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ЗАПАЗВАНЕ НА ВЛАЖНОСТТА НА ПОЧВАТА ПОД МУЛЧ ПРИ ОТГЛЕЖДАНЕ НА ДИНИ ПРИ ЗАСУШАВАНЕ
WATER SAVING ABILITY OF ARTIFICIAL COVER MULCHES IS MOST IMPORTANT FOR WATERMELON SHOOT GROWTH UNDER DROUGHT

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Резюме

Много разработки се занимават с идентификацията на решаващия фактор, който определя вегетативното нарастване и добива от мулчирани градински култури.

Засега нямаме никакви познания за измененията, които настъпват под влияние на засушаването. Целта на нашето изследване беше да потърсим отговор на този въпрос. Установихме, че има релативно силна отрицателна корелация между кумулативната дължина на стъблата “kdv” при динята и температурата на почвата в зоната на кореновата система на дълбочина 10 см в условия на достатъчен запас от вода в почвата. По време на дехидратацията този параметър се променя положително по отношение на относителното съдържание на вода в най-младия, напълно развит лист на главното стъбло. В началото на цикъла на дехидратацията отчитахме най-голямо “kdv” на растенията при бялото полиетиленово мулчиращо фолио, докато по време на дехидратацията при червеното полиетиленово и черното текстилно фолио тези резултати изследвахме в контекста на защита на растенията при стрес от висока температура и воден стрес.

Abstract

Many works point to identification of the principal environmental factor determining the vegetative growth and yield in horticultural crops mulched by cover materials. However, almost nothing is known about changes in this area caused by drought. Answering this question was the predominant aim of our work. We found that the relatively strong negative correlation between the cummulative shoot length (CSL) of watermelon plants (*Citrullus lanatus* (Thunb.) Matsum. & Nakai) and the root-zone temperature in 5 cm depth (T_{RZ5}) which was exhibited under sufficient water supply, switched to a positive dependency on the relative water content (RWC) in the youngest expanded leaf of the main shoot when under dehydration. At the beginning of the dehydration cycle the highest CSL values were exhibited by plants on white polyethylene (PE) mulch, whereas water witholding favoured red PE foil and black non-woven textile. These results are discussed in respect to plant protection against heat stress on the one hand, and, on the other hand, against water stress.

Ключови думи: диня, изкуствен покривен мулч, суша, засушаване, фотосинтетични пигменти, воден режим.
Key words: watermelon, artificial cover mulch, drought, shoot growth, photosynthetic pigments, water regime.

INTRODUCTION

In cultivation practise of many vegetable crops (sweet pepper, tomato, cucumber, watermelon, etc.) artificial cover mulches are widely applied (Carranca, 2006). Reasons for their extended use comprises ability to grow orchard plants in cooler stands (Karhu et al., 2007), getting higher yields (Diaz-Perez and Batal, 2002), improvement of fruit quality (Farias-Larios and Orozco-Santos, 1997) and cleaness (Kasperbauer and Hunt, 1998), and regulation of disease, pest and weed dynamics (Diaz-Perez et al., 2007; Fortnum et al., 2000; Webster, 2005). However, only a few works were dedicated to their characteristics in respect to plant/land water flux. More experience in this area has Kirnakr's group recently publishing papers on productivity in black-foil mulched bell pepper (*Capsicum annuum* L.) and cucumber (*Cucumis sativus* L.) under water stress (Kirnak et al., 2003; Kaya et al., 2005).

Despite of experiments focused on identification of the most proper material/colour for mulching respective crops or in distinct environment, a large effort has been exerted to explain how cover mulching functions, what is the principal factor or combination of factors determinig vegetative growth, yield and its quality. More papers refered the root zone temperature (RZT) as the most important trait for plant production on cover mulches (Ibarra-Jimenez et al., 2008; Saleh et al., 2003; Diaz-Perez and Batal, 2002). However, participation of altered light conditions in growth and production regulation may not be excluded. To enhance red light (R) reflection and increse far-red (FR) to red light ratio (FR/R), altering phytochrome-mediated regulation of photosynthate allocation, for tomato yield improvement, soil was covered by red plastic film or red over black plastic film. Early crop yield advantage of red mulch was evident whether it was placed directly over soil or over a layer of black plastic (Kasperbauer and Hunt, 1998). Thus, tuning of the red light wavelenght reflected from the mulch surface can markedly influence production outputs (Orzolek and Otjen, 2005). White plastic mulching is widely used in heated glasshouses to increase available light during periods of low radiation and thus improve plant growth. However, the reflection of solar radiation by this mulch reduced the mean substrate and air temperatures by up to 3 °C and 1,5 °C, respectively, during the early stages of canopy development. But when substrate and air temperatures were suboptimal, small temperature differences can be detrimental to crop growth and yield (Lorenzo et al., 2005).

On the other hand, very little is known how changes the role of these environmental factors in growth determination under proceeding water limitation. To clarify effects of different cover mulches on root zone temperature, water relations, photosynthetic pigmentation and shoot growth of watermelon plants under dehydration and find the most proper mulching material, as well as get answer this question, we realized a pot experiment.

MATERIAL AND METHODS

Plant material, cultivation and treatment

Watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai) seedlings of Paladin F1 hybride (Sakata Seed corp., Japan) with 4 right leaves were prepared in June 2008 under external conditions using substrate AB Extra for Vegetables (Agro CS a.s., Czech Republic). Thereafter they were transplanted into 5 litres-plastic pots with Potgrond H substrate (Klasmann-Deilmann GmbH, Germany) covered by 50 мм thick red (Maxithen HP 431641) or white (Maxithen HP 15101) coloured polyethylene film Bralen RA 2-63 (Plastika a.s., Slovakia), or by black non-woven textile (Milmar s.r.o., Czech Republic). To establish homogenous light conditions for whole above-ground plant part, the same material was layed under the pots (under non-covered control pots transparent plastic film was applied). During vegetation, water supply and pest management were ensured.

Measurements of physiological and growth parameters

After 20 days of growth, water was witheld to watermelon plants. At the begining and the end of dehydration sequence (when sustained wilting was observed, after 8 days) at 2 p.m. these physiological and growth parameters were determined:

- relative water content (RWC) of the youngest expanded leaf in main stem according to formula:

$$RWC = ((w_{act} - w_{dw}) / (w_{sat} - w_{dw})) . 100 \quad (\%)$$

where w_{act} – actual sample weight (g), w_{sat} – sample weight in water saturated state (g), and w_{dw} – sample dry weight (g).

- photosynthetic pigment concentration of this leaf following method of Sestak and Catsky (1966).

Leaf segments of known area were homogenized using mortar and pestle in the presence of sea sand, $MgCO_3$ and 100% acetone. After its evaporation, powder was quantitatively transferred into 80% acetone and filtered using vacuum pump. Then filtrate absorbance at wavelenghts 470, 647, 663 and 750 nm (Spekol 221, Zeiss, Germany) was measured. Photosynthetic pigments concentration was calculated according Lichtenthaler (1987):

$$chl.\ a = (12,25 . A_{663} - 2,79 . A_{647}) . T \quad (mg.l^{-1})$$

$$chl.\ b = (21,5 . A_{647} - 5,1 . A_{663}) . T \quad (mg.l^{-1})$$

$$carothenoids = ((1000 . A_{470} - (1,82 . chl.\ a + 85,02\ chl.\ b)) / 198) . T \quad (mg.l^{-1})$$

where A is filtrate absorbance at distinct wavelenght (A_{750} – cataract absorbance correction subtracted from absorbances), T – cuvette thickness (cm).

Transfer from volume to area units:

$$Y = (V / 1000 . A) . X \quad (mg.m^{-2})$$

where Y – pigment concentration ($mg.m^{-2}$), V – filtrate volume (ml), A – area of leaf segments (m^2), X - pigment concentration ($mg.l^{-1}$).

- cummulative shoot lenght (CSL) (sum of main shoot and branches lenghts), enabling calculation of CSL difference.

Meteorological data recording

During the experiment dynamics of maximal daily air temperature (T_{Amax}), precipitation (P), as well as root-zone temperature in the depth of 5 cm (T_{RZ5}) at 1 p.m. were recorded.

Statistical analysis

Obtained data were submitted to analysis of variance (ANOVA) using application Statgraphics Plus v. 4.0 and MS Excel. LSD tests on confidence level 99% were performed to relative water content, photosynthetic pigments concentration cummulative shoot lenght and CSL difference. Between these parameters as well as rhizosphere temperature linear regressions were drawn and coefficient of determination (R^2) calculated.

RESULTS

Weather characteristics (Figure 1) recorded during experimental period (from June the 6th to July the 3rd) point to changing atmospheric growth conditions. Values of daily global radiation (GR) as well as precipitation fluctuated most extemely. Days with GR round 8 kWh.m^{-2} can be taken as clear or relatively clear. This was the case of seven day lasting sequence right before starting dehydration, as well. However, on the last day came a huge rain scud (38,8 mm). Short dehydration period was characteristic by relatively clean sky but more times interrupted by cloudy days with small rain scuds. These two factors markedly infuenced the temperature parameters. Maximal daily air temperature (T_{Amax}) showed marked fluctuation in the first part of the cultivation period (from 20 to 28 °C) continuing with gradual increase to 31,5 °C. Just before water was witheld to plants a small T_{max} lowering was observed. Starting dehydration cycle, T_{Amax} fell down to 24 °C interrupted by short-term temperature increase, and then it stayed on the level of 28 °C till the end of experiment. At the beginning of dehydration, root-zone temperature 5 cm under the substrate surface (T_{RZ5}) was on the same level in mulched plants (Table 1). Non-mulched control plants exhibited round one degree centigrade higher value. Stopped watering enlarged treatment differences in this parameter. They could be ranked in near half a degree increment manner: control, black non-woven textile, white and red foil.

Before dehydration cycle, relative water content (RWC) of the youngest expanded leaf in the main stem showed similar values (about 90%) for every treatment (Figure 2). However, application of different mulch material resulted in distinct extent of water loss under dehydration. Plants mulched by black non-woven textile and red foil exhibited RWC of round 82 and 84%, respectively, whereas in those with no mulch values fell to 73%. There was a significant reduction in RWC decrease provided by the former mulch materials.

The highest chlorophyll *a* and *b* concentrations (approximately 365 and 145 mg.m^{-2}, respectively) at the beginning of the dehydration period were reached by control plants as well as plants mulched by white foil (Figure 3). With increasing mulch colour intensity (from red to black), a gradual pigments loss was observed, significant only in plants mulched by black non-woven textile (near 20 and 22%, respectively). Concentration of total carothenoids (Figure 3C) was not influenced by mulching material under sufficient water supply (approximately 100 mg.m^{-2}). However, under pronounced dehydration, it fell down in significantly larger extent (approximately 28%) in plants mulched by red polyethylene film than in control and white foil-mulched plants (round 14 and 12%, respectively). In spite of decrease induced by dehydration, chlorophyll *a* concentration showed almost the same treatment pattern like in watered plants. The only one observed difference was significant decrease in red foil-mulched plants instead of plants mulched by black non-woven textile. Chlorophyll *b* concentration was more sensitive to changes in water relations connected to mulching material. The average values were ordered in this sequence: red foil - 99,4 mg.m^{-2}, white foil - 106,7 mg.m^{-2}, black non-woven textile - 115,5 mg.m^{-2} and control - 125,5 mg.m^{-2}. Finally, in plants mulched by black non-woven textile, dehydration had the most negligible effect on photosynthetic pigments concentration.

Cover mulches enlarged cummulative shoot lenght (CSL) under sufficient water supply (Figure 4) but significant increase (50% in average) was identified only in white foil-mulched plants. Under restricted water, plants mulched by red foil mostly accelerated growth, what mirrored in significantly higher CSL (34% in average) compared to control. White foil and black non-woven textile treatments were intermediate in this parameter. Calculation of CSL difference revealed its positive relationship to colour intensity. However, significant increase compared to non-mulched control plants was observed in plants mulched by black non-woven textile, only.

Almost no (chlorophyll *a* and *b*) or weak (total carothenoids) relationships between T_{RZ5} and leaf photosynthetic pigment concentration was observed at the beginning of dehydration cycle (Figure 5). However, end of dehydration period showed a very strong negative correlation in case of chlorophyll *a* (R^2=0,93) and for chlorophyll *b* (R^2=0,99) but relatively weak one in total carothenoids (R^2=0,39). Decreasing correlation strength (R^2=0,83 for

Table 1. Root-zone temperature (°C) in the depth of 5 cm, under different mulching materials at the beginning and the end of dehydration cycle. NWT – non-woven textile

Phase of dehydration	Root-zone temperature (°C) in respective treatments			
	Control	White foil	Red foil	Black NWT
Beginning	26,2	25,2	25,4	25,5
End	28,8	29,8	30,4	29,4

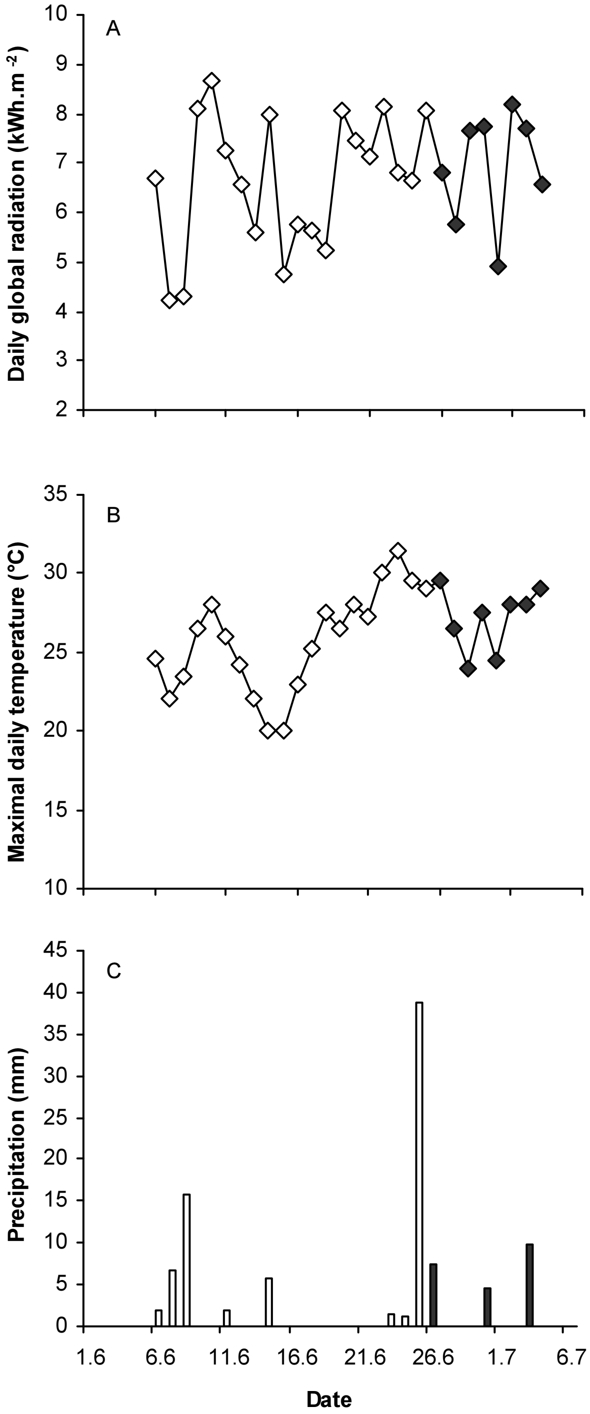

Fig. 1. Dynamics of daily global radiation (A), maximal temperature (B) and precipitation (C) during the summer 2008 experiment in Nitra, Slovakia. Empty symbols/columns represent vegetation period of sufficient water supply, full symbols/columns – dehydration period

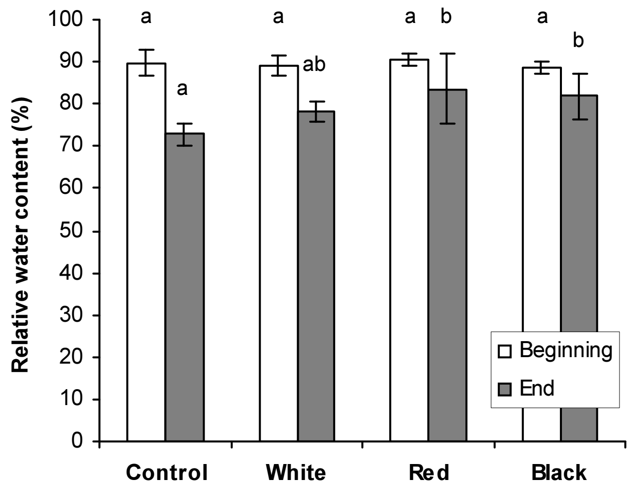

***Fig. 2.** Relative water content of the youngest expanded leaf in main shoot of mulched watermelon plants, as influenced by dehydration. Letters indicate statistically significant difference at P=0,01. Control – non-mulched plants, white – plants mulched by white polyethylene film, red – plants mulched by red polyethylene film, and black – plants mulched by black non-woven textile*

chlorophyll *a*, R^2=0,63 chlorophyll *b* and R^2=0,58 for total carothenoids) was obtained when they were related to leaf RWC after dehydration but no relation was found for them under sufficient water supply (Figure 6). Starting dehydration, there was no correlation between CSL and any of the photosynthetic pigment (Figure 7). However, relatively high coefficients of determination imply their important participation on CSL variability at the end of experiment. Drawing CSL against RWC at the bedinning of dehydration (Figure 8) revealed no connection of these two parameters but when it was related to T_{RZ5} a relatively strong (R^2=0,76) negative correlation was obtained. R^2 of 0,98 for RWC and 0,80 for T_{RZ5} gained in redard to CSL after dehydration cycle point to its stronger relationship to RWC than T_{RZ5}.

DISCUSSION

According to our former results (Ferus et al., 2009a), shoot growth is relatively strongly connected to male flower establishment, and thus pollination and fertilization probability in early stages of watermelon ontogeny. This is the reason for our simplyfied view on its productivity. Many works refer to principal role of root-zone temperature (RTZ) in vegetative growth and fruit production of mulched horticultural crops: Saleh et al. (2003) demonstrated that among red, blue, violet and yellow-green plastic mulch, the highest cucumber (*Cucumis sativus* L.) plant lenght, total leaf area, total fruit weight as well as air temperature, humidity and soil

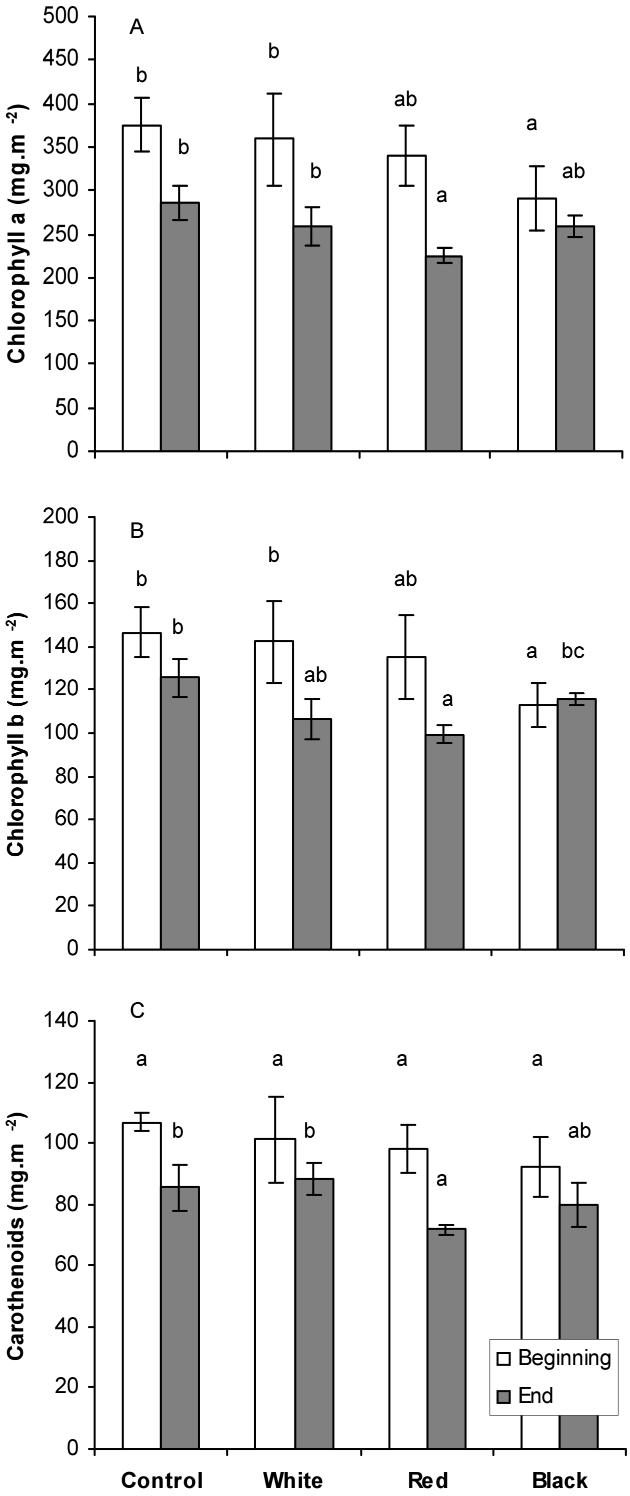

Fig. 3. *Photosynthetic pigment concentration in the youngest expanded leaf of main shoot. A – chlorophyll a, B – chlorophyll b, and C – total carothenoids, Control – non-mulched plants, white – plants mulched by white polyethylene film, red – plants mulched by red polyethylene film, and black – plants mulched by black non-woven textile. Letters indicate statistically significant difference at P=0,01*

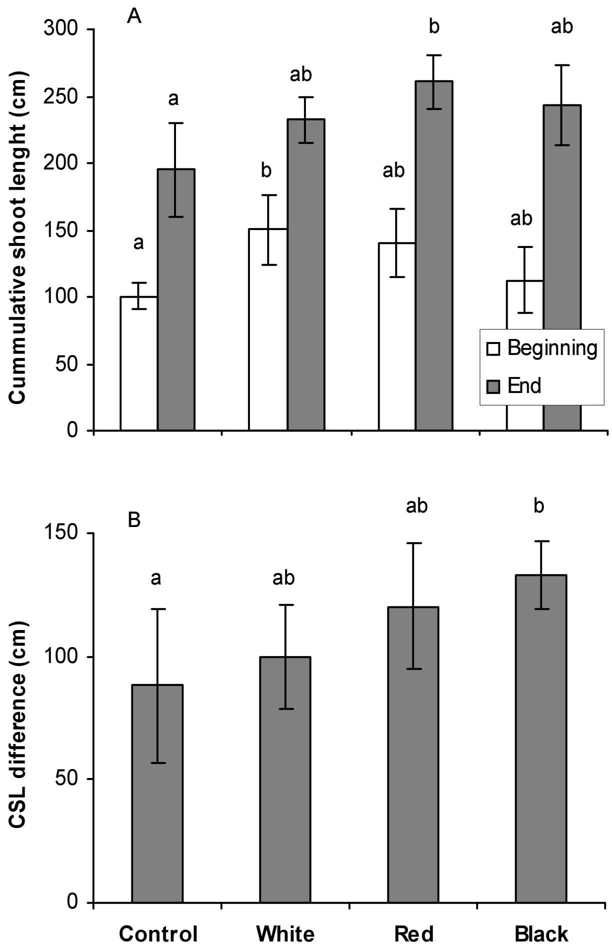

Fig. 4. *Cummulative shoot lenght (CSL) of mulched watermelon plants at the beginning and the end of dehydration cycle (A), and difference between them (B). Letters indicate statistically significant difference at P=0,01. Control – non-mulched plants, white – plants mulched by white polyethylene film, red – plants mulched by red polyethylene film, and black – plants mulched by black non-woven textile*

temperature were achieved on red mulch. Ibarra-Jimenez et al. (2008) amend a possitive relationship between RZT, as influenced by mulch, photosynthetic rate and fruit yield. In case of tomato (*Lycopersicon esculentum* L.), Diaz-Perez and Batal (2002) showed a strong negative correlation between light reflectance of mulching foil colour (decreasing from white, silver through grey, red to black) and root zone temperature, and a possitive quadratic relationship of RTZ to vegetative top fresh weight, fruit yield, fruit number and individual fruit fresh weight. However, we found a negative correlation between root-zone temperature in 5 cm depth (T_{RZ5}) and cummulative shoot lenght (CSL) after twenty days long growth under sufficient water supply (Figure 8). On

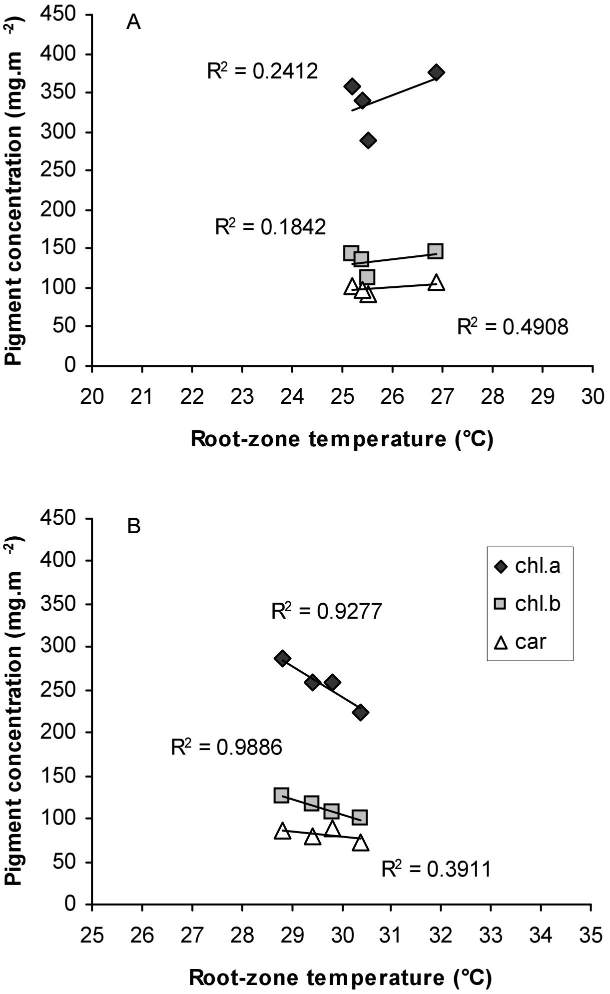

***Fig. 5.** Relationships of root-zone temperature 5 cm deep from the soil surface and leaf photosynthetic pigments starting (A) and finishing dehydration (B). Chl.a – chlorophyll a, chl.b - chlorophyll b, and car – total carothenoids*

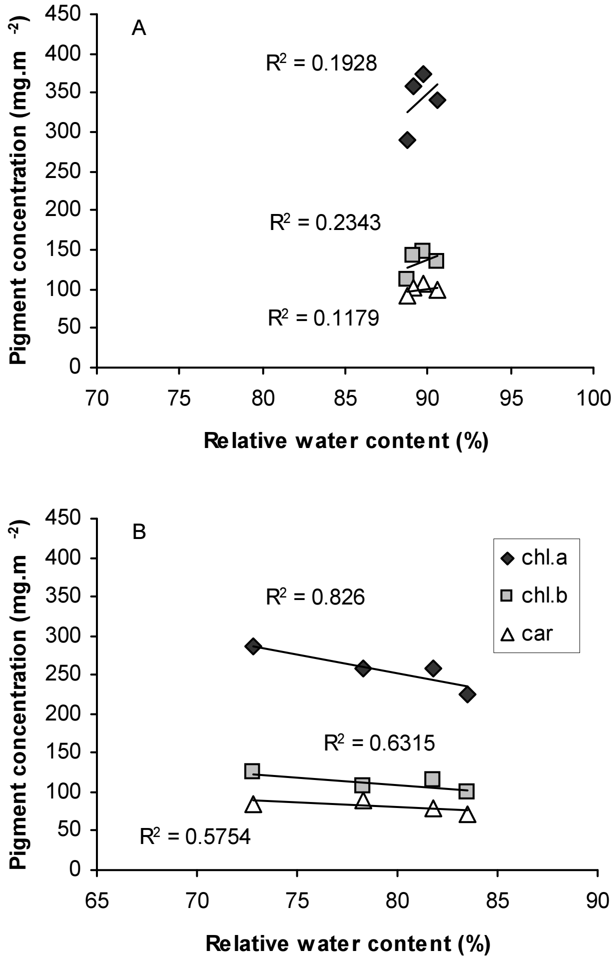

***Fig. 6.** Relationships of leaf relative water content and photosynthetic pigments at the beginning (A) and the end of dehydration (B). Chl.a – chlorophyll a, chl.b - chlorophyll b, and car – total carothenoids*

the contrary to above mentioned results, the largest CSL showed plants mulched by white foil mulch (Figure 4). Taking into account coefficient of determination ($R^2 = 0,76$) of relation between CSL and T_{RZ5}, and relatively homogenous leaf relative water content (RWC) at the beginnig of the dehydration, this growth enhancement could partly be a result of altered light conditions, as well. But most important for growth mainly at the end of this period of relatively clear and hot days (Figure 1) was termoprotective effect of white plastic mulch.

Light quality and temperature presumably determinated also photosynthetic pigment concentration (chlorophyll *a* and *b*) (Figure 3) because of weak or no correlation with T_{RZ5} and RWC (Figure 5 and 6). However, neither concentration of chlorophyll *a* nor chlorophyll *b* was connected with CSL (Figure 7). In literature only a few information of mulch effect on photosynthetic pigmentation occur. Karhu et al. (2007) describe that black compared to white polyethylene film decreased chlorophyll content in strawberry leaves. From the couple black polyethylene film – red polyethylene film, the latter led to deeper loss of chlorophyll (Wang et al., 1998). In our experiment, chlorophyll concentration decreased with mulch colour intesity (Figure 3), what could be commented by leaf acclimatory process to changing light and temperature environment.

Proceeding dehydration revealed water saving ability of applied mulch materials. Red foil and black non-woven textile were most excelent in this trait (Figure 2). However, enhanced leaf RWC was not achieved by osmotic adjustment (Ferus et al., 2009b). What is interesting, more water for plant meant higher T_{RZ5}, as well. However, leaf

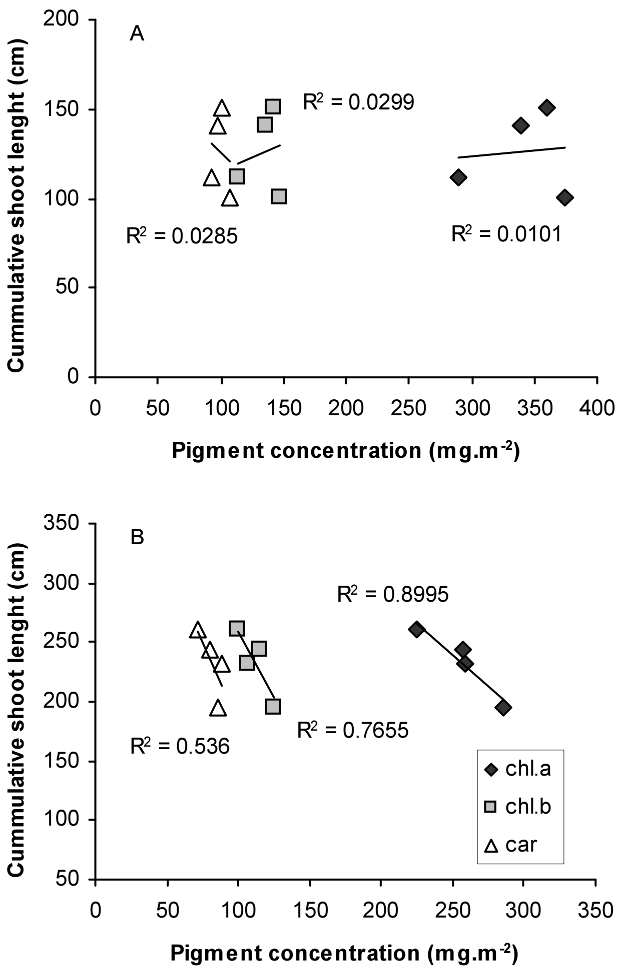

Fig. 7. *Relationships of leaf photosynthetic pigments and cummulative shoot lenght of watermelon plants at the beginning (A) and the end of dehydration (B). Chl.a – chlorophyll a, chl.b - chlorophyll b, and car – total carothenoids*

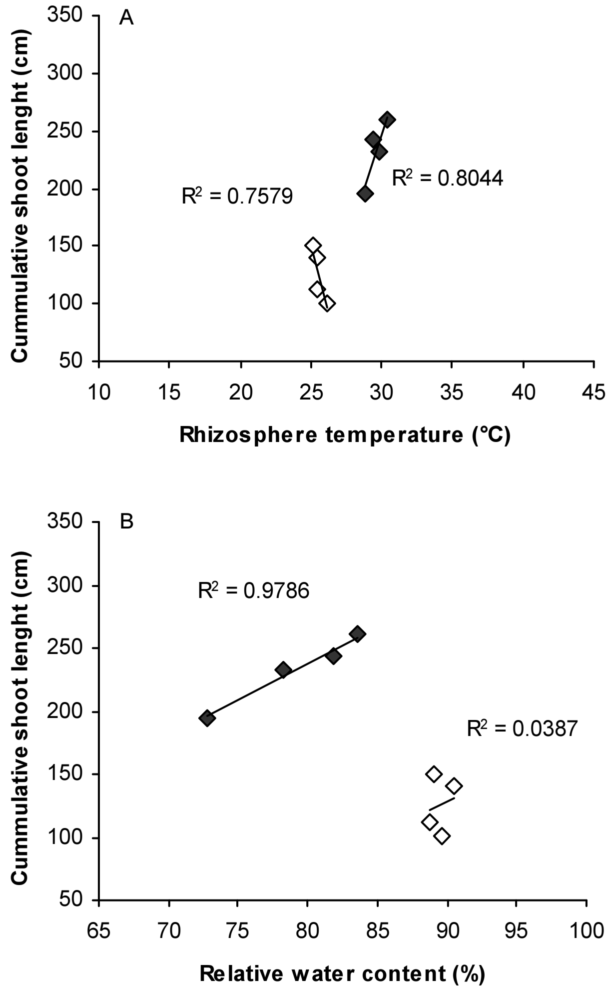

Fig. 8. *Correlation between cummulative shoot lenght of watermelon plants and root-zone temperature (A) or leaf relative water content (B) at the beginning (empty symbols) and the end of dehydration (full symbols)*

RWC was stronger correlated to CSL than T_{RZ5} (Figure 8). The highest values of CSL and CSL difference exhibited plants on black non-woven textile and red polyethylene foil (Figure 4). We can state that under dehydration mulch–related limitation of soil water efflux is more important for watermelon shoot growth than modulation of root-zone temperature. This is in contrast to observations of more researchers obtained under sufficient water supply, showing connection between RZT and vegetative growth as well as fruit production of mulched horticultural crops. On the other hand, chlorophyll *a* and *b* concentration was more related to T_{RZ5} than RWC (Figure 6). Carothenoids were relatively weakly correlated with both parameters. This could be a confirmation of well known clue: Photosynthetic appararus is more prone to disturbances caused by heat when contains more water (Lu and Zhang, 1999). However, it is questionable if leaves suffered from heat stress in case of relatively good water supply enabling transpiratory cooling. But small distance of creeping shoots to coloured mulch could markedly enhance air temperature close to them (Schmidt and Worthington, 1998), making sun light excessive for photosynthetic apparatus directly or through partial stomatal closure (Wahid et al., 2007). Modified light conditions (higher red light portion) could also participate in closing stomata (Salisbury and Ross, 1991). Kirnak et al. (2003) reported a positive effect of black polyethylene mulch on water stressed bell pepper (*Capsicum annum* L.). They found that this plant mulching reduced loss of tissue water, leaf chlorophyll content, plant dry matter caused by stress, and improved fruit yield and fruit size. Polyethylene mulch also increased plant water use efficiency (WUE) and caused better nutrient availability. The same was truth for cucumber (*Cucumis sativus* L.), as mentioned in a later study of this research collective (Kaya et al., 2005). These results indicate similar protective effects of black polyethylene foil and black non-woven textile from our experiment. We also observed that chlorophyll *a* and *b* concentration at the end of dehydration cycle relatively well corresponded with CSL (Figure 7). These relationships were negative, pointing to regulated acclimatory events on the level of photosynthetic apparatus (Allakhverdiev et al., 2008).

These results should be evaluated as consequences of longer cultivation periods of fluctuating light and temperature parameters and sufficient or restricted water supply. Although these two periods were completed on relatively sunny day, mostly distinguishing effects of distinct mulching materials, there are many „white places“ in understanding transient changes of growth and production traits induced by them. Therefore, there are many contradictory conclusions regarding principal factor or their relative participation in yield determination, and we are not able to choose mulching material optimal for a crop (Diaz-Perez et al., 2007; Locher et al., 2005) and cultivation conditions (Ibarra-Jimenez et al., 2008; Locher et al., 2005). Under sufficient water supply we observed the most intensive shoot growth in watermelon plants mulched by white plastic film. Testing drought protective character of different mulches, we concluded that red polyethylene foil and black non-woven textile more than white polyethylene foil alleviated water loss and growth restriction caused by dehydration. Although root-zone temperature was most important (negative) growth determinant under sufficient water supply, water availability were most responsive for shoot growth under limited water.

CONCLUSIONS

From our results we could conslude:

1. Watermelon shoot growth under sufficient water supply was regulated mainly by root-zone temperature (RZT). However, its infuence was negative.
2. The longest shoots were observed in plants on white polyethylene (PE) foil what points to thermo-protective effect of this mulching material under clear and hot weather.
3. The largest water saving ability had the red PE and black non-woven textile mulch. Plants mulched by them showed the highest relative water content as well as shoot lenght at the end of dehydration cycle.
4. Relative water content was the most important factor determining watermelon shoot growth under water deprivation.
5. Negative correlation of leaf chlorophyll concentration to RZT at the and of dehydration period describes leaf acclimatory process to plant temperature environment.

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