Asian Journal of Chemistry Vol. 19, No. 3 (2007), 2045-2052

Investigation of the Relationships between Stoma Resistance and Soil Water Matric Potential with other Environmental Factors in Respect of Mathematical Modelling of Plant Water Consumption

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The stoma resistance influences the determination of the transpiration, which is one of the main components of the water balance in the soil and which is one of the morphological properties of the plants. Stoma in the plants control plant water consumption by the cells key doing the functions of closure and disclosure of the apertures through their original structures. In this respect, in the pot experiments which were carried out in a greenhouse conditions, the matric potential of the soil water and plant stoma resistance together along with the other environmental factors were investigated. In this study, using Seri-82 and Adana-99 wheat varieties the matric potential of the soil water and the stoma resistance values at the field capacity and the low moisture levels were measured. In the study, it was observed that the plant stoma resistance was influenced rapidly by the matric potential of the soil water. Although the stoma resistance at the limits of soil water field capacity was found at the limits of 0.69-4.74 s cm^{-1}, the stoma resistance showed increments at the intervals of 7.6-54.8 s cm^{-1} against the increasing soil water tension.

Key Words: Stoma resistance, Soil water matric potential, Transpiration, Environmental factors, Mathematical modelling.

INTRODUCTION

Soil as an indispensable source of the plant production is subjected to the different environmental factors under the influence of various factors in a long period of time. Depending upon the environmental conditions, knowing the potential productivity and revealing and conserving of usage potential of each soil serial is a necessity. The response of developing technology must be the use of feasible agricultural techniques to the

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increase of soil productivity and at least the maintenance of the preceding soil productivity. Therefore, it is a major scientific interest of the investigation of the interactions possible to take place in an agricultural ecology by the advanced and credible scientific methods. Because of the various interactions in question are in the relationships known little about, investigating and evaluating of possible interactions to take place by the simulation techniques appear as a common applicable method. As known, the lose of water by the transpiration is high under the conditions of high temperature and low atmospheric moisture. The vaporing of water from the leaves is basically provided by the apertures called stoma. Closures and disclosures of the stoma depend on the factors so-called light, leaf water content and temperature. Under the conditions of high temperature and light intensity and in the case of plots efficiency to take sufficient water amount. Plants can resist to the high temperatures by the lose of water as a result of transpiration where the stoma is disclosuring. Because of these reasons, the level of transpiration is affected to the degree of disclosuring of the stoma. The stoma control plant water consumption by the functions of closure and disclosure through their original structures[1-3]. Moreover, developed mathematical models benefiting from the relationships between special measurement methods or transpiration and exogenous environmental conditions for the determination of accurate plant water consumption are being used.

EXPERIMENTAL

The soil sample used in the experiment was taken from the experimental and research station of the Department of Field Crop Sciences, Agricultural Faculty, University of Çukurova. Some physical and chemical properties of the disturbed and undisturbed soil samples were determined according to the following methods. Dry bulk density was measured by the core method[4], saturated hydraulic conductivity was determined according to the reported method[5] and particle size distribution was determined by the Bouyoucos hydrometer method[6]. Organic matter content, calcium carbonate, pH and total salt were all determined according to the reported method[7]. Water retention capacity (pF) was measured according to the method of Klute[8]. Some properties of soil are given in Tables 1 and 2.

In this study, wheat varieties of Seri-82 and Adana-99 were sown into the pots of 9 kg. Before the sowing per pot, 5 g N (NH_4NO_3) (half of the nitrogen on the sowing and the other half on branching), 0.15 g K (K_2SO_4), 5 mg Zn ($ZnSO_4$) were applied. Because of being non limiting factor of the levels of mineral nutrients applied and plants nutritional status, the experiment had an attention only in terms of the water level.

TABLE-1
DATA OF SOME PHYSICAL AND CHEMICAL PROPERTIES OF THE SOIL USED IN THE EXPERIMENT

Bulk density (g cm^{-3})	Hydraulic conductivity (cm h^{-1})	Sand (%)	Silt (%)	Clay (%)	Textural class	Total salt (%)	pH (1:2.5)	$CaCO_3$ (%)	Organic matter (%)
1.16	0.39	28.23	34.78	36.99	CL	0.053	7.53	26.89	1.34

TABLE-2
SOIL WATER CHARACTERISTIC VALUES OF THE SOIL USED IN THE EXPERIMENT

Volumetric water content (%)						
1 cm	100 cm	333 cm	1000 cm	5000 cm	10000 cm	15000 cm
57.57	34.49	29.95	27.66	20.67	19.74	18.81

Some dynamic parameters from the measurements of the pot experiment carried out were monitored by the measuring system developed by us. Stomatal resistance measurement using AP4-delta-T Eijkelkampt, Giesbech, The Netherlands type diffusion porometer was measured separately in the flag leaf in the lower and upper epidermis as s cm^{-1}.

Matric potential showing and measuring the energy of water retained in the soil was determined by the tensionmeters. As the matric potential of soil water has the negative values all the time, the positive values are being used in the studies substituting the matric potential by the term matric suction. Therefore, special tensionmeters used for the pot experiments particularly in the greenhouse conditions were employed and the values measured by the tensionmeters in the real time period were transferred to the chart recorder using electronic interfaces to be able to obtain sensitive measurements (a measurement per 10 min was done and the mean values in 1 h was taken). Micro-electro tensionmeters were inserted into the soil for the measurement of the matric suction of the soil water. Because of the changing electrical resistances (Ω) in the membrane resulting from the suction of the sensors, the calibration equation below was used for the voltage out of the effect of the current change

$$(V \approx (AC)): 1 \text{ mV} = 10 \text{ hPa } (32.0 \text{ mV} = 320 \text{ hPa} = 320 \text{ mBar}).$$

Soil water contents and available water levels were monitored continuously by the TDR tool in the real time periods. As soil water contents changing rate was found low in the short period of time, going through the study by the soil water matric suction sounds to be more logical. Because the matric suction in the change of low water contents depending on the soil texture fluctuates in the wide ranges and thus the values are at the levels which can be interrelated, too.

Physical scheme of the model developed for the monitoring of the relationships of plant-soil-water (matric suction-stoma relationship) in the greenhouse condition was given in Fig. 1.

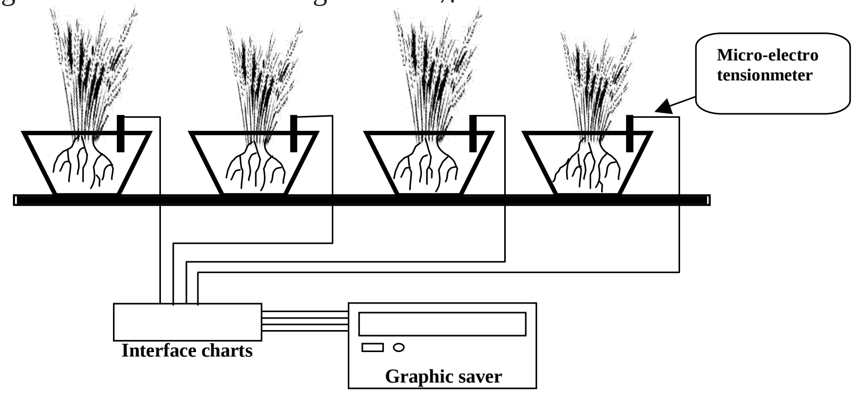


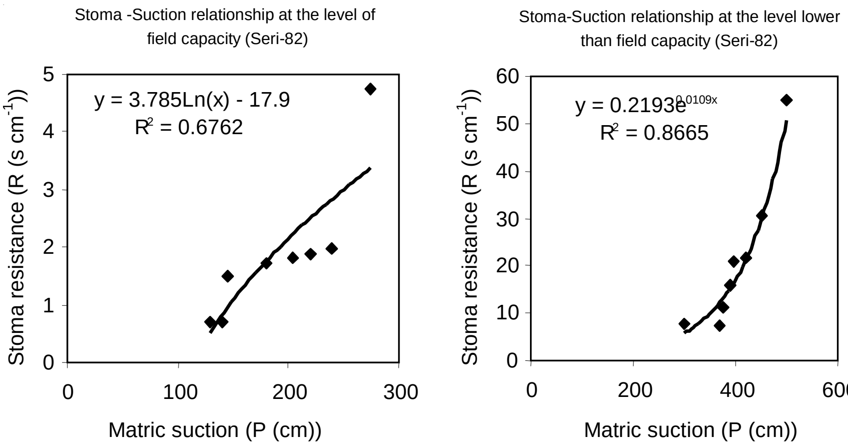
Fig. 1. Measurement system set up in the experiment

RESULTS AND DISCUSSION

It was seen that the stoma resistance increased rapidly on being a little overpassed of 1/3 atm. of the soil water matric suction under the greenhouse conditions (Figs. 2 and 3). So, the need of often irrigation appeared. As can be seen the availability of water around at 1/3 atm. is of major importance. In the consequence of that, the value field capacity is relative and in practice it can be considered as the water held at the suctions of around 1/3 atm. as for the values over it the plant was seen to go through the stress slowly in terms of the water. It was divided into two parts of the research as the water content level correspondent with the suction at over the value 1/3 atm. lower than field capacity and the one at lower and around of the value 1/3 atm. equal to the level field capacity[9,10].

The measurement results obtained from the pot experiment done by Seri-82 wheat variety were shown in Fig. 2. In the measurements, it was seen that the soil water content around field capacity level changed at the interval of *ca.* 1-3 s cm^{-1} of the plant stoma resistance (Fig. 2a). As for the soil water content at the levels lower than field capacity, the stoma resistance reaching higher values showed an exponential relationship (Fig. 2b).

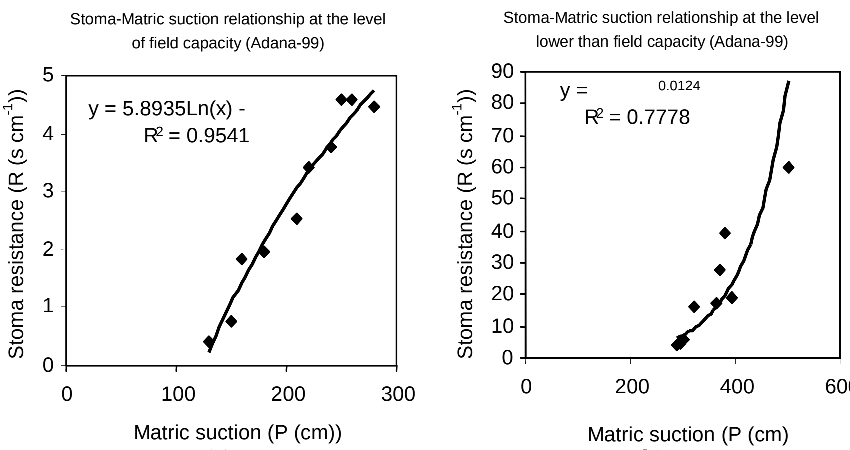
Fig. 3 was consistent with Fig. 2 with very slight differences in terms of the results. Accordingly, the measurement results obtained from the pot experiment done by Adana-99 wheat variety were shown in Fig. 3. In the measurements, it was seen that the soil water content at around the field capacity level changed at the interval of *ca.* 1-4 s cm^{-1} of the plant stoma resistance (Fig. 3a). As for soil water content at the levels lower than the field capacity, the stoma resistance reaching higher values showed an exponential relationship (Fig. 3b).



(a) (b)

Fig. 2. Soil water matric suction and stoma resistance (Seri-82) at the level of field capacity (a) and at the levels lower than the field capacity (b)

Beside the relationship above is stochastic correlations, the applicability of it in the other studies is limited. In the case of exceeding the certain soil water tension in both wheat varieties (in the case of over passing 500 cm water level of matric suction), it was seen that the plant stoma resistance went up rapidly. Maximum stoma resistance in the both wheat varieties was found close to each other (54.8 and 60.1 s cm^{-1}). In this case the availability of soil water was tried to keep over 60%. Otherwise, it was seen that plants went through stress in the greenhouse conditions and stoma resistance went up more.



(a) (b)

Fig. 3. Soil water matric suction and stoma resistance (Adana-99) at the level of field capacity (a) and at the levels lower than the field capacity (b)

The proposed mathematical model below (1) considers the moisture content of air, too, as well as the relationships of plant stoma resistance and soil water matric suction. In terms of the determinative model in question consists of two major components. The first component is to consider the effect of soil water matric potential (suction). The relationship of soil water matric suction and the plant stoma resistance as the main subject of the study was found in a close interaction. So that the higher soil water suction the higher stoma resistance according to the soil water level (it was determined as low at the close levels to the field capacity and as going up rapidly at the levels higher than that one). The other component, too, in the proposed mathematical model is the relative moisture level of the air affecting the increase and decrease of the plant stoma resistance, rapidly. In the low moisture levels, the vaporing of water or CO_2 diffusion from the plants go up rapidly. In this case, the plants stoma resistance are known by putting their auto control mechanism into the action in terms of not losing of turgor property of the plant rapidly for the balanced use of water, relatively (to be able to balance the drying effect of the air)[11]. So, the stoma resistance shows an increment as is below.

$$R_{st} = R_{st\,max} \cdot \left(\frac{\psi_s}{\psi_{sk} - a \cdot \psi_s} \cdot \frac{\varphi_a}{100 - b \cdot \varphi_a}\right) \tag{1}$$

where $R_{st\ max}$ is the maximum plant stoma resistance, ψ_s is the soil matric suction, ψ_{sk} is the critical soil matric suction (ψ_{sk} = 15 bar), **a** is the coefficient of the plant stoma resistance from the matric suction influence (sensitivity value), **a** can be accepted as 0.01 from the experiment results, φ_a is the relative moisture of the air and **b** is accepted as the value expressing the sensitivity of the plant stoma resistance against the relative moisture of the air and **b** = 1.12. In that respect, for instance, in the cases of being at the levels of ψ_s = 0.4-0.5 bar and φ_a is the average relative moisture level in the greenhouse = 70-80%, the value R_{st} obtained from the equation (1) gives the results consistent with the measured values (R_{st} = 12-16 s cm^{-1}). The presented values calculated by the expression (1) were in line with the literature[11]. Plants stoma resistance is not only affected by the two parameters above, but also it is affected significantly by the other environmental parameters (the radiation level, the air temperature and the plant leaf water potential, etcetera), too. In this case, a relationship in the way below should be looked for by considering each effect as whole.

$$R_{st} = R_{s\psi} \cdot R_{s\varphi_a} \cdot R_{s\phi} \cdot R_{sT} \tag{2}$$

In that respect, it seems to be possible to express the effect of the all environmental parameters on the plant stoma resistance by the mathematical model below.

$$R_{st} = R_{st\,min} \cdot ((\psi_{sk} - a \cdot \psi_s)/(\psi_{sk} - \psi_{s\,opt})) \cdot ((100 - b \cdot \varphi_a) /(100 - \varphi_{a\,kr})) \cdot ((1 + c / I_\phi)) \cdot ((T_{akr} - d \cdot T_a)/(T_{aopt} - T_{ast})) \quad (3)$$

where, $R_{st\,min}$ is the minimal value of the plant stoma resistance (0.5-1.5 sn cm^{-1}), ψ_{sopt} is the optimum soil matric suction ($\psi_{s\,opt}$ = 0.33 bar), I_ϕ is the radiation level (W cm^{-2}), T_a is the air temperature, T_{akr} is the air temperature at the moment of complete closure of the plant stomata (T_{akr} = 52ºC),T_{ast} is the lowest air temperature at the moment disclosure of the plants stomata, T_{aopt} is the optimum air temperature at the moment of the widest disclosure of the plant stoma apertures (T_{aopt} = 38ºC)[11], **c** and **d** are the coefficients reflecting the sensitivities of plant stoma resistance from the radiation and the air temperature, respectively.

As seen in the model (3), the maximum value of the plant stoma resistance is expressed mathematically in terms of what degree they affected the resistance in their own intrinsic potential limits of the affection as the environmental factors in the sequence above.

In the experiment carried out by the two wheat varieties (Seri-82 and Adana-99) it was seen that the plant stoma resistance went up by the increase of soil water matric suction (by the decrease of potential). In the investigation done in both wheat varieties the close correlations were seen in the relationships of plant stoma resistance and matric suction. The plant stoma resistance was determined at the intervals of 0.41-4.74 s cm^{-1} at the levels of low matric suction of soil water. As for at the levels of relatively high matric suction (500 cm), the stoma resistance was found at the maximum limits ($R_{st\,max}$ = 54.80 and 60.10 s cm^{-1}, respectively).

The proposed mathematical model (3) will be studied deeply by being developed furthermore in our future studies. Especially, in that respect, a basic model will be tried to be set up by investigating mainly the interaction from the plant stoma apertures PAR level and the other effective environmental conditions. Revealing of the relationships in question will also illumine to the studies of selection of various plants wheat starting the process photosynthesis by disclosing the stomas early at the lowest PAR value of the plants in particular.

ACKNOWLEDGEMENT

The authors would like to thank the Cukurova university research projects unit for providing financial supporting for project number (ZF.2002 BAP28).

REFERENCES

1. L.H.JR. Allen, D.W. Steward and E.R. Lemon, *Photosynthetica*, **8**, 184 (1974).
2. S.B. Idso, in ed.: L. Chandra, A Theoretical Framework for the Photosynthetic Modelling of Plant Communities, Advancing Frontiers of Plant Sciences, Vol. 23, p. 91 (1969).
3. R.B. Curry, Dynamic Modelling of Plant Growth, Winter Meeting ASEA, Sherman House, Chicago, Illionois, December 9-12, Paper No. 69-939, pp. 1-17 (1969).
4. G.R. Blake and K.H. Hartge, in ed.: A. Klute, Bulk Density, In: Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods, Agron. Monogr. 9, ASA-SSA, Madison, WI, pp. 363-375 (1986).
5. A. Klute and C. Dirksen, in ed.: A. Klute, Hydraulic Conductivity and Diffusivity, Lab. Methods, In: Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods, Agr. Monogr. 9, Madison, WI, pp. 687-734 (1986).
6. G.J. Bouyoucos, *Agron. J.*, **54**, 464 (1962).
7. A.L. Page, R.H. Miller and D.R. Keeney, Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties, 2nd ed. Agron. Monogr. 9, ASA-SSA, Madison, USA (1982).
8. A. Klute, Water Retention: Laboratory Methods. In: Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods, Agr. Monogr. ASA and SSSA Madison WI, pp. 635-662 (1986).
9. C.W. Rose, Pergamon Press, Oxford, New York (1979).
10. N. Çepel, Forestry Fac., Univ. of Istanbul, Univ. Publication No. 3794, The Institute Publication No. 5, ISBN 975-404-320-5, Istanbul (1993).
11. S.H. Bichle, H.A. Moldau and J.K. Ross, Gidrometoizdat, p. 223 (1980).

(*Received*: 18 April 2006; *Accepted*: 23 October 2006) AJC-5217