Effect of Soil Salinity on Photosynthesis and Growth of Paddy Rice

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ABSTRACT

Effect of soil salinity on the photosynthesis and growth of paddy rice was investigated with a measurement of chlorophyll fluorescence. A nursery rice of 61 days after seeding was transplanted in the 1/5,000 a pot of 3.8 L in volume. The pot was filled with soil of 3.0 L. Before the transplantation, the soil was prepared with spraying the NaCl water adjusted to the four concentrate conditions of 0 ppm as control, 1,000 ppm, 2,000 ppm and 4,000 ppm. The saline concentration means a mass ratio of NaCl to dry soil. To each saline condition, six pots were examined. Growth parameters (height and stem length) were measured weekly after transplantation. Photosynthetic parameters (Fv/Fm, Fv'/Fm',ΦⅡ, ETR, qP, NPQ) were also measured weekly with a chlorophyll fluorescence measurement tool. After harvesting, yield parameters (grain numbers, weight and density; root, stem and leaf dry weight) were measured. At the ripening stage of 150 days after seeding, the plant height reached maximum in every pot and was 70 cm (100%) in the control, 58 cm (83%) in 1,000 ppm, 50 cm (71%) in 2,000 ppm and 45 cm (64%) in 4,000 ppm. The plant height decreased strongly with an increase of saline concentration. Photosynthetic parameters except NPQ were decreased with an increase of saline concentration. NPQ (Non-photochemical quenching) means heat dissipation in PS (Photosystem) Ⅱ. Fm (the maximum chlorophyll fluorescence in the dark) and ΦⅡ (the effective quantum yield of PSⅡ) are related to the activity of the manganese cluster located at the end of PSⅡ. Decrease of Fm and ΦⅡ means that the manganese cluster reduces to electrolyze water into H^+ and O_2. In conclusion, we can explain the salt damage in plant as follows. An excessive salt brings water deficit in the photosynthesis in leaves by the water potential reduction in roots. The water deficit reduces the photosynthetic activity. Then photon energy is excessive and dissipated in heat. Thus excessive salt leads photosynthetic damage and brings yield loss.
Keywords: Chlorophyll fluorescence, chlorophyll intensity, paddy rice, photosynthetic activity, salt stress, Japan

1. INTRODUCTION

We suffered great salt damage to the farmlands caused by the tremendous tsunami, or high tidal waves, followed by the huge earthquake on March 11, 2011 in Northern Japan. In a government report (MAFF, 2012), the damaged area was estimated in

23,600 ha, shared in an area of 2.6% of the total farmlands of the six suffered local governments, including 20,151 ha in the rice paddy fields and 3,449 ha in the uplands.

Rice plant has low salt tolerance (e.g. Iwaki, 1956; Yeo and Flowers, 1986). In saline soil above 1,000 ppm, paddy rice reduces its growth, yield and quality due to water potential reduction, cellular dehydration and ion toxicity (Iwaki *et al.*, 1956; Dohkoshi and Maeda, 1959; Arai-Sanoh *et al.*, 2011). However photosynthetic mechanism of paddy rice has been rarely evaluated in high saline soil more than 1,000 ppm (Lutts *et al.*, 1996; Moradi and Ismail, 2007).

In this paper, effect of soil salinity on the photosynthesis and growth of paddy rice was investigated with a measurement of chlorophyll fluorescence.

2. MATELIALS AND METHOD

2.1 Cultivation Pots and Growth Conditions

A nursery rice of 61 days after seeding was transplanted in the 1/5,000 a Wagner pot of 3.8 L in volume. The pot was filled with a soil of 3.0 L. The soil is Andosol, one of major volcanic soils in Japan. Before the transplantation, the soil was screened with a sieve of 4.75 mm in mesh to avoid impurities and to keep the particle size uniform. After screening, the soil was prepared with spraying a saline water of NaCl adjusted to the four concentration conditions of 0 ppm as control, 1,000 ppm, 2,000 ppm and 4,000 ppm. The saline concentration means a mass ratio of NaCl to dry soil. To each saline condition, six pots were examined.

The nursery rice (*Oryza sativa* L. subsp. *Japonica* cv. 'Masshigura') was examined, which was obtained from the Institute of Agriculture and Forestry at Fujisaka in Towada of Aomori Prefecture, Japan. Chemical compound fertilizer was applied to the pot with an equivalent weight of N: P_2O_5: K_2O=24: 59: 24 (kg ha^{-1}), used 70% at beginning and the rest on 103 days after seeding at a boot stage. More than double value of P_2O_5 to other chemical compound fertilizers was due to the volcanic soil, which strongly absorbed P_2O_5.

During five months of Jun.10 to Oct. 25 in 2012, the experiment was done at an outdoor field of Kitasato University situated at latitude 40°37'24.17" North, or 40.623381°N., and longitude 141°14'14.96" East, or 141.237488°E.

2.2 Measurements of Weather, Growth, Photosynthesis and Yield

Three weather factors of air temperature, precipitation and sunshine duration were referred to analysis and those data were obtained from a meteorological station in Towada, operated by Japan Meteorological Agency (JMA) and situated at latitude 40°35'42.08" North, or 40.595023 °N., and longitude 141°14'57.03" East, or

141.249175° E. The meteorological station locates in a South direction approximately 6.0 km away from the experimental field at Kitasato University.

After transplantation, two growth parameters of height and stem length of the paddy rice in the pot were measured weekly. Those measurements were done manually with a scalar and a vernier micrometer.

Six photosynthetic parameters (Fv/Fm, Fv'/Fm',ΦⅡ, ETR, qP, NPQ) were used in analysis and also measured weekly with a portable chlorophyll fluorescence measurement tool (LI-6400, Li-Cor, USA).The tool depends on a method of PAM (pulse-amplitude-modulation fluorometer) as developed by Schreiber *et al.* (1986). The terminologies and definitions of those photosynthetic parameters were followed by van Kooten and Snel (1990).

Maximum quantum yield of open PSⅡ(Fv/Fm) was determined in a weak modulated measuring light of 500 μmol photon m^{-2} s^{-1} after a 20 min dark acclimation of selected leaves using a dark leaf clip made from tin aluminum foil. Then actual quantum yield of open PSⅡ (Fv'/Fm') was measured on the same leaves that were illuminated for 20 min in the room with an actinic light of 1,800 μmol photon m^{-2} s^{-1} (=PAR) after dark adaptation, with five measurements conducted per replication, and was calculated as effective quantum yield (ΦⅡ) .

Electron transfer rate (ETR) was calculated as ETR=ΦⅡ×PAR×0.84 ×0.5 (Schreiber *et al.*, 1986), where PAR is photosynthetically active radiation, assumed as the actinic light of 1,800 μmol photon m^{-2} s^{-1} in this experiments. The values of 0.84 and 0.5 are an absorption coefficient of PAR by a leaf, and a factor that accounts for the partitioning of energy between PSII and PSI, respectively. From the fluorescence data obtained with the same dark-adapted and steady-state-illuminated leaves, photochemical quenching (qP) and non-photochemical quenching (NPQ) were calculated as defined by Schreiber *et al.* (1986) and van Kooten and Snel (1990).

After harvesting the paddy rice on Oct.25, 2012, yield parameters of the number, bulk density, and dry weight of grains as well as those of the dry weight of root and shoot without grains were measured. Yield of paddy rice is characterized in general as a kernel weight production at a given field area of such as 10 a, or 0.1 ha (Takeda *et al.*, 1983). The kernel means brown rice, or unpolished rice, which is dried, hulled, screened with a sieve in 1.7 mm mesh and maintained at 15% moisture. The yield index is achieved from the four measurements of the panicle number per plant, the grain number per panicle, the ripening grain ratio and the 1,000-kernel-weight. The ripening grain ratio is determined by dipping a bulk grain in a salt water of 1.06 specific gravities, selecting the sinking grains and dividing the grains sank by the bulk. The 1,000-kernel-weight is the weight of the thousand particles of kernel.

In this report, we chose the three measurements of the panicle number per plant, the grain number per panicle and the ripening grain ratio due to lack of enough grains in pot cultivations. Those measurements were used as yield indices.

3. RESULTS AND DISCUSSION

3.1 Weather Conditions

The average air temperature was 18.9 °C ±4.0 °C during the paddy rice growth seasons from Jun. to Oct. in 2012, obtained from JMA (2013). In contrast with that of 17.7 °C ± 3.9 °C in the 30-year long term from 1981 to 2010 (JMA, 2013), a great increase of +1.2 °C was observed. This hot condition was related with a decrease of rainfall in 27% from 124.7 mm month^{-1} in the long term to 91.4 mm month^{-1} in 2012 as well as an increase of sunshine duration in 8% from 146.9 hrs. month^{-1} to 158.8 hrs. month^{-1}. However an indication of disease at high temperature was not observed due to a resistance of high temperature in paddy rice.

3.2 Growth and Yield

Effects of NaCl on growth of mean plant height and mean stem diameter at growing to ripening stages irrigated with different concentrations of NaCl are shown in Figure 1. In a range of 90 day to 150 day after seeding, plant height showed a large increase in both the control and the NaCl concentrations, resulted in a great difference between the control and the NaCl concentrations as well as among the NaCl concentrations. At the ripening stage of 150 day after seeding, the plant height reached maximum in every pot and was 70 cm (100%) in the control, 58 cm (83%) in 1,000 ppm, 50 cm (71%) in 2,000 ppm and 45 cm (64%) in 4,000 ppm. The plant height decreased strongly with an increase of NaCl concentration. A large increase of stem diameter was observed in a range of 90 day to 130 day, smaller than that of plant height. However the maximum

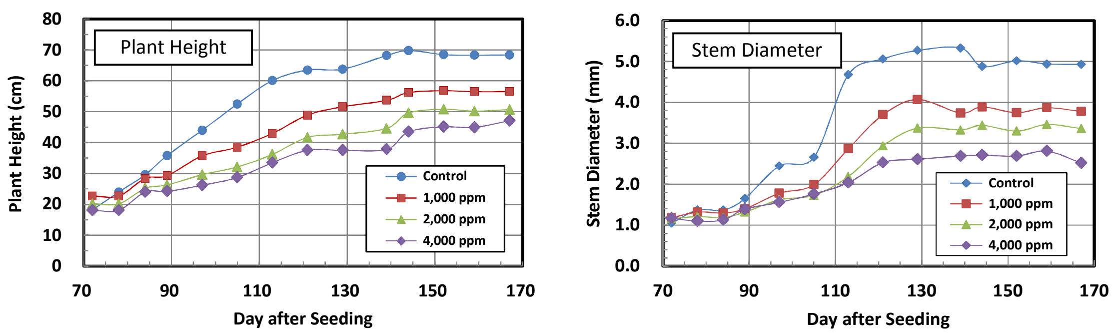

Figure 1. Effects of NaCl on growth of mean plant height and mean stem diameter at growing to ripening stages in the pot where soil was adjusted with different concentrations of NaCl.

difference between the control in 5.2 mm (100%) and the 4,000 ppm in 2.6 mm (50%) was attained at 130 day.

Dry matter yield of grain is shown in Table 1. To facilitate comparison, each red point in the (), followed by the mean, is added as the value in a percentage to the control's mean. Grain yield per pot was decreased ($p < 0.01$) remarkably with an increase of NaCl concentration. Grain number per pot was also decreased. On the other hand, grain number per panicle and ripening grain ratio showed no difference ($p < 0.01$) except the 2,000 ppm or 4,000 ppm. Those mean that the rice plant kept its grain size rather than its grain number in a NaCl concentration more than 1,000 ppm. Salinity damage in rice is caused in general by water potential stress or ion toxic stress (Chaves *et al*., 2009; Arai-Sanoh *et al*., 2011). Hence the rice plant response to keep its grain size rather than its grain number in the salinity conditions might be caused by water potential stress.

Table 1. Dry matter yield of grain at different salinity concentrations

NaCl Concentration	Control	1000 ppm	2,000 ppm	4,000 ppm
Grain Yield (dm g/ pot)	4.01 (100%) ± 0.5 [a]	1.64 (41%) ± 1.0 [b]	0.74 (18%) ± 0.4 [c]	0.33 (8%) ± 0.2 [d]
Grain Number (no. / pot)	182.4 (100%) ± 27.0 [a]	71.3 (39%) ± 43.0 [b]	33.2 (18%) ± 15.1 [c]	13.8 (8%) ± 10.7 [d]
Grain Number (no. / panicle)	36.9 (100%) ± 8.1 [a]	33.8 (92%) ± 5.9 [a]	24.8 (67%) ± 3.8 [b]	15.3 (41%) ± 6.6 [b]
Ripening Grain Ratio (%)	80.3 (100%) ± 5.4 [a]	81.4 (101%) ± 19.6 [a]	81.4 (101%) ± 19.6 [a]	58.6 (73%) ± 33.8 [b]

Each point represents the mean of six observations ± SD. Differences among treatments were tested by ANOVA. LSD tests were done at the 1% significance level; the same letter at row represents no significant difference. In addition, each poin in the (), followed by the mean, represents the value in a percentage to the control's mean.

In Table 2, dry matter yield of shoot part and root part is given. The shoot part per pot included stems, leaves and panicles without grains. Large discrepancies more than four times between the control and the NaCl concentrations were observed ($p < 0.01$) in both the shoot and the root parts. Hence the great damages in shoot and root rather than that of grain were occurred.

Table 2. Dry matter yield of shoot part without grain and root part at different salinity concentrations

NaCl Concentration	Stem, Leaf and Panicle without grain (dm g/ pot)	Root (dm g/ pot)
Control	8.95 (100%) ± 0.50 [a]	6.15 (100%) ± 2.39 [a]
1000 ppm	2.32 (26%) ± 1.33 [b]	1.34 (22%) ± 0.68 [b]
2000 ppm	1.23 (14%) ± 0.67 [c]	0.74 (12%) ± 0.37 [c]
4000 ppm	1.13 (13%) ± 0.50 [c]	0.42 (7%) ± 0.28 [d]

Each point represents the mean of six observations ± SD. Differences among treatments were tested by ANOVA. LSD tests were done at the 1% significance level; the same letter at column represents no significant difference. In addition, each poin in the (), followed by the mean, represents the value in a percentage to the control's mean.

3.3 Chlorophyll Fluorescence Analysis

In Figure 2, changes of maximum quantum yield of open PS II (Fv/Fm) and electron transport rate (ETR) at different salinity conditions are shown. Fv/Fm is an index of photosynthetic activity, which represents around 0.8 in a normal leaf (Terashima, 2002). At the NaCl conditions of 2,000 ppm and 4,000 ppm, their mean values of Fv/Fm showed 0.77 (95%) in contrast with that of 0.81 (100%) at the control. A decrease of 5% was observed. In particular, the Fm values of both the NaCl conditions were significantly different ($p < 0.01$) from that of the control. Mean value of ETR was decreased with an increase of NaCl concentration. ETR means an index of potential stress (Schreiber *et al.*, 1986). Hence a potential stress was occurred in the salinity conditions.

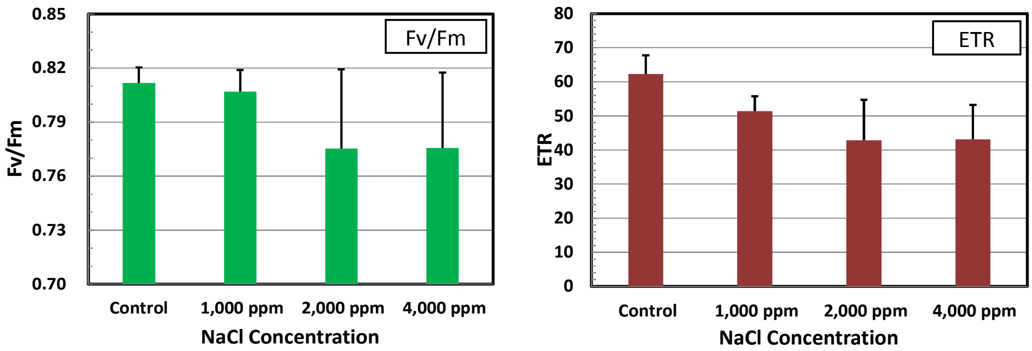

Figure 2. Changes of maximum quantum yield of open PS II (Fv/Fm) and electron transport rate (ETR) at different salinity conditions. The data are mean values of six samples. Vertical bars indicate SD.

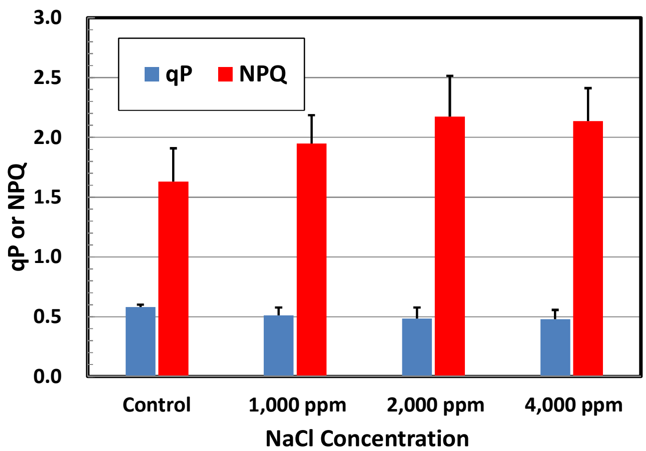

Figure 3. Changes of photochemical quenching (qP) and non-photochemical quenching (NPQ) at different salinity conditions. The data are mean values of six samples. Vertical bars indicate SD.

Photosynthetic parameters except NPQ were decreased with an increase of saline concentration (Figure 3). NPQ (Non-photochemical quenching) means heat dissipation in PS (Photosystem) Ⅱ. Fm (the maximum chlorophyll fluorescence in the dark) and Φ Ⅱ (the effective quantum yield of PS Ⅱ) are related to the activity of the manganese cluster located at the end of PS Ⅱ (Terashima, 2002). Decrease of Fm and Φ Ⅱ means that the manganese cluster reduces to electrolyze water into H^+ and O_2.

4. CONCLUSION

In conclusion, we can explain the salt damage in plant as follows. An excessive salt brings water deficit in the photosynthesis in leaves by the water potential reduction in roots. The water deficit reduces the photosynthetic activity. Then photon energy is excessive and dissipated in heat. Thus excessive salt leads photosynthetic damage and brings yield loss.

5. ACKNOWLEDGEMENTS

We received the nursery rice as well as useful advices on cultivation from the Institute of Agriculture and Forestry at Fujisaka in Towada of Aomori Prefecture, Japan. We express our deep acknowledgements to the Institute. Thanks are also due to K. Uehira, Y. Ban and S. Oguri, students at Kitasato University, for their help with the experiments.

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