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Short Communication

Experimental equations of seawater salinity and desalination capacity to assess seawater irrigation

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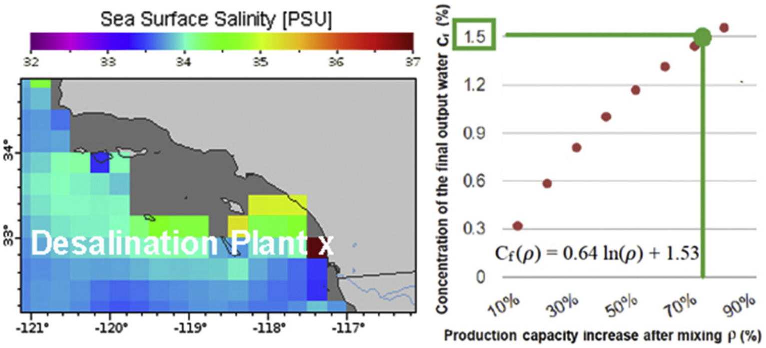
HIGHLIGHTS

- Increments of irrigation water salinity affect the salinity of drainage water.
- Salinities >7.1 dS m^{-1} did not change leaching fractions.
- Mathematical equations of production capacity and the concentration were derived.

GRAPHICAL ABSTRACT



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ABSTRACT

A central question in science and technology of desalting is, can we predict optimal coastal sites to implement seawater irrigation? Freshwater only makes up 2.5% of all water on Earth but crop irrigation is responsible for 70% of freshwater demand. First, we compared the growth rates and the dehydration rates of 5 alternative seawater irrigation experiments of wheatgrass over 3 weeks' periods. The average salt tolerance threshold of wheatgrass is 6 dS m^{-1}. When seawater salinity is increased >10.50 dS m^{-1}, the growth, drainage volumes, leaching, and drainage salinities of wheatgrass did not show significant variations. When seawater salinity is increased to 12.25 dS m^{-1}, grass leaves gradually turned light green, bent, and fell. Notably, pH in soil remained nearly constant in all experiments with mean pH of 6.05 ± 0.25 (mean ± SD). Next, we derived experimental equations to define a mechanistic link between salinity and desalination capacity in a Modified Saline Adjustable Desalination System (MSADS). A cost-benefit analysis for a MSADS in a coastal location of southern California indicated that this system is \$0.84 m^{-3} more expensive than using water from a natural reservoir, but \$0.08 m^{-3} less expensive than importing water. This study provides a general framework to assess the implementation of a desalination system in coastal locations.

1. Introduction

Water treatment technologies for desalination can be modified or combined into many different systems for various conditions in different regions (Rhoades, 1992; Singh, 2008; J. Park et al., 2018). In most

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cases, choosing the implementation of one of these technologies depends on the region's energy cost and its available natural water supply and demand (Aliku, 2017; Vanham et al., 2018; Voutchkov, 2017; Gómez-Gotor et al., 2018). Remarkably, there are novel capabilities enabled by innovative materials and physical concepts that have profoundly improved the desalination methods with membrane technology (Politano et al., 2018; Politano et al., 2017; Gugliuzza et al., 2017; Politano et al., 2016). Most of the commercial desalination plants require a pretreatment system to adjust the conditions of the feedwater intake. The quality of the feedwater intake can have great influence on production costs. For example, a typical commercial reverse osmosis (RO) membrane often operates in a warm water environment, usually at temperatures of 25 °C or higher (Dreizin, 2006). Operations below preferred temperatures and pressures can reduce the quality of the output water and increase the usage of power. Conversely, if we could lower the salinity of the output water required for crop irrigation, we can potentially decrease the costs of production (Munns and Gilliham, 2015). The success of operating a large desalination plant relies not only on advanced technologies, but also on an adequate cost and benefit analysis (Shahabi et al., 2017). It is important to understand the variability of seawater salinity in the region where the plant is going to be implemented, and the levels of salinity that the irrigated crops can tolerate.

Many studies have shown that while salt does not affect the growth of crops directly, an excess amount of salt can threaten their germination (e.g., Tchiadje, 2007; Martínez-Alvarez et al., 2017; Qader et al., 2018). Plants rely on osmosis to absorb water from the soil, germinate, and grow. When the cells of the plant are hypertonic compared to the surrounding soil, the tissues of the roots allow water to pass through. Conversely, if the cells of the plant are hypotonic compared to the surrounding soil, the flow of water towards the plant will slow down, and the plant can eventually die of dehydration (Perri et al., 2018).

In contrast to what is known about desalination plants and the production of crops, little is known about the growth variability and dehydration rates of crops when they are irrigated with seawater. Also, there is an incomplete understanding of how that variability can affect the desalination capacity of desalination plants. The main goal of the present work is to prescribe a framework to assess the implementation of a desalination system in coastal locations. To this end, we conducted five experiments with wheatgrass (*A. elongatum*) and a soil separation irrigation system, tested statistically the effect of increasing the salinity of the input water on four independent output variables, derived experimental equations of seawater salinity and desalination capacity of a desalination system, and finally discussed possible dynamic mechanisms and potential implications for the assessment of seawater irrigation in coastal sites.

2. Materials and methods

2.1. Seawater water irrigation and soil testing

The detailed steps to irrigate crops with seawater and test the salinity of soil were as follows:

1) Seed selection: We selected wheatgrass as our study system. Wheatgrass is a very tractable system because it is easy to grow and has a moderate tolerance to saline water with a threshold of saline tolerance of 6–8 dS m^{-1} (Rhoades, 1992; Chhabra, 2017; Qadir and Oster, 2004; Y. Park et al., 2018; Shtull-Trauring and Bernstein, 2018). This saline tolerance range is only a guideline and salt tolerance can vary depending upon climate, soil conditions, and cultural practices.
2) Seed germination: Wheatgrass seeds were germinated in water during two weeks before they were transported into the soil.
3) Soil container preparation: Wheatgrass seeds were planted in 10 self-made recyclable nursery bottles of 500 ml. Then we filled the bottles with 400 ml of dry soil and we left the bottom cap open for water leaching purposes. Here we define leaching as the loss of water-soluble plant nutrients from the soil, due to rain and irrigation.
4) Saline water preparation: We conducted five experiments of seawater irrigation of the ten bottles (replicates hereafter). In the first experiment we used fresh tap-water with a 2.14 dS m^{-1} salinity level that was the reference experiment for comparison between saline and non-saline irrigation. In the second to fifth experiments we used seawater with salinities of 7.14 dS m^{-1}, 10.50 dS m^{-1}, 12.25 dS m^{-1}, and 14.29 dS m^{-1}, respectively.
5) Irrigation routine: We used 5 spray bottles of 1000 ml, one for each experiment. A total of ten sprays were applied to each replicate every night during 15 days. Two soil leachings were performed during each experiment. The first leaching occurred on the 7th day, and the second occurred on the 14th day. The leaching water used on each sample was in the same salinity level as the irrigation water within ±0.02% off in instrument error.
6) Temperature and light control: The entire experiment was carried out under a closed nursery with a temperature between 75–77 F and a light of 10 W and 430–450 nm.

The leaching fraction was calculated for each experiment as the ratio between the amount of water leached through a volume of soil and the amount of water irrigated using the following equation:

$$LF = \frac{W_{in} - W_{abs}}{W_{in}} = \frac{W_{out}}{W_{in}}, \qquad (2.1)$$

where W_{in} is the volume of water input for irrigation [ml], W_{out} is the volume of water leaching through the soil [ml], and W_{abs} is the water absorbed by crops during evapotranspiration [ml] (Fig. 1).

The salinity of soil was determined using the following equation:

$$EC_{soil} = \frac{EC_{iw}}{LF}, \qquad (2.2)$$

where EC_{soil} is the salinity of soil, EC_{iw} is the salinity of the irrigation water, and LF is the leaching fraction. EC_{iw} was measured at five different depths: surface, 2.5 cm, 5 cm, 7.5 cm and 10 cm. Since salinity varies in different depths of root zone - depending on the density of soil - the average soil salinity was calculated using the following equation:

$$EC_{avg-soil} = \frac{1}{n} \sum_{i=1}^{i=n} (EC_{iw})_i, \qquad (2.3)$$

where $(EC_{iw})_i$ is the salinity of the irrigation water at each of the five different depths n.

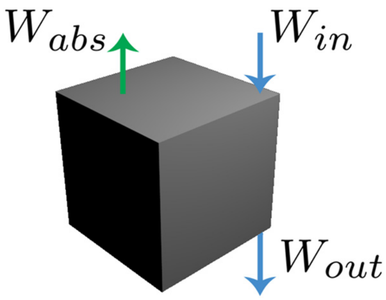

Fig. 1. Schematic diagram of the leaching process.