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INFLUENCE OF SUCKING PRESSURE OF SOIL WATER ON EVAPOTRANSPIRATION AND MEADOW YIELDING

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A b s t r a c t. In the present study soil-water coefficients k_{s1} were determined and evaluation of the influence of soil sucking pressure on the actual yield was carried out. Relations between these coefficients and soil sucking pressure in the root zone are used for the calculation of actual evapotranspiration or actual yield neglecting evaluation of the influence of evapotranspiration on yield.

K e y w o r d s: soil water, sucking pressure, evapotranspiration, meadow, yield.

INTRODUCTION

Water is one of the most important factors that influences evapotranspiration and grass yield. When water appears in the soil in abundance, evapotranspiration and yields are maximum. In dry periods, soil moisture content measured by the level of sucking pressure, becomes a restricting factor for evapotranspiration and, hence grass yield. There is a close connection between yield and the amount of water for evapotranspiration [7]. The influence of soil sucking pressure on the actual evapotranspiration (pattern 1) and yield (pattern 2) can be determined by means of soil-water coefficients k_{s1} and k_{s2} that are related to the sucking pressure of soil water. The aim of the present study was to evaluate the influence of soil water sucking pressure F on the level of soil-water coefficients k_{s1} and k_{s2}.

THEORETICAL BASIS

The influence of soil sucking pressure on the level of evapotranspiration can be determined from the soil-water coefficients k_s [4-6,9]. The above coefficients can be determined from the following equation:

$$ET - k_{s1} ET\,(\mathrm{Q_{max}}) \qquad (1)$$

where: ET - seasonal values of actual evapotranspiration in the conditions of differentiated sucking pressure of soil water F_s [in mm]; k_{s1} - soil-water coefficient related to the sucking pressure of soil water F; ET (Q_{max}) - seasonal values of actual evapotranspiration at the maximum yield level without abundant water consumption (in mm).

Polish literature on the relations between soil-water coefficients k_s and soil sucking pressure is relatively poor [5,6,8,9]. The Eq.(1) enables calculation of soil coefficients k_{s1} for the first and second swath on the basis of ET and ET (Q_{max}) values and determination of relation between k_{s1} and sucking pressure F measured in lysimeters.

Plant growth consists in the transformation of radiation energy in the process of photosynthesis into plant biomass. In the conditions of water deficiency in the soil (k_s 1.0), sucking pressure F decreases both the level of evapotranspiration ET and the yield level Q. If we assume identical reaction of both evapotranspiration and yield to water deficiency in the soil, then the influence of sucking pressure F on the actual yield level Q can be calculated from the following equation:

$$Q = k_{s2}\, Q_{max} \qquad (2)$$

where Q - actual yield level in the conditions of differentiated soil water sucking pressure F; k_{s2} soil-water coefficients dependent on the soil water sucking pressure F and calculated in the aspect of direct influence of sucking pressure on yield; Q_{max} - actual yield when k_{s2} =1 and Q=Q_{max}.

For the evaluation of k_{s2} coefficients and their relation to the soil water sucking pressure F, it is indispensable to get to know the Q, Q_{max}, and F values. In the present work an attempt to determine the values of k_{s1} coefficients from the Eq.(1) and k_{s2} coefficients from the Eq.(2) in relation to the soil water sucking pressure F was undertaken.

MATERIALS AND METHODS

The basis for the present work are the results of studies on the sucking pressure of peat-mucky soil, medium transformed soil utilised as 3-swath meadow together with yield and evapotranspiration of this meadow at differentiated depths of dewatering. The present studies were carried out in the region of Polesie Lubelskie in Sosnowica in the period 1977-1994. The values of sucking pressure and evapotranspiration taken every decade were then used for the determination of soil-water coefficients k_s in relation to sucking pressure F [9]. In the present study the values of sucking pressure, evapotranspiration and yield were determined for individual swaths in the period 1977-1981 at the dewatering depths of 40, 50, 60, 70, and 90 cm; at the dewatering depths of 50, 60, 70, 90, and 100 cm in the period 1989-1994 and 70 and 100 cm in the period 1989-1994, as well as without ground water and covered lysimeters in the period from June to August.

To determine the relation between the k_{s1} and k_{s2} coefficients and soil water sucking pressure F, a GRAPHER software programme was used. Threshold values of the correlation coefficient r_α and significance test F_α as given by Elandt [1] were applied. They were related to the r and F values obtained from the calculations.

RESULTS

Characteristics of actual evapotranspiration ET of a 3-swath highly fertilised meadow, yield Q and sucking pressure F at differentiated depths of dewatering h was limited to the mean daily values for the swaths in some chosen years, i.e., 1979, 1987, 1992 and for certain study periods (Table 1). Actual evapotranspiration Et at the maximum yield level Q_{max}, i.e., $ET\,(Q_{max})$ was assumed as an index of the highest water consumption by plants. Empirically determined values of $ET(Q_{max})$ and Qmax are given in Table 1.

Dewatering depth h influenced the value of sucking pressure F (Table 1). Mean daily sucking pressure was the lowest at the dewatering depth of 40 cm and the highest in the lysimeters with broken capillary rise from the saturated zone (without ground water). The pressure in the second swath was slightly higher when compared to the third swath due to higher evapotranspiration (Table 1). Soil sucking pressure is a changing value that is related to the depth of dewatering and evapotranspiration level. The above agrees with the results of model [7] and field experiments [8].

Influence of soil water sucking pressure on the level of meadow evapotranspiration

The influence of sucking pressure on the level of evapotranspiration is characterised by the values of k_{s1} coefficients calculated from the Eq.(1) and presented as examples for the years 1979, 1987, 1992 (Table 2) and relations between these coefficients and sucking pressure F in the second and third swath. The coefficients k_{s1}-1.00 characterise dewatering depth at which actual yield Q-Q_{max}, $ET=ET(Q_{max})$ - Table 1. There is a supplement of water in the soil. The values of coefficients $k_s<1.00$ in individual swaths decrease when dewatering depth h

Table 1. Daily means of actual evapotranspiration values (ET, mm d^{-1}) for individual swaths, yields (Q, q $ha^{-1}d^{-1}$) and soil sucking pressure in the 0-30 cm layer (F, hPa) at differentiated depths of dewatering (h, cm) in some years and study periods in Sosnowica

Dewatering depth, cm	Year, Study period	ET in swaths			Q in swaths			F in swaths	
40	1979	4.23	4.31	2.34	0.92	0.89	0.45	25	24
50		3.95	4.30	2.37	0.92	0.89	0.45	31	30
50		3.38	4.04	2.36	0.89	1.00	0.51	49	45
70		3.26	3.35	2.22	0.85	0.93	0.55	188	58
90		2.40	2.95	2.20	0.72	0.80	0.58	260	127
50	1987	2.60	4.46	2.02	0.70	1.01	0.31	85	78
60		2.25	3.50	1.91	0.73	0.92	0.43	99	95
70		2.46	3.60	1.83	0.82	0.81	0.33	113	75
90		2.05	2.52	1.56	0.69	0.42	0.29	258	114
100		1.54	2.08	1.32	0.61	0.48	0.30	295	160
70	1992	3.78	5.06	3.22	0.82	0.71	0.36	123	85
100		3.09	2.96	1.63	0.58	0.47	0.11	441	323
Without g. water		3.18	1.75	1.25	0.57	0.23	0.09	527	353
40	1977-1981	2.98	4.16	2.07	0.68	0.81	0.40	19	16
50	1977-1981; 1968-1988	2.80	4.12	1.92	0.66	0.97	0.38	58	51
60	1977-1981; 1986-1988	2.45	3.83	1.90	0.75	0.93	0.43	70	66
70	1977-1981; 1968-1994	2.95	4.07	1.93	0.86	0.86	0.37	123	95
90	1977-1981; 1986-1988	2.30	3.12	1.82	0.69	0.73	0.50	212	130
100	1986-1994	2.41	2.85	1.15	0.69	0.58	0.23	395	397
Without g.water	1989-1994	2.72	1.98	1.39	0.69	0.34	0.11	540	521

Table 2. Differentiation of soil-water coefficients $k_{s1}= ET/ET_{max}$ for a 3-swath meadow on the MtII bb in some years in relation to the dewatering depth (h, cm)

Swath	Year	K_{s2}-Q/Q_{max} the dewatering level h, cm					
		50	60	70	90	100	Without ground water
I	1979	1.00	0.86	0.83	0.61		
	1987			1.00	0.83	0.63	
	1992			1.00		0.82	0.84
II	1979		1.00	0.83	0.73		
	1987	1.00	0.78	0.81	0.57	0.47	
	1992			1.00		0.59	0.35
III	1979				1.00		
	1987		1.00	0.96	0.82	0.69	
	1992			1.00		0.51	0.39

increases. It results in a decrease of actual evapotranspiration ET due to the increase of sucking pressure F (Table 1).

The soil water coefficients $k_{s1} \leq 1.00$ and the values of sucking pressure F related to them that were determined during study period, were then assumed as the basis for the calculation of $k_{s1}(F)$ relations in the second and third swath. These relations for the second swath have the following form:

$$k_{s1} = 0.9919 - 0.0008F \tag{3}$$

where F - soil water sucking pressure in the root zone, in hPa.

It was obtained at the 44 degrees of freedom. This relation is characterised by the correlation coefficient r =0.7708 and the values of significance test F - 68.1. The threshold values of the correlation coefficient r_{α}- 0.3725 and significance test F_{α}=7.24 are lower than the calculated ones. Hence, this relation is significant. It can be used for the evaluation of k_{s1} coefficients in the second swath on the basis of sucking pressure F in the range from 21 to 723 hPa and for the calculations of actual meadow evapotranspiration ET on the basis of $ET(Q_{max})$ that was 4.1 mm d^{-1} on the average (Table 1) and k_{s1} coefficients in the range of F values given above. The $k_{s1}(F)$ relations for the third swath are as follows:

$$k_{s1} = 1.0206 - 0.0010\,F. \tag{4}$$

It was obtained at 32 degrees of freedom. This relation is characterised by: correlation coefficients r - 0.8248 and r_{α}=0.4475 and significance test F-73.5 and F_{α}-7.50. This relation can be useful in the evaluation of k_{s1} coefficients in the third swath on the basis of sucking pressure F in the range from 14 to 790 hPa. It can also be used for the evaluation of actual meadow evapotranspiration in the third swath on the basis of $ET(Q_{max})$ of 1.8 mm d^{-1} on the average (Table 1) and k_{s1} coefficients in the F range from 14 to 790 hPa.

The values of k_{s1} coefficients calculated on the basis of Eqs(3) and (4) at the sucking pressure F of 400 hPa are 0.65 and 0.62, respectively. They differ in their values, which confirms a significant influence of ET (Q_{max}) on the relation pattern $k_{s1}(F)$ according to earlier studies by Feddes *et al.* [3].

Influence of soil water sucking pressure on the meadow yields

The influence of sucking pressure F on the meadow yields are characterised by the values of k_{s2} coefficients calculated from the Eq.(2) and presented as examples for the years: 1979, 1987, 1992 (Table 3) and relations between k_{s2} coefficients

Table 3. Differentiated levels of soil-water coefficients k_{s2} -Q/Q_{max} for the 3-swath meadow in the Mt II bb soil in some years in relation to the depth of dewatering (h, cm)

Swath	Year	K_{s2}-Q/Q_{max} the dewatering level h, cm					
		50	60	70	90	100	Without ground water
	1979			0.92	0.78		
I	1987	1.00	0.97	1.00	0.83	0.73	
	1992			1.00		0.71	0.69
	1979		1.00	0.92	0.80		
II	1987	1.00	0.92	0.80	0.41	0.48	
	1992			1.00		0.67	0.32
	1979				1.00		
III	1987		1.00	0.75	0.68	0.70	
	1992			1.00		0.32	0.25

and sucking pressure F in the second and third swath. The k_{s2} coefficients equal to 1.00 characterise such a dewatering depth h at which Q-Q_{max}. In the above conditions there is abundance of water in the soil. The k_{s2} values <1.00 in the individual swaths decrease when the depth of dewatering increases. It results from the restrictions of Q yields imposed by sucking pressure F (Table 1). The soil-water coefficients $k_{s2} \leq 1.00$ and the values of sucking pressure F related to them that were determined during study period were then assumed as the basis for the calculation of k_{s2} (F) relations in the second and third swath. These relations for the second swath have the following form:

$$k_{s2} = 1.0007 - 0.0009F. \qquad (5)$$

It was obtained at the 44 degrees of freedom. This relation is characterised by the correlation coefficients r=0.7501 and r_{α}=0.3725 and the values of the significance test F-56.6 and F_{α}=7.24. This relation is then significant. It can be used for the evaluation of k_{s2} values on the basis of sucking pressure F in the range from 21 to 723 hPa and for the calculation of actual yields Q on the basis of maximum yields Q_{max} that are 0.97 q ha^{-1}d^{-1} (Table 1) and the values of k_{s2} coefficients in the F range given above. This relation takes the following form for the third swath:

$$k_{s2} = 0.9673 - 0.0008F. \qquad (6)$$

It was obtained at the 32 degrees of freedom. This relation is characterised by the correlation coefficients r=0.6711 and r_α=0.4475 and the values of significance tests of F=26.2 and F_α=7.50. Hence, this relation is significant. It can be applied for the evaluation of k_{s2} coefficients in the third swath on the basis of F sucking pressure in the range from 14 to 790 hPa and for the calculation of actual yields Q on the basis of Q-Q_{max} that are 0.50 q ha^{-1}d^{-1} (Table 1) and the values of k_{s2} coefficients in the F range given above.

The k_{s2} coefficients calculated from the Eqs(5) and (6) at the sucking pressure F=400 hPa are the same and equal to 0.64. It means that the level of maximum yield is not a differentiating factor for the relation pattern k_{s2} (F). The values of k_{s1} and k_{s2} coefficients calculated from the Eqs(3) and (5) at the sucking pressure F=400 hPa are 0.65 and 0.64, respectively. The values of these coefficients as calculated simultaneously from the Eqs(4) and (6) are 0.62 and 0.64, respectively. It means that the influence of soil sucking pressure on the level of evapotranspiration and yield is only slightly different, which is basically in agreement with the studies by Łabędzki [6] and Feddes [2]. The hypothesis that yield is a function of actual evapotranspiration [7] is then confirmed.

CONCLUSIONS

On the basis of analysis of the results obtained and calculations carried out, we can draw the following conclusions:

1. Soil-water coefficients $k_{s1}=ET/ET(Q_{max})$ and determined in this study and relations between these coefficients and soil sucking pressure in the second (Eq.(3)) and third (Eq.(4)) swath can be used for the evaluation of actual evapotranspiration of the meadow on the basis of evapotranspiration level at the maximum yield (Table 1) and k_{s1} coefficients in the sucking pressure range from 21 to 723 hPa and from 14 to 790 hPa, respectively.

2. The soil-water coefficients given in this study k_{s2} - Q/Q_{max} and relations between these coefficients and soil sucking pressure in the second (Eq.(5)) and third (Eq.(6)) swath can be used for the evaluation of actual yields on the basis of maximum yield (Table 1) and k_{s2} coefficients in the sucking pressure ranges from 21 hPa to 723 hPa, and from 14 to 790 hPa, respectively.

3. The relations (3), (4), (5), and (6) presented in this study are relevant for the 2-swath meadow on the peat-mucky soil determined as Mt II bb. They can be used for the evaluation of the actual evapotranspiration level and yield value in the moist water logged habitat determined as Pb.

REFERENCES

1. **Elandt R.**: Statystyka matematyczna w zastosowaniu do doświadczalnictwa rolniczego. Warszawa, PWRiL, 1964.
2. **Feddes R.A.**: Crop water use and dry matter production: state of the art. ICW Techn. Bull., No. 63: Les besions en eau 'des cultures. Paris, INRA, 1985.
3. **Feddes R., Kowalik P., Zaradny H.**: Simulation of Field Water Use and Crop Yield. Pudoc, Wageningen, 1978.
4. **Kaca E., Kasperska W.**: Model matematyczny ewapotranspiracji rzeczywistej użytków zielonych na glebie torfowo-murszowej. [W]: Torfoznawstwo w badaniach naukowych i praktyce. IMUZ, Falenty, Mater. Semin., 34, 315-321, 1995.
5. **Kasperska W.**: Wpływ uwilgotnienia gleby i stanu roślinności na wielkość ewapotranspiracji łąki w dolinie Noteci. IMUZ, Rozpr. doktorskie, 1998.
6. **Łabędzki L.**: Potrzeby nawadniania użytków zielonych - uwarunkowania przyrodnicze i prognozowanie. Wyd. IMUZ Falenty, Rozpr. habilit., 1997.
7. **Olszta W.**: Badania dynamiki uwilgotnienia gleb, wzrostu traw i prognozowanie nawodnień metodą modelowania matematycznego. IMUZ Falenty, Rozpr. habilit., 1981.
8. **Olszta W., Szajda J., Zawadzki S.**: Wpływ ciśnienia ssącego gleby na wielkość ewapotranspiracji. Zesz. Probl. Post. Nauk Roln., 390, 151-163, 1990.
9. **Szajda J.**: Roślinne i glebowo-wodne wskaźniki ewapotranspiracji łąki na glebie torfowo-murszowej. Wyd. IMUZ, Falenty, Rozpr. habilit., 1997.