Ecotoxicology and Environmental Safety 157 (2018) 395–402

Contents lists available at ScienceDirect

Ecotoxicology and Environmental Safety

journal homepage: www.elsevier.com/locate/ecoenv

# Combined effect of salt and drought on boron toxicity in *Puccinellia tenuiflora*

Chunguang Liu*, Zheng Dai, Jingye Xia, Can Chang, Hongwen Sun

*Key Laboratory of Pollution Processes and Environmental Criteria (Ministry of Education), Tianjin Key Laboratory of Environmental Remediation and Pollution Control, Nankai University, Tianjin 300350, China*

ARTICLE INFO

*Keywords:*
Boron toxicity
Salt stress
Drought stress
Combined stresses
*Puccinellia tenuiflora*

ABSTRACT

Boron toxicity is a worldwide problem, usually accompanied by salt (NaCl) and drought. The combined stresses may induce complex toxicity to the plant. The aim of the present study was to investigate how the combined stresses of salt and drought affect B toxicity in plants. *Puccinellia tenuiflora* seedlings were planted in vermiculite. A three (B) × three (salt) × three (drought) factorial experiment (for a total of 27 treatments) was conducted. After a 30-day cultivation, plants were harvested to determine dry weight and the concentrations of B, $Na^+$, $K^+$, $Ca^{2+}$, and $Mg^{2+}$. Plant growth was inhibited by B toxicity, which was alleviated by salt and drought. B stress enhanced B uptake and transport of the plant, which was inhibited by salt and drought. B stress had a little effect on $K^+$ and $Na^+$ concentration and caused $Ca^{2+}$ and $Mg^{2+}$ accumulation in the plant. Salt addition increased $Na^+$ concentration and inhibited $Ca^{2+}$ and $Mg^{2+}$ accumulation. Drought addition inhibited $Na^+$ accumulation and enhanced $Ca^{2+}$ and $Mg^{2+}$ accumulation. The combined stresses of salt and drought had a greater alleviation on the inhibition of dry weight caused by B than individual salt and drought. Besides, the combined stresses of salt and drought also enhanced B uptake and inhibited B transport. The results indicate that salt, drought, and the combined stresses of salt and drought all can alleviate B toxicity in *P. tenuiflora*, the main mechanism of which is the restriction of B and $Na^+$ uptake caused by salt and drought. The combined stresses of salt and drought have a greater effect on B toxicity than individual salt and drought.

## 1. Introduction

Boron (B) is an essential nutrient for plant growth, but it turns to be toxic to plants when presents excessively (Camacho-Cristóbal et al., 2008). Boron toxicity can induce the formation of reactive oxygen species (ROS) in plant cells, disrupt metabolic processes, and inhibit cell division and elongation (Ardıc et al., 2009; Reid et al., 2004; Chen et al., 2017). Boron toxicity is often found in natural and agricultural situations in soils (Naz et al., 2016). Soil excess B can be induced by the activities of B-related mining, fertilization, irrigation, atmospheric deposition, and the evaporation of B-laden groundwater (Parks and Edwards, 2005; Tanaka and Fujiwara, 2008; Wang et al., 2017). High levels of soil B commonly occurs in the subsoil and often presents with other abiotic stresses, including salt and drought, which may induce B toxicity to become confounded (Yau and Ryan, 2008).

Salt and drought are both stress factors for plant growth, and they may influence B toxicity when exposed to plants along with excess B. The effects of salt on B toxicity in plants are complicated. In some studies, salt was observed to aggravate B toxicity (Grieve and Poss, 2000; Alpaslan and Gunes, 2001). In contrast, salt was also found to alleviate B toxicity in some other works (Edelstein et al., 2005; Yermiyahu et al., 2008). Similarly, drought has been shown controversial effects on B toxicity in different plants. For example, drought has been shown to aggravate B toxicity in barley (Yau, 2002). In watermelon, however, drought was observed to inhibit B accumulation in plant tissue and facilitate plant growth (Hamurcu et al., 2015).

In arid or semi-arid regions, high concentrations of soil B is often associated with high salt and drought (Gupta et al., 1985). Consequently, plants are frequently exposed to B toxicity and the combined stresses of salt and drought simultaneously (Martínez-Ballesta et al., 2008a). Although the effects of salt or drought on B toxicity have been investigated previously, little is known about the combined effects of the two factors on B toxicity in plant. For the phytoremediation of B-contaminated soils, especially under the combined stresses of salt and drought, the choice of plant species tolerating B, salt, and drought is critical.

*Puccinellia tenuiflora*, a salt and drought-tolerant grass that is widespread in northern China, has been observed to tolerate B in our preliminary experiments (unpublished data). As a potential candidate for the phytoremediation of B-contaminated saline soils in arid regions, *P. tenuiflora* should be evaluated under high levels of B combined with salt and drought. The purpose of the present work is to investigate the

* Corresponding author.
*E-mail address:* liuchunguang@nankai.edu.cn (C. Liu).

https://doi.org/10.1016/j.ecoenv.2018.03.061
Received 24 January 2018; Received in revised form 19 March 2018; Accepted 23 March 2018

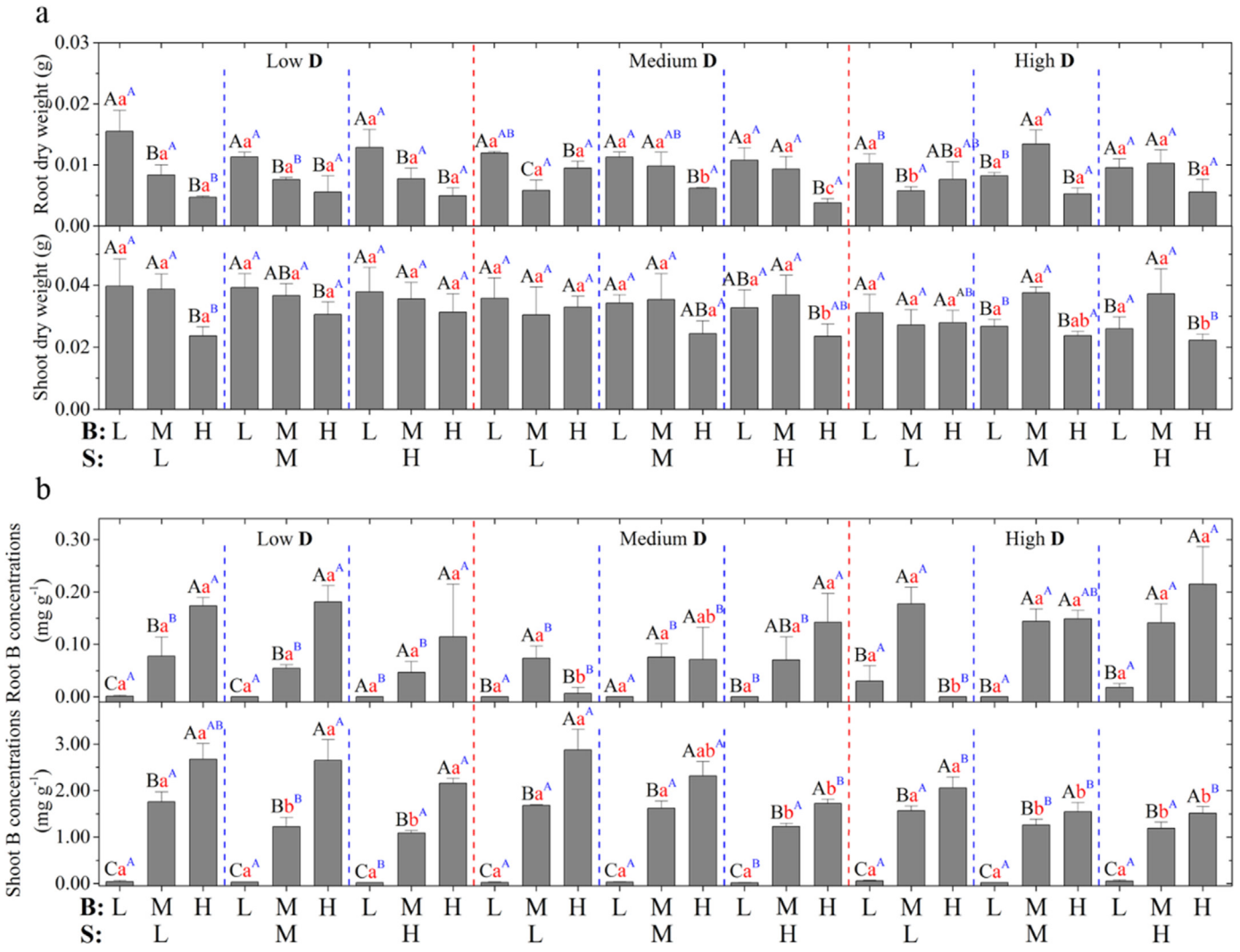


**Fig. 1.** Effect of boron, salt, and drought on shoot and root dry weight (g) of *P. tenuiflora* (a) and on boron concentrations in the shoot and root of *P. tenuiflora* (b). B, boron stress; S, salt stress; D, drought stress; L, low levels of stress; M, medium levels of stress; H, high levels of stress. Means with different uppercase letters indicate significant difference ($p < 0.05$) between boron treatments at a particular salt and drought level. Means with different lowercase letters are significantly different ($p < 0.05$) between salt treatments at a particular boron and drought level. Means with different uppercase superscript letters indicate significant difference ($p < 0.05$) between drought treatments at a particular boron and salt level.

effect of salt, drought, and their combined effects on B toxicity in *P. tenuiflora*. Therefore, a factorial potting trial was conducted under greenhouse conditions, as well as plant growth and elements accumulation were determined.

## 2. Materials and methods

### 2.1. Plant growth condition

The experiment was conducted in a greenhouse under natural light with the temperature of 28 ± 5 °C/22 ± 3 °C (day/night). *P. tenuiflora* seeds were provided by the Tianjin Landscape Institute. The seeds were germinated in seedling trays filled with vermiculite to obtain seedlings.

The seedlings were cultivated for several weeks to obtain ~ 15 cm of height and then transferred to plastic pots (18.2 cm in diameter and 13.5 cm in depth) containing 200 g of fine vermiculite, which was used as substrate. The seedlings were watered with half-Hoagland's solution prior to stress treatment.

### 2.2. Experimental design

The stress treatments were started one week after the transplantation. Half-Hoagland's solution was served as basic irrigation medium. Boron was supplied by means of boric acid ($H_3BO_3$) solution to create three levels: 0.25 mg $kg^{-1}$ (low), 200 mg $kg^{-1}$ (medium), and 400 mg $kg^{-1}$ (high). Salt was supplied with sodium chloride (NaCl) at 0 g $kg^{-1}$ (low), 2.5 g $kg^{-1}$ (medium), and 5 g $kg^{-1}$ (high). The drought was obtained as the water content of 75% (low), 55% (medium), and 35% (high) by weighing the entire pot and adding deionized water daily over the experiment. To avoid osmotic shock, the stresses were exerted gradually over a week. The experiment was a three (B) × three (salt) × three (drought) factorial combination (for a total of 27 treatments) with three replicates.

### 2.3. Plant measurements

After a 30-day cultivation, plants were harvested and washed with deionized water and then separated into root and shoot. Dry weight (DW) of plant samples was measured after the samples were completely dried in an oven at 85 °C. After DW was measured, the plant samples