I	SII	SIII
Akenohoshi	Panicle	620	−	22	78
	Leaf blade	611	64	24	12
	Leaf sheath+culm	619	42	35	23
	Dead leaf	758	−	53	47
	Root	99	14	29	57
	Total	2707	24	35	41
Koganemasari	Panicle	621	−	20	80
	Leaf blade	706	49	27	24
	Leaf sheath+culm	800	32	48	20
	Dead leaf	733	−	69	31
	Root	103	13	44	43
	Total	2963	21	42	37

[a]Total silicon uptake was calculated from the continuous Si supplied ptants (i. e. +++Si), [b] % uptake by stages were caluculated from total uptake in individual part during each stage divided by total uptake.

Table 5. Distribution of Si in different plant organs of rice during different growth stages

Variety	Stages	Distribution % in				
		Panicle	Leaf blade	Leaf sheath+culm	Dead leaf	Root
Akenohoshi	Vegetative(SI)	—	59	39	—	2
	Reproductitive(SII)	15	16	23	43	3
	Ripening(SIII)	44	7	13	32	5
Koganemasari	Vegetative(SI)	—	56	42	—	2
	Reproductive(SII)	10	15	31	40	4
	Ripening(SIII)	45	16	15	20	4

about 45% were distributed in panicle. This uptake and distribution might had played important role in ripening % of grain and individual grain weight.

(6) Conclusion :

Silicon uptake and distribution in different plant parts of both the varieties were similar during growth stages but its effects on dry matter production, crop growth rate and yield and yield components were varied between varieties. Its application particularly during reproductive period in akenohoshi showed positive effects on almost all characters and ultimately resulted beneficial effects on panicle weight and grain yield. Although in koganemasari it showed positive effects on some of its characters but their influences on panicle weight and yield were less compared to akenohoshi. It could be said from the results that silicon application has beneficial effects on rice particularly when applied during reproductive stage and its effects also vary from variety to variety.

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