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# EFFECTS OF DEFICIT IRRIGATION AND STRAW MULCHING ON GAS EXCHANGE OF CUCUMBER PLANTS (*CUCUMIS SATIVUS* L.)

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## Abstract

HNILIČKA, F., KOUDELA, M., MARTINKOVÁ, J., SVOZILOVÁ, L.: *Effects of deficit irrigation and straw mulching on gas exchange of cucumber plants (Cucumis sativus L.).* Acta univ. agric. et silvic. Mendel. Brun., 2012, LX, No. 3, pp. 43–50

Leaves gas exchange were studied in one cucumber (*Cucumis sativus* L.) cultivar Harriet F1 grown under control conditions (C), deficit irrigation (S) and straw mulch (M), as well as under control or deficit irrigation conditions and straw mulch in combination (CM or SM). Cucumber plants were grown in loose soil, foil tunnel. The photosynthesis rate ($P_N$) and transpiration rate (E) were measured in the leaves in situ using the portable gas exchange system *LCpro+*. It follows from the results obtained that water deficit ($P_N$ was 11.88 μmol $CO_2.m^{-2}.s^{-1}$ and E was 1.83 mmol $H_2O.m^{-2}.s^{-1}$) provably decreases the gas exchange rate in cucumber plants in comparison with the irrigated control group (average value of $P_N$ - 15.03 μmol $CO_2.m^{-2}.s^{-1}$ and E – 2.16 mmol $H_2O.m^{-2}.s^{-1}$). The application of mulch in the control and stresses plants statistically insignificantly reduced the photosynthesis rates –14.91 μmol $CO_2.m^{-2}.s^{-1}$ and 11.86 μmol $CO_2.m^{-2}.s^{-1}$, respectively. However, after the application of the mulch to the plants growing in the variant of deficit irrigation and control conditions with mulch, the transpiration rate increased. The rate of transpiration (E) by plants from control and deficit irrigation with mulch was 2.28 mmol $H_2O.m^{-2}.s^{-1}$ and 2.24 mmol $H_2O.m^{-2}.s^{-1}$, respectively. Photosynthesis and transpiration rate is also influenced by stomatal conductance ($g_s$). The obtained values of the coefficient of determination ($r^2$) is evident no stomatal inhibition of gas exchange for variants C ($r^2$ = 0.1404 – $P_N$; 0.2352 – E) and CM ($r^2$ = 0.2656 – $P_N$; 0.2483 – E). No stomatal inhibition of photosynthesis was observed in SM variant ($r^2$ = 0.2867), too. However, stomatal inhibition of photosynthesis and transpiration rate was based on the coefficient of determination found in plants with limited irrigation ($P_N$ – $r^2$ = 0.5222 and E – $r^2$ = 0.7191) and in SM variant ($r^2$ = 0.8972).

cucumber, *Cucumis sativus* L., photosynthesis rate, transpiration rate, mulch, irrigation

Drought is one of the most serious global problems. 61% of areas in the world have precipitation below 500 mm (Deng *et al.*, 2005). Drought, or respectively lack of soil moisture, may manifest itself by reducing the crop yield by up to 60%, as reported by Ebadi *et al.* (2007). The most frequent factor limiting the growing of field crops is the uneven distribution of precipitation during their vegetation and subsequent drought because the works by Várallyay (2008) suggest possible changes of climate in Central Europe.

The current changes in weather bring with them a evident fluctuation in temperatures and also a relatively irregular and random distribution of precipitation during the vegetation period of field crops. Therefore a study of plants' adaptation to a water deficit is ever more topical, as the water deficit leads to a fall in the uptake of nutrients, a restriction on photosynthesis, dry matter formation, the amount and quality of the yield (Hnilička *et al.*, 2007).

In response to water deficit, stomata tend to close reducing leaf conductance that ultimately affects leaf photosynthesis (Faver *et al.*, 1996). Under water stress or temperature stress, overall dry matter accumulation in tomato plants (Hniličková *et al.*,

2002) is decreased; expansion of leaf blades and plant growth is reduced, thereby promoting stunted growth (Gerik *et al.*, 1996).

The cucumber is crops, which it requires more water than grain crops (Li and Wang, 2000). Mao *et al.* (2003) found that fresh fruit yields of cucumber were highly affected by the total volume of irrigation regimes were those that had water deficiencies during fruiting stages. Variation in soil moisture in the root zone from beginning to end of growing season will be small under trickle irrigation due to the small volume of wetted soil (Kamal *et al.*, 2009).

Cucumber (*Cucumis sativus* L.) is one of the most popular vegetables cultivated in world. According Buchtová (2011) grown cucumbers in the total area of 367 ha, of which 99 ha of cucumbers and gherkins 268 ha in 2011 in the Czech Republic. The average yield per hectare of gherkins in 2010 was 14.58 t and cucumber 21.48 t.

This study aims of the experiment was to asses to determine:

a) the effect of irrigation and straw mulching on the gas exchange of cucumber;
b) the changes of gas exchange in the cucumber ontogeny phase.

## MATERIAL AND METHODS

The experiment was conducted in 2010 and 2011 in Prague 7 - Troja at the Faculty of Agrobiology, Food and Natural Resources of Czech University of Life Sciences Prague. The evaluation was conducted in four replications, at two different irrigation levels and under the straw mulch treatment. As a model plant was selected cucumber *Cucumis sativus* L. 'Harriet F1'. In 2010, cucumber was sown on May 13$^{th}$, but seeds of cucumber not sprouted. The second sowing was on June 6$^{th}$. In 2011, cucumber was sown on May 18$^{th}$.

Cucumber plants were grown in loose soil, foil tunel. Cultivation spacing of plants were 1.5 × 0.2 m. The cucumber plants grown under control conditions (C), deficit irrigation (S) and straw mulch (M), as well as under control or deficit irrigation conditions and straw mulch in combination (CM or SM). Drip irrigation was in the control variant was a limit value of 70% of EWC (efficient water capacity), deficit irrigation in 50% of EWC. Soil moisture was monitored using soil moisture sensors Virrib (Amet, Velké Bílovice, Czech Reublic). Once the value of soil moisture fell below the limit value, there is a solenoid valve opening and irrigation was started. The mulch was applied to a height of 80 mm.

The photosynthesis rate ($P_N$) and transpiration rate (E) were measured in the leaves *in situ* using the portable gas exchange system *LCpro+* (*ADC BioScientific Ltd.*, Hoddesdon, Great Britain) by Holá *et al.*, 2010. The physiological characteristics were measured at weekly intervals. The first measurement was on July 15$^{th}$ a last measurement was on September 2$^{nd}$.

All data were statistically evaluated by two-way analysis of variance (ANOVA) with treatment. The statistical significance of the differences between treatments was tested using LSD (least significant difference) test with 0.05 probability level as the significant one.

## RESULTS AND DISCUSSION

The photosynthesis rate in the cucumber plants was changing depending on the ontogenetic development of the plant, as shown in Figs. 1 and 2. Iqbal and Wright (1998) mention changes in the photosynthesis rate during ontogenetic development depending on the stress by draught in the *Phalaris minor*.

The Fig. 1 shows the gradual increase of the photosynthesis rate in all the monitored experimental groups until the 19$^{th}$ of August 2010 by all trials of experiment in the year 2010.

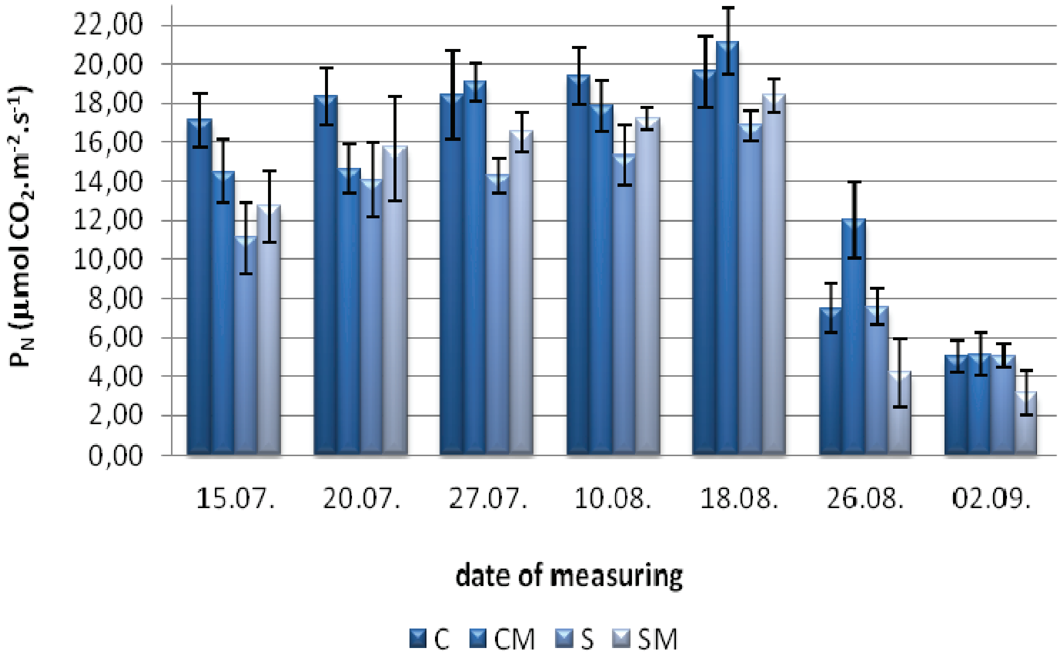
After achieving the maximum rate of photosynthesis was recorded its gradual reduction. Photosynthesis decreases due to senescence of leaves and downy mildew of cucumber. At the beginning of the period of measurement (July 15$^{th}$), the rate of photosynthesis was in the range of values from 11.07 µmol $CO_2.m^{-2}.s^{-1}$ (S) to 17.07 µmol $CO_2.m^{-2}.s^{-1}$ (C). At the time of its maximum value of the measured values of photosynthesis rate in the range of values from 16.84 µmol $CO_2.m^{-2}.s^{-1}$ (S) to 21.15 µmol $CO_2.m^{-2}.s^{-1}$ (CM). The most significant increase in photosynthetic rate of 6.67 µmol $CO_2.m^{-2}.s^{-1}$ was observed in plants by control conditions with mulch and in plants with deficit of irrigation (5.77 µmol $CO_2.m^{-2}.s^{-1}$).

The linear decrease of photosynthesis rate was identified in plants of variant CM from 21,16 µmol $CO_2.m^{-2}.s^{-1}$ (August 18$^{th}$) to 5,14 µmol $CO_2.m^{-2}.s^{-1}$ (September 2$^{nd}$). These plants were affected by downy mildew of cucumber. Vice-versa gradual decline was observed in plants of variant deficit of irrigation (S).

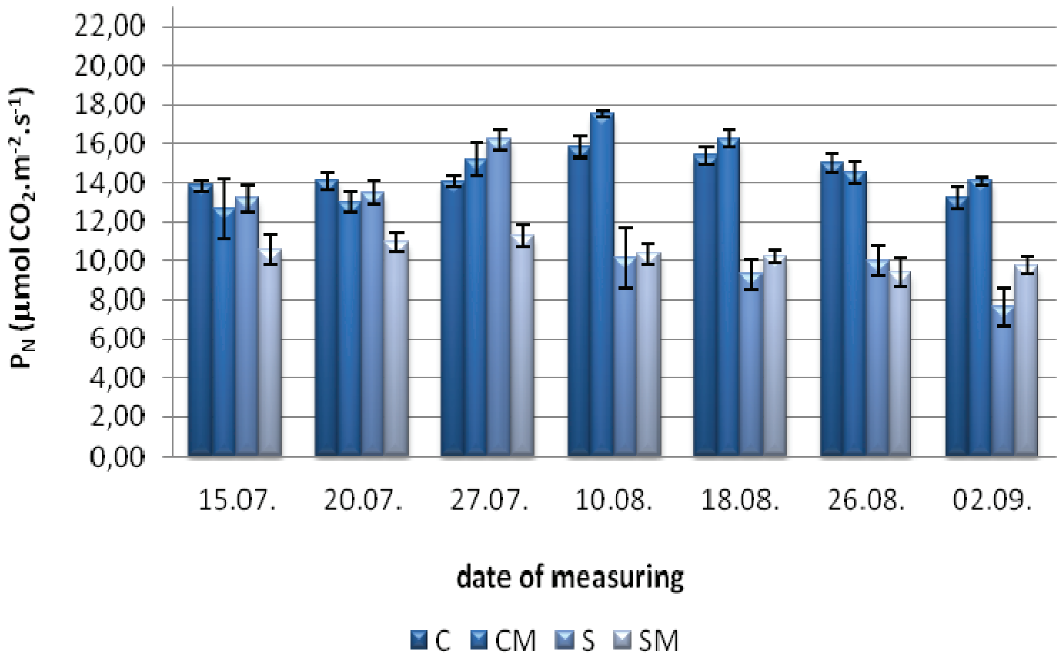
The lowest photosynthesis rate was identified in the deficit irrigation with mulch plants (SM) at the beginning of measurement in the year 2011, at this time it reached 10.57 µmol $CO_2.m^{-2}.s^{-1}$. Conversely, the highest photosynthesis rate was found in the plants at control conditions 13.86 µmol $CO_2.m^{-2}.s^{-1}$, see Fig. 2.

A similar trend in the rate of photosynthesis was identified in the control plants and control plants with mulch. The maximum of photosynthesis was measured on 10$^{th}$ of August 2011, when the control plants were values of photosynthesis 15.82 µmol $CO_2.m^{-2}.s^{-1}$ (C) and 17.49 µmol $CO_2.m^{-2}.s^{-1}$ (CM). A similar trend was observed in plants with limited irrigation.

The maximum of photosynthetic rate in these plants was measured in the 3$^{rd}$ term measurements (July 27$^{th}$). The rate of photosynthesis was in deficit irrigation plants of 16.18 µmol $CO_2.m^{-2}.s^{-1}$ and 11.28 µmol $CO_2.m^{-2}.s^{-1}$ in plants SM, see Fig. 2.




1: *The changes of photosynthesis rate (PN) – µmol $CO_2.m^{-2}.s^{-1}$ – in dependencies on ontogenetic development of plants and variants of trial in the year 2010*




2: *The changes of photosynthesis rate (PN) – µmol $CO_2.m^{-2}.s^{-1}$ – in dependencies on ontogenetic development of plants and variants of trial in the year 2011*

The very significantly reduced of photosynthesis rate was identified in the stresed plants at the end measurement – 7.65 µmol $CO_2.m^{-2}.s^{-1}$. Conversely, the gradual decline was determined in plants by variant SM, when the rate of photosynthesis decreased from 11.28 µmol $CO_2.m^{-2}.s^{-1}$ to 9.74 µmol $CO_2.m^{-2}.s^{-1}$.

It follows from the results of the statistical analysis, which is shown in Tab. I, that the plants under controlled conditions achieved the statistically provable highest rate of photosynthesis (15.04 µmol $CO_2.m^{-2}.s^{-1}$) and, conversely, the plants growing in the conditions with deficit irrigation achieved the lowest photosynthesis rate (11.88 µmol $CO_2.m^{-2}.s^{-1}$).

I: *Effect of different conditions on the examined physiological characteristics. Data are presented as mean ± standard deviation, n = 70*

| Variant | Photosynthesis rate ($\mu mol\ H_2O.m^{-2}.s^{-1}$) | Transpiration rate ($mmol\ H_2O.m^{-2}.s^{-1}$) | Stomatal conductance ($mmol.m^{-2}.s^{-1}$) |
|---|---|---|---|
| control (C) | $15.03 \pm 5.27^{b}$ | $2.16 \pm 1.09^{b}$ | $0.88 \pm 1.89^{c}$ |
| deficit irrigation (S) | $11.88 \pm 4.33^{a}$ | $1.83 \pm 0.63^{a}$ | $0.31 \pm 0.40^{a}$ |
| deficit irrigation + mulch (SM) | $11.86 \pm 5.70^{a}$ | $2.24 \pm 1.14^{b}$ | $0.39 \pm 0.48^{a,b}$ |
| control + mulch (CM) | $14.91 \pm 5.80^{b}$ | $2.28 \pm 1.01^{b}$ | $0.44 \pm 0.55^{b}$ |

*a, b, c – denoted differences are statistically significant on the level of significance α = 0.05*

The decrease of the photosynthesis rate resulting from a longer-time water deficit is confirmed by the works of Xu *et al.* (2007). According to Waraich *et al.* (2011), a limited water supply inhibits the photosynthesis of plants, causes changes of chlorophyll contents and components and damage to photosynthetic apparatus.

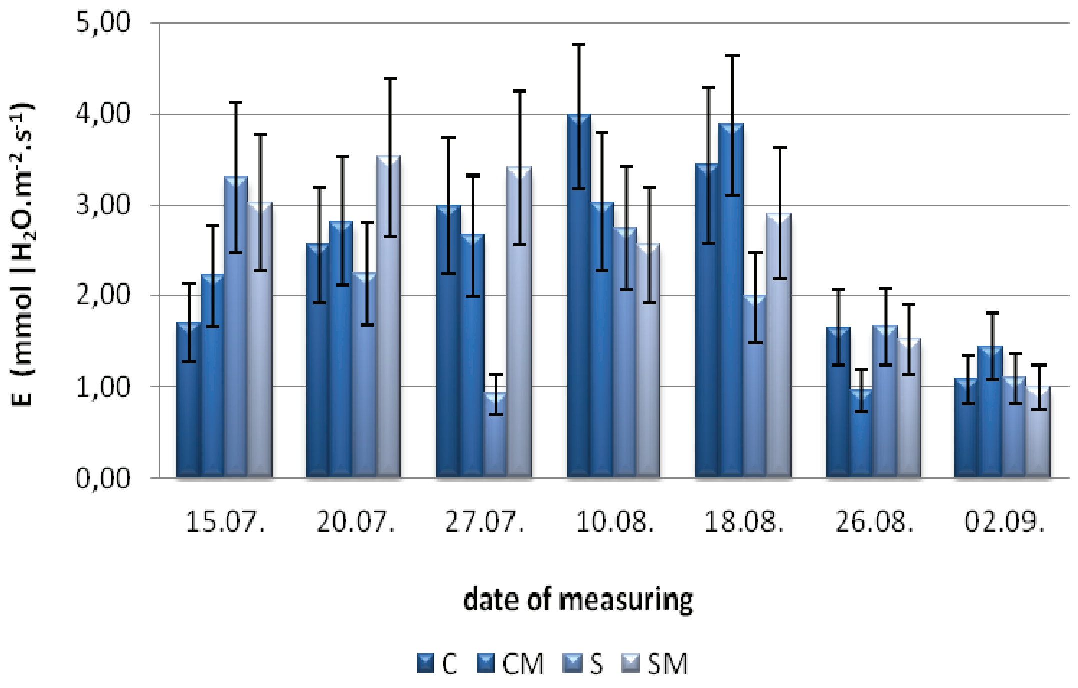
The rate of photosynthesis was statistically lower inconclusively in plants grown in variant with mulch. According to Bonds and Montague (2006), mulch also influenced gas exchange and growth of red oak (*Quercus shumardii* Buckli.) trees. This conclusion was confirmed in cucumber plants.

Another measured characteristic of gas exchange was the transpiration rate because a plant uses transpiration (E) to receive water but it also cools itself and cools its surroundings.

If there is lack of water in the nutritional material, i.e. in the soil, then the water potential and its components gradually change and this results in gradual closing of stomata. This trend is shown in Tab. I, which indicates that similarly like with the rate of assimilation of $CO_2$, the transpiration was different in the various groups used in the experiment; this follows from the results of the statistical analysis of the Tukey's HSD test. The said analysis shows a decrease of the transpiration rates in the deficit irrigation group (S) where the average level of transpiration rate (E) was 1.83 mmol $H_2O.m^{-2}.s^{-1}$ in these plants, while in the plants under the control conditions, the average level of E was 2.16 mmol $H_2O.m^{-2}.s^{-1}$. The decrease of the levels of transpiration in the plants growing in the conditions with deficit irrigation in comparison with the plants cultivated in the control groups, which were irrigated, is 15.28%.

It also follows from Tab. I that after the application of mulch to the plants growing in the deficit of irrigation and control plants, provable increase of transpiration by 21.31% and 5.55% (0.39 mmol $H_2O.m^{-2}.s^{-1}$ and 0.12 mmol $H_2O.m^{-2}.s^{-1}$) was identified in comparison with the untreated group.

The transpiration rate is limited not only by the experimental group but also by the ontogenetic development of cucumber plants, as documented




3: *The changes of transpiration rate (E) – mmol $H_2O.m^{-2}.s^{-1}$ – in dependencies on ontogenetic development of plants and variants of trial in the year 2010* by Figs. 3 and 4. The decrease of the transpiration rate in the plants growing in the conditions with deficit of irrigation, in comparison with the plants from the control group, during their ontogenetic development is also confirmed, for example, by the works of Ahmadi and Siosemardech (2005).

In both groups of plants from the control group, a increase of the transpiration rate was identified between the first time of measurement (1.70 mmol $H_2O.m^{-2}.s^{-1}$ – C and 2.21 mmol $H_2O.\ m^{-2}.\ s^{-1}$ – CM) and the 4th time of measurement for variant C (3.98 mmol $H_2O.m^{-2}.\ s^{-1}$) and the 5th time for variant CM (3.88 mmol $H_2O.m^{-2}.s^{-1}$) in the year 2010. After that the rate of transpiration decreases until the end of the experiment. Transpiration rate of control plants was lowest at the end of the experiment – 1.08 mmol $H_2O.m^{-2}.s^{-1}$, whereas in plants by control conditions and grown on the mulch transpiration increased by 0.49 mmol $H_2O.m^{-2}.s^{-1}$ to 1.44 mmol $H_2O.m^{-2}.s^{-1}$ at the end of the experiment compared with the previous measurement date, see Fig. 3.

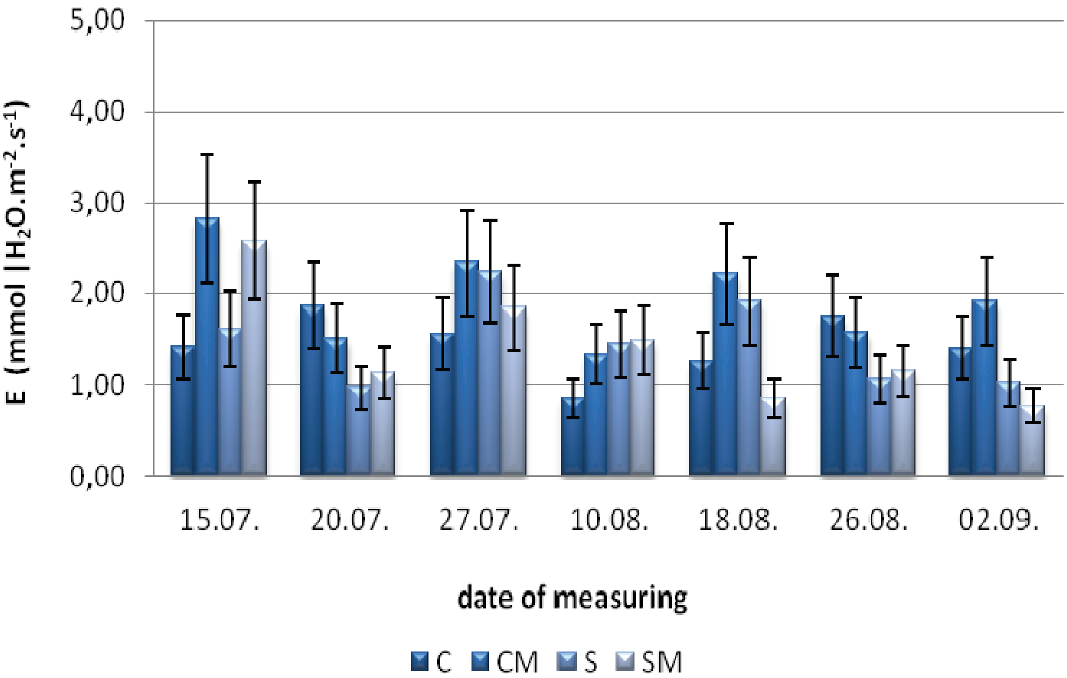
From Fig. 3 also shows that the rate of transpiration of plants growing in the conditions with deficit irrigation are at first almost linearly decreases from the value of 3.30 mmol $H_2O.m^{-2}.s^{-1}$ (July 15th) to 0.91 mmol $H_2O.m^{-2}.s^{-1}$ (July 27th). Then there is a significant increase of transpiration rate (2.74 mmol $H_2O.m^{-2}.s^{-1}$), which is relieved by the gradual reduction of transpiration rate to the value of 1.09 mmol $H_2O.m^{-2}.s^{-1}$.

In contrast, in plants grown in the deficit of irrigation with mulch at the rate of transpiration first inconclusively increased by 0.49 mmol $H_2O.m^{-2}.\ s^{-1}$ to the value of 3.52 mmol $H_2O.m^{-2}.s^{-1}$ (July 20th). This increase is succeeded by a gradual reduction in transpiration until to 5th term measurement of 2.90 mmol $H_2O.m^{-2}.s^{-1}$. Transpiration rate declined in these variants the end of the experiment, too.

The changes of transpiration rate in cucumber plants in 2011 are recorded in the Fig. 4. The lowest transpiration rate was identified in the stresses plants at the beginning of measurement (July 20th) – 0.96 mmol $H_2O.m^{-2}.s^{-1}$. Conversely, the highest transpiration rate was measured in control plants with straw mulch (CM) at the beginning of measurement, too – 2.82 mmol $H_2O.m^{-2}.s^{-1}$, see Fig. 4.

The application of mulch on the soil surface reduces evaporation from the soil and thus leads to better water supply of plants and also to increase of transpiration rate. The most significant increase transpiration rate was between plants control conditions – C and CM. The average value of transpiration rate in plants by variant CM was 1.96 mmol $H_2O.m^{-2}.\ s^{-1}$ and in control plant of 1.44 mmol $H_2O.m^{-2}.s^{-1}$. The transpiration rate increased in plants growing in the conditions with deficit of irrigation as well. Transpiration rate was higher in plants growing in the variant of trial deficit irrigation with mulch – 1.47 mmol $H_2O.m^{-2}.s^{-1}$, but transpiration rate in plants growing in the deficit of irrigation was 1.40 mmol $H_2O.m^{-2}.s^{-1}$.

It follows from the results of the statistical analysis (Tab. I), that the plants under controlled conditions achieved the statistically provable highest $g_s$ (0.88 mmol. $m^{-2}.\ s^{-1}$) and, conversely, the




4: *The changes of transpiration rate (E) – mmol $H_2O.m^{-2}.s^{-1}$ – in dependencies on ontogenetic development of plants and variants of trial in the year 2011* plants grown in the conditions of deficit irrigation achieved the lowest $g_s$ (0.31 mmol. $m^{-2}.s^{-1}$). The difference between the untreated experimental groups was 21.01% in disfavour of the deficit irrigation group. The stomatal conductance was statistically higher inconclusively in plants grown by variant with mulch and deficit irrigation. The statistically significant decline in $g_s$ was observed between control and control with mulch.

Photosynthesis and transpiration rate is also influenced by stomatal conductance ($g_s$). The obtained values of the coefficient of determination ($r^2$) is evident no stomatal inhibition of gas exchange for variants C and CM. The coefficient of determination for these variants was $r^2$ = 0.1404 and 0.2352 ($P_N$; E) and $r^2$ = 0.2656 and 0.2483 ($P_N$; E), respectively. The calculated regression equations are: $P_N$ (C) = 15.429 – 3.617.$g_s$; E (C) = 0.980 + 1.809.$g_s$; $P_N$ (CM) = 16.701 – 5.436.$g_s$; E (CM) = 1.498 + 1.285.$g_s$.

No stomatal inhibition of photosynthesis was observed in SM variant ($r^2$ = 0.2867). Calculated regression equation for photosynthesis is:

$$P_N (SM) = 9.218 + 6.640.g_s.$$

Stomatal inhibition of photosynthesis and transpiration was based on the coefficient of determination $r^2$ = 0.5222 and $r^2$ = 0.7191 found in plants with limited irrigation (S). In this case, the regression equation had the following form: PN (S) = 7,873 + 20,173.$g_s$ and E (S) = 0.772 + 3.962.$g_s$. Stomatal transpiration inhibition was observed in SM variant ($r^2$ = 0.8972) – E (S) = 0.130 + 8.565.$g_s$, too.

## CONCLUSION

It follows from the results obtained that water deficit provably decreases the gas exchange rate in cucumber plants in comparison with the irrigated control group. The application of mulch in the control and stressed plants reduced the photosynthesis rates. As opposed to that, after the application of the mulch to the plants grown in the deficit of irrigation, the transpiration rate increased. The application of mulch in the control and stresses plants reduced the photosynthesis rates. As opposed to that, after the application of the mulch to the plants growing in the conditions with deficit of irrigation, the transpiration rate increased. It follows from the above that the application of mulch increases the transpiration rate in the monitored plants and but causes to a better use of water from the soil, because cucumber has a sparse root system, approximately 85% of the root length is concentrated in the upper 0.3 m top of soil layer.

Based on the results it can be stated identically with the works by Carranca (2006); Ferus *et al.* (2009) that cultivation technologies of many vegetable crops (sweet pepper, tomato, cucumber, watermelon, etc.) include application of artificial cover mulches. Besides the positive effect on biomass/fruit production (Diaz-Perez and Batal, 2002), they also improve fruit quality (Farias-Larios and Orozco-Santos, 1997), and regulate pest development (Diaz-Perez *et al.*, 2007). However, in conditions of climate changes and global warming, drought protective properties emerge, as well (Xie *et al.*, 2005).

## SUMMARY

As a model plant was selected cucumber *Cucumis sativus* L. 'Harriet F1'. Cucumber plants were grown in loose soil, foil tunnel. The cucumber plants grown under control conditions (C), deficit irrigation (S) and straw mulch (M), as well as under control or deficit irrigation conditions and straw mulch in combination (CM or SM). The photosynthesis rate ($P_N$) and transpiration rate (E) were measured in the leaves *in situ* using the portable gas exchange system *LCpro+*. The physiological characteristics were measured at weekly intervals. The first measurement was on July 15th and the last measurement was on September 2nd. It follows from the results obtained that water deficit provably decreases the transpiration rate (average value of $P_N$ and E was 11.88 µmol $CO_2.m^{-2}.s^{-1}$ and 1.83 mmol $H_2O.m^{-2}.s^{-1}$) in cucumber plants in comparison with the irrigated control group ($P_N$ - 15.03 µmol $CO_2.m^{-2}. s^{-1}$; E – 2.16 mmol $H_2O.m^{-2}.s^{-1}$). The application of mulch in the control and stressed plants no statistically reduced the photosynthesis rates (14.91 µmol $CO_2.m^{-2}.s^{-1}$ and 11.86 µmol $CO_2.m^{-2}.s^{-1}$, respectively). However, after the application of the mulch to the plants grown in the control variant (2.28 mmol $H_2O.m^{-2}.s^{-1}$) and variant of deficit irrigation (2.24 mmol $H_2O.m^{-2}.s^{-1}$), the transpiration rate increased.

Photosynthesis and transpiration rate is also influenced by stomatal conductance ($g_s$). The obtained values of the coefficient of determination ($r^2$) is evident no stomatal inhibition of gas exchange for variants C ($r^2$ = 0.1404 – $P_N$; 0.2352 – E) and CM ($r^2$ = 0.2656 – $P_N$; 0.2483 – E). No stomatal inhibition of photosynthesis was observed in SM variant ($r^2$ = 0.2867), too. However, stomatal inhibition of photosynthesis and transpiration rate was based on the coefficient of determination found in plants with limited irrigation ($P_N$ – $r^2$ = 0.5222 and E – $r^2$ = 0.7191) and in SM variant ($r^2$ = 0.8972).

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