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Seawater desalination for crop irrigation — A review of current experiences and revealed key issues

V. Martínez-Alvarez [a,*], B. Martin-Gorriz [a], M. Soto-García [b]

[a] Escuela Técnica Superior de Ingeniería Agronómica, Universidad Politécnica de Cartagena, Paseo Alfonso XIII, 48., 30203 Cartagena, Spain
[b] Comunidad de Regantes del Campo de Cartagena, Paseo Alfonso XIII, 22., 30201 Cartagena, Spain

HIGHLIGHTS

- Seawater desalination for sustaining irrigated agriculture is an alternative water source in Spain and Israel.
- The use for crop irrigation is limited by its high cost when compared to other conventional water supplies.
- Agronomic issues should be considered to avoid unexpected adverse effects on agricultural productivity.
- Blending, management modelling, and on-farm technical means may mitigate these agronomics risks.
- Specific quality regulations are required for desalinated seawater use in agriculture.

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ABSTRACT

Increasing water scarcity in arid and semiarid regions is driving the demand for non-conventional water resources in irrigated agriculture. Seawater desalination for sustaining agricultural production is being reported as an alternative water source in some Mediterranean countries. It represents an abundant and steady water source which effectively removes the climatological and hydrological constraints. However, first experiences are highlighting that certain important issues can become a barrier to its spread for crop irrigation. First, the high-energy requirement is still an essential feature of seawater desalination, leading to production costs several times higher than other agricultural water sources. Moreover, the high greenhouse gas emissions linked to the intensive use of energy could exacerbate climate change. Additionally, there are important agronomic concerns related to the lack of desalinated seawater quality standards; which can cause risks for both crop production and the soil environment if not properly managed. Specific quality regulations for desalinated seawater production, blending and management modelling, on-farm technical means and water and soil monitoring may mitigate these risks for crop irrigation. This paper reviews current irrigation experiences with desalinated seawater and analyses the most important questions to be considered, with a particular focus on the agronomical aspects.

Contents

* Corresponding author.
E-mail address: victoriano.martinez@upct.es (V. Martínez-Alvarez).

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1. Introduction

Irrigated agriculture for food production drives global water demands, reaching figures of over 85% in arid and semiarid regions with a highly technical agriculture, such as south-eastern (SE) Spain [1] and Israel [2]. The required development of irrigated agriculture to cope with the increasing food demands from a growing population is also driving a current increase in global water demands [3]. Moreover, global climate change prospects predict that available water resources will diminish under arid and semi-arid climates, exacerbating water scarcity problems in the near future in many areas around the world [4]. The expansion of irrigated agriculture in water scarce regions is also competing with the growing demands for domestic and industrial uses, leading to potential conflicts between users that often give rise to more water being allocated to high-priority sectors at the expense of agriculture [5,6]. This complex scenario is putting pressure on agriculture in many regions that cannot meet current or future demand for irrigation by relying solely on conventional water sources, it has thus become necessary to explore new agricultural water supply options as food demand and water scarcity intensify [7,8].

There are multiple strategies to augment water resource availability for irrigated agriculture, including water conservation, infrastructure modernisation, implementation of smart irrigation systems, regional water transfers, treatment of low-quality local water sources, etc. However, most of these strategies can only improve the use or change the location of existing conventional water resources, not increase them. For regions that already implemented these kind of measures, non-conventional water resources (desalination and recycling) are the only methods to increase water supply beyond that available from the hydrological cycle [9,10]. Whereas recycling and brackish groundwater desalination are sometimes limited by the domestic wastewater production and the exhaustion of aquifers, respectively, seawater desalination may serve as a reliable source of water for sustaining agricultural production, playing an important role in addressing the challenge of global water scarcity [11].

Desalinated seawater (DSW) represents an abundant and steady source of water without impairing continental aquatic ecosystems, which effectively removes the climatological and hydrological constraints associated with conventional water resources (i.e. droughts). Moreover, it circumvents the social opposition and conflict increasingly associated with river regulation through dam building and long-distance inter-basin water transfers [12]. These intrinsic characteristics have made DSW an attractive alternative for high-return agriculture, especially in arid coastal regions lacking clear alternative water sources.

Brackish water desalination for agriculture is reported worldwide and has dramatically increased in recent years since its cost is typically less than half that of DSW costs [8,13,14]. As DSW remained more expensive, it had rarely been considered for agricultural purposes, but nowadays it is emerging as a feasible option for crop irrigation in Spain [15,16] and Israel [17,18]. Furthermore, DSW agricultural application is currently being assessed or planned in some USA states such as Florida [19] and California [20]. DSW is mostly managed as a supplementary source for crop irrigation, blending it with other conventional sources, but direct irrigation is also being practised in some arid islands such as Lanzarote (Canary Islands, Spain), where desalination has been the only option for supplying agriculture [21,22]. Therefore, DSW is increasingly being considered as an alternative water source for agriculture and this trend is expected to continue and even intensify in the near future.

At the outset DSW was only used to supply domestic and industrial needs. However, as desalination technology improves and the DSW cost decreases, its application is likely to be extended to other sectors, especially to agriculture. In this sense, the FAO experts' report *Water desalination for agricultural applications* [7] concludes that although the costs of desalination are still prohibitively high for most irrigated agriculture, its use with high-return crops has become economically feasible.

Reverse osmosis (RO) has emerged as the leading technology for seawater desalination plants (SWDPs) because of its relatively low energy consumption, compared to other technologies [23]. Most authors consider RO technology as being the most adaptable for agricultural use [7,8,18,24], which is endorsed by the fact that the SWDPs for the current agricultural experiences in Spain and Israel rely on this technology. However, DSW produced through RO is not problem free, especially when compared with other conventional water resources. Some important issues become a barrier to its use for crop irrigation, such as the concern about the lack of plant nutrients [2]; the compliance of stringent boron and chloride standards for agricultural irrigation [25]; the effects of sodium accumulation in soil structure and productivity [26]; the energy requirements and resulting cost [27]; the high emission of greenhouse gases that further exacerbates climate change [28]; or even the impacts of massive brine disposal on oceanic life [29]. In spite of these concerns, most authors agree with the FAO experts' report, considering that with the technological advances in RO technology, DSW is becoming a technically and economically feasible solution for high-return agriculture, especially where the costs of surface water and groundwater are increasing.

Because of the potential role of DSW in meeting the increasing global water demands in the context of growing water scarcity, it is of interest to review, analyse and discuss the key issues revealed by current experiences of crop irrigation with DSW. Therefore the objective of this paper is to provide an overview of the concerns of using DSW produced by RO in agriculture, with a particular focus on the agronomical aspects, but avoiding the technological questions of desalination and post-treatments processes, which have been widely discussed in other reviews [25,30–34]. The information obtained will be useful for water planners and managers in a growing number of water-scarce coastal regions with a highly technical agriculture, where a significant fraction of crop water requirements will rely on seawater desalination in the future.

The document is organised as follows. In Section 2 we detail the current experiences of agricultural DSW application worldwide. Section 3 introduces water quality standards in the context of crop irrigation as a reference for subsequent discussions. Section 4 examines the most important agronomic concerns regarding DSW, including low essential nutrients concentration; crop toxicity due to high levels of boron and chloride; low buffering capacity and derived pH stability problems; and sodicity risk affecting soil physical properties. In Sections 5 and 6 we analyse the energy requirements of SWDPs and their production costs, respectively, as the main limiting factors for DSW agricultural