Photosynthetic Responses in Reed (*Phragmites australis* (CAV.) TRIN. ex Steud.) Seedlings Induced by Different Salinity-Alkalinity and Nitrogen levels

Ch. Deng¹,², G. Zhang¹*, and X. Pan³

ABSTRACT

Many *Phragmites*-dominated wetlands have been markedly salinized and alkalinized in the Songnen Plain, northeastern China. Agricultural wastewater with high nitrogen content has been discharged into these alkalinized-salinized wetlands. To understand the effect of salinity-alkalinity on reed (*Phragmites australis*) seedlings at various nitrogen levels, we examined photosynthesis rate, chlorophyll fluorescence characteristics, and chlorophyll content of reed seedlings using gas exchange and chlorophyll *a* fluorescence tests. The greatest decreases (by 82%, 15%, 82% and 98%) of net photosynthesis rate (*P*ₙ), maximal efficiency of photosystem II (PSII) photochemistry (Fᵥ/Fₘ), comprehensive photosynthesis performance index (PIₐ₃₈) and plant height growth rate were observed at high salinity-alkalinity (mixed with 150 mM NaCl and 100 mM NaHCO₃). Stomatal limitation was the main reason for decreased photosynthesis rate at low salinity-alkalinity (mixed with 50 mM NaCl and 25 mM NaHCO₃). The activity of PSII was significantly inhibited at high salinity-alkalinity. Both donor and acceptor sides of PSII are the target sites of high salinity-alkalinity. High N (30 mM) at low salinity-alkalinity and moderate N (15 mM) at high salinity-alkalinity mitigated the toxicity of salinity-alkalinity on reeds and promoted plant height growth, chlorophyll synthesis, and PSII activity. Proper levels of N partly reduced the toxicity of salinity-alkalinity on the donor and acceptor sides of PSII. This suggests that agricultural wastewater containing high level of nitrogen may be helpful in restoration of *Phragmites*-dominated salinized wetland, though the N level needed for salinity-alkalinity stressed reed varies with the salinity-alkalinity level.

Keywords: Alkalinized-salinized wetlands, Chlorophyll fluorescence, Gas exchange, Nitrogen, *Phragmites australis*.

INTRODUCTION

Salinization of wetlands is increasingly getting serious in arid and semi-arid areas. Excess salinity induces adverse effects on plants photosynthesis (Long and Baker, 1986) including reduction of CO₂ assimilation and stomatal conductance and decelerating activity of photosystem II (PSII) (Everard *et al.*, 1994). The reduction of photosynthesis is often due to both stomatal and non-stomatal limitations (Loreto *et al.*, 2003; Jeranyma and DeMoranville, 2008). Excess alkalinity also inhibits photosynthesis and retards plant growth (Shi and Wang, 2005; Yang *et al.*, 2009). When soil salinization and alkalinization co-occur, their effect on plants is much more complex. To our best knowledge, only a few reports are...
available about the effect of combined salinity-alkalinity stress on photosynthesis rate of plants (Anjum et al., 2005; Zhang and Yin, 2009). Previous limited studies showed that salinity-alkalinity mixed stress led to decrease in chlorophyll concentration (Kaya et al., 2002), reduction of stomatal conductance and transpiration rate (Khan and Abdullah, 2003), and inhibited the plant growth. However, the underlying knowledge about the inhibitory effects of combined salinity-alkalinity stress on photosynthetic activity is yet not fully understood.

The metabolic process of plants is largely dependent upon an adequate supply of nitrogen. There is a strong correlation between the nitrogen supply and plant photosynthetic capacity. Nitrogen limitation to plant production is believed to be widespread, especially in salinized soil (van Wijnen and Bakker, 1999). Plants growing under nitrogen-limited conditions exhibit decreases in photosynthetic capacity and leaf chlorophyll concentrations (Terashima and Evans, 1988; Lu and Zhang, 2000). Nitrogen, as a crucial macronutrient for plants, and Cl, as a micronutrient and a major salinity agent, are known to be antagonistic to each other in the nutrient uptake system of plants (Tisdale et al., 1993). Increasing salinity usually decreases nitrogen availability and affects nitrogen movement to plants. Increasing nitrogen supply decreases the toxicity of salinity to the plants (Tisdale et al., 1993). Apparent increases in salt tolerance (Papadopoulos and Rendig, 1983) and photosynthetic rate have been found when excess N is supplied under saline conditions (Kao et al., 2001), implying that excess N may overcome some of the inhibitory effects of salinity. Although many researchers have studied the interaction of nitrogen and salinity (Papadopoulos and Rendig, 1983; Kao et al., 2001; Tabatabaei, 2006), there is little information available on the effect of nitrogen on plant physiology under combined salinity-alkalinity stress.

Chlorophyll a fluorescence is a sensitive indicator of photosynthetic efficiency in plants and has been proved as a rapid, non-invasive, and reliable method to assess photosynthetic performance under various environmental stresses (Krause and Weis, 1991; Schreiber et al., 1994). The O-J-I-P fast chlorophyll a fluorescence transient has been found to be very sensitive to various environmental stresses (Strasser et al., 2000). The JIP-test is thus a useful tool for the in vivo investigation of the behavior of the photosynthetic apparatus. In the present study, we employed this approach to get a more thorough insight into the responses of PSII to salinity-alkalinity stress under various N conditions.

*Phragmites australis* is one of the most widespread and productive wetland plant species. In the Songnen Plain, northeastern China, a number of *Phragmites*-dominated wetlands have been markedly salinized and alkalinized due to overexploitation or irrational development of water resources and climate change. Agricultural wastewater containing high nitrogen has become a source of water for alkalinized-salinized wetlands; while it has been purified by wetlands. Knowledge about the effects of nitrogen level on plant stressed by salinity-alkalinity is important for understanding nutrient source control in agricultural wastewater discharged into alkalinized-salinized wetlands. The objective of this study was to investigate the photosynthetic responses of *P. australis* to combined salinity-alkalinity stress at various nitrogen levels by gas exchange measurement and in vivo chlorophyll a fluorescence test.

**MATERIALS AND METHODS**

**Materials and Treatments**

Rhizomes of reed (*P. australis*) were taken from Momoge wetland in the Songnen Plain, northeastern China. Rhizomes of about 20cm were cultivated in outdoor sand tanks and watered with pond water for 3 weeks until seedlings emerged. *P. australis* seedlings, about 15 cm long, were transplanted into 8-L plastic pots with sands under a photosynthetic photon flux density...
Table 1. Concentrations of various compounds of salinity-alkalinity and N levels in different treatments.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>NaCl (mM)</th>
<th>NaHCO₃ (mM)</th>
<th>N level (mM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>control</td>
<td>0</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>SA₁</td>
<td>50</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>SA₂</td>
<td>150</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>SA₁+N₁</td>
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<tr>
<td>SA₂+N₂</td>
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<td>100</td>
<td>15</td>
</tr>
<tr>
<td>SA₂+N₃</td>
<td>150</td>
<td>100</td>
<td>30</td>
</tr>
</tbody>
</table>

Chlorophyll Fluorescence Measurement

The fourth fully expanded leaf was used for fast Chlorophyll a fluorescence measurements with a portable fluorometer (FP100, PSI, Brno, Czech Republic). The plant leaf was dark-adapted for 10 min using leaf-clip before fluorescence measurement. This fluorometer instrument is devised for measurements of fast fluorescence transients (O-J-I-P rise) according to the commonly accepted illumination protocol. Chlorophyll fluorescence is excited by a visible light band peaking at 475 nm (half bandwidth 25 nm). Fast fluorescence transients induced by actinic light were recorded at sampling intervals varying from 10 µs to 10 ms. The polyphasic fast fluorescence induction curve provides valuable information about the function of PSII (Strasser et al., 1995). Upon the triggering of strong actinic light, the increase in Chlorophyll a fluorescence of dark-adapted photosynthetic materials will follow a triphasic kinetic from its initial level (F₀), two intermediate levels (Fᵢ and Fⱼ) to its maximal level (Fₘ or Fₚ). The initial Chl fluorescence F₀ (fluorescence intensity at 50 µs) indicates all molecules of QA are in the oxidized state. Fᵢ (fluorescence intensity at around 2 ms) reflects the accumulation of QA⁻. Fⱼ (fluorescence intensity at around 30 ms) demonstrates an accumulation of QA⁻QB⁻, whereas Fₘ (maximal fluorescence intensity, usually reached at 200-500 ms) indicates all molecules of QA are in the reduced state with

Growth Measurement

Plant heights were recorded at the beginning and the end of the 15-day treatment. Height was measured as the distance between the stem base and the shoot tip. The plant growth rate was estimated as follows: Height rate =H₂ - H₁, H₁= plant height at the start of treatment; H₂ = plant height at the end of treatment.
the accumulation of $Q_A Q_B^{-2}$ (Strasser and Govindjee, 1992; Strasser et al., 1995). It can be used to analyze changes in electron transfer reaction on both donor (Delosme and Joliot, 2002) and acceptor side of PSII (Strasser and Govindjee, 1992). The JIP-test analysis (Strasser and Strasser, 1995) was employed to analyze each chlorophyll $a$ fluorescence transient. The JIP-test represents translation of the original data to biophysical parameters that quantify the energy flow through PSII. $F_0$, $F_{300\mu s}$, $F_1$ and $F_M$ from the original measurements were used. Other JIP-test parameters were derived from these original parameters (Table 2) (Strasser et al., 2000).

**Gas Exchange Measurement**

After Chlorophyll $a$ fluorescence measurement, the same leaves were used for measurement of net photosynthesis ($P_a$), stomatal conductance ($g_s$), internal CO$_2$ concentration ($C_i$) at a PPFD level of 1500 µmol m$^{-2}$ s$^{-1}$ at ambient CO$_2$ concentration (350 µmol mol$^{-1}$) with a portable photosynthesis system (LI-6400, LI-COR Biosciences Inc., Lincoln, NE, USA).

**Table 2. Equations and terms used in the JIP-test analysis (Strasser et al., 2000)**

<table>
<thead>
<tr>
<th>Formulae and terms</th>
<th>Illustrations</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_J = (F_{2ms} - F_0)/(F_M - F_0)$</td>
<td>Relative variable fluorescence intensity at the J-step</td>
</tr>
<tr>
<td>$F_V = F_M - F_0$</td>
<td>Variable fluorescence</td>
</tr>
<tr>
<td>$M_O = 4 (F_{300\mu s} - F_0)/(F_M - F_0)$</td>
<td>Approximated initial slope of the fluorescence transient</td>
</tr>
</tbody>
</table>

Quantum efficiencies or flux ratios

- $\varphi_{F_0} = \text{TR}_O/\text{ABS} = [1 - (F_0/F_M)] = \text{Maximum quantum yield for primary photochemistry (at } t = 0)$
- $\varphi_{F_E} = \text{ET}_O/\text{ABS} = [1 - (F_0/F_M)] \Psi_O = \text{Quantum yield for electron transport (at } t = 0)$
- $\varphi_{T_D} = 1 - \varphi_{F_0} = F_0/F_M = \text{Quantum yield for energy dissipation (at } t = 0)$
- $\Psi_O = \text{ET}_O/\text{TR}_O = (1-V_J)$ |

Probability that a trapped exciton moves an electron into the electron transport chain beyond $Q_A$ (at $t = 0$)

Specific fluxes or specific activities

- $\text{ABS/RC} = M_O (1/V_J) (1/\varphi_{F_0}) = \text{Absorption flux per reaction center}$
- $\text{TR}_O/\text{RC} = M_O (1/V_J) = \text{Trapped energy flux per reaction center (at } t = 0)$
- $\text{ET}_O/\text{RC} = M_O (1/V_J) \Psi_O = \text{Electron transport flux per reaction center (at } t = 0)$
- $\text{DL}_O/\text{RC} = (\text{ABS/RC}) - (\text{TR}_O/\text{RC}) = \text{Dissipated energy flux per reaction center (at } t = 0)$

Performance indexes

- $\text{PI}_\text{ABS} = (\text{RC/ABS}) [\varphi_{F_0} / (1 - \varphi_{F_0})] [\Psi_O / (1 - \Psi_O)] = \text{Performance index on absorption basis}$

**Determination of Chlorophyll Content**

The chlorophyll content indices (CCI) of the same leaves used for chlorophyll fluorescence and gas exchange measurement were measured with a CCM-200 chlorophyll content meter (Opti-Sciences, Tyngsboro, MA, USA). The relative change in chlorophyll content ratio was used to characterize the degree of stress-induced inhibition of plant chlorophyll synthesis, which was expressed as:

The change in chlorophyll content (%) = ($C_2 - C_1$) / $C_1 \times 100\%$, where $C_i$s the chlorophyll content at the start of treatment and $C_2$ is the chlorophyll content at the end of treatment.

Data were presented as the means ± standard errors for each treatment ($n = 5$). Analysis of variance was performed using the SPSS software (ver.13.0).

**RESULTS AND DISCUSSION**

**Growth Measurement**

The plant height growth rates were significantly inhibited after SA$_1$ and SA$_2$ treatments (Figure 1), being 40% and 2% of the
control, respectively. The plant height growth was markedly reduced with increasing salinity-alkalinity level. Restriction on plant height and shoot biomass is one of the obvious symptoms of salinity-alkalinity stress (Guan et al., 2009), which mainly resulted from the inhibition of expansion growth of new leaves and shoot elongation rate. The restriction on leaf expansion under saline-alkaline conditions minimizes water losses, which happens to many species under osmotic stress (Tabatabaei, 2006). Low N level (7.5 mM) had no improvement on plant height growth under salinity-alkalinity stress. The height rate of plants under SA1+N2, SA1+N3 and SA2+N2 treatments were less stressed, being 67%, 79%, and 11% of the control, respectively. It was demonstrated that the high level of N (30mM) partially mitigated the adverse effects of low salinity-alkalinity on plant height growth (Figure 1), while moderate N level (15mM) showed the greatest mitigation effect at high salinity-alkalinity. One reason for the mitigation effect is that ammonium nitrate might convert NaHCO3 into NH4HCO3, resulting in decreased alkalinity. Besides, enough fertilization enhanced the plant resistance to stress. Under the high salinity-alkalinity and N supply condition, salinity-alkalinity was the dominant factor governing the reed growth and N uptake, and over-fertilization did not improve N uptake. Thus, moderate N level mitigated the adverse effect induced by high salinity-alkalinity. Abdelgadir et al. (2005) reported that N supply increased rice growth under salinity stress. Tabatabaei (2006) found that plants growth were improved at 200 mg l⁻¹ N in two olive cultivars (cvs Manzanillo and Zard), but it was reduced when the N concentration increased to 300 mg l⁻¹. However, the growth of another olive cultivar (Mission) progressively increased with the increase in both salinity and N level. These findings are similar to our results, in which the optimum N concentration for mitigation varies between species and the levels of salinity-alkalinity.

**Photosynthesis Rate Analysis**

The net photosynthesis rate ($P_n$), stomatal conductance ($g_s$), and intercellular CO₂ concentration ($C_i$) are shown in Table 3. Compared with the control, plants $P_n$ decreased by 41% and 82% under SA1 and

**Figure 1.** The height increment of the control and 15-day old salinity-alkalinity stressed reed seedlings under various N conditions. Vertical lines are standard error of the means (n = 5)
Table 3. The leaf net photosynthesis ($P_n$), stomatal conductance ($g_s$) and intercellular CO$_2$ concentration ($C_i$) of the control and 15-d salinity-alkalinity stressed reed seedlings under various N conditions.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>$P_n$ ($\mu$mol CO$_2$ m$^{-2}$ s$^{-1}$)</th>
<th>$g_s$ (mol H$_2$O m$^{-2}$ s$^{-1}$)</th>
<th>$C_i$ (µmol mol$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>control</td>
<td>24.23 ± 2.36</td>
<td>0.693 ± 0.012</td>
<td>291 ± 22</td>
</tr>
<tr>
<td>SA$_1$</td>
<td>14.20 ± 1.25</td>
<td>0.286 ± 0.005</td>
<td>279 ± 17</td>
</tr>
<tr>
<td>SA$_2$</td>
<td>4.38 ± 0.31</td>
<td>0.099 ± 0.002</td>
<td>359 ± 10</td>
</tr>
<tr>
<td>SA$_1$+N$_1$</td>
<td>12.97 ± 0.88</td>
<td>0.180 ± 0.002</td>
<td>241 ± 8</td>
</tr>
<tr>
<td>SA$_1$+N$_2$</td>
<td>20.47 ± 1.55</td>
<td>0.284 ± 0.007</td>
<td>233 ± 11</td>
</tr>
<tr>
<td>SA$_1$+N$_3$</td>
<td>19.90 ± 2.23</td>
<td>0.297 ± 0.010</td>
<td>243 ± 14</td>
</tr>
<tr>
<td>SA$_2$+N$_1$</td>
<td>14.67 ± 2.15</td>
<td>0.217 ± 0.012</td>
<td>266 ± 20</td>
</tr>
<tr>
<td>SA$_2$+N$_2$</td>
<td>9.80 ± 0.92</td>
<td>0.075 ± 0.004</td>
<td>229 ± 6</td>
</tr>
<tr>
<td>SA$_2$+N$_3$</td>
<td>9.58 ± 1.05</td>
<td>0.059 ± 0.006</td>
<td>174 ± 15</td>
</tr>
</tbody>
</table>

SA$_2$ treatments, respectively. The sensitivity of $P_n$ shows that it is an ideal indicator of salinity-alkalinity stress, as also shown in a pervious study (Xu et al., 2008). Reduction in net photosynthesis rate strongly correlated with stunted growth, implying that inhibition of plant growth can be at least partially attributed to the reduction of carbon assimilation under stress. Stomatal conductance ($g_s$) decreased significantly in plants under SA$_2$ treatment at various N levels. Intercellular CO$_2$ concentration ($C_i$) decreased by 4% in plants under SA$_1$ treatment, but increased by 23% under SA$_2$ treatment. According to Farquhar et al. (1989), lower $P_n$ accompanied by lower $g_s$ and $C_i$ at low salinity-alkalinity (SA$_1$) might be mainly ascribed to stomatal closure, which restricts entry of CO$_2$ into leaves. However, lower $P_n$ accompanied by lower $g_s$ and higher $C_i$ at high salinity-alkalinity (SA$_2$) may be attributed to non-stomatal limitation, including changes in leaf biochemistry that results in inhibition or down-regulation of photosynthesis and the reduction of the chlorophyll content. Previous studies demonstrated that stomatal limitation is more significant at medium salinities and non-stomatal restriction is more pronounced at high salinity levels (Everard et al., 1994; Netondo et al., 2004). A similar change pattern in response to salinity-alkalinity stress was found in the present study. Our study suggests that the stomatal closure is likely the first defense mechanism of plant against salinity-alkalinity stress. Non-stomatal limitation increases progressively under high salinity-alkalinity stress. This means that non-stomatal limitation may play a major role through inhibiting biochemical metabolism and adversely affecting chlorophyll $a$ fluorescence.

Similar to the observation of Kao et al. (2001), who reported that increasing nitrogen availability increased CO$_2$ assimilation of the mangrove species, N supply enhanced the photosynthetic capacity of plants under salinity-alkalinity stress in the present study. There was a clear recovering tendency of photosynthesis rate for plants treated with low salinity-alkalinity at moderate and high N levels. As shown in Table 3, $P_n$ for SA$_1$+N$_1$ and SA$_2$+N$_1$ treated plants were up-regulated to 84% and 61% of the control, respectively. The stomatal conductance ($g_s$) changed little at moderate and high N and low/high salinity-alkalinity levels, but showed an increase at low N and high salinity-alkalinity, suggesting that low N supply decreased stomatal closure at high salinity-alkalinity. Intercellular CO$_2$ concentration ($C_i$) decreased slightly for plants at various N levels at low/high salinity-alkalinity. A higher $P_n$ accompanied by lower $C_i$ suggests that optimum N supply may increase photobiochemical activity. These results revealed that N supply increased the photosynthesis rate of reed stressed by low/high salinity-alkalinity; the decrease of non-stomatal limitation being one of the important reasons. This was further confirmed by the results of chlorophyll fluorescence measurements (Table 4).
<table>
<thead>
<tr>
<th>Treatment</th>
<th>$F_M$</th>
<th>$F_V$</th>
<th>$V_j$</th>
<th>$F_{m}/F_O$</th>
<th>$F_{v}/F_O$</th>
<th>$F_{v}/F_M$</th>
<th>$M_o$</th>
<th>$\Psi_O$</th>
<th>$\varphi_{Dp}$</th>
<th>$\varphi_{Dd}$</th>
<th>$P_{ABS}$</th>
<th>ABS/RC</th>
<th>TR/RC</th>
<th>ET/RC</th>
<th>DI/RC</th>
</tr>
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<td>1</td>
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</tr>
<tr>
<td>SA1</td>
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<td>0.91</td>
<td>1.05</td>
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<td>0.97</td>
<td>1.18</td>
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<td>1.12</td>
<td>0.65</td>
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<td>1.3</td>
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<td>0.64</td>
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</tr>
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<td>0.96</td>
<td>0.99</td>
<td>1.06</td>
<td>0.95</td>
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<td>1.02</td>
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<td>0.93</td>
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<td>0.87</td>
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<td>0.84</td>
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<td>0.99</td>
<td>0.8</td>
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<td>1.04</td>
<td>1.3</td>
<td>0.96</td>
<td>0.95</td>
<td>1.1</td>
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<tr>
<td>SA2+N1</td>
<td>0.99</td>
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<td>0.78</td>
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</table>
Chlorophyll Fluorescence

To investigate the effects of salinity-alkalinity and N level on the electron transport of PSII of plants, the poly-phases fast fluorescence induction test was performed. Examples of the fast kinetic induction curves of plants treated with various salinity-alkalinity and various concentrations of nitrogen are shown in Figure 2. No significant change of $F_0$ was found under salinity-alkalinity stress. $F_M$ decreased drastically and the J-P phase gradually leveled off with high salinity-alkalinity concentration (Figure 2 and Table 4), suggesting that electron transport was hindered after $Q_A$ (Haldimann et al., 1995; Strasser et al., 1995; Toth et al., 2005), and OEC failed to provide electrons for PSII to reduce the quinone acceptors (Falk and Palmqvist, 1992); that is, the electron transport on the donor side of PSII was inhibited, and P680+, a strong fluorescence quencher, accumulated at higher salinity-alkalinity (Govindjee, 1995), indicating that high salinity-alkalinity stress had inhibitory effects on the donor side of PSII. The depression of $F_M$ was also found in higher plants and algae stressed by pollutants (Appenroth et al., 2001; Pan et al., 2008). The decrease of $F_M$ led to a decrease of the variable fluorescence ($F_V$), and finally led to a decline of $F_V/F_M$. The values of $F_V/F_M$ were significantly reduced under SA$_2$ treatment with respect to the control (Table 4). This was in accordance with many other studies (Larcher et al., 1990; Xu et al., 2008; Kafi, 2009). According to Kafi (2009), the non-stomatal limitation such as reduction in $F_V/F_M$, show that plant might experience some degree of photo inhibition at high salinity, indicating that the RuBP regeneration, which needs adequate electron translocation from PSII to electron acceptors, might be disturbed by high salinity. Usually, under moderate stress, $F_V/F_M$ of plants changes little and its decline under severe stress reflects weakened ability of PSII to reduce the primary acceptor $Q_A$ (Calatayud and Barreno, 2001).

Since the O-J-I-P fluorescence transient reflects the state of $Q_A$, $Q_B$, and PQ pool (Strasser and Govindjee, 1992), more information was obtained from parameters extracted from fluorescence rises (Table 4). Results of the JIP-test (Table 4) demonstrated that high salinity-alkalinity stress resulted in an increase in the effective antenna size per reaction center (ABS/RC,

![Figure 2](image-url) 

**Figure 2.** Examples of fast chlorophyll fluorescence transient of the control and salinity-alkalinity stressed reed seedlings under various N conditions.
29%) and a decrease in electron transport flux (ET/RC, φEo, Ψo). Under SA2 stress, lower φEo (49% of the control) and Ψo (57% of the control) revealed that the activity of electron transport beyond QA, i.e., the acceptor side of PSII, was considerably hindered at high salinity-alkalinity. The increasing trend of fluorescence intensity at J step at high salinity-alkalinity (SA2, Figure2) is usually interpreted as an evidence of accumulation of reduced QA pool (Strasser et al., 1995), possibly due to a decrease of electron transport beyond QA. The value of φEo under SA2 stress increased to 163% of the control, resulting in a decrease of the performance index (PIABS) by 82%. Parameters such as PIABS, φEo, and ABS/RC showed higher sensitivity than Fv/FM to salinity-alkalinity stress, which is in agreement with many other studies (Christen et al., 2007). This is because these parameters provide information on the heterogeneity of PSII reactive centers while Fv/FM only reflects the efficiency of all the PSII units including both activated and inactivated reactive centers (Wen et al., 2005).

Nitrogen addition at high salinity-alkalinity caused Fv/FM to recover to 95-97%, suggesting N supply promoted the ability of PSII to reduce the primary acceptor QA. The greatest improvement of electron transfer (ET/RC, φEo and Ψo), dissipated energy (DI/RC, φDo), and performance index (PIABS) occurred at moderate N with high salinity-alkalinity, indicating that the activity of electron transport beyond QA was enhanced. Plants growing under N-limited conditions exhibit decreases not only in photosynthetic capacity but also in leaf chlorophyll concentrations (Demmig-Adams and Adams, 2003), suggesting that photodamage may occur under N deficiency. Increased thermal energy dissipation under N deficiency has been found in maize (Lu and Zhang, 2000). Therefore, nitrogen supplement counteracts these adverse effects on the PSII, i.e., nitrogen supplement promotes electron transfer and decreases the energy dissipation, thus, enhances the PSII activity.

### Chlorophyll Content

To further understand the damage of salinity-alkalinity stress to photosynthetic apparatus, chlorophyll content change was calculated. Fifteen days after the onset of the treatments, the chlorophyll content of reed seedlings decreased by 15% and 28% under SA1 and SA2 treatments, respectively (Figure 3). A decrease in leaf chlorophyll content has been described in plants irrigated with water containing high concentrations of NaCl (Demir and Kocacaliskan, 2008). This decrease may be attributed to the formation of proteolytic enzymes, such as chlorophyllase, which degrade chlorophyll and damage the photosynthetic apparatus (Yasseen, 1983). Chlorophyll content of the reeds receiving high N (30 mM) with low salinity-alkalinity and moderate N (15 mM) with high salinity-alkalinity showed the greatest increase, i.e. 94% and 22%, respectively. Increase in chlorophyll content after addition of nitrogen might be explained by the fact that the synthesis of chlorophylls and related proteins, as well as precursor molecules such as amino acids, is dependent on N availability (Terashima and Evans, 1988). Under high salinity-alkalinity stress, N uptake of reed seedling will decrease, thus, high nitrogen may cause more inhibitory effect on it. Therefore, chlorophyll content reduction in SA2+N decreased significantly. The changes of the chlorophyll content in various conditions were in accordance with the change of chlorophyll fluorescence and plant height growth.

### CONCLUSION

The growth of reed seedling was retarded by salinity-alkalinity stress through downregulation of chlorophyll content and inhibition of photosynthesis. Decreased
photosynthesis rate under low salinity-alkalinity condition is associated with the increase in stomatal closure, while under high salinity-alkalinity stress it may mainly be attributed to non-stomatal limitation, i.e. down-regulation of photochemical activity and damage of photosynthetic apparatus. Both donor and acceptor sides of PSII are the target sites under high salinity-alkalinity. At high salinity-alkalinity, the electron transfer was markedly inhibited and energy dissipation was enhanced, eventually, leading to decrease in the comprehensive photosynthesis performance index and photosynthesis rate. The highest N supply in low salinity-alkalinity treatment, or moderate N supply in high salinity-alkalinity treatment, partially mitigated the toxicity of salinity-alkalinity to plants. The mitigation effect included promotion of the plant height growth and chlorophyll synthesis and decreasing the inhibitory effects of salinity-alkalinity on PSII activity. Nitrogen supply could enhance the electron transfer on the donor side and the acceptor side of PSII, decrease the energy dissipation, and increase the comprehensive photosynthesis performance and photosynthesis rate. These results suggested that agricultural wastewater with high nitrogen content may be used for the recovery of Phragmites-dominated alkalized-salinized wetland.

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واکنش فتوستزی گیاهچه نی در مصرف مختلف شوری-قیلیان و سطوح نیتروژن

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چکیده

یسایار از تغییر در شرایط حیاتی در آب‌های دشت سوکول داشت. تحقیق پستانداری برای بررسی در مورد شیوع و بهره‌وری Phragmites australis (فتوستزی و قیلیان نی) میزان فتوستزی و فروش و گیاهچه نی با استفاده از سیستم‌های تست بادل گازی و فروش و گیاهچه نی بالا (محدود ۰.۵ میلی مولار NaHCO۳ و ۲۵ میلی مولار NaCl) به میزان (۲۵٪ / ۸۸٪ و ۹۸٪) در میزان

فتوستزا (Fv/Fm)، میزان پیشگیری فتوسیم (PIABS) و میزان افزایش ارتفاع بونه مشاهده شد. در مورد قیلیان بالا (فتوستزی II) به طور معمول میزان افزایش ارتفاع بونه مشاهده شد. در مورد بازمی‌گردد PSII تعابیر زیاد می‌تواند با رشد قیلیان بالا (فتوستزی II) در مورد نیتروژن با بودن میزان (۲۵٪ / ۸۸٪ و ۹۸٪) در میزان

سپهری-قیلیان نی را نشان داد. و افزایش ارتفاع بونه، سپهر-کلروفیل فعالیت PSII و برای انجام جدید منابع های شوری که در آنها

موجود شد. بر این پایه، این نتایج نشان داد که در برخی از استهلاک ایجاد داشته که مقدار N مورد نیاز برای گیاه نی تحت نش شوری با شدت شوری-قیلیان غیر می‌کند.