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Overhead-irrigation with saline and alkaline water: Deleterious effects on foliage of Rhodes grass and leucaena

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ABSTRACT

Saline and alkaline water represents a potentially valuable resource provided its irrigation does not decrease plant growth. Although the adverse effects of salts within the rooting environment are well-studied, comparatively little is known regarding the direct effects of overhead-irrigation of saline and alkaline water on plant foliage. The present study examined the potential deleterious effects of saline (electrical conductivity, EC, ≤15 dS m^{-1}) and alkaline (≤2000 mg L^{-1}, $CaCO_3$ equivalent) water on foliage of Rhodes grass (*Chloris gayana* cv. Reclaimer) and leucaena (*Leucaena leucocephala* ssp. *glabrata* cv. Tarramba) under a range of growing-conditions. Foliage of leucaena was sensitive, with necrosis and chlorosis evident for saline water at an EC ≥3 dS m^{-1} and alkaline water containing ≥500 mg L^{-1} ($CaCO_3$ equivalent). For leucaena, this damage to the foliage reduced relative shoot fresh mass and chlorophyll fluorescence for saline-treatments, but alkalinity did not reduce relative shoot fresh mass or chlorophyll fluorescence in any treatment. In contrast to leucaena, relative shoot fresh mass of Rhodes grass was not reduced by foliar-applied salinity in any treatment (nor did alkalinity reduce growth of Rhodes grass). It was noted that growing conditions influenced the magnitude of the deleterious effects, with salinization of the soil slightly increasing tolerance to foliar-applied saline water for leucaena. This study has demonstrated that whilst saline and alkaline water can potentially be used for overhead irrigation, differences in observed tolerance exist between plant species, and are influenced by growing conditions.

1. Introduction

In low-rainfall environments, the extraction of saline and alkaline groundwaters provides a potentially valuable resource for agricultural production. For example, the Great Artesian Basin (Australia), the largest artesian basin in the world, contains an estimated 65,000 million ML of groundwater (Nevill et al., 2010). This groundwater (including the water extracted from coal seams during natural gas production) can be beneficially used to increase agricultural production. However, much of the water in the Great Artesian Basin is saline and alkaline, with the electrical conductivity (EC) values typically ranging from 1 to >10 dS m^{-1} (Great Artesian Basin Consultative Council, 1998). Therefore, it is important that the irrigation of these waters does not result in degradation of the soil resource and that it does not reduce agricultural production.

The potential adverse effects of salts within the rooting environment (soil) are well-known, causing plant osmotic stress, ion toxicity, and decreased photosynthesis and growth (Munns, 2002; Paz et al., 2012; Tester and Davenport, 2003). However, comparatively little information is available regarding the direct effect of the overhead irrigation of saline and alkaline waters on plant foliage. A report by FAO (1985) indicated that for equal water quality, plant physiological responses vary between overhead and direct irrigation of soil. For example, whilst *Citrus* sp. displayed foliar symptoms when sprinkler-irrigated with water containing 3 mM Na and Cl (corresponding to an EC of ca. 0.4 dS m^{-1}), no effects were observed when the same water was applied through flood and furrow irrigation. Similarly, studying the yield of bell pepper (*Capsicum frutescens*) irrigated using furrow, drip, and sprinkler at an EC of 4 dS m^{-1}, Bernstein and Francois (1973) found a reduction in yield of 18% for furrow irrigation, 2% for drip irrigation, and 59% for sprinkler irrigation. However, in this study of Bernstein and Francois (1973), the reduction in yield for the sprinkler-irrigated plants was due to the combined absorption of

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salt by both the roots and the foliage, and hence an estimate of the foliar damage caused by Na and Cl absorbed directly by leaves is not possible (also see Sevostianova et al. (2011), for example). The effects of the overhead-irrigation of coal seam water (CS-water) on cotton (*Gossypium hirsutum*), barley (*Hordeum vulgare*) and Italian ryegrass (*Lolium multiform*) were evaluated by Beletse et al. (2008) using water with a total alkalinity of 4712 mg L^{-1} (CaCO3 equivalent) and an EC of 7.5 dS m^{-1}. These authors found that overhead-irrigation caused leaf scorching in cotton but not in the other species, but again, the potential movement of this saline and alkaline water into the rooting media prevents separation of the deleterious effects caused by exposure to the shoots from those due to exposure to the roots. Maas (1985) reported that overhead-irrigation with saline water can produce foliar injury (chlorosis and necrosis) due to increased foliar absorption of Na and Cl, however, the magnitude of these symptoms differs substantially depending upon the plant species.

Although previous studies have demonstrated that the overhead-irrigation of saline and alkaline water can potentially produce adverse effects on plant foliage, these studies have generally applied the saline irrigation water to both plant foliage and to the soil, thereby making it difficult to separate the effects of salts within the soil from those applied to the foliage. The present study aimed to establish the threshold for the safe overhead irrigation of saline and alkaline water (including CS-water) by examining the potential deleterious effects of synthetic irrigation waters when applied to the foliage of Rhodes grass (*Chloris gayana* Kunth) and leucaena (*Leucaena leucocephala* (Lam.) de Wit ssp. *glabrata* (Rose) Zárate)—these two species being widely used for fodder within the Great Artesian Basin region. The effect of growth conditions was also examined, with plants grown either inside the glasshouse or in ambient conditions (i.e. external to the glasshouse) and either in a non-saline soil or in a saline soil. Plant performance was assessed using a range of parameters, including visual symptoms, chlorophyll fluorescence, and fresh mass production. The results of this experiment will assist in the development of regulatory guidelines for the beneficial use of saline and alkaline water in overhead-irrigation programs.

2. Materials and methods

2.1. Soil preparation and experimental design

This experiment aimed to investigate whether saline and alkaline water has deleterious effects when it is overhead-irrigated and exposed directly to plant foliage. The surface 0–25 cm of a non-saline Red Kandosol (Ultisol) was collected from a field irrigation site northeast of Injune (Queensland, Australia) (25.713°S; 148.992°E). The soil was air-dried and sieved to 10 mm. Given the low pH of the soil (pH 3.9, 1:5 water), $Ca(OH)_2$ was added at a rate of 1.5 g kg^{-1}—this being determined from a preliminary experiment as being sufficient to increase pH to ca. 5.5. A basal application of gypsum was added at a rate equivalent of 3 t ha^{-1} (2 g kg^{-1}) as is common agricultural practice for these soils in the field. Furthermore, a basal application of slow release fertiliser (Osmocote Exact Standard, 5 g pot^{-1}) was mixed through the soil, providing on a surface area basis the equivalent of ca. 150 kg ha^{-1} of N and ca. 50 kg ha^{-1} of P. After mixing the soil with amendments, 2.8 L was placed in pots and wetted up on a capillary mat. Additional liquid fertiliser (Grow Force, Flow Feed EX7) was applied after seedlings were established (see later) and every three weeks until plants were harvested.

Two types of overhead-irrigation water were investigated for their potential adverse effects on plant foliage, with treatments either increasing in salinity or increasing in alkalinity (Table 1 and Supplementary Table S1). For each of these two water types (i.e. saline or alkaline), the experiment investigated two plant species (Rhodes grass and leucaena), two soil salinities (non-saline or saline), and two environmental conditions (glasshouse or ambient, although only a limited number of treatments were grown in ambient conditions). For the saline overhead-irrigation water, NaCl was added at rates sufficient to increase EC to 0, 3, 4, 5, 6, 8, 10, 12, or 15 dS m^{-1} for Rhodes grass and 0, 3, 4, 5, 6, or 8 dS m^{-1} for leucaena (Table 1 and Supplementary Table S1). For the alkaline overhead-irrigation water, NaCl and $NaHCO_3$ were added at rates sufficient to increase alkalinity to 0, 250, 500, 750, 1250, or 2000 mg L^{-1} ($CaCO_3$ equivalent), with all alkalinity treatments having a basal EC of 4 dS m^{-1} (Table 1 and Supplementary Table S1). The salinity (i.e. EC) and alkalinity values chosen exceeded values found in CS water, but were selected because they cover the range of values likely to influence plant growth (FAO, 1985; Maas et al., 1982b) and hence would enable limits to be defined for the safe overhead-irrigation of these two crops.

The experiment consisted of a total of 37 treatments (Supplementary Table S1) with three replicates, yielding a total of 111 experimental units arranged in a randomised design. Specifically, the treatments consisted of (i) Rhodes grass and leucaena grown in the glasshouse and overhead-irrigated with waters with increasing EC values (Treatments 1–15), (ii) Rhodes grass and leucaena grown in the glasshouse and overhead-irrigated with waters with an increasing alkalinity but a constant EC of 4 dS/m (Treatments 16–25), (iii) Rhodes grass and leucaena grown in the glasshouse in a saline soil and overhead-irrigated with waters with increasing EC values (Treatments 26–31), and (iv) Rhodes grass and leucaena grown in ambient conditions and overhead-irrigated with waters with increasing EC values (Treatments 32–37).

Table 1
Rates at which NaCl and $NaHCO_3$ were added to prepare the solutions listed in Supplementary Table S1.

Electrical conductivity (dS m^{-1})	Alkalinity (mg L^{-1}, $CaCO_3$ equivalent)	NaCl (mM)	$NaHCO_3$ (mM)
0	0	0	0
3	0	27	0
4	0	36	0
5	0	46	0
6	0	55	0
8	0	74	0
10	0	94	0
12	0	110	0
15	0	140	0
4	250	31	5.0
4	500	26	10
4	750	22	16
4	1250	15	25
4	2000	4.4	41