THE EFFECT OF WATER DEFICIT AND SUBSEQUENT REGENERATION ON SELECTED PHYSIOLOGICAL CHARACTERISTICS IN TOMATOES (*LYCOPERSICUM ESCULENTUM* MILL.)

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The effect of water deficit and subsequent regeneration in tomatoes (*Lycopersicum esculentum* Mill., the varieties Monika F1, Stupické polní rané and Start F1) as affected the rate of photosynthesis (P_N), rate of transpiration (E) and stomatal conductance (g_s) was studied in pot trials in the years 2000 and 2001. Irrigation was discontinued in a stressed variant (S) for five days, then it was again renewed. Five measurements were done in total (on the 2nd and the 5th days of dehydration, and on the 1st, 2nd and 4th days of rehydration) using the portable analyser LCA 4. Water deficit resulted in potato plants in reduction of stomatal conductance up to zero value and at the same time the rate of photosynthesis and transpiration decreased. Zero stomatal conductance was reached in the variety Monika F1 on the fifth day of dehydration and in the varieties Stupické and Start F1 on the first day of rehydration. The measured differences in the rate of photosynthesis among control and non-irrigated plants were statistically significant ($F = 4.428$, $p = 0.035193$, Table 2, Fig. 1). The rate of photosynthesis was measured on the second day of dehydration on average on the level 65.44% of photosynthesis of control plants. The taken values of the rate of photosynthesis ranged between 5.78 up to 8.20 μmol $CO_2.m^{-2}.s^{-1}$. The drop of dehydration (5th day) resulted in decrease of photosynthesis was on average 20.91% in the varieties Start F1, Monika F1 and Stupické polní rané, whereas lowest rate of photosynthesis was recorded in the variety Monika F1 (1.21 μmol $CO_2.m^{-2}.s^{-1}$). Gradual regeneration of physiological processes appears during the first four days after rehydration, but pre-stress level was not reached within the trial in any of the studied parameters. The rate of photosynthesis achieved on the fifth day on average solely 51.8% of the rate of photosynthesis of the control plants. The conclusion on the tolerance or sensibility of studied varieties to water stress cannot be made unambiguously by the results obtained and partial "indications".

water deficit; tomato; *Lycopersicum esculentum* Mill.; varieties; rate of photosynthesis; rate of transpiration; stomatal conductance

INTRODUCTION

Availability of water is one of the factors that determine production and its parameters on the Earth's surface. Soil drought occurs in case of limitation of availability of soil water and deficit of precipitation. Drought or water deficit lead to interferes water balance and to discrepancy between uptake and distribution of water and demands for water during ontogeny. Plants are continuously affected by unfavourable factors under natural conditions to those they have to response on different level of hierarchy of structures and processes.

The stress is the state in which the plant's organism exists in mobilisation of defensive or corrective mechanisms. There are several approaches to stress characterisation, but it can be defined generally as a sum of non-specific reactions of an organism to action of extraordinary sources of irrigation of various character inducing tension of functions of the biological system and providing mobilisation of the whole organism, its adaptation or keeping of homeostasis (Brestič, Olšovská, 2001).

Action of moderate water stress is induced in majority of mesophytic plants by the values of water potential of leaves up to –0.5 MPa. The values between –0.5 and –1.5 MPa show medium stress and the values of water potential below –1.5 MPa mean a very strong stress at which a turgor pressure often falls in leaf cells to zero and the leaves start to wilt. The growth is usually the most sensible reaction to water stress. Measurable deceleration of growth appears at a very low loss of water when turgor falls only by 0.1 to 0.2 MPa. The growth stops earlier than wilting of leaves or influence of major metabolic processes including photosynthesis (Gloser, Prášil, 1998).

The effect of water deficit on the processes connected with photosynthesis has been described in many complex studies. The initial effect associated with closing of stomata and decrease of CO_2 concentration in intercellular spaces was called a stomatal inhibition of photosynthesis (Cornic, 1992). Non-stomatal limitation of photosynthesis occurs in further deepening of water deficit that consists in decrease of the activity of photosystem II (PS II), damage to its reaction centre, inhibition of activity ATP-synthetase and in changes of electron transport (Baker, 1993; Cornic, Massacci, 1996), furthermore in decrease of concentration and RUBISCA activity (Chaves, 1991).

Water deficit a lot of changes of morphological and physiological characters on the level of microstructures, cells and different organs that fundamentally limit a production activity of plants and resulting production of biomass including reduction of different yield-forming components (Švihra, 1984). Water deficit can be applied within ontogeny of plants in different degree. Cultural plants have the so-called critical periods in view of the claim for water supply that affect the resulting level of production in a decisive way. Renquist, Reid (2001) studied the effect deficit of moisture in tomatoes in the period of anthesis and formation of fruits as affected the yield and quality. They reported that 38% reduction of fruit yield due to the fall of the fruit size by 35% appeared at the water deficit in the period of fruit formation. Rao et al. (2000) stated that maximal drop of the rate of photosynthesis (by 53.1%) occurred in the studied tomato cultivar in anthesis.

Genotype differences of different species and above all varieties to tolerance or sensibility to water deficit and their different response particularly to the level of production should be also mentioned. Lutfor-Rahman et al. (2000) studied the effects of water stress and temperature on water potential of leaves the yield and yield-forming properties in sensible and tolerant tomato variety. They reported that the level of decrease of dry matter production, yield-forming properties and the yield was higher due to water stress in sensible variety than in the tolerant variety, also water potential of leaves was reduced in both varieties, the decrease was higher in sensible variety. Rahman et al. (1999) came to similar conclusions in their experiments.

The aim of the authors' experiments was to study the effect of induced water deficit on selected physiological processes in three tomato varieties (*Lycopersicum esculentum* Mill.) and their regeneration after repeated watering.

MATERIAL AND METHOD

Tomato plants (*Lycopersicum esculentum* Mill.) were an experimental material in the developmental stage of five right leaves, cultivated in greenhouse in pots 1.6 dm^3 of the volume containing sowing substrate, i.e. the varieties Stupické polní rané, Monika F1 and Start F1. The experiments were carried out in two replications in the years 2000 and 2001 and were established in two variants: the control variant (K) and the stressed variant (S).

Watering was stopped for five days in stressed plants. After relapsing of this time watering was again renewed. The control plants were watered to full saturation of the substrate in the pot. We measured the rate of photosynthesis (P_N), the rate of transpiration (E) and stomatal conductance (g_s), in three experimental plants of both variants during the trial. Five measurements were done in total (on the 2nd and 5th day of dehydration and on the 1st, 2nd and 4th day of rehydration; in brief 2d, 5d, 1r, 2r and 4r).

The values taken were statistically processed using the program StatSoft, Inc. (2001) – STATISTICA Cz (Software system for data analysis), version 6. The evaluation itself was done on the basis of multifactor analysis of variance with interactions of the second degree where variety, variant and date of measurement were settled as a category of independent variables (factors).

The portable analyser LCA 4 (infrared gas analyser made by Eijkelkamp, the Netherlands). The measurement itself was performed under controlled conditions of climatic box (irradiance 430 $\mu mol.m^{-2}.s^{-1}$, temperature 26 °C) on the same leaf in the same hour of day during the whole experiment. The device LCA 4 recorded selected parameters in half-minute intervals for 20 minutes. The collection of 20 measured values was selected of the whole series of measurements when conditions inside measuring chamber were stable. Mean values of studied physiological characteristics were calculated from them.

RESULTS AND DISCUSSION

The values taken of studied physiological characteristics are presented in Table 1. We studied action of dehydration in different dates and at the same time in selected varieties. Stomatal conductance, rate of photosynthesis and transpiration fell after stopping of watering in non-irrigated plants. Haupt-Herting and Foch (2000) reported that water stress induced in tomatoes decreased of values of stomatal conductance and photosynthesis. Rahman et al. (1999) also recorded identical results.

The differences found in the rate of photosynthesis between the control and non-irrigated plants were statistically significant ($F = 4.428$, $p = 0.035193$, Table 2, Fig. 1). The rate of photosynthesis measured on the second day of dehydratation was on average 65.44% of photosynthesis of control plants. The taken values of the rate of photosynthesis ranged between 5.78 and 8.20 $\mu mol\ CO_2.m^{-2}.s^{-1}$.

The drop of dehydration (5d) resulted in decrease of photosynthesis was 20.91% on average in the varieties Start F1, Monika F1 and Stupické polní rané, whereas the lowest rate of photosynthesis was recorded in the variety Monika F1 (1.21 $\mu mol\ CO_2.m^{-2}.s^{-1}$). Rao et al. (2000) studied the effect of water stress in five tomato cultivars as affected the rate of photosynthesis, transpiration and stomatal conductance. They stated that a significant decrease of the rate of photosynthesis, transpiration and stomatal conductance appeared in all tomato cultivars. Rahman et al. (1999) studied the effect of water stress in more tolerant and sensible cultivars to water stress. They stated that despite it, photosynthesis and transpiration were reduced in all cultivars.

The differences in the values of stomatal conductance between the variants were statistically insignificant (Table 3, Fig. 4). It can be seen based on the taken values that zero stomatal conductance was reached in the variety Monika F1 on the fifth day of dehydration. Zero stomatal

Table 1. Measured physiological characteristics in tomato plants

Variety		2nd day of dehydration	5th day of dehydration	1st day of rehydration	2nd day of rehydration	4th day of rehydration
Monika K	P_N	8.92	8.45	7.35	6.63	7.01
	E	0.62	0.64	0.61	0.76	0.77
	g_s	0.02	0.02	0.02	0.03	0.03
Monika S	P_N	5.78	1.21	2.23	3.46	3.73
	E	0.58	0.17	0.24	0.45	0.43
	g_s	0.02	0	0.01	0.02	0.01
Start K	P_N	11.02	8.96	5.94	5.85	8.22
	E	1.62	1.32	0.74	0.77	0.98
	g_s	0.11	0.05	0.03	0.03	0.04
Start S	P_N	7.06	2.27	1.58	2.6	3.95
	E	0.87	0.49	0.23	0.34	0.57
	g_s	0.06	0.01	0	0.01	0.02
Stupické polní rané K	P_N	11.52	11.00	9.09	10.04	9.03
	E	1.30	1.03	1.45	1.35	0.96
	g_s	0.07	0.04	0.06	0.06	0.04
Stupické polní rané S	P_N	8.20	2.54	1.25	2.33	4.89
	E	0.98	0.30	0.18	0.33	0.50
	g_s	0.06	0.01	0	0.01	0.02

Legend: K – control variant, S – stressed variant, P_N – rate of photosynthesis in µmol $CO_2.m^{-2}.s^{-1}$, E – rate of transpiration in mmol $H_2O.m^{-2}.s^{-1}$, g_s – stomatal conductance in mol $CO_2.m^{-2}.s^{-1}$

Table 2. Table of semi-results and results of analysis of variance of double classification – photosynthesis

	SČ	Degrees of freedom	PČ	*F*	*p*
Variety	14.272	2	7.136	9.054	0.008817*
Variant	197.377	1	197.377	250.420	0.000000*
Date of measurement	57.057	4	14.264	18.098	0.000451*
Variety x variant	5.090	2	2.545	3.229	0.093754**
Variety x date of measurement	7.765	8	0.971	1.231	0.387785
Variant x date of measurement	13.961	4	3.490	4.428	0.035193*

Legend: SČ – sum of squares of deviations, PČ – variance, *F* – *F*-test, *p* – level of significance

Table 3. Table of semi-results and results of analysis of variance of double classification – stomatal conductance

	SČ	Degrees of freedom	PČ	*F*	*p*
Variety	0.002540	2	0.001270	9.2927	0.008200*
Variant	0.005333	1	0.005333	39.0244	0.000247*
Date of measurement	0.004900	4	0.001225	8.9634	0.004729*
Variety x variant	0.000607	2	0.000470	3.4390	0.171086
Variety x date of measurement	0.003760	8	0.000470	3.4390	0.049965*
Variant x date of measurement	0.000167	4	0.000042	0.3049	0.866890

Legend: SČ – sum of squares of deviations, PČ – variance, *F* – *F*-test, *p* – level of significance

conductance was found in the variety Stupické and Start F1 as late as on the first day of rehydration when watering was renewed (Table 1). The differences found in the rate of transpiration between irrigated and non-irrigated plants were statistically significant ($F = 3.7571$, $p = 0.081026$, Table 4). The lowest values were taken in the variety Monika on the fifth day of dehydration (0.17 mmol $H_2O.m^{-2}.s^{-1}$) and in the variety Stupické (0.18 mmol $H_2O.m^{-2}.s^{-1}$) and Start F1 (0.23 mmol $H_2O.m^{-2}.s^{-1}$) on the first day of rehydration. As mentioned above zero

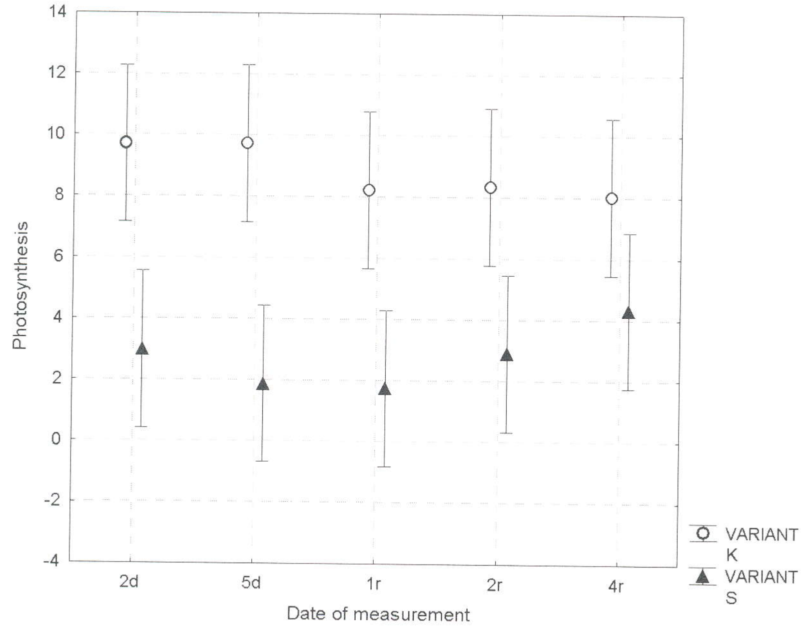

Fig. 1. Average rate of photosynthesis in studied variants in different dates of measurement; *F* (4.8) = 4.428, *p* = 0.035193

Legend: Vertical columns denote 0.95 intervals of reliability, 2d – 2nd day of dehydration, 5d – 5th day of dehydration, 1r – 1st day of rehydration, 2r – 2nd day of rehydration, 5r – 5th day of rehydration

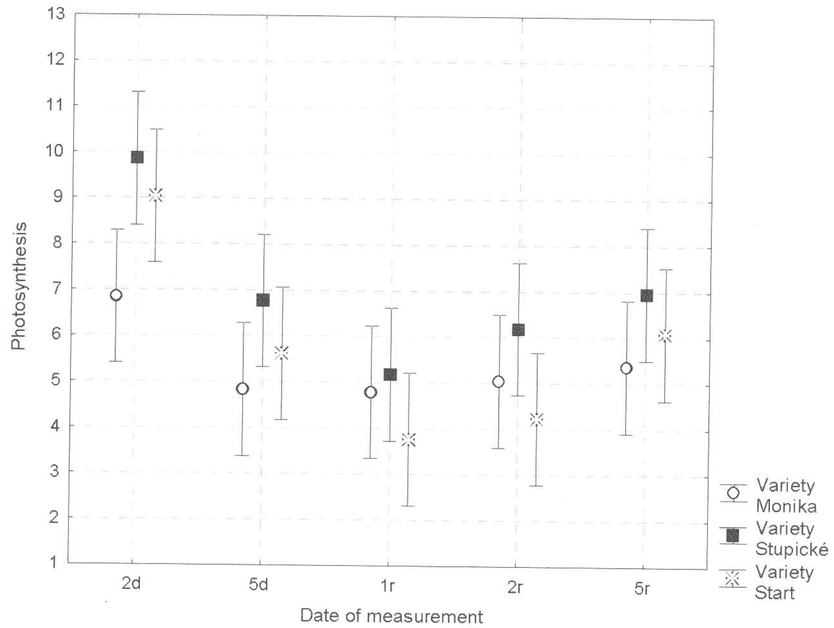

Fig. 2. Average rate of photosynthesis in different studied varieties in different dates of measurement; *F* (8.8) = 1.2314, *p* = 0.38778

Legend: Vertical columns denote 0.95 intervals of reliability, 2d – 2nd day of dehydration, 5d – 5th day of dehydration, 1r – 1st day of rehydration, 2r – 2nd day of rehydration, 5r – 5th day of rehydration

Table 4. Table of semi-results and results of analysis of variance of double classification – transpiration

	SČ	Degrees of freedom	PČ	*F*	*p*
Variety	0.68641	2	0.34320	9.7672	0.007126*
Variant	2.44245	1	2.44245	69.5097	0.000032*
Date of measurement	0.46839	4	0.11710	3.3324	0.069255
Variety x variant	0.19493	2	0.09746	2.7737	0.121600
Variety x date of measurement	0.61189	8	0.07649	2.1767	0.146015
Variant x date of measurement	0.10641	4	2.92660	3.7571	0.081026**

Legend: SČ – sum of squares of deviations, PČ – variance, *F* – *F*-test, *p* – level of significance

stomatal conductance was measured, i.e. it was cuticular transpiration, what prevented the losses of water in non-irrigated plants.

After renewal of watering the rate of photosynthesis was gradually increasing, but despite it, it reached only 51.8% of the rate of photosynthesis of control plants on the last day of measurement. It is evident from comparison of different varieties that on the first day of rehydration the rate of photosynthesis was greater in the variety Monika F1 and it even fell in the varieties Stupické and

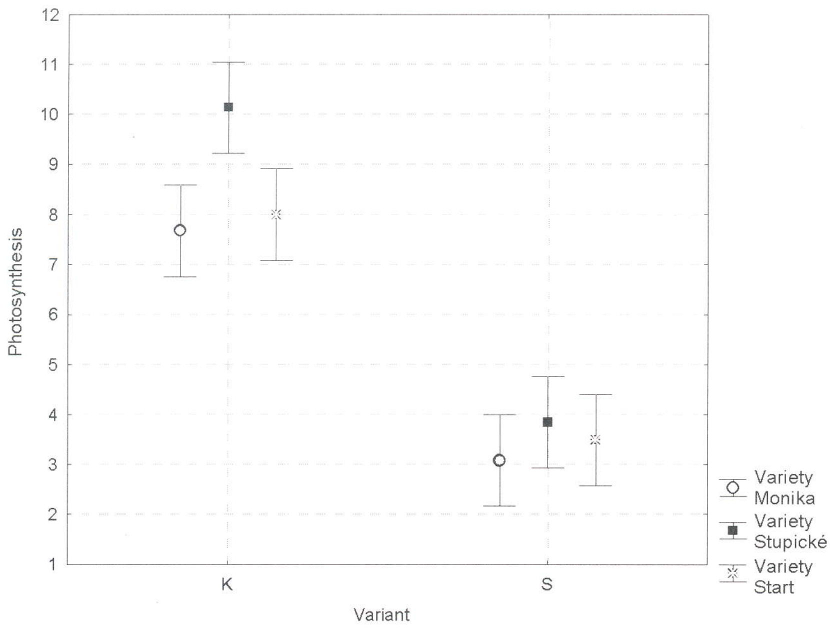

Fig. 3. Average rate of photosynthesis in the studied varieties in the experimental variants; F (2.8) = 3.2287, p = 0.09375

Legend: Vertical columns denote 0.95 intervals of reliability, K – control variant, S – stressed variant

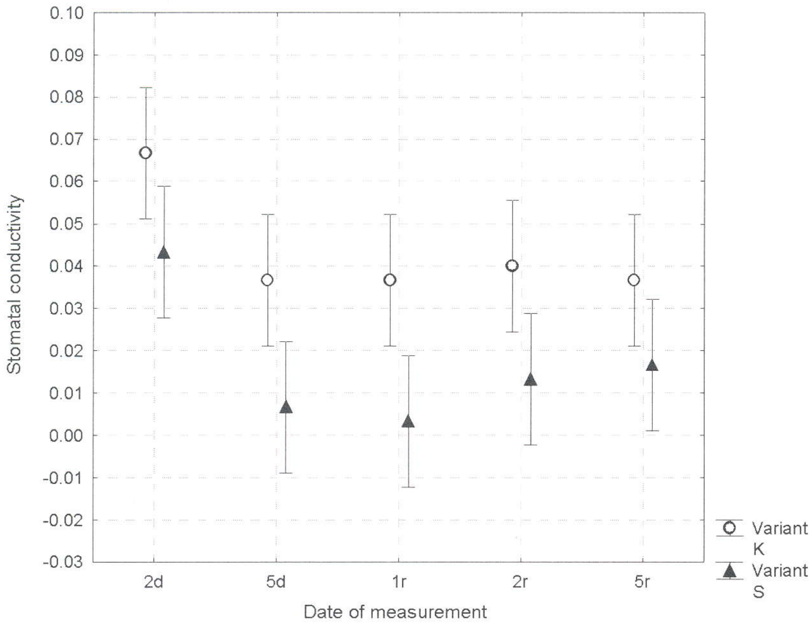

Fig. 4. Average stomatal conductance in studied variants in different dates of measurements; F (4.8) = 0.30488, p = 0.86689

Legend: Vertical columns denote 0.95 intervals of reliability, 2d – 2nd day of dehydration, 5d – 5th day of dehydration, 1r – 1st day of rehydration, 2r – 2nd day of rehydration, 5r – 5th day of rehydration

Start F1 (Table 1). Rahman et al. (1999) reported on the basis of their observations that after renewal of watering physiological processes return to the normal of physiological processes, whereas this regeneration is faster in tolerant varieties to water stress compared with more sensible varieties.

No significant differences in the rate of photosynthesis (F = 1.231, p = 0.387785, Table 2, Fig. 2) were taken in different dates of measurements. When comparing in view of experimental variants significant differences were recorded (level of significance 0.093754) in the rate of photosynthesis among the control plants. The greatest rate of photosynthesis had the variety Stupické polní rané (Table 2, Fig. 3). No significant differences among the varieties of irrigated plants in the rate of photosynthesis were recorded.

Based on the results obtained it can be said that by induction of water deficit non-irrigated tomato plants responded by gradual decrease of stomatal conductance to zero value what is connected with decrease of the rate of photosynthesis and transpiration up to the level of cuticular transpiration. Gradual regeneration of physiological processes appears during the first four days after rehydration but within the trial pre-stress level was achieved in none of the studied parameters. No unambiguous conclusion can be made from the results obtained and partial "indications" in view of the tolerance or sensibility of the studied varieties to water stress.

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HNILIČKOVÁ, H. – DUFFEK J. (Česká zemědělská univerzita, Agronomická fakulta, Praha, Česká republika):

Vliv vodního deficitu a následné regenerace na vybrané fyziologické charakteristiky u rajčat (*Lycopersicum esculentum* Mill.).

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V letech 2000 a 2001 byl v nádobových pokusech studován vliv vodního deficitu a následné regenerace u rajčete (*Lycopersicum esculentum* Mill., odrůdy Monika F1, Stupické polní rané a Start F1) na rychlost fotosyntézy (P_N), rychlost transpirace (E) a stomatální vodivost (g_s). U stresované varianty (S) byla na dobu pěti dnů přerušena závlaha, poté byla opět obnovena. Celkem se uskutečnilo pět měření (2. a 5. den dehydratace a 1., 2. a 4. den rehydratace) pomocí přenosného analyzátoru LCA 4. Vodním deficitem se u rostlin rajčat snížila stomatální vodivost až na nulovou hodnotu a zároveň poklesla rychlost fotosyntézy a transpirace. Nulové stomatální vodivosti bylo dosaženo u odrůdy Monika F1 pátý den dehydratace a u odrůd Stupické a Start F1 až první den rehydratace. Naměřené rozdíly v rychlosti fotosyntézy mezi kontrolními a nezavlažovanými rostlinami byly statisticky průkazné (F = 4,428, p = 0,035193, tab. 2, obr. 1). Druhý den dehydratace byla naměřena rychlost fotosyntézy v průměru na úrovni 65,44 % fotosyntézy kontrolních rostlin. Naměřené hodnoty rychlosti fotosyntézy se pohybovaly v rozmezí 5,78 až 8,20 µmol $CO_2.m^{-2}.s^{-1}$. Poslední den dehydratace (5. den) bylo snížení fotosyntézy v průměru u odrůd Start F1, Monika F1 a Stupické polní rané 20,91 %, přičemž nejnižší rychlost fotosyntézy byla zaznamenána u odrůdy Monika F1 (1,21 µmol $CO_2.m^{-2}.s^{-1}$). Během prvních čtyř dnů po rehydrataci dochází k postupné regeneraci fyziologických procesů, ale v rámci pokusu nebyla dosažena předstresová úroveň ani v jednom sledovaném parametru. Pátý den regenerace dosahovala rychlost fotosyntézy v průměru pouze 51,8 % rychlosti fotosyntézy kontrolních rostlin. Ze získaných výsledků a částečných „náznaků“ nelze jednoznačně učinit závěr z hlediska tolerance či citlivosti sledovaných odrůd k vodnímu stresu.

vodní deficit; rajče; *Lycopersicum esculentum* Mill.; odrůdy; rychlost fotosyntézy; rychlost transpirace; stomatální vodivost

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