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# Salt Exclusion Rate in Rice Roots in Relation to Ion Species

Mikio TSUCHIYA, Hitoshi NAITO, Yumi TAKAGI and Seiichi KUMANO
*(Department of Eco-physiology for Crop Production)*

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## Introduction

The growth rate of rice under saline conditions is negatively correlated with top-Na content[12], therefore, to maintain growth, it is important that sodium uptake and transport to the top is reduced. It is reported[1,2] that with root anoxia, the exclusion mechanism in corn broke down so that much greater amounts of Na reached the shoots. It is considered that this exclusion mechanism is an active ion transport. Using metabolic inhibitors, Tanaka and Tadano[8] showed that iron exclusion by rice roots was dependent on the metabolic activity of the roots, and Yamanouchi[11] showed that Na content of the shoots increased upon the pre-treatment with a metabolic inhibitor. We express exclusion in rice as the transpiration stream concentration factor (TSCF) which is the ratio of ion concentration in transpiration stream to that of root medium. In our previous report[9], our results showed that TSCF decreased with an increase in the transpiration rate which implied that sodium-exclusion efficiency changed with the transpiration rate. Moreover, we showed that the amount of Na translocated to the top decreased with an increase in the transpiration rate. This result indicates that an increase in the tranpiration rate contributes to a decrease in the amount of Na translocated to the top through the lowering of TSCF of $Na^+$. On the other hand, root respiration did not affect top-Na content. Therefore, it was suggested that sodium exclusion in rice roots was a non-metabolic process and not directly related to the metabolism of root respiration.

In this study, we investigated the exclusion rate of some ion species to discover the characteristics of the salt exclusion in rice roots.

**Table 1** Components of treatment solution and radius of a hydrated ion

| Ion | Radius of a hydrated ion[a] (Å) | Components of treatment solution | Concentration (mM) |
|---|---|---|---|
| $K^+$ | 3.31 | KCl | 99.54 |
| | | $KNO_3$ | 0.28 |
| | | $KH_2PO_4$ | 0.18 |
| $Na^+$ | 3.58 | NaCl | 100.00 |
| $Li^+$ | 3.82 | LiCl | 100.00 |
| $Ca^{2+}$ | 4.12 | $CaCl_2$ | 99.63 |
| | | $Ca(NO_3)_2$ | 0.37 |
| $Mg^{2+}$ | 4.28 | $MgCl_2$ | 99.45 |
| | | $MgSO_4$ | 0.55 |

a) From the data in the reference 6).

## Materials and Methods

Salt tolerant rice variety : Kala-Rata 1-24 (KR1) and salt sensitive rice variety : IR28 were used. In May 12, 1992, germinated seeds were placed on a mesh in a plastic vessel filled with water. At the 2nd leaf stage, half strength of Kimura B nutrient solution was used, and at the 3 rd leaf stage, seedlings were transplanted into styrofoam at 4 cm intervals and the plastic vessel (50*l*) was filled with standard concentration of Kimura B

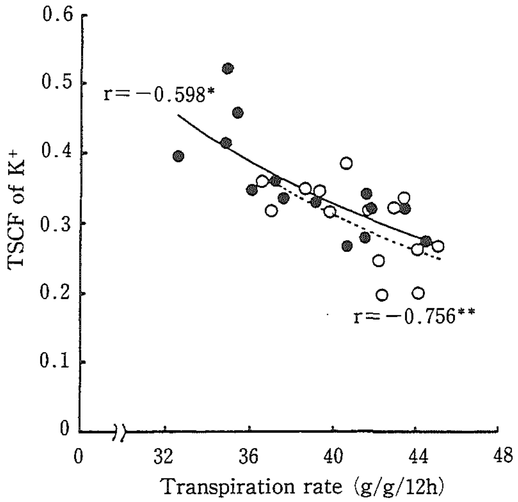

**Fig. 1** Relationship between transpiration rate and transpiration stream concentration factor (TSCF) of $K^+$.
●—— : KR1, ○----- : IR28.

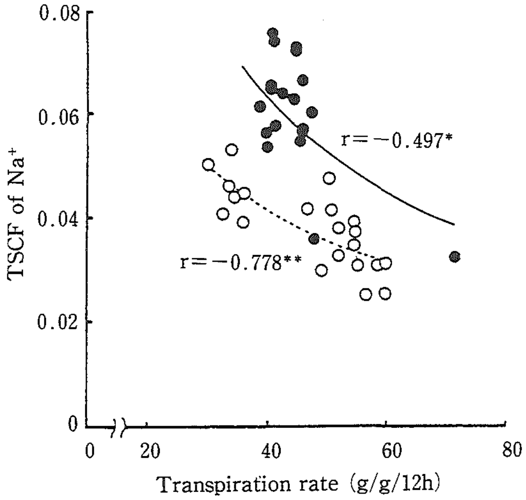

**Fig. 2** Relationship between transpiration rate and transpiration stream concentration factor (TSCF) of $Na^+$.
●—— : KR1, ○----- : IR28.

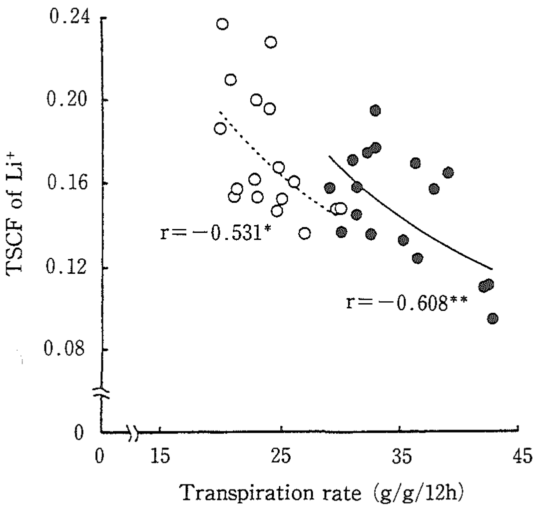

**Fig. 3** Relationship between transpiration rate and transpiration stream concentraion factor (TSCF) of $Li^+$.
●—— : KR1, ○----- : IR28.

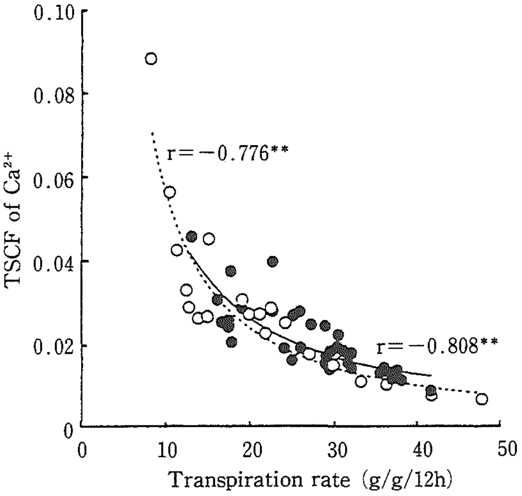

**Fig. 4** Relationship between transpiration rate and transpiration stream concentration factor (TSCF) of $Ca^{2+}$.
●—— : KR1, ○----- : IR28.

nutrient solution. Culture solution was changed every 4 days, and the pH of culture solution was maintained at 5.5 everyday. At the 7 or 8th leaf stage, seedlings were transplanted into plastic bottles (250 m*l*), the stem base was supported with cotton, and treated with $K^+$, $Na^+$, $Li^+$, $Ca^{2+}$ or $Mg^{2+}$ respectively for 12 hours under 40, 60 and 80 % relative humidity. Transpiration was measured by the decrease of bottle weight during the treatment. Each treatment solution was made by adding chloride to Kimura B nutrient solution to make a 100 mM concentration of each cation (Table 1). Transpira-

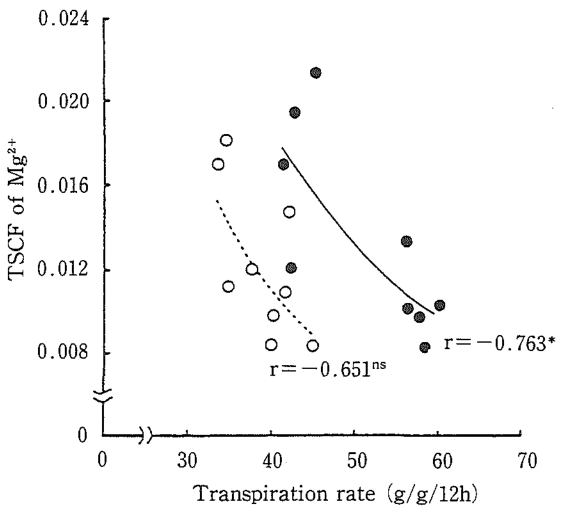

**Fig. 5** Relationship between transpiration rate and transpiration stream concentration factor (TSCF) of $Mg^{2+}$.
●—— : KR1, ○----- : IR28.

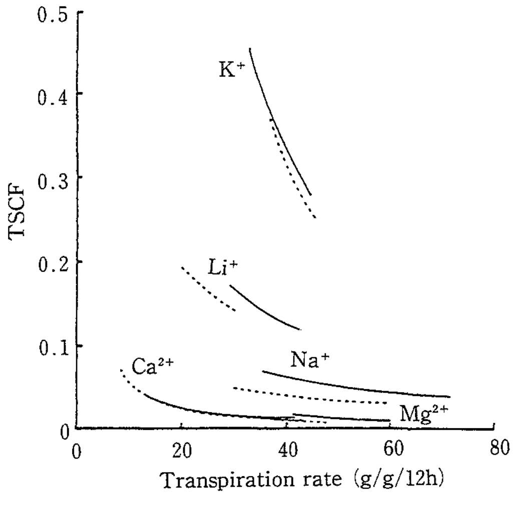

**Fig. 6** Relationship between transpiration rate and transpiration stream concentration factor (TSCF) of each cation.
—— : KR1, ----- : IR28.

tion stream concentration factor indicates the ratio of ion concentration in transpiration stream to that of the root medium, and was calculated as follows.

TSCF = ion concentration in transpiration stream/ion concentration in root medium
= [(ion content of shoot after treatment − ion content before treatment)/amount of transpiration]/ion concentration of treatment solution.

$K^+$, $Li^+$ and $Mg^{2+}$ were extracted by hydrochloric acid, and $Ca^{2+}$ was extracted by wet ashing. After extraction, K, Li, Mg and Ca content was measured by atomic

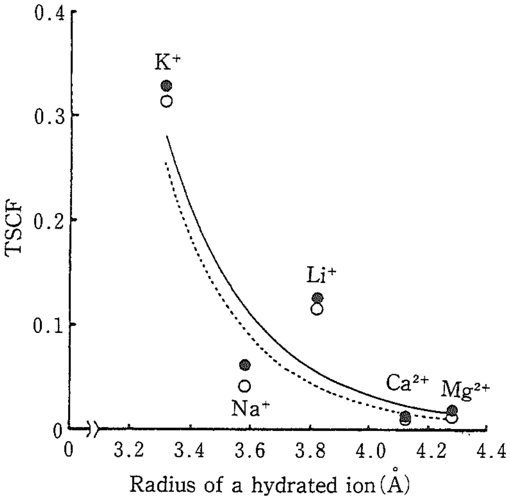

**Fig. 7** Relationship between radius of a hydrated ion and transpiration stream concentration factor (TSCF) of each cation at 40 (g/g/12hr) transpiration rate.
●—— : KR1, ○- - - - : IR28.

spectrometer (Hitachi 180-30). $Na^+$ was extracted in boiling water and content was measured by ion chromatography (Shimadzu HIC-6A).

## Results and Discussion

It was reported⁹⁾ that TSCF of $Na^+$ was negatively correlated with transpiration. TSCF of each cation was also negatively correlated with transpiration as in the case of $Na^+$ (Fig. 1~5). These results indicate that ion exclusion rates change with transpiration. In another report⁵⁾, TSCF of $Cl^-$ was highly correlated with TSCF of $Na^+$ under 100 mM NaCl condition, and the ratio of exclusion of $Na^+$ to that of $Cl^-$ was almost constant. Therefore, it was considered that the exclusion mechanism also works on anions. At the same transpiration rate, TSCF of IR28 was lower than that of KR1 and indicated that exclusion efficiency was essentially higher in IR28 than in KR1. It was considered that the varietal difference in exclusion efficiency at the same transpiration rate was related with differences in the root structure and chemical compositions such as cellulose and silica content¹⁰⁾. The differences in TSCF of $K^+$, $Ca^{2+}$ and $Mg^{2+}$ between both varieties were relatively smaller than those of $Na^+$ and $Li^+$ (Fig. 6). This result indicates that the difference of exclusion rate between varieties was affected by ion species. In rice plants, Tanaka⁷⁾ investigated the relationship between transpiration and ion absorption from the nutrient solution, and showed that $K^+$ was absorbed actively,whereas $Na^+$, $Mg^{2+}$ and $Ca^{2+}$ were excluded. In spite of the difference in the ion concentration of the root medium, the result that $K^+$ was relatively well absorbed, while, $Na^+$, $Mg^{2+}$ and $Ca^{2+}$ (in this order) were hardly absorbed, corresponds with our result. In the case of coexistence of monovalent and divalent cations, rice root with lower cation exchange capacity (CEC) absorbs monovalent cation more readily than divalent cation like as $Ca^{2+}$ and $Mg^{2+}$ ³·⁴⁾.

It was suggested that the difference in exclusion rate between ion species might be affected by the electrical characteristics of roots. TSCF at the same transpiration rate seemed to be larger with the decrease in radius of hydrated ion[6] (Fig. 7). This implied that ion exclusion rate was affected by the radius of hydrated ion.

## Summary

We investigated the exclusion rate of some ion species in order to discover the features of salt exclusion in rice roots. TSCF of each cation was negatively correlated with the transpiration rate as in the case of $Na^+$. These results indicated that ion exclusion rates change with the transpiration rate. At the same transpiration rate, TSCF of IR28 was lower than that of KR1, which indicated that exclusion efficiency was essentially higher in IR28. The differences in TSCF of $K^+$, $Ca^{2+}$ and $Mg^{2+}$ between both varieties were relatively small compared with those of $Na^+$ and $Li^+$. These results indicated that the difference in exclusion rate between varieties was affected by ion species. TSCF at the same transpiration rate seemed to be larger with the decrease in radius of hydrated ion. From these results, it was suggested that the exclusion system of $Na^+$ in rice under saline conditions also works for $K^+$, $Li^+$, $Ca^{2+}$ and $Mg^{2+}$, and is driven by transpiration. It was also noted that exclusion may be affected by the radius of hydrated ion.

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# イネの根における塩排除効率のイオン種による差異

土屋幹夫・内藤　整・高木由美・熊野誠一
（作物機能調節学講座）

高塩分濃度条件下のイネにみられるナトリウム排除機能が他のイオンにはどの様に働くのかを調べた．その結果，供試イネ2品種において，$K^+$，$Li^+$，$Ca^{2+}$および$Mg^{2+}$に対しても$Na^+$の場合と同じく，蒸散速度の増加に伴う蒸散流濃度係数（TSCF）の低下が認められ，蒸散速度の大小によってイオンの排除効率が変化することが明確となった．同じ蒸散速度の場合にはIR28のTSCFがKR 1より小さく，本来的にIR28でイオンの排除効率が高いことが明らかとなった．また，$K^+$，$Ca^{2+}$および$Mg^{2+}$ではIR28とKR 1のTSCFの差は小さく，$Na^+$，$Li^+$ではその差がより大きい傾向が認められ，イオンの種類によって品種間差異の程度が異なることが明らかとなった．そして，イオンの大きさとTSCFの関係については，水和半径の大きいイオンほどTSCFが小さい傾向が認められ，イオンの水和半径の大小によってもイオンの排除効率が変化することが推察された．

以上の結果より，高塩分濃度条件下におけるイネに認められた$Na^+$の排除システムが$K^+$，$Li^+$，$Ca^{2+}$および$Mg^{2+}$に対しても，$Na^+$の場合と同様に蒸散を駆動力として働き，本来的にはIR28で排除効率が高く，そしてイオンの大きさによって排除効率が影響をうけるシステムであることが推察された．