Nitrogen nutrition of rice plants under salinity

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Abstract

Two rice (*Oryza sativa* L.) cultivars, Koshihikari and Pokkali, were grown in solution culture at three concentrations of NaCl or Na_2SO_4 [0 (S0), 50 (S1), and 100 (S2) mmol dm^{-3}] and three N contents [0.7 (N1), 7 (N2) and 14 (N3) mmol dm^{-3}]. Salinity significantly decreased dry matter of both cultivars. Pokkali had better growth than Koshihikari under both saline and non-saline conditions. Applications of N enhanced development of shoot dry mass under S0 and S1 treatments up to N2. Under S2, N application had no effect on shoot dry mass of both cultivars. Root dry mass of both cultivars decreased with increasing N application at S1 and S2. Shoot and root NO_3-N content in both rice cultivars increased with increasing N concentration in the nutrient solutions. The absorption of NO_3-N was less in Koshihikari than Pokkali plants, and also was much less in Cl^- than SO_4^{2-} salinity suggesting the antagonism between Cl^- and NO_3^-. In addition a significant negative correlation between concentrations of NO_3-N and Cl^- in the shoots or roots was observed in both cultivars.

Additional key words: Cl^-, cumulative transpiration, NO_3-N, *Oryza sativa*, SO_4^{2-}.

Introduction

Salinity problems are generally related to the presence of high concentrations of NaCl or Na_2SO_4 in the root zone. Plants grown under these conditions absorb excessive amounts of cations and anions, with frequently Cl^- and Na^+ being the predominant ions absorbed. Therefore, various interactions during their uptake with other soil nutrients may be expected. For example, the presence of Cl^- inhibits the absorption of NO_3^- (Cerezo *et al*. 1997, Peuke and Jeschke 1999), while increasing NO_3^- fertilization reduces Cl^- concentration in the leaves (Deane-Drummond 1986). Under such situations, several investigators have reported that excess salt in soil or nutrient solution caused a decrease in total N uptake by plants such as bean (Chakrabarti and Mukherji 2003), barley (Luque and Bingham 1981) and rice (Palfi 1963). Many experiments have been conducted to study the combined effects of salinity and fertility on several agricultural crops. Most of this work has been focused on N fertilization applied as NO_3^- (Kafkafi *et al*. 1982, Papadopoulos and Rendig 1983). Using different species and experimental conditions these workers reported that the presence of Cl^- suppressed NO_3^- uptake by the plants, indicating a direct competitive effect between these ions. Wallace and Berry (1981) suggested that wheat (*Triticum aestivum* L.) yield reduction due to increased salinity might not be due entirely to Cl^- toxicity, but partly to induced deficiency of NO_3^- caused by the high external Cl^- concentration.

The interaction between salinity, N nutrition and crop yield is a major concern in improving crop production. Therefore, the objectives of this study were: *1*) to confirm the hypotheses that increasing NO_3^- in the nutrient solution will decrease Cl^- uptake, to clarify this antagonism by comparing NO_3^- uptake under NaCl and Na_2SO_4 salinity in rice plant; *2*) to study the relationship between salt tolerance and the ability of N absorption of rice plant. For this purpose, a comparative study between cv. Koshihikari, which is known to be salt sensitive and cv. Pokkali considered as salt tolerant was carried out.

Received 15 October 2003, *accepted* 21 April 2004.
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Materials and methods

The experiments were conducted in a glasshouse at the Faculty of Agriculture, Tottori University, Japan. The plant materials used were two rice (*Oryza sativa* L.) cultivars: Koshihikari (a salt sensitive cultivar) and Pokkali (a salt tolerant cultivar). The seeds of both cultivars were soaked in tap water for 4 d. Germinating seeds were transferred to a vinyl net floating on tap water in a plastic vessel and grown for 7 d. Four seedlings per variety were transplanted into 4 dm^3 plastic pots. The pots were filled with the control solution (Table 1). Each of the experiments consists of 9 treatments with three salinity levels factorially combined with three nitrogen (N) levels and replicated three times. The concentrations of NaCl or Na_2SO_4 were 0, 50, and 100 mmol dm^{-3} and hereafter referred to S0, S1, and S2, respectively. The N concentrations in all experiments were 0.7 (N1), 7 (N2) and 14 (N3) mmol dm^{-3} (Table 1). The treatments were started 15 d after transplanting of both cultivars. The (N1) solutions were renewed every 2 d. The pots were weighed every 2 d to determine cumulative transpiration. One plant per pot was harvested just before imposition of salinity and N treatments and at 1, 2 and 3 weeks after the start of the treatments. Plants were separated into roots and shoots and oven-dried (48 h at 70 °C) and dry mass were determined. After milling into a homo-geneous powder samples of roots and shoots were analyzed for total N using the NCH analyser (*SumiGraph HCN-21*, *Sumica Chemical Analysis Service Corp*., Tokyo, Japan). Chloride, NO_3-N and SO_4^{2-} were analyzed by ion chromatograph (*HIC-6A Shimadzu Corp*., Kyoto, Japan).

Table 1. Composition of solutions [mmol dm^{-3}] and electrical conductivity [dS m^{-1}] in different treatments. The pH of the culture solution was adjusted to 5.0 by the addition of 1:1 H_2SO_4 solution. P, K, Ca, and Mg concentrations [mmol dm^{-3}] were 0.2, 3.2, 4.2 and 3.0, respectively. Micronutrient concentration [µmol dm^{-3}] were as follows: Fe: 50, B: 23, Mn: 5, Zn: 0.4, Cu: 0.2, Mo: 0.1.

Treatments		N	Na	Cl^-	SO_4^{2-}	EC
Cl^--dominated	S0N1	0.7	0	6.5	3.0	1.26
	S0N2	7.0	0	0.2	3.0	1.14
	S0N3	14.0	0	0.2	3.0	1.83
	S1N1	0.7	50	56.5	3.0	6.40
	S1N2	7.0	50	50.2	3.0	6.30
	S1N3	14.0	50	50.2	3.0	6.90
	S2N1	0.7	100	106.5	3.0	11.30
	S2N2	7.0	100	100.2	3.0	10.80
	S2N3	14.0	100	100.2	3.0	12.20
SO_4^{2-}-dominated	S0N1	0.7	0	3.0	6.5	1.26
	S0N2	7.0	0	3.0	0.2	1.14
	S0N3	14.0	0	3.0	0.2	1.83
	S1N1	0.7	50	53.0	6.5	5.70
	S1N2	7.0	50	53.0	0.2	5.70
	S1N3	14.0	50	53.0	0.2	6.40
	S2N1	0.7	100	103.0	6.5	9.90
	S2N2	7.0	100	103.0	0.2	10.10
	S2N3	14.0	100	103.0	0.2	9.90

Results and discussion

Salinity in general significantly decreased the dry mass of both cultivars. Pokkali had a higher shoot dry mass than Koshihikari under both saline and non-saline conditions, irrespective of N application (Fig. 1). Averaged across cultivars and treatments, shoot dry mass was significantly lower under Cl^- than SO_4^{2-} salinity. Applications of N up to N2 significantly: *1*) increased shoot dry mass under S0 in both cultivars, *2*) increased shoot dry mass of Koshihikari under SO_4^{2-} at S1, but had no effect under Cl^- salinity at the same level, and *3*) increased shoot dry mass of Pokkali at S1 level at both salinities with more pronounced effect under SO_4^{2-} than Cl^- salinity. At S2, N application had no effect on shoot dry mass of both cultivars.

Cultivar Pokkali accumulated significantly greater dry mass in the root than did cv. Koshihikari, irrespective of N and salinity treatments (Fig. 1). The root growth of both cultivars was reduced by increasing salinity, with more inhibition being observed under Cl^- salinity than under SO_4^{2-} salinity. Application of N under S0 had no effect on root growth of both cultivars. Under SO_4^{2-} salinity, the root growth of both cultivars decreased with increasing N supply, with more pronounced effects at S1 than at S2. Under Cl^- salinity, application of N up to N2 reduced root growth of both cultivars at S1, while at S2 root growth was reduced with increasing N for cv. Pokkali, but not for cv. Koshihikari.

For both cultivars shoot and root N concentration was significantly enhanced by N application up to N2 (Fig. 2). There were no differences in shoot N concentration between Cl^- and SO_4^{2-} salinity treatments at the same N level. Root N concentration was higher in SO_4^{2-} than Cl^- treatments except for Koshihikari in S1N1 and Pokkali plants in S2N1 treatment. At each salinity N concentration in the shoots was higher than in the roots of both cultivars.

Cumulative transpiration decreased with increasing salinity in both cultivars, especially for cv. Koshihikari (Fig. 3). Cv. Pokkali showed higher transpiration than cv. Koshihikari at S0 treatment and at S1 and S2 treatments. For both cultivars, N application improved cumulative transpiration up to N2 under S0 and S1. At S2,

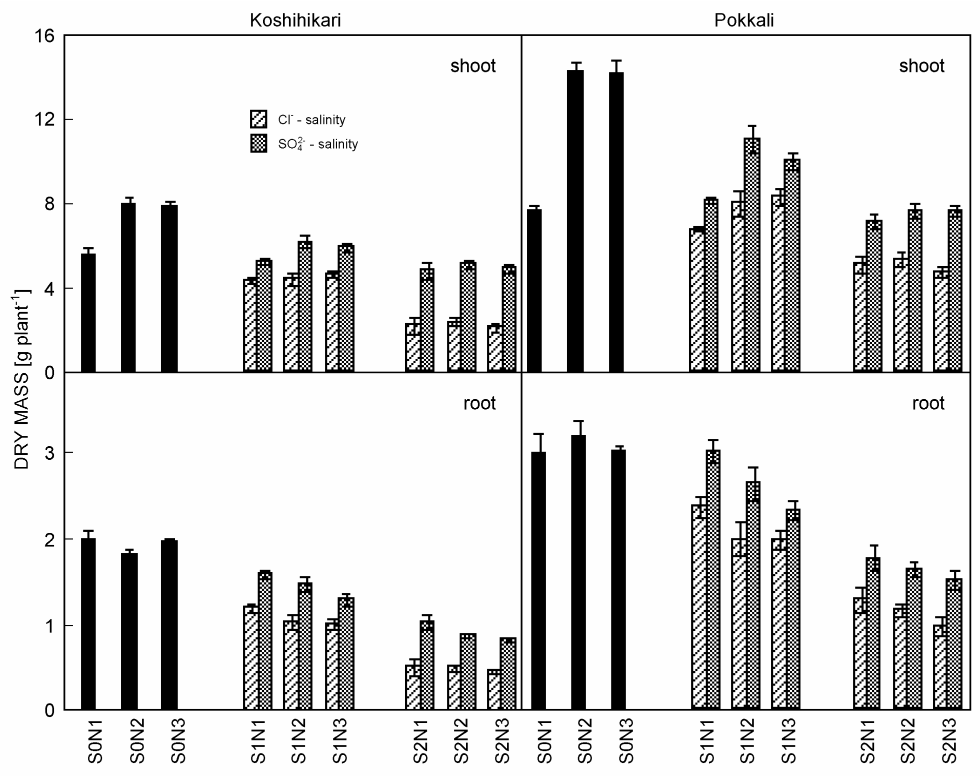

Fig. 1. Dry mass of the two rice cultivars, Koshihikari and Pokkali 3 weeks after the start of the treatment. Means ± SE, *n* = 3.

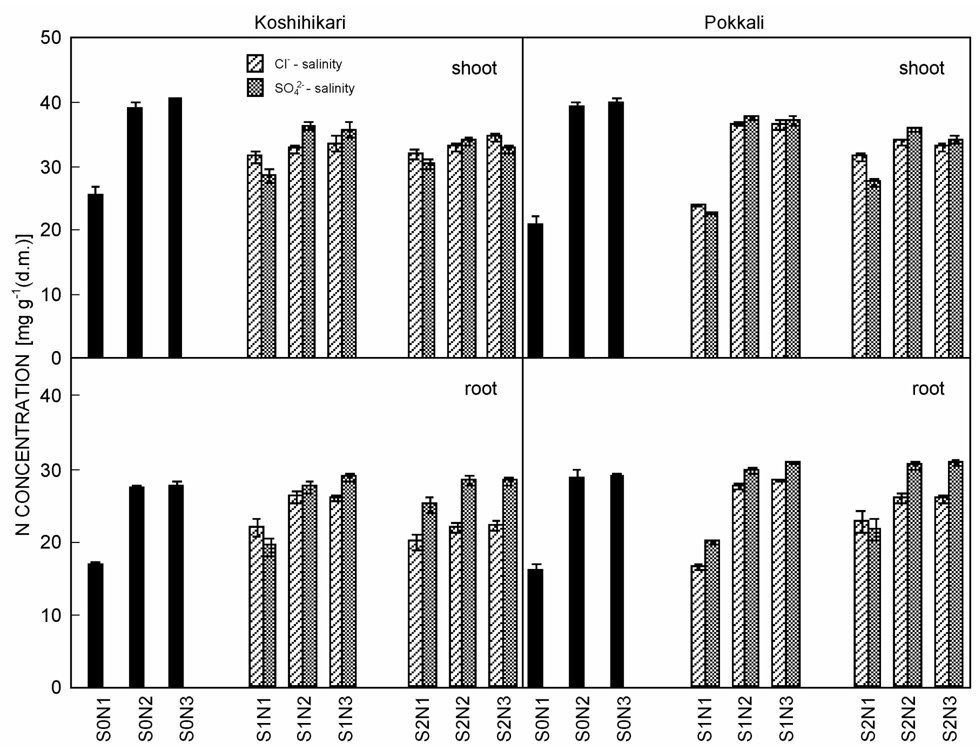

Fig. 2. Total N concentration in shoot and root of the two rice cultivars, Koshihikari and Pokkali 3 weeks after the start of the treatment. Means ± SE, *n* = 3.

no differences in transpiration were found among N treatments in both cultivars (Fig. 3). Cumulative transpiration was higher under SO_4^{2-} than that under Cl^- treatments in both cultivars. At S1 and S2, the decrease in cumulative transpiration was more pronounced in cv. Koshihikari than cv. Pokkali at all N levels.

Shoot and root NO_3-N concentration in both rice cultivars increased with increasing N level in the nutrient solutions (Fig. 4). The solution culture with NaCl inhibited NO_3-N absorption much more than that with Na_2SO_4 except at S1N1 in both cultivars and at S2N3 treatments in Koshihikari. Shoot NO_3-N concentration in salt stressed plants was lower than in non-stressed plants. For both cultivars, the concentration decreased with increasing salinity. Shoots NO_3-N was lower in cv. Koshihikari than that observed in cv. Pokkali. However, salinity did not affect the NO_3-N concentration in cv. Pokkali root. The differences in root NO_3-N concentration between Cl^- and SO_4^{2-} for both rice cultivars were observed only at S2. There was a significant negative correlation between concentrations of shoot or root NO_3-N and Cl^- for both cultivars, except at S2 for the shoot of cv. Koshihikari (Fig. 5).

Increasing salinity irrespective of the source, significantly decreased growth of the two rice cultivars. The lower growth reduction of cv. Pokkali as compared with cv. Koshihikari under salt stress (Fig. 1) indicates that cv. Pokkali is more tolerant to salt than cv. Koshihikari. Growth reduction was often accompanied by leaf necrosis, and this was more severe in NaCl treated plants than in plants treated with Na_2SO_4.

The beneficial effect of N application on plant dry mass may be attributed to improve NO_3^- uptake and impaired Cl^- uptake (Kafkafi *et al*. 1982). At S2, N application had no effect on shoot dry mass of both

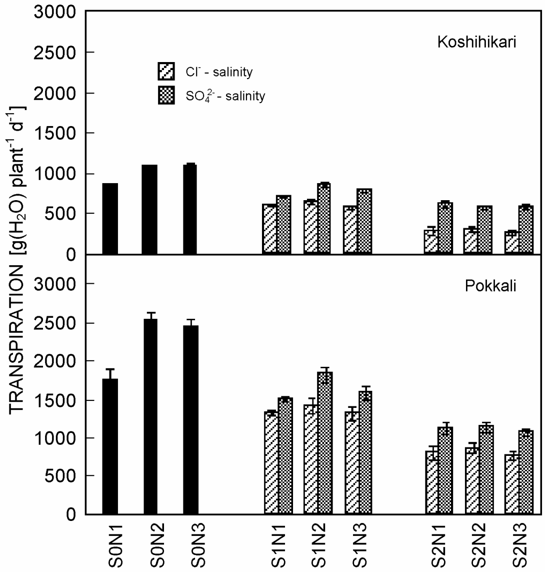

Fig. 3. Cumulative transpiration of the two rice cultivars, Koshihikari and Pokkali during the experiment period. Means ± SE, n = 3.

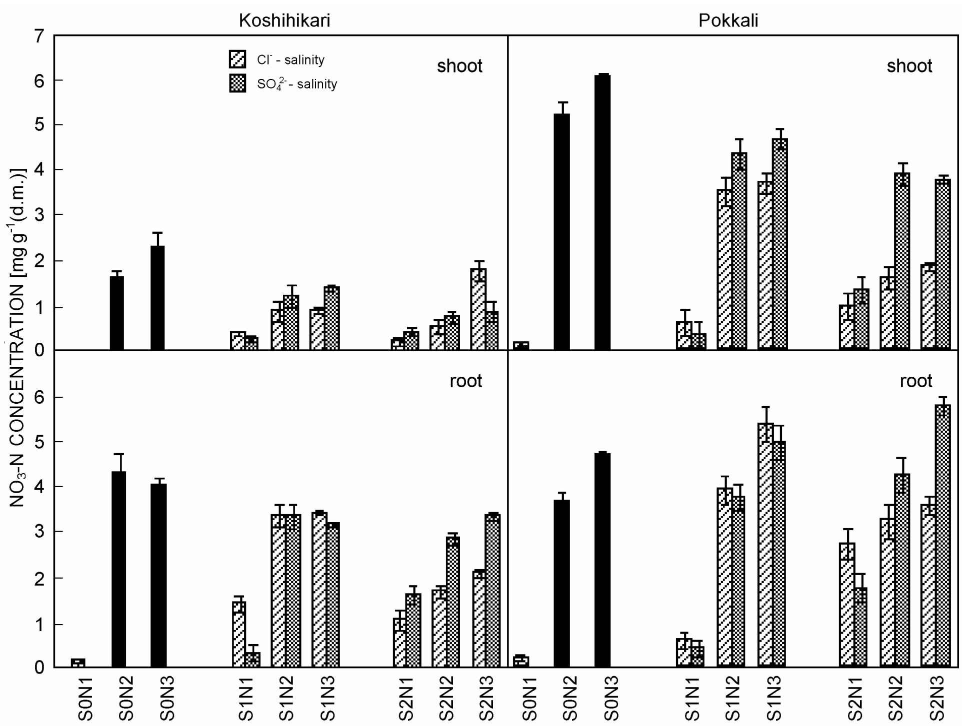

Fig. 4. NO_3-N concentration in shoot and root of the two rice cultivars, Koshihikari and Pokkali 3 weeks after the start of the treatment. Means ± SE, n = 3.

cultivars, suggesting that rice plant was more sensitive to high salinity than to N status. While the dry mass of the shoots was considerably increased by raising the rate of N application, that of the root was decreased by increasing N application in solution for both Cl^- and SO_4^{2-} treatments at S1 and S2 in both cultivars. These results demonstrate the most commonly accepted view that an increase in the levels of nutrients to the plant as a whole benefits the shoots rather more than the roots. However, a reduction in root growth did not prevent the production of higher dry mass at the N2 and N3.

In the present study, the growth pattern of both rice cultivars varied positively with cumulative transpiration. It is evident from these results that water uptake was directly related to the total biomass produced. Under saline conditions, Papadopoulos and Rendig (1983) and Bar *et al*. (1987) have shown that additions of NO_3^- resulted in increased water uptake associated with enhanced growth rate of tomato and avocado. The reduction in transpiration under salinity and accompanying reduction of N was greater under Cl^- than under SO_4^{2-}, especially for cv. Koshihikari. This result might be attributed to the fact that SO_4^{2-}, in contrast to Cl^-, is relatively less injurious to rice plants. There is also a possibility that growth reduction is not entirely due to Cl^- toxicity, but may be partially due to Cl^- induced NO_3^- deficiency (Torres and Bingham 1973). The continued accumulation of N and reduced dry mass under saline conditions was primarily due to retardation of plant growth under saline conditions, rather than a reduction in N uptake. Also, the observed differences in NO_3-N absorption by plant roots between Cl^- and SO_4^{2-} salinity at S2 suggest the antagonism between Cl^- and NO_3^- ions. In addition a significant negative correlation between concentrations of shoots or roots NO_3-N and Cl^- was observed in both cultivars (except in S2 in cv. Koshihikari). The higher NO_3-N in shoot of S2N1 under Cl^- than SO_4^{2-} salinity treatments in both cultivars might be attributed to dilution effects due to higher growth under SO_4^{2-} than Cl^- treatments and low uptake of NO_3-N in these treatments compared with other N treatments. In contrast, no such relationships between cumulative transpiration and NO_3-N concentration were observed for both rice cultivars, which may indicate that transpiration was not related to NO_3^- uptake. The results of this study showed that the effect of salt stress on the growth of rice is reflected in lower dry weights and decreased NO_3-N uptake. Nitrate absorption was more influenced by antagonism by Cl^- than by reduced water uptake in both cultivars. Koshihikari appeared to be more sensitive to a reduction in nitrate absorption caused by Cl^- than Pokkali.

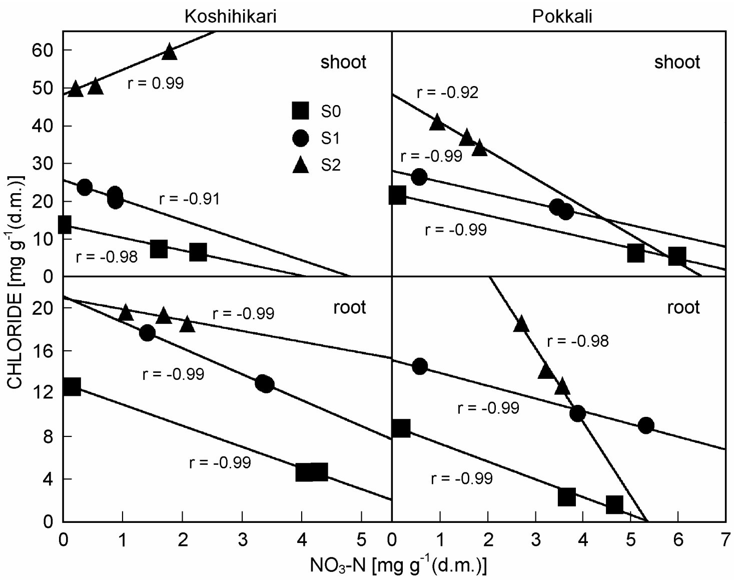

Fig. 5. Relationship between Cl^- and NO_3-N in shoot and root of the two rice cultivars Koshihikari and Pokkali plants.

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