Assessing macroscopic salinity models for predicting canola response to salinity under bud stage

Vahidreza. Jalali[A] and Mehdi. Homaee[A]

[A]Tarbiat Modares University, Faculty of Agriculture, Department of Soil Science. Tehran, Iran. 14115-335,
Email mhomaee@modares.ac.ir

Abstract

Plant response to salinity varies during growth stages. Canola is more sensitive to salinity at earlier growth stages but becomes resistant at germination stage. Earlier growth stages including bud stage are very important parts of plant life, because their survival in these stages will determine their final yield. Few macroscopic models have been proposed to quantify the plant response to average root zone salinity during the whole growth period. Since plant response to salinity varies during different growth stages, developing appropriate models for quantitative characterization of plant response to salinity at each growth stage seems to be crucial. To determine the effect of salinity on canola at bud growth stage, an extensive experiment was conducted with a natural saline loamy sand soil, using some salinity treatments including one non-saline water (tap water) and 8 natural saline waters of 3 to 17 dS/m. The Maas and Hoffman (1977), van Genuchten and Hoffman (1984), Dirksen *et al.* (1993), and Homaee *et al.* (2002) function were used as macroscopic models to predict relative transpiration (T_a/T_p). To compare the models and their efficiency, some statistics were used. The results showed that the calculated statistical parameters were same for Homaee *et al.* (2002) and Dirksen *et al.* (1993) model, but since input parameters for Homaee *et al.* (2002) model are easier to obtain, it is recommended to be used for simulating canola response to salinity at bud growth stage.

Key Words

Canola, salinity, relative transpiration, bud stage.

Introduction

The adverse effects of salinity are generally most pronounced in arid and semi-arid regions because of insufficient annual rainfall to flush out accumulated salts from the root zone (Bresler *et al.* 1982). Plants in response to salinity, represents various resistances with respect to its phonologic stages. Most plants are resistant at germination stage. However, at seedling or earlier growth stages, plants usually become more sensitive to salinity but their tolerance increases with age. Salt tolerance of various plants has been extensively studied by different researchers (e.g. mer *et al.* 2000. Keshta *et al.* 1999 and Francois 1994) with the main conclusion that plant response to salinity highly depends on their phonologic stages. Plant water consumption is low at primary growth stage but increases with plant growth and reaches its maximum at bud and rosette stages. Measurement of transpiration or evapotranspiration is necessary for determining plant water demand. Several researchers (e.g. deWit 1958; Hanks 1984) showed a linear relationship between plant growth and transpiration or evapotranspiration rate (Homaee and Schmidhalter 2008). Water absorption by plants decreases with increasing salinity. Water movement in unsaturated soils is described with the Richard's equation (Richards 1931). Including the root extraction term S, it reads:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[K(h)\frac{\partial h}{\partial z} + K(h)\right] - S \qquad (1)$$

where Θ is volumetric water content (L^3/L^3), t is the time (T), h is the soil water pressure head (L), z is gravitational head, as well as the vertical coordinate (L) taken positive upward, k is the soil hydraulic conductivity (L/T), and S is the water extraction rate by plant roots ($L^3/L^{-3}/T$). Feddes *et al.* (1978) introduced a macroscopic sink term depending on soil water pressure head h only as:

$$S = \alpha(h) S_{\max} \qquad (2)$$

where $S_{\max}$ is the maximum rate of water uptake and $\alpha(h)$ is a dimensionless function of pressure head. Analogously, one may introduce a soil salinity reduction term, $\alpha(h_o)$, instead of $\alpha(h)$ in Eq. (2). This salinity function can be put in the form of the Maas and Hoffman (1977) equation. Written in terms of the soil solution osmotic head h_o, this gives (Homaee *et al. 2002*):

$$\alpha(h_o) = 1 - \frac{a}{360}(h_o^* - h_o) \qquad (3)$$

where h_o^* is the osmotic threshold value and 360 is a factor to convert the salinity-based slope to centimetres osmotic head. Since the linear assumption in Eq. (3) does not fully meet the real field conditions, van Genuchten and Hoffman (1984) proposed:

$$\alpha(h_{\circ}) = \frac{1}{1+\left(h_o/h_{o50}\right)^P} \tag{4}$$

Where h_{o50} is the soil salinity at which $\alpha(h_o)$ is reduced by 50%, and p is an empirical parameter. Dirksen *et al.* (1993) proposed the following as modification for Eq. (4):

$$\alpha(h_{\circ}) = \frac{1}{1+\left((h_o^* - h_o/(h_o^* - h_{o50})\right)^P} \tag{5}$$

The most important limitation for both Eqs. (4) and (5) arises from the difficulty involved in obtaining h_{o50} (Homaee and Schmidhalter, 2008).

Homaee *et al.* (2002) proposed:

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

The reduction in α due to salinity beyond h_o^* continues significantly until a certain degree of salinity ($h_{o\max}$) is reached; beyond $h_{o\max}$, the salinity increase do not cause significant further reduction in α. The exponent p is further defined as (Homaee *et al.* 2002):

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

Methods

In this study, natural saline water with electrical conductivity of 600 dS/m was first provided from Hoze Soltan Lake, Qom, Iran. Table 1 shows some chemical properties of lake water. Considering the experimental salinity treatments, the lake water was diluted by adding proportional amount of tap water to gain the desired salinities. The experimental salinity treatments were tap water (control treatment), 3, 5, 7, 9, 11, 13, 15, and 17 dS/m with three replicates. A natural saline soil (4 dS/m) with loamy sand texture was delivered to greenhouse; air dried and sieved through 5mm sieves. Some experimental pots were carefully packed with this saline soil at bulk density of 1.35gr/cm^3. Each pot was then irrigated with relevant natural saline water until the desired salinity was reached. The main reason to select loamy sand texture was to apply maximum leaching fraction in order to obtain the designated soil salinities. Then, the leaching fraction (LF) of 0.5 was applied to all experimental soils. To insure the accuracy of applied leaching, the electrical conductivity of drainage water was continuously monitored. To avoid any salinity stress, canola plants were irrigated with tap water before reaching bud stage and the salinity treatments were applied afterward. To minimize water evaporation from soil surface, a 3-Cm sand layer was laid on the top of each pot. Three canola plants were maintained in each pot and the daily transpiration was calculated by weighting the pots at regular times sequence. The Maas and Hoffman (1977), van Genuchten and Hofman (1984), Direksen *et al.* (1993) and Homaee *et al.* (2002) models were used to predict relative transpiration in different salinity levels. The p and o are denoted for predicted and observed data. The Maximum Error (ME), Root Mean Square Error (RMSE), and Modelling Efficiency (EF) statistics were computed to compare the models.

Table 1. Some chemical properties of the lake water.

(NO_3^-) mg/L	(Na^+) g/L	(Mg^{2+}) g/L	(Ca^{2+}) g/L	(B) mg/L	(SO_4^{2-}) mg/L	(CL^-) g/L	(HCO_3^-) g/L	(CO_3^{2-}) mg/L	(EC) dS/m	pH
2.75	115	22.4	1.2	54.8	341.5	161	8.6	0.0	600	7.25

Results

Figure 1 shows the measured and predicted relative transpiration (T_a/T_p) of canola at bud stage by different models. Based on the data reported by Maas and Hoffman (1977), the threshold value for canola is 11 dS/m for the whole growth period. However, the results given in fig. 1 indicate that salinity threshold value for canola (ECm) is 4 dS/m at bud stageThe estimated parameters of all four used models and the related statistics are given in Table 2. As can be seen in Fig.1, the nonlinear models including van Genuchten and Hoffman (1984) Direksen *et al.* (1993) and Homaee *et al.* (2002) models provided better estimation than the linear response model of Maas and Hoffman (1977). Based on Table 2, in spite of having identical R2 value for all nonlinear models, a model with less ME and RMSE values and definable parameters is preferred.

Accordingly the Homaee *et al.* (2002) model provided lower ME and RMSE values (Table 2). Taking the advantage of its accessible parameters, this model provided the most reliable estimation at bud phonologic stage.

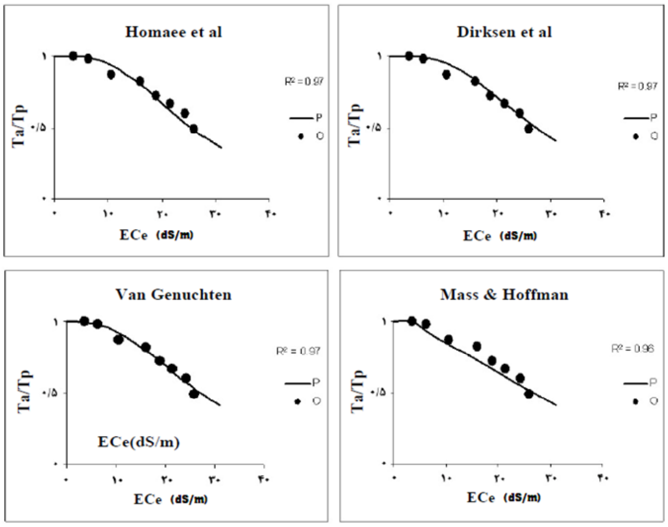

Figure 1. Simulation canola plant response to salinity at bud growth stage.

Table 2. The estimated parameters and calculated statistics for different salinity response models.

Models	EC_p	EC_o	EC_{50}	EC_{max}	b	α	ME	EF	RMSE	R^2
	(------------dS/m------------)				-	-	-	-	-	-
4	3	4	-	18.59	-	0.72	0.05	0.98	3.4	0.97
3	3	4	28.1	-	-		0.05	0.98	3.4	0.97
2	-	4	27.3	-	-		0.046	0.98	3.4	0.97
1	5.2	4	-	-	0.021		0.06	0.97	3.98	0.96

Conclusion

Unlike data reported by several investigators (e.g. Maas and Hoffman, 1977) the canola threshold value for the whole growth period, depends on growth stage. This threshold value for canola was 4 dS/m at bud growth stage. Simulating canola relative transpiration by four different response models indicated that the nonlinear models provide better estimation than the linear model for this growth stage. The predicted threshold values (ECp) obtained by these models were less than those reported by Maas and Hoffman (1977). The statistical analysis showed that Homaee *et al.* (2002) model can provide more accurate predictions than the other models. Since the required input parameters for Homaee *et al.* model are easier to obtain, it is recommended to be used for evaluating canola response to salinity under bud stage.

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