Application of Silica Nutrients Improves Plant Growth and Biomass Production of Paddy under Saline Conditions

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Abstract

Salinity makes disorder to plant physiological causes decreasing in biomass production. Applying silica nutrients is expected to increase paddy (*Oryza sativa* L.) tolerance to salinity. The study aims to examine the effects of the application of silica nutrients under saline conditions regarding plant growth analysis and its correlation to paddy biomass production. The research was arranged in a factorial completely randomized design with two factors. The first factor was NaCl concentrations consisting of four levels, including non-saline, 4 dS m^{-1}, 8 dS m^{-1} and 12 dS m^{-1}. The second factor was silica doses per kg soil with three levels including 300 mg, 450 mg and 600 mg. The treatments were repeated three times. The result showed that the NaCl concentration affected root shoot ratio at harvest. Silica dosage affected leaf area index 8 weeks after planting (WAP), root shoot ration at harvest and net assimilation rate. Interaction of NaCl concentration and silica dose affected root shoot ratio in 8 WAP and at harvest. Plant growth analysis illustrated on leaf area index, plant growth rate and root shoot ratio correlated positively with biomass production. However, the harvest index and net assimilation rate showed negative correlations to biomass production. The application of silica nutrients had the potential to improve paddy growth and yield under saline conditions.

Keywords: assimilation; micronutrients; plant physiology; rice growth; salt-affected soil

INTRODUCTION

Salinity is one of the abiotic stresses and causes losses in agricultural crop production (Iqbal, 2018; Hernandez, 2019). It caused damage in crop production at least 20% globally (Liu et al., 2019). The estimation is that about 3% of the soil in the world was salt-affected (Gorji et al., 2015). Based on BPS-Statistics Indonesia (2020) data, Indonesia has 10.78 million hectares of rice harvested area and 20% of the land is predicted to be affected by soil salinations. Indonesia is an archipelago with a coastline of 68,216 km (BPS-Statistics Indonesia, 2016)

and saline-vulnerable land. The land consists of alluvial basin landforms, estuarine land, tidal land and coastal areas, which cover an area of 12,020 million hectares or 6.20% of the total land area in Indonesia (Karolinoerita and Annisa, 2020). Soil Research Institute (2009) classifies salinity in the soil into four categories, namely very low if < 1 dS m^{-1}, low if 1 to 2 dS m^{-1}, moderate if 2 to 3 dS m^{-1}, high if 3 to 4 dS m^{-1} and very high if > 4 dS m^{-1}. This condition causes soil salination and decreased in rice production (Yang et al., 2015). Saline soil has many constraints such as high salt levels, pH < 8 and exchangeable sodium percentage (ESP) < 15 (Mindari et al., 2015).

Salinity affects plant growth, physiology and yield of rice plants (Anshori et al., 2018) through osmotic and ionic stress (Radanielson et al., 2018). The osmotic effect in salinity stress induces metabolism change in plants similar to water stress, while the ionic effect reduces plant growth due to specific ion and nutrition imbalances (Munns and Tester, 2008; Machado and Serralheiro, 2017). Salinity causes stomatal closure and inhibits the development of shoot elongation (Reddy et al., 2017). In rice, salinity delays flowering and affects yield components, including the number of panicles, grain size, floret fertility and fertile tillers per plant (Zeng et al., 2001). Salinity decreased leaf area, biomass production and yield (Aguilar et al., 2017). According to Zeng (2005), high salinity affects rice plants differently based on the growth phases. The decrease of photosynthesis indicates that NaCl's effect is more toxic than Na_2SO_4, reduced assimilates to grain and decreased productive tillers (Irakoze et al., 2020).

Silica nutrient can improve rice productivity by increasing the development of vegetative organs, including stems, leaves and roots, to become thicker in the epidermal cell layer (Liang et al., 2007). The absorption of silica is accumulated in the epidermal cell layer surface and it can improve the structure of cell walls during the plants were gripped by abiotic stress (Puspitasari and Indradewa, 2019). Based on Frasetya et al. (2019), the combination of silica with Jajar Legowo system improved the growth and rice productivity as indicated by 1,000 grains, productivity per plot, number of tillers, plant height and yield of paddy per hill. Under saline conditions, silica can increase rice growth and lowered ion Na^+ in shoots. Silica had minor effects in roots and reduced ion Na^+ translocation in some of the cultivars, such as IR29 and Pokkali (Flam-Shepherd et al., 2018). Silica also increased the resistance of rice plants to biotic stress through a thick silicate epidermal cell layer (Dobermann and Fairhurst, 2000) and increased the resistance of rice plants to abiotic stress (Ikhsanti et al., 2018). According to the research of Tampoma et al. (2017), the addition of 1 L ha^{-1} silica nutrients in rice could increase the biomass production, grain weight per clump and weight of 1000 grains. Hence, the addition of silica nutrients can maintain rice production under saline prone rice ecosystem.

Plant growth analysis is a variable to determine plants' physiological processes and economic yield (Gardner et al., 1991). Plant growth variable such as leaf area index is related to a total of light interception on the plant for photosynthesis (Mungara et al., 2013). The net assimilation rate illustrates the product of photosynthesis in plants. The poor net assimilation rate decreased rice productivity (Firmansyah et al., 2016). Here we study the application of silica nutrients to improve plant growth and biomass production of sensitive variety IPB 4S. This variety was reported to have a high yield under normal low land conditions but unadapted to saline conditions (Widyastuti, 2017). The information about the growth analysis and biomass production under a saline condition with the treatment of silica nutrients remains limited. Therefore, this research is for further study, especially in the physiological response of rice plants and its correlation to plant growth analysis under saline conditions. Silica nutrients improve paddy plants under saline conditions as a sustainable agricultural system. Shokat and Großkinsky (2019) stated that the use of beneficial microbes and superior varieties improved plant properties under saline conditions and increased plant resistance to salinity. It is used as a sustainable agricultural system. The study aims to examine the effects of the application of silica nutrients under saline conditions regarding plant growth analysis and its correlation to rice biomass production.

MATERIALS AND METHOD

This research was conducted from February to July 2020 in the greenhouse of Agriculture Faculty, Universitas Perjuangan Tasikmalaya, located 359 m above sea level (7°21'07.8" S 108°13'23.5" E). The daily temperature ranged from 24 to 37°C, with relative humidity ranging from 50 to 80%.

Rice plants were planted in polybags sized 30 cm x 40 cm filled with 5 kg and mixed by cow manure with a ratio of 1:1 as a planting medium. The nutrient status of the planting medium is shown in Table 1. The experiment was arranged in a completely randomized design (CRD) with two factors and three replications. The first factor was the concentration of NaCl, including non-saline, 4 dS m^{-1}, 8 dS m^{-1} and 12 dS m^{-1}. The second factor was the dosages of silica nutrients (SiO$_2$ 65%) per kg of soil including

300 mg, 450 mg and 600 mg. Salinity level was achieved through dissolving NaCl in water and then measured using portable EC & TDS meter by the given stress level.

The parameters observed were leaf area (cm^2), plant biomass (g), leaf area index, leaf area ratio (cm^2 g^{-1}), root shoot ratio, net assimilation rate (g dm^{-2} $week^{-1}$), plant growth rate (g m^{-2} $week^{-1}$) and harvest index. Leaf area was measured by drawing the leaves on millimeter blocks of paper. Plant biomass was measured by drying the shoots and roots using the Memmert oven type UN 260 at 80°C for 48 hours. Leaf area and plant biomass were observed at 4 and 8 weeks after planting (WAP) and at harvest. After being dried, the samples were weighed using a digital scale. Leaf area index was measured the leaf area per plant with a spacing. After the data was obtained, then it was calculated using the equation I.

$$\text{Leaf area index } = \frac{1}{\text{land area}} \times \text{leaf area} \quad \text{(I)}$$

Leaf area ratio was measured by using the leaf area per plant and plant biomass. After the data was obtained, then it was calculated using equation II.

$$\text{Leaf area ratio (cm}^2\text{ g}^{-1}) = \frac{\left(\frac{\text{leaf area at 8 WAP}}{\text{plant biomass at 8 WAP}}\right) + \left(\frac{\text{leaf area at 4 WAP}}{\text{plant biomass at 4 WAP}}\right)}{2} \quad \text{(II)}$$

Root shoot ratio was measured by weighed root and shoot using the equation III.

$$\text{Root shoot ratio} = \frac{\text{root dry weight}}{\text{shoot dry weight}} \quad \text{(III)}$$

Net assimilation rate was measured by using the leaf area per plant and plant biomass using the equation IV.

$$\text{Net assimilation rate (g dm}^{-2}\text{ week}^{-1}) = \frac{W2 - W1}{T2 - T1} \times \frac{\ln La2 - \ln La1}{La2 - La1} \quad \text{(IV)}$$

The plant growth rate was measured by weighed plant biomass per plant at the time using the equation V.

$$\text{Plant growth rate (g m}^{-2}\text{ week}^{-1}) = \frac{1}{Ga} \times \frac{W2 - W1}{T2 - T1} \quad \text{(V)}$$

Where; W2 = plant biomass at 8 WAP and harvest; W1 = plant biomass at 4 WAP and 8 WAP; La2 = leaf area at 8 WAP; La1 = leaf area at 4 WAP; T2 = time of observed at 8 WAP and harvest; T1 = time of observed at 4 WAP and 8 WAP; and Ga = land area.

Harvest index was measured based on dried grain per clump which was weighed using a digital scale of 500 x 0.01 g. Dried plant biomass was weighed using a digital scale. After the data was obtained, then it was calculated using equation VI.

$$\text{Harvest index} = \frac{\text{dried grain per clump (g)}}{\text{plant biomass per clump (g)}} \quad \text{(VI)}$$

The data were analyzed by analysis of variance (ANOVA). The mean differences were analyzed using Duncan's multiple range test (DMRT) at 5% significant level. Correlation analysis was performed using Pearson correlation (Gomez and Gomez, 1995). Data analysis was performed using the Statistical Tools for Agricultural Research (STAR) ver 2.0.1 and Microsoft excel 2019.

RESULTS AND DISCUSSION

Environmental conditions

During the research, the average daily temperature at 7 to 9 am ranged from 24 to 29°C, in the daytime at 11 am to 1 pm ranged from 28 to 37°C and at 4 to 5 pm ranged from 27 to 30°C with average air humidity ranged from 50 to 80%. The soil used was suitable for growing rice. Some nutrient content includes pH H_2O, available N, available K, P_2O_5 and K_2O were very high in the soil. However, organic C content and total Si are low and very low, respectively (Table 1).

Table 1. Planting medium analysis

Parameters	Unit	Value	Criteria*
pH H_2O		7.48	Neutral
organic C	%	1.09	Low
Available N	%	1.02	Very high
Available K	ppm	78	Very high
P_2O_5	ppm	244	Very high
Total N	%	0.35	Medium
P_2O_5 potential	mg 100 g^{-1}	122	Very high
K_2O potential	mg 100 g^{-1}	783	Very high
Total Si	ppm	3,399	Very high

Note: * criteria based on Sumida (1992); Indonesian Soil research Institute (2009)

Plant growth analysis of IPB 4S rice variety

Table 2 showed that the results of ANOVA on the effect of NaCl concentrations, the addition of silica dose and interaction between NaCl concentration and silica dose. NaCl concentration did not affect leaf area index, leaf area ratio, root shoot ratio, net assimilation rate, plant growth rate and harvest index, but NaCl concentration affected root shoot ratio at harvest. Silica dose affected leaf area index when the plant 8 WAP, net assimilation rate and root shoot ratio at harvest. Interaction between NaCl concentration and silica dose affected shoot ratio when the plant 8 WAP and root shoot ratio at harvest.

Table 2. P values of two-way analysis of variants (ANOVA) of NaCl concentration (N), silica dose (S), and their interaction (N x S) for the parameters listed

Parameters	N	S	N x S
Leaf area index (4 WAP)	0.486^{ns}	0.984^{ns}	0.914^{ns}
Leaf area index (8 WAP)	0.789^{ns}	0.002**	0.666^{ns}
Leaf area ratio	0.847^{ns}	0.863^{ns}	0.929^{ns}
Root shoot ratio (4 WAP)	0.567^{ns}	0.842^{ns}	0.278^{ns}
Root shoot ratio (8 WAP)	0.227^{ns}	0.670^{ns}	0.026*
Root shoot ratio (at harvest)	0.469*	0.448*	0.618*
Net assimilation rate	0.577^{ns}	0.022*	0.696^{ns}
Plant growth rate (0-4 WAP)	0.288^{ns}	0.973^{ns}	0.924^{ns}
Plant growth rate (4-8 WAP)	0.697^{ns}	0.183^{ns}	0.819^{ns}
Plant growth rate (8-17 WAP)	0.640^{ns}	0.523^{ns}	0.838^{ns}
Harvest index	0.615^{ns}	0.580^{ns}	0.608^{ns}

Notes: $^{*}P < 0.05$; $^{**}P < 0.01$; ^{ns} = not significant, numbers represent P values at 5% significant level

The leaves are one of the organs in the plants that have the main functions to grow and develop. The leaf area and chlorophyll content of the leaf is the main factors for the photosynthesis process to produce high plant biomass. The high plant biomass will promote the vegetative organs and grain filling in rice plants. Table 3 showed that the NaCl concentrations and the addition of silica did not affect leaf area index, leaf area ratio and root shoot ratio at 4 WAP. It suggests that at 4 WAP the plants still able to withstand the saline conditions up to 12 dS m^{-1} NaCl concentration without the addition of silica nutrients. However, salinity affected the root shoot ratio at harvest. Table 3 showed that increased salinity up to 12 dS m^{-1} caused decreased shoot ratio due to the toxic effect of NaCl which caused a nutrient imbalance. Puvanitha and Mahendran (2017) stated that salinity reduced root growth due to the osmotic and ionic stress. This condition affected water and nutrients uptake by plants which decreased photosynthesis rate and shoot growth.

Silica doses affected leaf area index in 8 WAP and root shoot ratio at harvest. The addition of 600 mg kg^{-1} of silica decreased leaf area index and root shoot ratio. The presence of salt stress inhibits root growth; therefore shoot root ratio is lower. However, silica plays a role

in increasing the root cell walls; therefore they have tolerant to salt stress and were still able to absorb water and minerals even in suboptimal conditions. Availability of Si in the leaves increased the leaf area due to the increase of the cell wall size. However, in another observation, Si did not affect to root and shoot growth (Toledo et al., 2012). The mechanism of Si absorbent through transpiration will cause thickening of the epidermal cell in vegetative organs on plants (Dobermann and Fairhurst, 2000). In the leaves, the increase of cell wall size due to Si cause plants tolerance to biotic and abiotic stress (Meena et al., 2014). In this study, higher Si caused a decrease in leaf area index and will produce low assimilation due to narrower leaves that affect net assimilation rate and plant biomass.

Table 3. The effect of NaCl concentration and the addition of silica nutrients to leaf area index at 4 and 8 WAP, leaf area ratio and root shoot ratio at 4 WAP and at harvest on rice cv. IPB 4S

Treatment	Leaf area index		Leaf area ratio	Root shoot ratio	
	4 WAP	8 WAP	$(cm^2\ g^{-1})$	4 WAP	at harvest
NaCl concentration					
non-saline	0.19	8.48	1396.91	0.17	0.59[a]
4 dS m^{-1}	0.67	8.52	1239.90	0.20	0.36[ab]
8 dS m^{-1}	0.57	9.53	1615.10	0.19	0.37[ab]
12 dS m^{-1}	0.53	9.29	1293.04	0.21	0.34[b]
Silica dose					
300 mg kg^{-1}	0.49	9.76[p]	1227.82	0.18	0.35[b]
450 mg kg^{-1}	0.46	11.35[p]	1342.57	0.20	0.58[a]
600 mg kg^{-1}	0.51	5.75[q]	1588.32	0.19	0.33[b]
Interaction	-	-	-	-	-
CV (%)	21.00*	20.57*	13.67*	4.67*	9.63*

Notes: - = no interaction; * = CV with the data that has been transformed using ($\sqrt{x+0.5}$). The number followed by the different letters in the same column were significantly different in the Duncan's Multiple Range Test at 5% significant level

Table 4 showed that the higher addition of silica dose given to rice plants planted under NaCl concentrations at 4 to 8 dS m^{-1} provides larger root shoot ratio compared to other treatments. Under normal and saline conditions in 12 dS m^{-1}, the addition of silica decreased the root shoot ratio at 8 WAP but increase the root shoot ratio at harvest. The rice roots absorbed nutrients in the soil that are needed by plants to optimally grow. The absorption competition between essential nutrients with ions Na$^+$ causes the need of silica nutrients also increase. Pontigo et al. (2015) stated that the Si uptake by vascular plants was very complex. Si was taken by the roots and translocated from cortical cells to the stele, then Si was released to the xylem and translocated through the transpiration process to the shoots. However, silica plays a role in plant growth when the salt concentration is lower and effectively increases the root shoot ratio. In the process of silica uptake, it can be also deposited in the root cells. Root growth is greater due to the assimilation of plants produced more to the roots than other organs (Firmansyah, 2016). This is also consistent with the results of the correlation analysis which showed that the leaf area was negatively correlated to the root shoot ratio (r = -0.38).

Table 5 showed that the NaCl concentrations did not affect the net assimilation rate, but the addition of silica affected the net assimilation rate. The higher silica doses increased net assimilation rate because Si can reduce ion Na$^+$ competition with other minerals so that plants can maintain the metabolism processes to grow. The higher net assimilation rate will increase rice productivity (Firmansyah et al., 2016). Under saline condition, plants need to translocate their assimilates to root growth compared to normal condition (Tatar et al., 2010) and reduce some parameters such as the number of tillers, leaf area, root length, plant biomass and plant growth rate (Ghosh et al., 2016).

Table 5 showed that the NaCl concentration and silica dose did not affect plant growth rate and harvest index. This is because under saline condition, the shoot dry weight and root

dry weight decrease, while increase of ion Na^+ will decrease ion K^+ in the leaves. Nevertheless, rice grown in non-saline conditions had the same plant growth rate and harvest index compared to that under saline conditions. Although the rice plant has same plant growth rate and harvest index, the results of harvest index value were significantly different in both non-saline and saline soil conditions due to the exchangeable sodium percentage (ESP). If the EC value in the saline soil is > 4 dS m^{-1}, the ESP is more than 15%.

Table 4. The effect of the interaction of NaCl concentrations levels and the addition of silica nutrients on root shoot ratio in rice cv. IPB 4S at 8 WAP and at harvest

	Silica dose	NaCl concentration				Average
		non-saline	4 dS m^{-1}	8 dS m^{-1}	12 dS m^{-1}	
Root shoot ratio at 8 WAP	300 mg kg^{-1}	0.221[b]	0.143[b]	0.217[b]	0.213[b]	0.198
	450 mg kg^{-1}	0.219[b]	0.211[b]	0.196[b]	0.190[b]	0.204
	600 mg kg^{-1}	0.128[b]	0.383[a]	0.298[ab]	0.107[b]	0.229
	Average	0.189	0.246	0.238	0.170	0.210 (+)
	CV (%)			6.19*		
Root shoot ratio at harvest	300 mg kg^{-1}	0.351[b]	0.402[b]	0.369[b]	0.281[b]	0.351
	450 mg kg^{-1}	0.265[b]	0.358[b]	0.373[b]	0.311[b]	0.327
	600 mg kg^{-1}	1.171[a]	0.325[b]	0.386[b]	0.425[b]	0.577
	Average	0.596	0.362	0.376	0.339	0.418 (+)
	CV (%)			11.43*		

Notes: + = there is interaction; * = CV with the data that has been transformed using ($\sqrt{x+0.5}$). The number followed by the different letter in the same row and column were significantly different in the Duncan's Multiple Range Test at 5% error level

Table 5. Effect the NaCl treatment and the addition of silica nutrients to NAR, PGR at 0 to 4 WAP, 4 to 8 WAP and 8 to 17 WAP and harvest index on rice cv. IPB 4S

Treatment	NAR (g dm^{-2} $week^{-1}$)	PGR (g m^{-2} $week^{-1}$)			Harvest index
		0-4 WAP	4-8 WAP	8-17 WAP	
NaCl concentration					
non-saline	0.63	0.47	4.49	4.65	0.50
4 dS m^{-1}	0.58	1.59	4.34	5.56	0.45
8 dS m^{-1}	0.44	0.75	5.16	5.57	0.40
12 dS m^{-1}	0.47	1.40	5.16	5.89	0.44
Silica dose					
300 mg kg^{-1}	0.38[q]	1.03	4.89	4.91	0.47
450 mg kg^{-1}	0.45[p]	1.05	5.46	5.91	0.46
600 mg kg^{-1}	0.76[p]	1.08	4.01	5.43	0.41
Interaction	-	-	-	-	-
CV (%)	15.75*	12.99*	20.09*	16.52*	7.97*

Notes: - = no interaction; * = CV with the data that has been transformed using ($\sqrt{x+0.5}$); NAR = net assimilation rate; PGR = plant growth rate. The number followed by the same letter in the same column were not significantly different in the Duncan's Multiple Range Test at 5% error level

The presence of leaching due to the irrigation process is also the reason that the harvest index was not significantly different. The leaching of NaCl caused hydrolysis of ESP and will produce more OH^- to increase pH in the soil (Keshavarzi et al., 2016). In addition, in the saline and non-saline soil, water and mineral availability can be absorbed optimally by plants. Meanwhile, the absorbance of NaCl causes the competition of cation such as Na^+, K^+, Ca^{2+}, NH_4^+ and Mg^{2+}. However, the increase of NaCl concentration led to an increase of Ca/Mg ratio. Generally, the increase of Ca^{2+} helps plants stimulate the formation of root hairs, harden stems,

stimulate the seed formation and neutralize the compounds in unfavourable soil (Mindari et al., 2013). This might be caused by the decrease of photosynthesis process which was also shown in the reduction of leaf area, net assimilation rate and plant growth rate (Neto et al., 2004). Based on the result of this study, salinity decreased harvest index.

The decrease of harvest index on plants given by NaCl in all concentrations and also on plants without NaCl was due to the attack of *Leptocorisa oratorios* with rate of 60% at reproductive phase and caused empty grains. The correlation analysis showed that the harvest index had a negative correlation to net assimilation rate (r = -0.29) and plant growth rate (r = -0.40), respectively. When plants were exposed to salinity, water and mineral absorption will be inhibited, whereas the plants still conduct the transpiration process (Tunçtürk et al., 2011). High ion Na^+ concentration decreased ratio K^+/Na^+ and increase the uptake of ion Na^+ to the leaves and will disturb the photosynthesis rate, water and mineral uptake to the plants (Abbas et al., 2013). This condition caused a decrease in grain yield and quality which in this study indicated based on the decrease of harvest index.

Table 6 showed that there is a positive correlation between plant growth rate and plant biomass shown by leaf area index to leaf area (r = 1), leaf area index to plant biomass (r = 0.83 and r = 0.64), plant growth rate to leaf area (r = 0.84 and r = 0.66), plant growth rate to plant biomass (r = 1; r = 0.99; and r = 0.94) and root shoot ratio to plant biomass (r = 0.36). Wide leaves increase leaf area index which indicate during the vegetative phase, plants invest their photosynthesis to leaf area growth. Gardner et al. (1991) stated that the large portion of assimilates produced by plants invested in leaf area growth during the vegetative phase. The high leaf area index caused by an increased leaf area represents the light intercept so that plant biomass can be predicted (Syamsuddin et al., 2011; Zakariyya, 2016). Mungara et al. (2013) stated that the total light intercept by leaves will increase the photosynthesis rate. The increasing photosynthesis due to light intercept by leaves affects biomass production which is indicated by increasing plant growth rate.

In the present study, NaCl concentrations affected root growth that indicates an increase in root shoot ratio. The results of this study differed from Haq et al. (2009) who stated that salinity will reduce the water potential and inhibit root growth due to osmotic stress. Kandil et al. (2012) stated that NaCl gradually decrease root dry weight and root length. Furthermore, the addition of Si to soil, including in the plant under salinity stress can increase the absorption of minerals so that the process of plant metabolism continued. However, most of the assimilation from the plant metabolism process is used for root growth.

Some of plant growth analysis also has a negative correlation with biomass production (Table 6) which is indicated by net assimilation rate to leaf area (r = -0.41 and r = -0.66), net assimilation rate to plant biomass (r = -0.37 and r = -0.62) and harvest index to plant biomass (r = -0.41). Its correlation illustrated that increase in the leaf area and plant biomass was not followed by an increase in the net assimilation rate. As previously state, in this study, most of the assimilates were translocated to root growth so it has a negative correlation with leaf area. In this condition, salinity had a role in inhibiting the assimilates translocation due to higher osmotic potential in the cell so that the absorption of minerals especially those function in the assimilates translocation was inhibited. The limited assimilating which is translocated for the development of plant organs, especially roots will affect grain fill. This caused a decrease in rice productivity as illustrated by the harvest index which was negatively correlated with biomass production.

The NaCl concentration given to the plants did not affect all parameters of plant growth analysis observed in this research. However, the addition of silica nutrients can increase root growth as indicated by root shoot ratio. The addition of silica up to 600 mg kg^{-1} did not increase the resistance of plant to pest and disease which decrease harvest index. The parameters of leaf area index, plant growth rate and root shoot ratio have positive correlations to leaf area and plant biomass. However, harvest index and net assimilation rate have negative correlations to plant biomass.

Table 6. The correlation matrix between plant growth analysis and biomass production of cv. IPB 4S rice varieties with the addition of silica nutrients in saline conditions

Variable	NAR	LAI 1	LAI 2	LAR	PGR 1	PGR 2	PGR 3	RSR 1	RSR 2	RSR 3	HI	LA 1	LA 2	BIO 1	BIO 2	BIO 3
NAR	1^{**}															
LAI 1	-0.41^*	1^{**}														
LAI 2	-0.66^{**}	0.05^{ns}	1^{**}													
LAR	-0.14^{ns}	0.25^{ns}	0.09^{ns}	1^{**}												
PGR 1	-0.37^*	0.83^{**}	0.04^{ns}	-0.21^{ns}	1^{**}											
PGR 2	-0.60^{**}	0.33^*	0.66^{**}	0.02^{ns}	0.25^{ns}	1^{**}										
PGR 3	0.36^*	-0.05^{ns}	0.11^{ns}	0.01^{ns}	-0.13^{ns}	-0.05^{ns}	1^{**}									
RSR 1	-0.01^{ns}	-0.18^{ns}	0.09^{ns}	-0.11^{ns}	-0.11^{ns}	0.22^{ns}	0.03^{ns}	1^{**}								
RSR 2	-0.03^{ns}	0.52^{**}	-0.03^{ns}	0.07^{ns}	0.36^*	0.34^*	0.14^{ns}	0.13^{ns}	1^{**}							
RSR 3	0.32^*	-0.16^{ns}	-0.38^*	-0.13^{ns}	-0.11^{ns}	-0.09^{ns}	-0.37^*	-0.16^{ns}	-0.24^{ns}	1^{**}						
HI	-0.29^*	0.09^{ns}	0.24^{ns}	0.08^{ns}	0.11^{ns}	-0.08^{ns}	-0.40^*	-0.02^{ns}	-0.23^{ns}	-0.07^{ns}	1^{**}					
LA 1	-0.41^*	1^*	0.05^{ns}	0.25^{ns}	0.83^{**}	0.33^*	-0.05^{ns}	-0.18^{ns}	0.52^{**}	-0.16^{ns}	0.09^{ns}	1^{**}				
LA 2	-0.66^{**}	0.05^{ns}	1^*	0.09^{ns}	0.04^{ns}	0.66^{**}	0.11^{ns}	0.09^{ns}	-0.04^{ns}	-0.38^*	0.24^{ns}	0.05^{ns}	1^{**}			
BIO 1	-0.37^*	0.83^{**}	0.04^{ns}	-0.21^{ns}	1^{**}	0.25^{ns}	-0.13^{ns}	-0.11^{ns}	0.36^*	-0.10^{ns}	0.11^{ns}	0.83^{**}	0.04^{ns}	1^{**}		
BIO 2	-0.62^{**}	0.41^*	0.64^{**}	0.01^{ns}	0.34^*	0.99^{**}	-0.06^{ns}	0.20^{ns}	0.36^*	-0.10^{ns}	-0.07^{ns}	0.41^*	0.64^{**}	0.34^*	1^{**}	
BIO 3	0.14^{ns}	0.08^{ns}	0.32^*	0.01^{ns}	-0.01^{ns}	0.28^*	0.94^{**}	0.09^{ns}	0.26^*	-0.39^*	-0.41^*	0.08^{ns}	0.32^*	-0.01^{ns}	0.27^*	1^{**}

Note: ns = not significant; ** = highly significant correlated at the level of 1%; * = significant correlated at the level of 5%; NAR = net assimilation rate; LAI = leaf area index; LAR = leaf area ratio; PGR = plant growth rate; RSR = root shoot ratio; HI = harvest index; LA = leaf area; BIO = plant biomass

CONCLUSIONS

NaCl concentration affected root shoot ratio; the increase in the NaCl concentration decrease root shoot ratio at harvest. Application of silica nutrients affected leaf area index, root shoot ratio and net assimilation rate. The addition of silica nutrients up to 600 mg kg^{-1} increased net assimilation rate. Under non-saline and saline conditions, 4 and 8 dS m^{-1} silica caused the highest root shoot ratio. Leaf area index, plant growth rate and root shoot ratio had positive correlations to biomass, however harvest index and net assimilation rate had negative correlations to biomass. Based on the data, paddy planted under saline conditions with silica application had 9.19% higher growth rate compared to paddy planted under non-saline conditions with silica application. Application of silica nutrients were effective in increasing root growth. Further research is needed on the application of silica nutrients with additional doses or different application methods.

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