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Quantification of root water extraction under salinity and drought

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Abstract

Widely different approaches have been proposed for modelling root water uptake and most of them are essentially empirical and contain parameters that depend on specific crop, soil, and environmental conditions. The existing root water uptake functions can be categorized into microscopic and macroscopic approaches. Microscopic models consider the radial flow of soil water toward a representative root of infinite length, uniform thickness, and uniform absorptivity. Because the required input parameters at the soil-root interface are rather difficult to measure, it has not proven practical to test the proposed microscopic models directly. Macroscopic models regard the root system as a whole and assume that under optimal conditions the root water uptake is simply equal to potential transpiration over the root zone. Under non-optimal conditions, i.e. low soil water pressure head and/or high salinity, the potential transpiration decreases based on specified soil water pressure head-dependent and/or osmotic head-dependent reduction functions. Because the parameters needed in macroscopic models are practical to measure, this concept is most widely used in numerical simulation models. The macroscopic concept remains essentially empirical, however, and the input parameter values need to be derived for different plants and climatic conditions. This paper focuses on macroscopic models for separate and combined soil water osmotic and pressure heads varying in time and space.

Introduction

Quantification of water uptake by plant roots becomes more complicated when the low soil water pressure (h) and osmotic (h_o) heads simultaneously influence the uptake process. Whereas root water uptake is reduced due to low h and h_o, it is not clear how these stresses interact when they occur together, and vary with time and depth. The simple additivity of soil water pressure and osmotic potentials as proposed by early investigators (Wadleigh and Ayers 1945, Wadleigh *et al.*, 1946, U.S. Salinity Laboratory Staff, 1954) is still questionable. Because soil water pressure and osmotic heads are additive in reducing the free energy of soil water, it was assumed that their effects on transpiration is also additive through reduction in the availability of water for plants. Some investigators (Shalhevet, 1994) clearly indicated that one unit of h is not equivalent to one unit of h_0. Such a conclusion remains useless, however, unless an empirical proportionality coefficient can be determined. The so-called multiplicativity concept is based upon the product of the separate reduction terms for h and h_0 (Van Genuchten, 1987). Homaee (1999) and Homaee and Feddes (1999) extensively reviewed the water uptake models and introduced a new combination method which is neither additive nor multiplicative. The model appeared to fit the experimental data well.

Materials and methods

Alfalfa was grown in densely instrumented laboratory soil columns and harvested at approximately 50-day intervals for one year. Stresses imposed on the plants lasted for about 20 days. The soil containers were PVC cylinders, 67 cm high and 21 cm in diameter. The containers were filled up and packed uniformly to 65 cm with soil and the remaining 2 cm was filled with coarse sand to reduce evaporation from the soil surface. In the top 30 cm of the columns three parallel ports for TDR sensors, tensiometers, and salinity sensors were made at 5-cm increments. In the lower 30 cm of the columns the same ports were located at 10 cm intervals. Soil water contents (θ) were measured nondestructively with the TDR equipment. Soil water pressure heads (h) were obtained by converting θ to h based on the soil water retention characteristics. In-situ soil solution electrical conductivities were measured manually with salinity sensors, while the actual transpiration T_a was determined by suspending the columns and weighing them. The water was applied to the soil columns by flood irrigation immediately before turning off the lights in order to allow as much water as possible to move downward at night. All measurements were started after switching on the lights. The experimental measurements consisted of four periods. The first phase was carried out under salinity stress without water stress, consisting of five treatments. The imposed salinity levels were related to the salinity threshold value of alfalfa, EC_e = 2 dS/m. Accordingly, the EC of the irrigation water was 1.5, 2.0, 3.0, 4.0, and 5.0 dS/m for the treatments S_1W_0, S_2W_0, S_3W_0, S_4W_0, and S_5W_0, respectively. The target leaching fraction was 0.50. In the second phase two levels of water stress were introduced to the plants, denoted as S_0W_1 and S_0W_2 for 70% and 50% of R. In the third phase salinity and first level of water stresses jointly introduced to the plants consisted of five treatments denoted as S_1W_1, S_2W_1, S_3W_1, S_4W_1, and S_5W_1, respectively. The amount of applied irrigation water for all replicates was about 0.7 of R. In the fourth phase salinity and the second level of water stress (0.5R) were investigated, having five treatments denoted as S_1W_2, S_2W_2, S_3W_2, S_4W_2, and S_5W_2, respectively.

Results and discussion

In the combined water and salinity stress experiments, the measured data indicated provided almost a linear trend. According to the multiplicative models the separate reductions due to salinity and water stress can simply be multiplied. The data presented in Table 1 can potentially confirm or reject this concept. The product of $T_a/T_p = \alpha$ of S_1W_0 and $T_a/T_p = \alpha$ of S_0W_1 is 0.92 x 0.66 = 0.61. This product of the reduction terms due to the individual stresses S_1 and W_1 is smaller than the reduction term of the combined stress S_1W_1, for which $T_a/T_p = \alpha = 0.74$. Similarly, for W_1 and S_2, S_3, S_4, and S_5 this product is 0.56, 0.51, 0.44, and 0.39, respectively, while the reduction term for the combined stresses S_2W_1, S_3W_1, S_4W_1, and S_5W_1 is 0.72, 0.65, 0.60, and 0.50. The same comparison yields (0.92x 0.50 =) 0.46, 0.42, 0.39, 0.33, and 0.30 versus 0.67, 0.64, 0.62, 0.40, and 0.26 for S_1W_2, S_2W_2, S_3W_2, S_4W_2, and S_5W_2, respectively. The multiplicative approach underestimates the actual transpiration, except for S_5W_2. Thus, the presented experimental data do not confirm the multiplicative concept. This conclusion can be drawn irrespective of any multiplicative function. Also, the results (not presented here) indicate that neither the multiplicative nor the additive reduction functions fit the experimental data satisfactorily. The best fits were obtained with Homaee's approach. The additive concept gave the worst agreement with the experimental data.

References

Homaee M 1999. PhD thesis. Wageningen Agricultural University. 173pp.

Homaee M and Feddes RA 1999 *In* Modelling of transport processes in soils. Eds. J Feyen and K Wiyo. pp. 416-427. Wageningen pers.

Shalhevet J 1994 Review article. Agricultural water management 25, 233-269.

U. S. Salinity Laboratory Staff. 1954 Handbook 60, U. S. Government printing office. Washington, DC.

Van Genuchten MTh 1987 Res. Report, U. S. Salinity Lab. Riverside, CA.

Wadleigh CH and Ayers AD 1945 Plant Physol. 20, 106-132.

Wadleigh CH, Gauch HG and Magistad OC 1946 Tech. Bull U. S. Dept. Agric. 925.

Table 1. Comparison between relative transpiration T_a/T_p, relative applied water I_w/I_{wR}, ratio of transpired and applied water T_a/I_w, relative fresh weight $(Y/Y_m)_w$, and relative dry weight $(Y/Y_m)_d$ of the separate and combined water and salinity stress treatments.

Treatment		T_a/T_p	I_w/I_{wR}	T_a/I_w	$(Y/Y_m)_w$	$(Y/Y_m)_d$
		-	-	-	G	g
S_iW_0	S_1W_0	0.92	1	0.98	0.89	1.00
	S_2W_0	0.85	1	0.98	0.76	0.87
	S_3W_0	0.78	1	0.98	0.56	0.65
	S_4W_0	0.67	1	0.98	0.49	0.58
	S_5W_0	0.59	1	0.98	0.37	0.55
S_0W_i	S_0W_1	0.66	0.57	1.05	0.61	0.87
	S_0W_2	0.50	0.39	1.18	0.56	0.69
S_iW_1	S_1W_1	0.74	0.52	1.33	0.59	0.74
	S_2W_1	0.72	0.52	1.29	0.57	0.70
	S_3W_1	0.65	0.52	1.17	0.48	0.69
	S_4W_1	0.60	0.52	1.08	0.47	0.64
	S_5W_1	0.50	0.52	0.89	0.45	0.55
S_iW_2	S_1W_2	0.67	0.43	1.30	0.52	0.70
	S_2W_2	0.64	0.41	1.30	0.48	0.65
	S_3W_2	0.62	0.41	1.28	0.47	0.59
	S_4W_2	0.40	0.41	0.82	0.45	0.58
	S_5W_2	0.26	0.29	0.76	0.25	0.36