Pedosphere **25**(4): 501–511, 2015
ISSN 1002-0160/CN 32-1315/P

Published by Elsevier B.V. and Science Press

PEDOSPHERE

www.elsevier.com/locate/pedosphere

Salt Accumulation and Physiology of Naturally Occurring Grasses in Saline Soils in Australia

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(Received June 24, 2014; revised December 17, 2014)

ABSTRACT

Salinity is a major soil contamination problem in Australia. To explore salinity remediation, we evaluated the concentrations of sodium (Na), potassium (K), magnesium (Mg), and calcium (Ca) in roots and shoots and in the supporting soil of the naturally occurring grasses, *Cynodon dactylon* and *Thinopyrum ponticum*, at two salt-affected sites, Gumble and Cundumbul in central-western New South Wales, Australia. The physiological parameters of the two grass species, including net photosynthetic rate (P_n), stomatal conductance (g_s), and intercellular CO_2 concentration (C_i), were investigated using one mature leaf from *C. dactylon* and *T. ponticum* populations. Increasing salinity levels in the topsoil had a significant influence on C_i and g_s, whereas no significant effect occurred on P_n in *C. dactylon* and *T. ponticum*. The P_n values in *C. dactylon* and *T. ponticum* were greater at Cundumbul than at Gumble. The greater Mg concentration facilitated greater P_n in *C. dactylon* and *T. ponticum* populations at Cundumbul than Gumble. With increasing salinity levels in the soil, Na accumulation increased in *C. dactylon* and *T. ponticum*. The ratio between K and Na was > 1 in roots and shoots of both populations irrespective of the sites. Bioaccumulation factor (BF) and translocation factor (TF) results revealed that K and Na translocations were significantly higher in *T. ponticum* than in *C. dactylon*, whereas Ca and Mg translocations were significantly higher in *C. dactylon* than in *T. ponticum*. Accumulation of Na, K, Mg, and Ca ions was higher in *T. ponticum* than in *C. dactylon*; therefore, we suggest that *T. ponticum* as a greater salt accumulator than *C. dactylon* could be used for revegetation and phytoremediation of the salt-affected soils.

Key Words: bioaccumulation factor, intercellular CO_2 concentration, net photosynthetic rate, phytoremediation, revegetation, soil contamination, stomatal conductance, translocation factor

Citation: Bhuiyan M S I, Raman A, Hodgkins D S, Mitchell D, Nicol H I. 2015. Salt accumulation and physiology of naturally occurring grasses in saline soils in Australia. *Pedosphere*. **25**(4): 501–511.

INTRODUCTION

Metal contamination in soils is a major issue throughout the world. Metals, particularly the heavy metals such as cadmium (Cd), zinc (Zn), and lead (Pb), mostly from industrial sources, inflict immense changes to the soil environment (*e.g.*, Mani *et al.*, 2014, 2015). Salinity, too, is one of the major soil contamination problems across the world, due to human-induced landscape-scale changes of land use and modification of soil properties by human activity (Rengasamy, 2006). In Australian landscapes, dryland salinity (*e.g.*, New South Wales, South Australia) and transient salinity (*e.g.*, Western Australia) predominate with nearly 17 Mha of land affected (Rengasamy, 2006). Salinity in New South Wales (NSW) is known to affect 0.062 Mha of productive agricultural land and in the central-western region of NSW 0.04 Mha (DECCW, NSW, 2009). For restoring the saline land, drainage and plant-based remediation are the two major options (Hajkowicz and Young, 2005). Drainage is energy and cost intensive, site specific, and can not be deployed in extensively salinity-affected areas (Barrett-Lennard *et al.*, 2005). An alternative viable salinity-mitigation option is the establishment of salt-tolerant vegetation (Dickinson *et al.*, 2009). Several studies (Qadir *et al.*, 2007; Ravindran *et al.*, 2007; Rabhi *et al.*, 2009, 2010) have indicated that plant-based remediation is a well-established option for reclamation and restoration of salt-affected land throughout the world. For restoring saline land, two plant-based strategies are currently being considered: 1) genetic manipulation of plant species for greater salinity tolerance and 2) utilization of naturally occurring salt-

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tolerant species in salt-affected landscapes. Using naturally occurring plants in salinity-affected landscapes is one economically viable option in rendering the affected landscape arable.

Salinity affects plant performance by inducing osmotic stress and ion imbalance (Niu *et al.*, 2012). Osmotic stress depresses soil-water potential by increasing salt concentration. The drop in soil-water potential results in reduced uptake of water by plants (Ondrasek *et al.*, 2009), which, in turn, induces a reduction in the life span of plants (Munns, 1993). Salt-tolerant plants, however, overcome osmotic stress by sequestering salt ions in them (Ferguson and Grattan, 2005). Sodium, the most common cation of salinized soils, is generally stored in salt-tolerant plants, helping to mitigate the negative effects of salinity (Wei *et al.*, 2006). For example, salt-tolerant grass taxa in *ex-situ* conditions take up Na to maintain a constant osmotic potential between shoot tissues and the external solution (Glenn, 1987). When individual salt ions concentrate in soil in high quantity and plants store them beyond their holding capacity, ion-specific toxicity eventuates (Ferguson and Grattan, 2005). When Na levels are high in soils, Na competes with other ions such as K, Ca, and Mg. Na ions have a capacity to disrupt the uptake of ion transporters, such as K. As a result, ion-specific toxicity damages photosynthesis (Dubey, 2005). Salt-sensitive species (*e.g.*, *Phaseolus vulgaris*, Fabaceae) (Brugnoli and Lauteri, 1991) usually show low stomatal conductance and net CO_2 assimilation when grown under saline conditions. Plants respond to salt stress by altering gene expression concurrently with physiological and biochemical alterations; the response occurs even under modest levels of stress, by down regulating some of the genes controlling photosynthesis. Salt stress affects photosynthesis, reflecting the combined effects of dehydration and osmotic stress in plants (Chaves *et al.*, 2009).

Many salt-tolerant taxa, such as *Puccinellia ciliata* and *Thinopyrum ponticum* (both Poaceae) also used as fodder plants, have been trialled in saline environments in an effort to restore the landscape *via* revegetation (Rogers *et al.*, 2006). Fodder plants such as *Leptochloa fusca* (FitzGerald and Fogarty, 1992), *Sporobolus virginicus*, *S. mitchellii*, and *Paspalum vaginatum* (all Poaceae) have shown promises in field evaluation (Truong and Roberts, 1992). *Cynodon dactylon* (Poaceae) in California (USA) in black-alkali soil (Kelley, 1937) and *L. fusca* in Faisalabad (Pakistan) in calcareous saline-sodic soil (Qadir *et al.*, 1996) have been evaluated for their salt accumulation and soil salinity remediation capacities. *Cynodon dactylon*, *S. virginicus*, and *P. vaginatum* (all Poaceae) have been found to perform well in different saline landscapes in the Murrumbidgee and central-western regions of NSW (Australia) (Semple *et al.*, 2001). However, the salinity in California and Faisalabad is Ca rich (Kelley, 1937; Qadir *et al.*, 1996), whereas that in the central-western regions of NSW is Na rich (Semple *et al.*, 2006, 2008). Moreover, *P. ciliata*, *T. ponticum*, *S. virginicus*, *P. vaginatum*, and *C. dactylon* have been used in revegetating salt-affected sites in different parts of Victoria (Rogers *et al.*, 2007), Queensland (Loch and Lees, 2001), and NSW (Semple *et al.*, 2001) of Australia.

Several grass taxa including *C. dactylon* have been trialled under greenhouse and laboratory conditions to characterize their physiology of salinity tolerance (Bizhani and Salehi, 2014), establishing that the rate of gas exchange of plants decreases with rising salinity levels. Other grass taxa, such as *T. ponticum*, *Lolium perenne*, *Austrodanthonia richardsonii*, and *A. bipartita*, have been used in naturally salt-affected landscapes as an effort to reclaim the landscape in Victoria (Rogers, 2007). Among the four grasses, *T. ponticum* and *L. perenne* accumulated more Na than K with rising salinity levels, and were found to be a better performer than the other two grasses. *T. ponticum* is more salt-tolerant than *L. perenne* (Rogers *et al.*, 1996). Therefore, we aimed at evaluating the salt-accumulation capacity and other vital physiological traits using *T. ponticum* and *C. dactylon*, both of which occur naturally in salt-affected areas in central-western NSW. The objectives of this study were to measure 1) the levels of storage of salt ions (*e.g.*, Na, K, Ca, and Mg) in the shoot and root systems, 2) ion translocation capacity including bioaccumulation factor and translocation factor, and 3) the net photosynthetic rate (P_n), stomatal conductance (g_s), and intercellular CO_2 concentration (C_i) in the selected grasses.

MATERIALS AND METHODS

Study sites

Two salt-affected sites were selected in this study: 1) Gumble, 20 km west-northwest of Molong in central-western NSW and 2) Cundumbul, 33 km north of Molong in central-western NSW. Gumble has 4.13 ha saline area, 25% of which is bare and scattered as patches; Cundumbul has 4.45 ha saline area, 45% of which is bare and scattered as patches. Some physicochemical properties of the soils at both sites are presented in Table I. The climate of the Molong region is semiarid (Mitchell, 2007, 2009).