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Modeling sorghum response to irrigation water salinity at early growth stage

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ABSTRACT

Agricultural water management in arid and semi-arid regions largely depends on availability and quality of irrigation water at different plant growth stages. In saline environments, plant response to salinity varies at different growth stages. Information on plant response to salinity at various growth stages can be used in managing saline waters for irrigation. This study was conducted to quantitatively assess response of sorghum (*Sorghum bicolor* L. *Moench*) to salinity at seedling stage. Consequently, an extensive experiment in natural saline sandy loam soil with five natural saline water treatments including 4, 6, 8, 10, and 12 dS/m was conducted. The reason for selecting natural sources of saline water and a saline soil was to minimize deviations from natural conditions under which sorghum grows. Sorghum seeds were planted and seedles counted at 24 h time intervals. The macroscopic models of Maas and Hoffman, van Genuchten and Hoffman, Dirksen et al., and Homaee et al. were used to predict relative seedlings at different salinity levels. The obtained results indicated that salinity threshold value EC^* for sorghum at seedling stage is 1 dS/m and the seedling rate reduces to 50 percent at 11 dS/m of soil salinity. All evaluated models overestimated the EC^* value. Calculated statistics indicated that the nonlinear salinity models are more accurate than the linear model. Among those, Homaee et al. model provided better predictions at seedling growth stage.

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1. Introduction

Among cereals, sorghum is considered as relatively more salt tolerant than maize and has the potential as a grain and fodder crop for salt affected areas (Maas and Hoffman, 1977; Krishnamurthy et al., 2007; Ould Ahmed et al., 2007b). The main sorghum producing countries are United States (17% of the world production), Nigeria, India (each with 14%) and Mexico (11%). It also produces over 60 million tons in the world. The US population consumes most sorghum through intermediary livestock that consumes it, but the prevalence of sorghum in many other countries such as South America and Africa, indicate the areas where human nutrition depends heavily on grain sorghum (FAO, 1996). From nutrition point of view, sorghum has an advantage over corn in drier and hotter climates. Also, it is more tolerant to wet soils and flooding than most other grains. In addition to these, sorghum adapts well to different soil types and toxicities, and these factors together make it an ideal crop for growing in abiotically stressful environments. Unlike corn, however, sorghum yield under different conditions is not so varied. Its fairly stable yield across these conditions reduces the risk of crop failure in such areas (FAO, 1996).

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. Salinity influences the whole plant growth stages, but sensitivity of growth stages to salinity also differs for each plant. Plant survival is important for salinity tolerance at germination stage, while after this, yield and growth reduction is a tolerance criterion. Some researchers reported that plant tolerance to salinity at germination stage is higher than other stages (e.g. Debez et al., 2004; Grattan et al., 2004; Lauchli and Grattan, 2007).

Salinity reduces plant yield and growth by reducing osmotic potential, ion toxicity and nutritional imbalances. The prime effect of salinity on plant relates to the total soluble salts, which reduces osmotic potential. With reducing osmotic potential, the free energy of water reduces and plants need to spend more biological energy to take up water from the soil solution (Homaee and Schmidhalter, 2008; Homaee et al., 2002b,d; Ramos et al., 2012). Salinity reduces seeds water absorption at first, and after that, makes toxicity and changes the enzyme activity (Massai et al., 2004; Feng et al., 2003a,b; Yaron et al., 2012). Plant sensitivity to salinity varies at

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whole growth stages. Most plants are tolerant at germination stage, but are sensitive at seedling and primary growth stages (Maas and Grattan, 1999; Grattan et al., 2004; Lauchli and Grattan, 2007; Steppuhn et al., 2005a,b). Some researchers reported that plant sensitivity to salinity increases after germination stage. Among these reports, one may refer to wheat (Udovenko and Alekeseeva, 1973; Maas and Poss, 1989a; Ayers et al., 1952; Steppuhn and Asay, 2005; Steppuhn et al., 1996), barley (Ayers et al., 1952), rice (Pearson and Bernstein, 1959; Kaddah, 1963; Heeman et al., 1988), Tomato (Dumbroff and Cooper, 1974), Corn (Maas et al., 1983), peanut (Shalhevet et al., 1969), sorghum (Begdullayeva et al., 2007; Ould Ahmed et al., 2007a), and soybean (Wang and Shannon, 1999). It is also reported that salinity causes delay in emergence, but if the salinity is lower than the threshold value, salinity cannot affect the emergence (Maas and Grattan, 1999). Plant tolerance to salinity increases with age (Kaddah and Ghowail, 1964; Lunin et al., 1963; Francois, 1985; Wahid et al., 1999). Plant tolerance to salinity at germination is more than flowering and seedling stages. These results have been reported for sorghum (Maas et al., 1986; Da Paix et al., 2007), wheat (Maas and Poss, 1989a) lupan (Maas and Poss, 1989b), barley (Pandya et al., 2004) and canola (Keshta et al., 1999).

Sorghum is relatively tolerant to salinity (Maas and Hoffman, 1977; van Genuchten and Gupta, 1993; Krishnamurthy et al., 2007; Ould Ahmed et al., 2007b). Khoshkholgh Sima et al. (1997) reported that in 300 mM NaCl solution, germination rate of sorghum decreases to about 70 percent. In another investigation on sorghum, Mahmood (2012) concluded that accumulation of salt varies according to the differences in irrigation style. The amount of salts accumulated in the soil increased by using continuous irrigation, while the use of alternant irrigation led to reduce accumulation of salts and thus led to increase crop production. The amount of decrease in the accumulation of salts depended on the method of alternant irrigation and on the applied leaching requirements.

Plants need water for photosynthesis and transpiration. Water absorbed from roots and then move through plant and transpires from leaves. The needs of plants to water for growth are depended on several factors such as type of plant, growth stage, soil properties and climatic conditions (Skaggs et al., 2006). Plant water consumption is low at the primary growth stages, but, increases with plant growth and warmer conditions and is maximum at flowering and fruit stages.

Measurement of transpiration or evapotranspiration is necessary for determining plant water demand. Several studies have showed a linear relationship between plant growth and transpiration or evapotranspiration rate (De Wit, 1958; Hanks, 1984; Feddes et al., 1974, 1976; Ould Ahmed et al., 2008). It is also recognized that water absorption by plants decreases with increasing salinity (Homaee and Feddes, 2002).

A widely used macroscopic water uptake model is that proposed by Feddes et al. (1978). This macroscopic function can be modified to account for soil water osmotic head h_o (Homaee et al., 2002a):

$$S = \alpha(h_o) S_{max} \tag{1}$$

in which S is the soil water extraction rate by plant roots ($L^3\,L^{-3}\,T^{-1}$), S_{max} is the maximum water uptake rate and $\alpha(h_o)$ is a dimensionless function of osmotic head.

Similar to De Wit (1958) and van Genuchten (1987), the reduction function $\alpha(h_o)$ can be defined as relative uptake (S/S_{max}) or relative yield (Y/Y_{max}) for the same crop and growing season and thus could be used to account for seedles yield.

Several salinity-dependent functions are proposed by different researches (e.g. Maas and Hoffman, 1977; van Genuchten and Hoffman, 1984; Homaee et al., 2002a,b,c,d). The salinity function in Eq. (1) can be put in form of Maas and Hoffman (1977) model (Homaee et al., 2002d). Written in terms of soil solution osmotic head h_o, gives:

$$\alpha(h_o) = 1 - \frac{a}{360}(h_o^* - h_o) \tag{2}$$

where h_o^* is osmotic threshold value and 360 is a value to convert the salinity-based slope to centimeter osmotic head (US Salinity Laboratory Staff, 1954). Since the linear assumption in Eq. (2) does not fully meet the real field conditions, van Genuchten and Hoffman (1984) proposed an alternative S-shaped equation for Eq. (2):

$$\alpha(h_o) = \frac{1}{1 + [h_o/h_{o50}]^p} \tag{3}$$

where h_{o50} is the soil salinity at which $\alpha(h_o)$ is reduced by 50 percent, and p is an empirical, presumably crop, soil and climate-specific dimensionless parameter.

For some crops, the value of p was found to be about 3 when the S-shape function was applied to salinity stress data. Eq. (3) was found to describe crop salt tolerance data equally well or better than Eq. (2) (van Genuchten and Gupta, 1993).

Dirksen et al. (1993) proposed as modification for Eq. (3):

$$\alpha(h_o) = \frac{1}{1 + [(h_o^* - h_o)/(h_o^* - h_{o50})]^p} \tag{4}$$

Eq. (4) is more reasonable than Eq. (3), incorporating a salinity-dependent threshold value. The most important limitation for both Eqs. (3) and (4) arises from difficulties involved in obtaining h_{o50} value. Furthermore, the p parameter is not yet defined either physically or empirically. The p parameter is a shape parameter as are h_o^* and h_{o50}, but the influence of h_{o50} on response function is larger than that of h_o^*. To overcome this difficulty, Homaee et al. (2002b) similar to van Genuchten and Hoffman (1984) assumed that p is a crop, soil and climate-specific parameter and proposed the following to account for the p parameter:

$$p = \frac{h_{o50}}{h_{o50} - h_o^*} \tag{5}$$

Furthermore, to resolve the difficulty of obtaining h_{o50}, they replaced h_{o50} with h_{omax} parameter and have proposed as modification for Eq. (4) the following nonlinear two-threshold reduction function to account for the tailing effect (Homaee and Feddes, 1999, 2001; Homaee et al., 2002a,d):

$$\alpha(h_o) = \frac{1}{1 + [(1 - \alpha_0)/\alpha_0][(h_o^* - h_o)/(h_o^* - h_{o\,max})]^p} \tag{6}$$

The reduction in α due to salinity beyond h_o^* continues significantly until a certain degree of salinity (h_{omax}) is reached; beyond h_{omax} the salinity increase does not cause further significant reduction in α. This reflects the fact that at $h_o \le h_{omax}$, plant is steel alive but the biological activities are at their minimum rate. The factor α_0 is the value of α corresponding to h_{omax}. The exponent p similar to Eq. (5) can be obtained from:

$$p = \frac{h_{o\,max}}{h_{o\,max} - h_o^*} \tag{7}$$

The main objective of this study was to introduce a macroscopic salinity-dependent predictive model at seedling growth stage when plant imposed to both original soil and water salinities. It was also aimed to find out the salinity threshold value of sorghum at early growth stage.

2. Materials and methods

A large greenhouse experiment was conducted in PVC pots with 40 cm height and 20 cm diameters in a natural saline sandy loam soil to quantify the effect of salinity on sorghum (*Sorghum bicolor*

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