Desalination 416 (2017) 122–128

Contents lists available at ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal

Feasibility of desalination as an alternative to irrigation with water high in salts

Avigail Kaner[a,b], Effi Tripler[c], Efrat Hadas[d], Alon Ben-Gal[a,*]

[a] Institute of Soil Water and Environmental Sciences, Agricultural Research Organization, Gilat Research Center, Israel
[b] Robert H. Smith Faculty of Agriculture, Food and Environment, Hebrew University of Jerusalem, Rehovot, Israel
[c] Central and Northern Arava-Tamar Research and Development Center, Sapir, Israel
[d] Israel Ministry of Agriculture and Rural Development, Israel

ARTICLE INFO

Keywords:
Brackish groundwater
Water price
Crop sensitivity
Crop value
Agriculture

ABSTRACT

Interest in desalination to provide irrigation water is on the rise, but there are few tools enabling consideration of feasibility based on both crop responses and economic parameters. We present a biological-physical model for crop response to salinity coupled with economic calculations of farm based costs and benefits to determine profitability of irrigation of various crops in Israel as a function of water salinity. We then evaluate the economic feasibility of investment in farm- or community-scale desalination plants to supply high quality water as an alternative to irrigation with brackish water.

The predicted profit from production of high-value, salinity-sensitive crops irrigated with either pure desalinated or desalinated blended with locally available brackish water was high enough to justify desalination for agriculture at prices expected in the market today, at least for mid- to large-capacity scale plants (> 1 MCM/yr). The coupled model, accessible as an online application (http://app.agri.gov.il/AnswerApp/) was demonstrated as an effective tool to evaluate the sensitivity of any or all variables affecting crop profitability, combining both sound agronomic, biological and physical understanding of crop growth and response processes with sound economic data and considerations.

1. Introduction

Agriculture in semi-arid and arid regions is highly dependent on water for irrigation. Scarcity of fresh water in such areas has led to increased utilization of low quality, recycled wastewater and brackish groundwater [13,30,40]. In Israel, > 50% of all irrigation water originates from such wastewater effluent or brackish groundwater characterized by significant concentrations of dissolved salts [21,28]. Irrigation water salinity is known to negatively affect crop growth and yields [25].

Determination of irrigation regimes when salts are present must consider not only supply of crop evapotranspiration needs, but of additional water whose objective is to leach salts and maintain root zone conditions acceptable for growth and production [2]. Insufficient leaching leads to build up of salts, to osmotic stress that reduces water uptake and suppresses growth and eventually to toxic responses by the plants [2,17]. The amount of leaching needed in any given agricultural situation is a function of the relative tolerance of the crop, soil hydraulic properties, meteorological conditions, and, of course, the specific salinity of the irrigation water [14,33]. While leaching has been shown to be a successful strategy to maintain crop performance and yields, the cost, particularly to the environment as leached salts accumulate in soils and groundwater, can be high. Without collection and treatment of leachate, irrigation with high salinity water is likely unsustainable in the long term in dry areas without natural drainage to the sea [5,29].

Due to the combined agronomic, economic and environmental costs of irrigation with low-quality water, desalination has been suggested as a strategy for long-term sustainable irrigated crop production in dry areas. In principle, substituting water high in salts with pure water can improve yields and decrease irrigation requirements without local negative environmental effects in addition to allowing production of crops with low tolerance to salinity [6,41]. In fact, there are cases of both coincidental (water desalinated for municipal consumption reaching agricultural areas) and directed irrigation with desalinated water. While presenting some fertilization challenges to farmers used to receiving many minerals required by plants in the irrigation water, the utilization of desalinated water for irrigation has generally brought about positive repercussions [23,41].

Some economic consideration of large scale desalination for aquifer

* Corresponding author at: Agricultural Research Organization, Gilat Research Center, Israel.
E-mail address: bengal@volcani.agri.gov.il (A. Ben-Gal).

http://dx.doi.org/10.1016/j.desal.2017.05.002
Received 22 January 2017; Received in revised form 23 April 2017; Accepted 1 May 2017

management has been presented previously. In a preliminary analysis, Goldfarb and Kislev [16] suggested that desalination, while expensive, would be the most economical method for maintaining Israel's coastal aquifer. They suggested [16] that at least some water resources, especially used for irrigation, must be desalinated in order to guarantee sustainable salt regime in the aquifer. Their evaluation was based solely on social responsibility for a sustainable water economy and did not consider the agricultural benefits of reducing salts. Haruvy [19] demonstrated that when the degradation of the coastal aquifer was considered, desalination of wastewater prior to irrigation became economically beneficial. This study as well considered only environmental costs and not agronomic costs or benefits of the desalination.

Desalination has long simply been dismissed as a solution for agriculture due to its perceived high costs and the low benefit to cost ratio expected for most agricultural crops. The evolution of desalination technology, making it cheaper, reliable, less energy intensive and more environmentally friendly [11,31] has opened discussion regarding the need to re-evaluate these assumptions and has led to recent interest [3,15,20,24,42,43]. Desalination for agriculture is expected to be relevant first and foremost in water-scarce areas of countries with strong economies where currently irrigation is practiced with low quality water, either brackish groundwater or recycled wastewater [8,11]. In these cases, the costs of the high salinity water are realized as lowered yields, restricted choices of crops, and environmental contamination [14,29]. Alternatively, purchase of desalinated water for irrigation could be feasible in regions where large-scale desalination of seawater is practiced to supply municipal and drinking water [41].

A number of recent studies have begun to attempt to address the economics of desalination for agriculture. Zarzo et al. [42] described the Spanish case and showed that many agricultural products can support the cost of desalination, particularly in the southeast part of the country where large communities of irrigators growing high value crops are organized. Barron et al. [3] suggested that while farmers are unlikely to pay the estimated cost for desalination of groundwater (AU\$1.2/m^3) for field crops, that desalination for irrigation of high value crops in greenhouses could be feasible. Multsch et al. [24] addressed the economics of desalination for agriculture while considering available land and temporal water supply and showed the feasibility for cash crops in Saudi Arabia through a model for optimal planning of cropping patterns in a region to best utilize a given desalination plant.

We present utilization of a biological-physical model for crop response to salinity coupled with economic calculations of farm based costs and benefits to 1) determine profitability of irrigation of various crops in Israel as a function of water salinity and 2) evaluate economic feasibility of investment in farm or community scale desalination plants to supply high quality water as an alternative to brackish water application.

We begin by reintroducing the Shani et al. [33,34] analytical model used to calculate root zone salinity and yield response of crops. Taking Israel's Arava Valley as a case study, we continue with calculation of the relative yield, according to the analytical model, for five crops – as a function of different water salinities and irrigation (leaching) amounts. Based on the current water pricing policy in Israel, we then continue to calculate the expected profit for the five crops irrigated by brackish water. We culminate with an evaluation of the maximum profit for the same crops, using estimated water prices for various local desalination plant options, for 2 water salinities, EC = 0.5 and EC = 1.5, based on blending desalinated water with local brackish groundwater.

2. The crop response model

ANSWER (ANalytical Salt WatER), introduced by Shani et al. [33,34] is an analytical solution for steady state conditions of soil water and salinity in the root zone and plant water uptake. The model has been found to well represent average soil conditions and crop response to water-salinity combinations in a variety of soils and climates and for crops including bell pepper, melons, dates, grapevines, and olives [4,5,33]; and has been previously used in a theoretical regional irrigation water management exercise coupled with an economic model [7].

ANSWER combines water and salt balance with a calculation of root-zone soil moisture and soil hydraulic conductivity according to the Brooks-Corey [10] soil hydraulic model:

$$K(\psi) = \min\{K_S, K_S(\psi_w \cdot \psi^{-1})^{\eta}\}$$
$$\theta(\psi) = \min\{\theta_S, (\theta_S - \theta_r)(\psi_w \cdot \psi^{-1})^{\beta} + \theta_r\} \tag{1}$$

where K is the soil hydraulic conductivity [L t^{-1}], θ is the volumetric soil moisture content [L^3 L^{-3}], subscript S denotes saturated, subscript r denotes residual, ψ is the soil matric head [L], ψ_w is air-entry head [L], and η and β are empirical soil characteristic parameters.

Transpiration rate (T_w) is the product of the soil's unsaturated hydraulic conductivity and the gradient of water potential between soil and root [26]:

$$T_w = \min\{T_P, b \cdot K(\psi) \cdot (\psi_{root} - \psi)\};\quad \psi > \psi_{root} \tag{2}$$

where T_p is potential transpiration, b [L^{-1}] is a coefficient characteristic of the effective distance for flow between roots and soil and ψ_{root} is the minimum possible water head at the root soil interface allowing water uptake. ψ_{root} is a plant specific parameter that defines the plant sensitivity to available water. Transpiration decrease as a function of salinity is considered by a plant-specific reduction term characterized by a logistic curve with an initial plateau and subsequent decreasing section [39].

$$f_{EC} = \frac{1}{1 + \left(\frac{\mathrm{ECe}}{\mathrm{ECe}_{50}}\right)^{p}} \tag{3}$$

where f_{EC} is a reduction function due to salinity. The ECe_{50} represents the EC of the soil saturated paste extract solution where relative yield = 0.5, and p is a plant parameter describing steepness of the function. The model assumes a proportional relationship between the ratio of yield to potential yield and the ratio of transpiration to potential transpiration following de Wit [12] and Hanks [18], thus allowing a prediction of biomass production (yield).

An application that solves ANSWER can be accessed at http://app.agri.gov.il/answerapp/. The online application includes default input values for 12 crops and 5 soils and a coupled solution for profitability. Default economic parameters are based on current Israeli data (in Hebrew) from The Ministry's Extension Service (http://shaham.moag.gov.il/) and the Israeli Central Bureau of Statistics (http://www.cbs.gov.il/), normalized according to the 2014 consumer price index of 2014. All input parameters can be adjusted by the user to accommodate local conditions or alternative crops and soils.

The model was used to predict plant performance and to evaluate salt and water balance for different irrigation regimes and each irrigation water quality. Input variables included the quantity and salinity of the applied water, plant sensitivity to salinity and water stress, ETp, and soil hydraulic parameters (Table 1b). The salinity reduction curves for the various crops, defined by ECe_{50}, were adapted from previously published experimental data. The model was used to predict biomass production (Y) for five crops, bell pepper, date palm, table grape, parsley and corn grown in Israel's Arava Valley. Crop and soil parameters for model application are shown in Table 1. The minimum possible water head at the root soil interface, ψ_{root}, was taken as − 6000 mm for all crops. The p parameter of the salinity response curve was assumed to be 3 [38].