Boron distribution shows sodium distribution in rice leaves to be independent of transpiration.

Asch\textsuperscript{a}, Folkard, Monika A. Wimmer\textsuperscript{a}, Keshav Prasad Dahal\textsuperscript{b} and Uday Sankar Das\textsuperscript{c}

\textsuperscript{a} Universität Bonn, Institut für Pflanzenernährung, Karlrobert-Kreiten-Str. 13, 53115 Bonn, Germany. Email fa@uni-bonn.de.
\textsuperscript{b} Ministry of Agriculture, Chitwan, Nepal.
\textsuperscript{c} Bangladesh Agricultural University, Mymensingh, Bangladesh

Abstract

Rice grown under saline conditions takes up sodium relative to its water use. Earlier work found higher concentrations of sodium in the stem tissues than in the leaves, although the leaf sodium load was thought to be correlated with transpirational water loss. Since in most grasses the stems are bulk leaf sheaths, the question remained if we observed an artifact or a preferential retention of sodium in the leaf sheaths. Sodium, like boron, is translocated acropetally with the transpiration stream and should, just like B, which is not phloem mobile in rice, accumulate at the end points of transpiration, i.e. in the leaf blades. In a hydroponic system, two lowland rice genotypes were subjected to two levels of salinity (0 and 60 mM). Four times, in intervals of ten days, leaves were sampled in the order of appearance, separated into blades and sheaths, and analyzed for Na and B content. Cumulative transpirational water losses were calculated for individual leaves based on leaf area and transpiration measurements. Genotypes differed in Na and B uptake as well as water loss. In all cases total Na and B content was linearly correlated with water loss. B accumulated almost exclusively in the leaf blades, whereas Na accumulated preferentially in the leaf sheaths resulting in low Na contents in the leaf blades of the tolerant genotype and a 50% share of Na in the leaf blades of the sensitive genotype. Retaining large shares of the Na in the leaf sheaths is an important tolerance mechanism as it protects photosynthetically active leaf blades from salinity damage. In rice, B distribution could be used to determine the amount of water loss and the site at which it occurs.

Introduction

Salinity is one of the major soil constraints limiting rice yields in coastal areas and former flood plains. Rice varieties suffer from excess uptake of Na into photosynthetically active tissue, leading to reduced grain yields. Na is known to be taken up and transported within the plant via the transpiration stream, therefore accumulating in transpiring leaf blades (Yeo et al., 1985). However, earlier work showed that bulk stem tissue had higher sodium concentrations than leaf blades, leading to the question whether the salt load of individual leaves is indicative of their transpiration history and thus accumulated water loss (Asch et al., 2003). Irrigation water often has moderate NaCl levels but can carry high loads of boron. Combined with low soil pH a combination of sodium and boron toxicity can occur under saline conditions, accompanied by secondary deficiencies of potassium and calcium. Like Na, B is taken up passively, with transpiration being the main driving force for distribution within the plant (Shelp et al., 1995). B
accumulates at the end of the transpiration stream and leaf blade concentrations increase with leaf age in plants with low phloem B mobility (Brown and Shelp, 1997). A similar distribution would be expected for Na in rice. This study aimed at (1) using B distribution as an indicator for transpiration driven ion distribution in salt stressed rice, and (2) determining if the sodium content of rice leaf blades is indicative of their transpiration history.

**Materials and methods**

Two rice cultivars differing in salt tolerance were grown hydroponically in a greenhouse for 80 days. The cultivars were the salt tolerant IR4630-22-2 and the salt sensitive IR31785-58-1-2-3-3. Two salinity levels (0 and 60mM NaCl) were induced after 40 days and plants were sampled in 10 day intervals. Transpirational water loss of individual intact leaves was calculated from transpiration rates (LCA 4, ADC) and leaf area. For elemental analysis, all leaf positions were sampled individually, separated into leaf blades and sheaths. Na, Ca and K concentrations were determined using a flame photometer, B was determined photometrically using a miniaturized curcumin method.

![Figure 1](image-url)

**Figure 1.** Distribution of Na, K, B and dry matter of leaf sheaths and blades of two rice cultivars subjected to 0 and 60 mM NaCl. L0 = youngest, L1 = youngest fully expanded leaf, L2-L4 = succeeding leaf positions.
Results

B and Na concentrations increased from the emerging leaf to lower leaf positions (Fig. 1), whereas the opposite was observed for K. Calcium distribution was almost identical to that of B (not shown). Na distribution was different as leaf sheaths contained similar or higher Na concentrations than leaf blades (Fig. 1). High salt treatment did not affect the B distribution pattern, but decreased K and increased Na levels especially in leaf sheaths (Fig. 1).

Figure 2. Sodium and boron contents of successive leaves separated into leaf blades and leaf sheaths of two rice cultivars subjected to 60mmol NaCl as related to cumulative transpirational water losses from the leaf blades.

A positive relation was found between water loss of individual leaf blades and B accumulation in both cultivars (Fig. 2). Na accumulation was proportional to the water loss in leaf blades of IR 31785, but not of IR 4630. In the latter, Na accumulated preferably in leaf sheaths. A stratification of ion accumulation was observed.

Discussion

Controlling the uptake and distribution of Na is a major trait for resistance to salinity, preferably combined with a high tissue tolerance to Na. The tolerant IR4630 accumulated less Na than the sensitive IR31785 and concentrations were relatively higher in leaf sheaths. This was combined with high K concentrations particularly in the sheaths of the upper leaves and an increase in B concentrations in the leaf blades (Fig. 1). B distribution did not indicate phloem mobility in either rice cultivar. Overall water loss of IR4630 was lower than in IR31785 for both treatments indicating a higher water use efficiency (not shown). When related to transpirational volume loss
of individual leaves, both cultivars accumulated B almost exclusively in leaf blades, proportional to transpiration rates, accumulated water loss and leaf age (Fig. 2). Na, however, accumulated in both leaf blades and sheaths with IR 4630 accumulating significantly more Na in leaf sheaths than in leaf blades (Fig. 2). Since B accumulates at the end points of transpiration, sheath sodium contents cannot be due to transpirational water loss, but rather to Na immobilization in the sheath tissue. This immobilization may be related to the transpiration rate, as this determines the travel speed of ions being transported in the xylem. The highly transpiring IR31785 accumulates less Na in the leaf sheaths, whereas IR4630 has lower transpirational losses and higher leaf sheath Na contents, suggesting an influence of the speed of xylem sap movement. Finally, K distribution seems to play a role for salinity resistance in maintaining high K/Na ratios in leaf blades and in supporting Na immobilization in leaf sheaths (higher K concentrations in leaf sheaths of IR4630 – Fig 1). It remains open if the observed pattern of B and Na and its relation to transpirational volume loss under salt stress will also appear under additionally B toxic conditions. Future research will focus on the possibility of calibrating the B uptake in relation to transpirational water loss across genotypes. Thus it would be possible to estimate both water use efficiency and leaf sheath sodium retention from measurements of leaf B and Na contents.

**Conclusion**

Comparison of B and Na distribution in relation to the transpirational water loss indicated that rice has a transpiration independent mechanism to immobilize Na in physiologically less active leaf sheath tissue, thus protecting leaf blades from excessive Na accumulation.

**Acknowledgments**

We are grateful to Lili Wittmaier for competent assistance.

**References**


Yeo A, Yeo M, Caporn S, Lachno D and Flowers T 1985 The use of 14C-ethane diol as a quantitative tracer for the transpirational volume flow of water and an investigation of the effects of salinity upon transpiration, net sodium accumulation and endogenous ABA in individual leaves of *Oryza sativa* L. J. Exp. Bot. 36 (168), 1099-1109.