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Evaluating performance of macroscopic water uptake models at productive growth stages of durum wheat under saline conditions

Vahidreza Jalali[a,*], Safoora Asadi Kapourchal[b], Mehdi Homaee[c]

[a] Department of Soil Science, Faculty of Agriculture, Shahid Bahonar University of Kerman, Iran
[b] Department of Soil Science, Faculty of Agricultural Sciences, University of Guilan, Rasht, Iran
[c] Department of Irrigation and Drainage, Faculty of Agriculture, Tarbiat Modares University, Tehran, Iran

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ABSTRACT

Water management in agricultural lands largely depends on quantity and quality of available soil and water resources. In arid and semi arid regions, scarcity of fresh water and soil salinity are two main important limiting factors for crop production. Under such limiting conditions, one practical alternative for crop production is the use of unconventional or brackish water. If used, the quantitative response of plants to salinity must be carefully analyzed by means of modeling. On the other hand, plant response to salinity varies under different growth stages. Durum wheat (*Triticum turgidum* L.) is an important crop cultivated in some arid and semi-arid areas across the world such as Middle East and North Africa. This study was aimed to quantitatively characterize the Durum wheat response to salinity under different productive growth stages. Consequently, a large experiment in natural saline sandy loam soil (Typic Toriorthent) with five natural saline water treatments including 2, 4, 6, 8 and 10 dS/m each with three replicates was conducted. Furthermore, four predictive linear and nonlinear models of Maas and Hoffman, van Genuchten and Hoffman, Dirksen et al. and Homaee et al. were evaluated to predict relative transpiration and relative yield of durum wheat under heading and ripening growth stages. Three statistics including modified coefficient efficiency (E'), modified index of agreement (d') and coefficient of residual mass (CRM) were used to compare the used models and to assess their performances. Results indicated that among the examined models, the macroscopic model of Homaee et al. can provide more reasonable predictions at heading stage, while the piece-wise linear model of Maas and Hoffman provided slightly better prediction at ripening growth stage. The obtained threshold value and slope of reduction yield were quite different from those previously reported in the literature. These findings reveal that the widely cited tables describing the relationship between relative yield and electrical conductivity of saturated extract, averaged over the root zone as well as the entire growing season, are quite approximate and carry significant uncertainty. More experimental studies are still needed to obtain reliable data under different growth stages.

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1. Introduction

Providing sustainable food to the world's growing population is one of the most important challenges in recent years. Thus, greater demand for agricultural production is an important concern for governments as well as farmers (Ricker-Gilbert et al., 2014). In this regard, limitation of good water and soil quality is a major detrimental factor for gaining optimal and healthy agricultural productions (Asadi Kapourchal et al., 2009; Chinnasamy et al., 2015). By such limitations, planning for optimal use of available water as well as the use of saline water with poor quality in agricultural activities becomes quite important (Yang et al., 2015; Pedrero et al., 2015).

In arid and semi-arid regions, in addition to soil salinity, sharp decline in rainfall and sharp drop in groundwater levels in recent years requires efficient use of limited soil and water resources (Chinnasamy et al., 2015; Homaee and Schmidhalter, 2008; Homaee et al., 2002b). Such considerable decline in rainfall in those areas in recent years has taken worrying concerns for safe food productions (Lyle, 2013). As an example, according to Iran's Water Resources Management Co. (2015), the average rainfall in October of agricultural year (2013–2014) was only 4.7 mm. This amount compares to the average of 45 years period (7 mm) and to

* Corresponding author
E-mail addresses: V.Jalali@uk.ac.ir (V. Jalali), safooraasadi@guilan.ac.ir (S. Asadi Kapourchal), mhomaee@modares.ac.ir (M. Homaee).

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the same period of previous agricultural year (6.2 mm) shows 33 and 24% reductions, respectively.

The shortage of water resources foreseen by actual climate change scenarios worldwide requires serious attention to search for new water supplies for agriculture (Nouri et al., 2016). Therefore, it is important to evaluate the use of water with increasing electrical conductivity such as saline or brackish waters (Gerosa et al., 2014). Fresh water scarcity and drought is the main factor limiting agricultural productivity in arid and semi-arid regions (Homaee and Feddes, 1999). Furthermore, salt accumulation in water and soil has detrimental effect on crop yield and results in substantial losses of arable soils particularly in arid and semi-arid regions (Esmaili et al., 2008; Hosaini et al., 2009).

One well recognized way to apply saline or brackish water for agricultural purposes is the use of tolerant and/or relatively tolerant crops to salinity. Consequently, in order to use brackish water for agricultural production, it is required that its quantitative response to salinity stress be analyzed by means of simulation models in such regions.

Wheat is the most widely cultivated cereal worldwide with over 218 M ha in cultivation (FAOSTAT, 2013). Wheat is one of the eight main food sources including rice, corn, sugar beet, cattle, sorghum, millet and cassava which provide 70–90% of all calories and 66–90% of the protein consumed in developing countries. Globally, wheat alone provides nearly 55% of the carbohydrate and 20% of the calories consumed (Safa and Samarasinghe, 2011). Iran with 14.5 million tons of wheat production is the 12th producing country among the biggest wheat producers in 2010 (FAO, 2010). Durum wheat (*Triticum durum* L.) represents 6–8% of the total worldwide wheat production and its major use is the manufacturing of pasta, couscous and traditional dishes (Troccoli et al., 2000). The largest global durum wheat production is concentrated in the Mediterranean basin that contributes, on average, 60% of global production (FAOSTAT, 2013). Durum wheat is grown mainly in subhumid dry lands like Mediterranean countries under non-irrigated or rain-fed conditions, which makes grain yield uncertain. In these environments, yield is generally constrained by water scarcity and heat stress during grain filling, low and unpredictable seasonal rainfalls and high temperatures are common at the end of the crop cycle (Loss and Siddique, 1994). Total cumulative evapotranspiration (ET) of wheat crops typically ranges from 200 to 500 mm, although it can be less in non-irrigated semi-arid areas and reach 600–800 mm under heavy irrigation (FAO, 2010).

Southern Iran is characterized by its semi-arid climate condition with low annual rainfall of about 200 mm/y. Thus, if available, groundwater is the most important source of freshwater in agricultural production in such areas. However, due to unsustainable practices in groundwater extraction and insufficient rainfall in recent years, groundwater storage is depleting at alarming rates (Iran Water Resources Management Co, 2015). One important problem associated with extreme water withdrawals from groundwater resources is the decrease of water table and land subsidence. This phenomenon causes a sudden subsidence in sandy aquifers or a gradual summit in clay aquifers. Most important samples of land subsidence have been occurred in some plains of Kerman provinces. For instance, in recent years for every 10 m decrease in groundwater depths, 42 and 27 mm land subsidence has been reported in Rafsanjan and Sirjan plains, respectively (National Geoscience Database of Iran, 2015). Another serious challenge associated with excessive water withdrawal from groundwater is the tendency of water quality towards brackish and saline waters. Thus, not only it is quite important to manage using freshwater in agricultural activities by planning and management, but the use of low-quality saline and brackish waters must be considered as potential water resources for agricultural productions. Efficient water management in areas where water quality is not suitable requires sensitivity analysis of plant response to salinity at each growth stage. Therefore, any accurate prediction of crop yield and its proper management requires quantifying the impact of salinity on yield under each growth stage (Saadat and Homaee, 2015; Homaee and Feddes, 2001). Although several investigators have studied the effects of salinity on various plants, but most of these studies have not been presented in a quantitative manner (Homaee and Feddes, 2002; Homaee and Schmidhalter, 2008).

Salinity as an abiotic stresses can cause excessive disturbance for seed germination and plant sustainable production (Kubala et al., 2015). There is plentiful information about crop salt tolerance in the literature and abundance of data exists for the whole plant salt tolerance as a function of averaged root zone salinity (Chaali et al., 2013). Chamekh et al. (2015) analyzed yield stability of component traits in 25 durum wheat genotypes under contrasting irrigation water salinity. They concluded that reduction in grain yield can be linearly correlated with increased water salinity. Hosaini et al. (2009) investigated the combined effect of salinity and excess boron on germination and seedling emergence of canola. They showed that salinity as well as excess boron, reduces germination and causes further delay in germination. Sayar et al. (2010) investigated effect of salinity stress of NaCl and PEG on initial growth parameters of two varieties (Omrabia and BD290273) of durum wheat. Their results showed that the stress resulting from NaCl solution in comparison with the PEG solution, has less negative impact on germination rate, the final percentage germination and seedling establishment rates in both species of durum wheat.

Katerji et al. (2005) investigated the salinity effects on grain quality of two durum wheat in a lysimeteric experiment. They have assigned three water qualities for irrigation: fresh water as a control with an EC of 0.9 dS/m and two saline waters with EC of 4 and 8 dS/m, obtained by adding equivalent amounts of NaCl and $CaCl_2$ to fresh water. They concluded that salinity had a slight positive effect on the grain quality of the Cham-1 variety, whereas the Haurani variety showed no salinity effect on grain quality. Gerosa et al. (2014) studied the contrasting effects of water salinity and ozone concentration on two cultivars of durum wheat. Two durum wheat cultivars (Neodur and Virgilio) exposed to two different levels of ozone (charcoal-filtered air and ozone-enriched air) and irrigation water salinity (tap water as control and a 75 mM NaCl solution once a week). They found out that the most ozone-sensitive cultivar was the more tolerant to saline irrigation. However, saline irrigation reduced the grain yield and biomass in durum wheat.

As can be seen, in most studies about the effect of salinity on plant yield and growth, synthetic saline water which is generally consisted of NaCl or a mix of NaCl + $CaCl_2$ has been used, regardless of the negative effects of toxic elements and their impact on the availability of other nutrients in the root absorption and transport within the plant. This is not consistent with the real conditions of saline soils and waters. For this reason, in this study, the use of natural saline water was followed rather than synthetic brine.

In all existing models that quantify plants responses to salinity it has been assumed that soil salinity is constant during the entire growth period. However, it is now well recognized that the sensitivity of plants to salinity varies largely during the growth season. Most plants are resistant at the germination stage, but at the seedling or earlier growth stages become more sensitive to salinity. Their tolerance usually increases with age (Saadat and Homaee, 2015), resulting different threshold salinity values at each growth stage.

Although salt tolerance of durum wheat has been extensively studied, most published results are either qualitative or expressed as averaged values of root zone salinity for the whole growth season. However, the accuracy of these data needs to be reconsidered. Besides changes in solute concentrations, many other crop-environment interactions may cause variations in salinity-

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