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RELATIVE GROWTH RATE AND ION TRANSPORT IN RICE GROWN UNDER SALINE ENVIRONMENT

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Abstract

An experiment was conducted in solution culture with two rice cultivars of varying salt tolerance: NIAB 6 (salt tolerant) and IR 1561 (Salt sensitive), to compare their growth rate and ion transport from root to shoot when exposed to salinity levels of 0 and 100 mol m^{-3} NaCl. NIAB 6 had a faster rate of growth than IR 1561 under saline conditions. At early seedling stage, rate of transport of Na^+, K^+ and Cl^- was much higher in IR 1561 but later on, transport of Na^+ and K^+ was greater in NIAB 6 whereas Cl^- transport was higher in IR 1561. The higher rate of Na^+ translocation from root to shoot in NIAB 6 was probably mitigated by the dilution of Na^+ due to faster rate of growth of this cultivar.

Introduction

The concentration of ions in the plant depends on the growth rate of the shoot in relation to the rate of entry of ions from the roots as well as rate of export of these ions out of the shoot. The processes which may affect these interrelationships include active transport of ions across the roots, movement in the transpiration stream, retranslocation in the phloem, localization in certain tissues and photosynthetic rates which has an overall control on many of these processes (Pitman, 1972; Greenway & Munns, 1980).

Resistance to salt entry into plant shoot and percent survival are often proportional to the relative growth rate and, consequently, the dilution of ionic concentration through rapid growth rates is being used as an index of salt tolerance in higher plants (Greenway, 1962; Kingsbury *et al.*, 1984; Yeo & Flowers, 1984). Akita & Cabuslay (1986) indicated that faster growth rate was one of the prerequisites for higher salt tolerance, although cultivars having faster growth rate are not always tolerant due to many other growth limiting factors. In the present study, relative growth rates and the transport of Na^+, K^+ and Cl^- under saline environment were compared for the two rice varieties of varying salt tolerance.

Materials and Methods

Two rice cultivars viz., NIAB 6 salt tolerant and IR 1561 salt sensitive were grown in solution culture during August-September, 1986, Fourteen-day old seedlings were transferred into holes made in thermopal sheets suspended over 15 litres

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of Yoshida nutrient solution (Yoshida *et al.*, 1972) in plastic tubs. Salinity levels were 0 and 100 mol m^{-3} NaCl. Three days after transplanting, NaCl was added @ 33 mol m^{-3} per day to the medium to achieve a concentrations of 100 mol m^{-3}. Experiment was laid out in a completely randomized design with three replicates. Three harvests at 7, 14 and 28 days interval after salinization were taken. Each harvest consisted of 8 plants. Fresh and dry weights of shoot and root were recorded. After each harvest, plants were separated into stem + leaves and roots. The upper portion of plants (stem + leaves) was washed with distilled water and dried with tissue paper before storage (in the freezer) for cell sap extraction. Frozen plant samples were thawed and crushed thoroughly using a glass rod with tapered end, then centrifuged at 1500 rpm for 15 min. The supernatant cell sap was removed by micropipette and stored in eppendorf tubes. A portion was diluted for ion determination. Cell sap of whole shoot and root was analysed for Na^+, K^+ (Petracourt Flame Photometer) and Cl^- (Chloride Analyser 925). Relative growth rate (RGR) and rate of ion transport were calculated according to the formulae described by Salim & Pitman (1983).

$RGR = (Log_e W_2 - log_e W_1) \Delta T$ --- i

where W_2 = dry weights of plant tissue (g) at ------------------------------- harvest 2,

W_1 = dry weight of plant tissue (g) at ------------------------------- harvest 1,

ΔT = difference in time (days) between two harvests, and RGR = relative growth rate in g g^{-1} plant tissue dry weight day^{-1},

Rate of ion transport from root to shoot per g root (J) is defined as 'rate of change in the amount of ion in the plant tissue divided by root fresh weight' i.e.,

$J = (I/WR)(dM/dT) = M_2 - M_1 / (WR \times \Delta T)$ - ii where WR was the fresh root weight and M was the amount of ion in the plant tissue (µ mol per plant).

For experiments based on two or three harvests, the rate of ion uptake was calculated as:

$J = (M_2 - M_1) / (\overline{WR} \times \Delta T)$. ---------- iii, where M_1 and M_2 are the amount of ion at harvest 1 and 2, respectively. The $\overline{WR}$ is the log mean root fresh weight (g) which is given by:

$\overline{WR} = (W_2 - W_1) / log_e (W_2/W_1)$ -- iv,

or

$$J = \frac{M_2 - M_1}{W_2 - W_1} \times \frac{log_e W_2 - log_e W_1}{\Delta T}$$ -- v,

where W_2 and W_1 are the root fresh weight at harvest 2 and harvest 1, respectively.

Results

Relative growth rate of shoot and root: Relative growth rate of shoot (RGR d^{-1}) of both the cultivars decreased with salinity (Table 1); decrease being more pronounced during the first growth period. (7-14 days of salt stress) as compared to the second growth period at 100 mol m^{-3} salinity. The average reduction in RGR under saline conditions during first and second period of growth was 64% and 15 % as compared to their respective controls. During first growth period, the salt sensitive cultivar (IR

Table 1. Relative growth rate (g g^{-1} d. wt. d^{-1*}) of shoot and root of two rice cultivars viz., NIAB 6 and IR 1561 under saline condition.

Varieties/ Lines	Salinity level mol m^{-3}			
	0 (Control)		100	
Harvesting time Days	14 - 7	28 - 14	14 - 7	28 - 14
		Shoot		
NIAB 6	0.059	0.028	0.024 (41)	0.027 (95)
IR 1561	0.075	0.026	0.024 (32)	0.019 (73)
Mean	0.067	0.027	0.024 (36)	0.023 (85)
		Root		
NIAB 6	0.047	0.013	0.040 (85)	0.019 (147)
IR 1561	0.050	0.013	0.038 (75)	0.012 (98)
Mean	0.048	0.013	0.039 (80)	0.015 (123)

*d^{-1} = per day

Harvesting time: (7, 14 and 28 days) after salt stress values in the parenthesis ( ) represent percentages of respective controls.

1561) had better RGR in control treatment as compared to salt tolerant cultivar (NIAB 6) but when salt stress was imposed, salt tolerant cultivar maintained faster rate of growth than the sensitive cultivar, both on absolute and percentage of control values basis for both harvests. During the second growth period value for NIAB 6 was 95 % of its control, whereas the comparable value was 73 % for IR 1561 under 100 mol m^{-3} NaCl salinity. However, both the cultivars made compensation in RGR which showed much less reduction in the second harvest period as compared to their controls than in the first harvest period. Root RGR values (Table 1) though decreased with salinity during the first harvest, but decrease was of less magnitude than in the shoot. At the second harvest, both cultivars showed much improvement in root.

Na^+ concentration at all harvests than the salt sensitive cultivar IR 1561 at 100 mol m^{-3} NaCl salinity. Rate of Na^+ transport from root to shoot increased with salinity during both growth periods but was much higher in the early growth period (Table 3). The two cultivars differed greatly in this respect as well and IR 1561 had four times higher Na^+ transport rate ($J_{Na}+$) than NIAB 6 during first growth period but later on its $J_{Na}+$ was lower than NIAB 6. There was only a small difference for $J_{Na}+$ among the cultivar in the control treatments. It is interesting to note that with the passage of time NIAB 6 (salt tolerant) had higher rate of Na^+ transport ($J_{Na}+$) than the salt sensitive cultivar IR 1561.

***Rate of K^+ transport*:** Potassium concentration in shoot increased significantly with aging both at control and in the salinity treatment. However, salt stress decreased K^+ concentration significantly as compared to control (Table 2). Further, NIAB 6 and IR 1561 cultivars showed difference in behaviour which was statistically significant at control but non-significant at the higher salinity level although the tolerant cultivar had higher K^+ concentration both under control and salinity. Rate of K^+ transport (Table 3) from root to shoot (J_K+) decreased considerably in the second period of growth under control and at 100 mol m^{-3} salinity but the drop in K^+ transport (J_K+) was spectacular in the sensitive cultivar i.e., from 193.2 to 5.9u mol (g. $d.wt^{-1}$) d^{-1} as against from 98.7 to 45.3u mol (g.d.wt^{-1}) d^{-1} in the tolerant cultivar at 100 m mol salinity. IR 1561 had higher J_K+ during early stress period but it could not maintain the rate of K^+ transport and it dropped drastically. The salt tolerant cultivar NIAB 6, on the other hand, transported K^+ at a lower rate during early growth period and then maintained it at a moderate level even during the later stage of growth under saline environment.

***Rate of Cl^{-1} transport*:** As in the case of Na^+, the concentration of Cl^- in shoot increased significantly with the age of plant and salt addition (Table 2). There was no difference between the cultivars in control but they differed at 100 mol m^{-3} NaCl salinity. NIAB 6 had significantly lower Cl^- concentration than IR 1561; the differ-

Table 2. Sodium, potassium and chloride concentration in shoot of two rice cultivars at different harvests under saline condition.

Varieties/ lines	Salinity level mol m^{-3} NaCl					
	0 (Control)			100		
	H_1	H_2	H_3	H_1	H_2	H_3
			Na^+ mmol Kg^{-1} cell sap			
NIAB 6	6.7 e	8.3 e	8.7 e	40.6 d	52.6 c	74.8 b
IR 1561	5.5 e	8.1 e	8.1 e	40.6 d	52.6 c	74.8 b
Mean	6.1 D	8.2 D	8.4 D	45.1 C	66.3 B	93.1 A
			K^+ mmol Kg^{-1} cell sap			
NIAB 6	254 cd	317 ab	333 a	175 fg	218 d-f	240 de
IR 1561	203 ef	291 bc	308 b	149 g	197 ef	237 de
Mean	292 CD	304 AB	320 A	168 E	208 D	239 C
			Cl^{-1} mmol kg^{-1} cell sap			
NIAB 6	26 jk	36 hi	45 g	96 f	133 d	145 c
IR 1561	23 k	33 ij	43 gh	120 e	164 b	225 a
Mean	25 F	35 E	44 D	108 C	131 B	185 A

Harvesting time: H_1 (7 days), H_2 (14 days), H_3 (28 days) after salt stress.

Means with different letters differ significantly according to Duncan's Multiple Range Test ($P = 0.05$) (Duncan, 1955). Extra letters have been omitted except the first and the last one to simplify the table.

Rate of Na^+ transport: Sodium concentration of shoot increased with age of plant and salt addition (Table 2). The salt tolerant cultivar NIAB 6 had significantly lower Na^+ concentration at all harvests than the salt sensitive cultivar IR 1561 at 100 mol m^{-3} NaCl salinity. Rate of Na^+ transport from root to shoot increased with salinity during both growth periods but was much higher in the early growth period (Table 3). The two cultivars differed greatly in this respect as well and IR 1561 had four times higher Na^+ transport rate (J_{Na^+}) than NIAB 6 during first growth period but later on its J_{Na^+} was lower than NIAB 6. There was only a small difference for J_{Na^+} among the cultivar in the control treatments. It is interesting to note that with the passage of time NIAB 6 (salt tolerant) had higher rate of Na^+ transport (J_{Na^+}) than the salt sensitive cultivar IR 1561.

Rate of K^+ transport: Potassium concentration in shoot increased significantly with aging both at control and in the salinity treatment. However, salt stress decreased K^+ concentration significantly as compared to control (Table 2). Further, NIAB 6 and IR 1561 cultivars showed difference in behaviour which was statistically significant at control but non-significant at the higher salinity level although the tolerant cultivar had higher K^+ concentration both under control and salinity. Rate of K^+ transport (Table 3) from root to shoot (J_{K^+}) decreased considerably in the second period of growth under control and at 100 mol m^{-3} salinity but the drop in K^+ transport (J_{K^+}) was spectacular in the sensitive cultivar i.e., from 193.2 to 5.9u mol (g. d.wt^{-1}) d^{-1} as against from 98.7 to 45.3u mol (g.d.wt^{-1}) d^{-1} in the tolerant cultivar at 100 m mol salinity. IR 1561 had higher J_{K^+} during early stress period but it could not maintain the rate of K^+ transport and it dropped drastically. The salt tolerant cultivar NIAB 6, on the other hand, transported K^+ at a lower rate during early growth period and then maintained it at a moderate level even during the later stage of growth under saline environment.

Rate of Cl^{-1} transport: As in the case of Na^+, the concentration of Cl^- in shoot increased significantly with the age of plant and salt addition (Table 2). There was no difference between the cultivars in control but they differed at 100 mol m^{-3} NaCl salinity; NIAB 6 had significantly lower Cl^- concentration than IR 1561; the difference was of much higher order at the 14 days than at 7 days. Under saline conditions, rate of Cl^{-1} transport from root to shoot was also much lower for NIAB 6 than for IR 1561, particularly at the 1st growth period (Table 3). It decreased substantially at 2nd harvest although it was still higher for IR 1561 than for NIAB 6. J_{Cl^-} of the tolerant rice (NIAB 6) was lower than of the salt sensitive rice (IR 1561) at 100 mol m^{-3} NaCl salinity and at the later stage of growth under control treatment.

Discussion

The effect of salinity on growth of the two cultivars were similar to those observed earlier for rice and other crops (Rashid, 1986; Aslam *et al.*, 1989). The growth rate was reduced substantially with salinity. The effect on RGR in rice varied with change in external salt concentration, tolerance level of the variety, age of the plant and the plant tissue involved. During the time course studies; RGR of shoot was affected to a greater extent than root. Similar results were reported for barley

Table 3. Rate of ion transport from root to shoot in two rice cultivars under saline condition.

	Growth periods			
	H_2 - H_1 (7 - 14 days)		H_3 - H_2 (14 - 28 days)	
	Salinity levels mmol m^{-3} NaCl			
	0 (Control)	100	0 (Control)	100
	Rate of Na^+ transport umol (g d.wt.) $^{-1}$ d^{-1}			
NIAB 6	6.0	26.1	2.2	23.7
IR 1561	9.2	106.1	1.7	17.9
	Rate of K^+ transport umol (g d.wt.)$^{-1}$ d^{-1}			
NIAB 6	235.4	98.7	80.2	45.3
IR 1561	325.4	193.2	78.1	5.9
	Rate of Cl^- transport umol (g d.wt.)$^{-1}$ d^{-1}			
NIAB 6	30.1	76.6	15.3	26.8
IR 1561	37.1	170.2	16.4	33.9

(Greenway, 1962), wheat (Kingsbury *et al.*, 1984; Rashid, 1986), cotton (Khan, 1987) and rice (Yeo & Flowers, 1984; Sharma, 1986). Such differences could be related to the rate of accumulation of various specific ions in different plant organs of various varieties. For example, salt sensitive cultivar maintained significantly higher concentrations of Na^+ and Cl^- and a lower concentration of K^+ than the tolerant cultivar. The present study, shows that salt sensitive line accumulated much more quantities of salt during early growth stage and rate of growth was also poor. It seems that the cause of salt sensitivity in this line was probably poor ion regulation (excessive ion entry, poor compartmentation and little dilution due to poor rate of growth during early seedling stage) and resultant osmotic (at cellular level) and specific ion effects.

J_{Na^+} and J_{Cl^-} increased with external salinity and were higher during first growth period than the later period of growth. J_{Na^+} and J_{Cl^-} were high in the case of IR 1561 for the 1st growth period. Pitman (1984) related this phenomenon with "demand" for solutes set up by the growing plants for osmoregulation in the shoot especially the leaves. The salt tolerant cultivar NIAB 6 had higher J_{Na^+} than the salt sensitive cultivar IR 1561 during the later stage of growth which was obviously related to the growth rate as envisaged by Pitman (1984). However, the concentration of Na^+ in NIAB 6 was lower than IR 1561 at any stage of growth at high external salinity. This clearly indicated that low shoot Na^+ concentration in the salt tolerant cultivar was not always due to lower Na^+ transport rates from root to shoot but was also controlled by the dilution effect regulated by the rapid vegetative growth (Yeo & Flowers, 1984; Akita & Cabuslay, 1986). However, lower J_{Cl^-} values for NIAB 6 variety at high salinity for both growth periods indicated better Cl^- exclusion mechanism in the tolerant variety and, in conjunction with a higher RGR, it kept shoot Cl^- concentration in NIAB 6 at a much lower level than in IR 1561. Janardhan & Murty (1970) also associated the salt tolerance in rice with low electrolyte concentrations as well as low Na^+ and Cl^- in shoots.

Although J_{K^+} values for the sensitive cultivar (IR 1561) were higher than for the tolerant cultivar (NIAB 6) at the early growth stage, but the J_{K^+} decreased drastically and was much lower for IR 1561 at the second growth stage. Reduced rates of K^+ transport from root to shoot could be due to reduction in the rates of transpiration, feedback inhibition of ion uptake resulting from the very high concentration of $Na^+ + K^+$ in mature leaves (Delane *et al.*, 1982), or higher $Na^+ : K^+$ ratio in the case of older leaves (Sharma, 1986). Studies indicate that the complex interactions between growth, ion uptake and transport in rice under saline environments determine the success of a variety in saline conditions. In addition to RGR, the ability to localize the ions among leaves, their partitioning at tissue, cell, and subcellular levels or, more likely, a combination of these factors may be involved in the salt tolerance of rice. Apparently, the ability of a rice cultivar to maintain low concentrations of Na^+, and particularly Cl^-, and a high concentration of K^+ in the cell sap through high growth rates or controlled ion transport determined its level of tolerance to salinity.

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