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Using saline soil and marginal quality water to produce alfalfa in arid climates

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ABSTRACT

The gradual increase in the amount of land and water resources affected by salt in arid and semi-arid regions requires strategies to optimize the use of these marginal-quality resources. Recent field and greenhouse experiments have demonstrated the potential of growing certain 'pre-selected' varieties of alfalfa in highly saline conditions. A greenhouse study was conducted to determine the impact of irrigation with saline groundwater on alfalfa growth and production in saline-sodic soils. The sustainability of the system in terms of forage yield and quality was also evaluated. The study included three varieties of alfalfa (*Medicago sativa*, vars. SW8421S, PGI908S and WL656HQ) planted in pots filled with saline-sodic soil (Calcic Haplosalids) collected on the island of Lanzarote (Spain) and irrigated for 18 months with increasingly saline water. Although the yield of the alfalfa varieties was reduced by an average of 7, 20, 31 and 46% as the salinity of the irrigation water increased from 0.4 dS m^{-1} to 2.5, 5.0, 7.5 and 10.0 dS m^{-1}, respectively, their relative salt tolerance, based on the average electrical conductivity of the saturated soil extract (EC_e), was much higher than those established in the literature. Based on their nutritional quality, all alfalfa varieties are categorized as 'supreme' quality, with metabolizable energy (ME) values in excess of 10 MJ kg^{-1}. Moreover, no detriment to quality was observed at the higher levels of irrigation water salinity. Mineral composition analysis revealed S, K and B levels near or above the established maximum tolerable levels (MTLs) suggesting that this forage could only be safely consumed by ruminants over the long term if combined with other forages with lower mineral content.

1. Introduction

The gradual reduction in the quantity and quality of conventional water resources for agricultural use in arid and semi-arid regions, representing 40% of the world's 270 million irrigated hectares (Smedema and Shiati, 2002), has necessitated the supplementation of new water resources obtained from the desalination of saline groundwater and seawater (Díaz et al., 2013a,b; Martínez-Alvarez et al.,2017). In both cases, salt removal by reversible electrodialysis or reverse osmosis entails high energy costs with a correspondingly high CO_2 footprint that prevents the extensive use of this water for irrigation. Irrigation with such water is economically feasible only for high value agricultural crops (Beltran and Koo-Oshima, 2006). Moreover, even if desalinized water of this type is considered high quality water by farmers, initial experiences with desalinated water have not proven totally positive (Yermiyahu et al., 2007; Ben-Gal et al., 2009). In addition, desalination processes generate considerable amounts of brine which can negatively impact the quality of surface and groundwater sources and marine biological communities that develop naturally under saline conditions (Riera et al., 2012).

Along with desalination processes for providing additional water resources, alternative agricultural practices that rely on the use of marginal soil and water resources affected by salinity are needed (Rozema and Flowers, 2008). Biosaline agriculture (i.e. economically sustainable crop production using irrigation water and soils with a wide range of salinity levels) has gained popularity in recent years in arid and semiarid regions in various parts of the

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Table 1
Average ionic composition of desalinated seawater and simulated groundwater treatments used for irrigation during the experiment; mean ± standard deviation; n = 35.

Treatment (EC target) $dS\,m^{-1}$	pH	EC $dS\,m^{-1}$	SAR $(mmol\,L^{-1})^{0.5}$	Ca^{2+} $mmol_c\,L^{-1}$	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	SO_4^{2-}	Cl^{-}	NO_3^{-}	B $mg\,L^{-1}$
0.4	7.1 ± 0.6	0.4 ± 0.1	5.3 ± 0.8	0.4 ± 0.1	0.3 ± 0.2	3.0 ± 0.4	0.1 ± 0.0	0.1 ± 0.2	0.7 ± 0.5	0.2 ± 0.2	2.7 ± 0.3	0.0 ± 0.0	2.2 ± 0.2
2.5	8.2 ± 0.2	2.9 ± 0.2	16.9 ± 1.7	0.8 ± 0.2	2.0 ± 0.5	24.6 ± 1.5	0.3 ± 0.0	0.6 ± 0.6	1.6 ± 0.4	5.0 ± 0.8	18.6 ± 1.6	0.2 ± 0.0	2.2 ± 0.2
5.0	8.4 ± 0.3	5.3 ± 0.3	23.8 ± 1.7	1.3 ± 0.7	3.7 ± 0.4	47.4 ± 3.4	0.6 ± 0.1	1.0 ± 0.6	2.6 ± 0.6	9.9 ± 1.0	35.8 ± 4.2	0.5 ± 0.2	2.2 ± 0.1
7.5	8.4 ± 0.1	7.8 ± 0.2	29.2 ± 1.0	1.6 ± 0.7	5.8 ± 0.7	72.6 ± 2.3	0.9 ± 0.1	1.1 ± 0.5	4.2 ± 0.7	16.0 ± 1.8	56.1 ± 3.2	0.7 ± 0.2	2.2 ± 0.1
10.0	8.4 ± 0.1	9.9 ± 0.3	33.6 ± 0.7	2.0 ± 0.7	7.5 ± 0.3	95.1 ± 3.2	1.1 ± 0.1	1.2 ± 0.5	5.3 ± 0.7	21.5 ± 2.2	73.7 ± 3.9	0.9 ± 0.2	2.2 ± 0.1

world, due primarily to the limited supply of good-quality irrigation water (Masters et al., 2007). This type of farming, based on plants capable of growing in saline conditions, can lead to an economically viable market for salt-tolerant crops while also expanding crop production into marginal lands, thus alleviating pressure on conventional water resources (Díaz and Grattan, 2009). Potential benefits range from the production of food for human consumption, renewable energy (bioethanol and biodiesel) and materials for industrial use (fibre and oil), to a series of applications in revegetation, soil rehabilitation and carbon fixation projects (Grattan et al., 2008). One of the main potential benefits of biosaline agriculture is the production of forage for livestock (Masters et al., 2007).

The production of forage in biosaline agriculture, however, is not problem free. The most important problems include 1) the salinisation of the soils, 2) imbalances in the mineral composition of the forage and 3) the accumulation of trace elements in forage tissue to levels that can be toxic for livestock (Díaz and Grattan, 2009; Grattan et al., 2004a). The first of these problems requires control and application of management techniques, particularly adequate leaching, to prevent the continued accumulation of salt in the soil. In order to address nutritional imbalances and toxicity, it is important to control the mineral composition of the forages, choosing those that are not only tolerant to salinity but which also minimise the accumulation of toxic elements and offer a more balanced composition. Moreover, most potential nutritional disorders caused by biosaline agriculture forages can be avoided by using the latter only as a supplement to the overall animal diet, never as the sole forage (Robinson et al., 2004).

The present study evaluates the use of saline soils and saline groundwater to grow different varieties of alfalfa (*Medicago sativa* L.), which is one of the most important forages in arid and semi-arid regions across the world (Djilianov et al., 2003). Alfalfa has historically been classified as moderately sensitive to saline conditions, with significant yield declines as the electrical conductivity of the saturated soil paste extract (EC_e) exceeds $2\,dS\,m^{-1}$ (Ayers and Westcott, 1985). However, a series of recent studies have shown that some 'pre-selected' alfalfa varieties can thrive in much higher salt concentrations, both in soil and in irrigation water, without significant negative effects on productivity (Putnam et al., 2017). Given the potential interest of these results for arid and semi-arid regions, it is important to confirm these findings in a broader range of soils and environmental conditions. In addition, although alfalfa is one of the most important forage crops regarding its high protein content, digestibility, palatability and milk production qualities, very few studies provide information concerning the effects of salinity on the nutritional quality of the crop (Ferreira et al., 2015).

The present greenhouse study used saline-sodic soils and saline groundwater, both of which are common in arid and semi-arid parts of the Canary Islands, to grow varieties of alfalfa marketed as tolerant to salinity. The primary objective was to determine the impact of different saline conditions on biomass production, nutritional quality and mineral composition of the selected varieties, and to evaluate the evolution of the soil salinity under the study conditions.

2. Material and methods

2.1. Experimental design

A two-way factorial experiment with four replications per treatment (3 alfalfa varieties * 5 irrigation water qualities * 1 soil type * 4 replications; n = 60) was conducted using mesocosms (soils placed in containers 40 cm in diameter and 50 cm in height, with an apparent soil bulk-density of approximately $1.2\,g\,cm^{-3}$). Pots were arranged using a completely randomized design. The experiment was conducted in a greenhouse belonging to the Canarian Institute for Agricultural Research on the island of Tenerife (Spain), where the air temperature during the study period (November 2014–April 2016) ranged from 9 to 47 °C (average ~21.5 °C) and relative humidity from 17 to 94% (average ~68.4%).

Five water quality treatments with salinity levels (EC_{iw}) of ~0.4, 2.5, 5.0, 7.5 and $10.0\,dS\,m^{-1}$ were applied. The water with salinity of $0.4\,dS\,m^{-1}$ – corresponding to seawater desalinated using reverse osmosis – was used as the control treatment. The other treatments simulated the quality of sodic chloride-dominated groundwater typically found in coastal wells on the islands of Lanzarote and Fuerteventura (Spain), with the EC_{iw} adjusted to between 2.5 and $10\,dS\,m^{-1}$, the salinity range frequently found in coastal groundwaters in the Canary Islands. The boron concentration was set at $2.5\,mg\,L^{-1}$ for all treatments, representing the maximum concentration found in the groundwaters of these areas. The simulation of the irrigation waters was conducted using desalinated seawater, with NaCl, $MgSO_4$, $CaSO_4$, Na_2SO_4, KNO_3, $NaHCO_3$, and H_3BO_3 added in proper proportions to reflect the composition of the reference groundwater.

The different irrigation waters were analysed fortnightly to ensure salt concentration targets were met. The following parameters were tested: pH, EC_{iw}, cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}), anions (CO_3^{2-}, HCO_3^{-}, SO_4^{2-}, Cl^{-}, NO_3^{-}) and boron (B). The waters were analysed according to official methods (APHA, 1998). Water was applied using an automatic drip irrigation system, with four pressure-compensating emitters per container, each with a flow of $2\,L\,h^{-1}$. Water distribution uniformity was evaluated periodically using the low-quarter distribution uniformity method (DUlq; Burt et al., 1997), and values were consistently >0.98. Monitoring of volumetric water content with EC-5 sensors (Decagon Devices) allowed calculation of the required irrigation dosages to maintain the soils close to pot capacity (comparable to 'field capacity') throughout the whole study period. Table 1 shows the average chemical composition of the waters used for irrigation during the experiment. As can be seen, the salinity obtained with the different treatments (EC) differed slightly from the target concentrations (EC target). The pH of the waters obtained was slightly alkaline, varying between 7.8 and 8.7, as is common in the sodic chloride-dominated waters of coastal parts of the Canary Islands.

The soil used was a Calcic Haplosalids from the island of Lanzarote (Soil Survey Staff, 2006). Physicochemical characterisation of the soil was performed prior to application of fertilisers and irrigation in accordance with standard methods (Soil Survey Staff, 1996). The following parameters were analysed: texture, moisture