Europ.J.Hort.Sci., **70** (3). S. 135–141, 2005, ISSN 1611-4426. © Verlag Eugen Ulmer GmbH & Co. Stuttgart

# Influence of Coloured Mulches on Soil Temperature and Yield of Sweet Pepper

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## Summary

One of the main objectives of using plastic mulch is to increase soil temperature. However, under high temperature conditions some plastic mulches warm the soil to temperatures that might be harmful to plant growth. A 2-year study was carried out in northern Hungary (Gödöllö) to determine the optimal colour of the plastic mulch for sweet pepper under specific, unsettled climatic circumstances, in some years with high temperature conditions. The increase of soil temperature caused by certain mulches was the same in both years. In case of light, coloured mulches (clear, violet, light green) the soil temperature was 2.5–2.9 °C higher than in case of the un-mulched control. The dark coloured mulches (black, dark green, red) caused 1.4–2.1 °C soil temperature increase compared to the un-mulched control. The rate of soil temperature values optimal for sweet pepper (between 20 and 30 °C) was the highest in case of dark coloured mulches. Due to the warmer weather in 2003 the soil warmed up under the clear and violet mulches extremely, which had a harmful effect on vegetative growth and yield. According to the higher soil temperatures mulched treatments produced higher yields than the un-mulched treatment except the clear mulch in 2003. The use of dark coloured mulches is the safest solution in the examined region because even in case of high air temperature and solar radiation the soil does not warm to a harmful degree.

## Zusammenfassung

**Einfluss von farbigen Mulchfolien auf die Bodentemperatur und auf den Ertrag von Gemüsepaprika** Eine der wichtigsten Ziele der Anwendung von Mulchfolien ist die Erhöhung der Bodentemperatur. Bei einer hohen Lufttemperatur und Sonneneinstrahlung erwärmen einige Mulchfolien den Boden sogar in dem Maße, dass das Wachstum der Pflanzen schon negativ beeinflusst werden kann. Ein zweijähriger Versuch wurde in Nordungarn durchgeführt, um die optimale Farbe der Mulchfolie für Gemüsepaprika in einem Gebiet mit spezifischen, wechselhaften Klimaverhältnissen, in einigen Jahren mit besonders hohen Lufttemperaturen und starker Sonneneinstrahlung zu bestimmen. Die verwendeten Mulchfolien erwärmten den Boden in beiden Jahren in gleichem Masse. Bei den hellen (durchsichtigen, lila, hellgrünen) Mulchfolien war die Bodentemperatur 2,5–2,9 °C höher als bei der unbedeckten Kontrollgruppe. Die dunkelfarbigen (schwarzen, dunkelgrünen, roten) Mulchfolien führten zu einer Steigerung der Bodentemperatur von 1,4–2,1 °C im Vergleich zu der unbedeckten Kontrollbehandlung. Die Häufigkeit der für den Gemüsepaprika optimalen Bodentemperaturwerte (zwischen 20 und 30 °C) war bei den dunkelfarbigen Mulchfolien am größten. In dem wärmeren Jahr 2003 erwärmte sich der Boden unter den durchsichtigen und den lila Mulchfolien zu sehr, was schon eine negative Wirkung auf das Wachstum und den Ertrag der Pflanzen hatte. Wegen der höheren Bodentemperatur wiesen die bedeckten Behandlungen höhere Erträge auf als die unbedeckten, die durchsichtige Mulchfolie ausgenommen. Aufgrund unserer Ergebnisse ist in dem untersuchten Gebiet die Verwendung von dunkelfarbigen Mulchfolien am sichersten, weil sich unter ihnen der Boden bei einer hohen Lufttemperatur und starker Sonneneinstrahlung nicht in schädlichem Masse erwärmt.

**Key words.** *Capsicum annuum* – earliness – growth – mulch colour – polyethylene mulch

## Introduction

The cornerstone of the intensive production systems for certain vegetables is plastic mulch (LAMONT 1993). Plastic mulches provide many advantages for the user, such as higher yields, better fruit quality, earlier harvest, better moisture retention, inhibition of weed growth, reduced fertilizer leaching, decreased soil compaction, fruit protection from soil deposits and from soil microorganisms (LAMONT 1993; BOSLAND and VOTAVA 1999).

One of the main objectives of using plastic mulch is to increase soil temperature in the root-zone (BOSLAND and VOTAVA 1999). The favourable root-zone temperature promotes the uptake of water and mineral nutrients,

which in turn promotes better foliage, growth and fruit set (TINDALL et al. 1990; BOSLAND and VOTAVA 1999). The increase of soil temperature is especially important when warm season crops are being grown in areas with short growing season or when price premiums for an early crop necessitate planting into cold soil (DUFAULT and WIGGANS 1981; WATERER 2000). But in case of high air temperature and high solar radiation certain plastic mulches can warm the soil to temperatures that may be harmful for plant growth (MILLER 1986; TINDALL et al. 1991).

Although Hungary is situated on the northern border of the open field sweet pepper production zone, the sweet pepper is one of the most important vegetables in our country. Therefore the increase of soil temperature could be of great importance, mainly in spring (May) and in autumn (September, October). However, due to the specific climate of Hungary (continental climate, which is influenced by maritime climate and Mediterranean climate) the weather is changeable, unsettled, as it was shown in a long-term tomato study (HELYES and VARGA 1994). In some years high air temperature and solar radiation in May and during the summer can possibly result in too high root-zone temperature in case of using plastic mulches.

The effect of plastic mulch on soil temperature is determined primarily by the optical properties (reflectance, transmittance, absorbance) of the material (HAM et al. 1993), so the different coloured mulches warm the soil to a different degree. The best mulch colour for a crop may vary with season and geographic area (DECOTEAU et al. 1989; HATT et al. 1994).

The object of our trial was to determine the optimal colour of the plastic mulch for sweet pepper under specific, unsettled climatic circumstances. Therefore we set up field trials to determine the effect of different plastic mulches on soil temperature, growth, earliness and yield of sweet pepper.

## Materials and methods

Two experiments were conducted in northern Hungary at Gödöllö (47 °61 ' N, 19 °32 ' E) during 2002 and 2003, with soil classified as Cambisol (pH = 7.5, organic matter content=1.65 %, loamy sand soil). Air temperature conditions during the growing season are shown in Table 1.

Experimental design was both years a complete block with one control treatment (un-mulched) and five mulch treatments. In the trials plastic mulches available in Hungary were used. Plastic mulches used in 2002 were violet (0.02 mm thick) (Mikroplast, Lajosmizse, Hungary), light green (0.02 mm thick) (Mikroplast), dark green (0.04 mm thick) (Helioplast, Tiszaújváros, Hungary), red (0.08 mm thick) (Mikroplast), and black (0.12 mm thick) (Helioplast). In the treatments carried out in 2003 only one change was applied: we used clear mulch (0.04 mm thick) (Helioplast) instead of light green mulch.

On the basis of soil analysis basic fertilisation of 102 kg $ha^{-1}$ of nitrogen and 62 kg $ha^{-1}$ of potassium in 2002, and 127 kg $ha^{-1}$ of nitrogen and 250 kg $ha^{-1}$ of potassium in 2003 were broadcast and incorporated. Raised beds were both years 0.9 m wide at the base and 0.2 m high, and were situated in north-south direction. Before lying mulches manually drip irrigation line (0.1 m emitter spacing) was placed on the surface of the soil in the centre of the bed. Kapia-type sweet pep-

Table 1. Monthly average soil temperatures (°C) and average soil temperature for the whole growing season (AST) under different coloured plastic mulches, and air temperatures (AT).

| | **Growing season 2002** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **May 28 –** | **June** | **July** | **August** | **Sep.** | **Oct. 07** | **AST (°C)** |
| Light green | 25.1 | 27.1 | 26.5 | 22.2 | 16.7 | 11.7 | 22.6 |
| Violet | 24.8 | 26.9 | 27.0 | 23.0 | 17.1 | 12.0 | 22.9 |
| Dark green | 23.7 | 25.1 | 25.0 | 22.1 | 17.1 | 12.1 | 21.8 |
| Red | 23.9 | 25.7 | 25.0 | 22.1 | 17.8 | 12.2 | 22.0 |
| Black | 22.7 | 24.8 | 24.9 | 21.6 | 16.7 | 11.7 | 21.5 |
| Un-mulched | 20.1 | 22.5 | 23.4 | 20.7 | 16.0 | 11.1 | 20.1 |
| LSD 0.05 | 0.6 | 0.6 | 0.6 | 0.6 | 0.5 | 0.5 | 0.5 |
| AT (°C) | 19.1 | 19.9 | 22.2 | 20.7 | 15.4 | 10.9 | 19.3 |
| | **Growing season 2003** | | | | | | |
| | **May 19 –** | **June** | **July** | **August** | **Sep.** | **Oct. 02** | **AST (°C)** |
| Clear | 26.3 | 28.9 | 25.7 | 25.7 | 18.2 | 16.3 | 24.3 |
| Violet | 25.5 | 28.6 | 25.0 | 24.9 | 17.4 | 15.8 | 24.0 |
| Dark green | 24.5 | 27.8 | 24.4 | 24.6 | 17.4 | 15.6 | 23.5 |
| Red | 24.1 | 27.0 | 24.1 | 24.1 | 17.3 | 15.6 | 23.1 |
| Black | 23.5 | 26.7 | 23.9 | 23.7 | 17.0 | 15.4 | 22.8 |
| Un-mulched | 21.5 | 24.9 | 22.8 | 22.5 | 15.8 | 14.6 | 21.4 |
| LSD 0.05 | 0.9 | 0.7 | 0.7 | 0.7 | 0.6 | 0.4 | 0.6 |
| AT (°C) | 19.0 | 21.1 | 21.5 | 23.1 | 15.3 | 14.5 | 19.7 |

per plants, cv. 'Kárpia', were seeded into a peat-fruit compost mix in seedling trays (4 x 4 cm cell-size) in the first week of April. Six-week-old pepper seedlings (40 plants/plot) were transplanted in two rows per bed, 0.3 m between rows and 0.25 m between plants (5.7 plants $m^{-2}$) on 14th May 2002 and on 19th May 2003. Fertigation was done by drip irrigation system 1 to 2 times per week. A total of 290 kg $ha^{-1}$ of nitrogen, 55 kg $ha^{-1}$ of phosphorus and 298 kg $ha^{-1}$ of potassium in 2002, and 291 kg $ha^{-1}$ of nitrogen, 52 kg $ha^{-1}$ of phosphorus and 307 kg $ha^{-1}$ of potassium in 2003 was applied by fertigation. Time of fertigation was determined by soil matric potential monitored by tensiometers. Equal quantities of water and fertilizers were added in each treatment. In the beds weeds were mechanically eradicated in the control and in the clear, violet and light green treatments two times during the growing season.

Soil temperature was measured with thermorecorders (Tinytag Plus; Gemini Data Loggers Ltd., Chichester, England) in all plots. Temperature sensors were placed at 10 cm depth under the plant row on the west side of the raised beds, halfway between two plants. The soil temperature was recorded hourly from 28th May in 2002 (due to technical problems not from the time of the transplanting) and from 17th May in 2003 until the end of the growing period.

The effect of the different plastic mulches on vegetative growth was measured by stem diameter (on 2nd August 2002 and on 24th July 2003) and by plant height (on 31st July 2002 and on 23rd July 2003) on every plant in all plots about two weeks before the first harvest, when the plants were not burdened from the fruits. Stem diameter was measured by digital sliding calliper 1 cm above the cotyledon. Plant height was measured from the soil surface to the highest point of the plant.

Fruits were harvested in the stage of full ripeness (at red mature stage) five occasions in 2002 and six occasions in 2003 during the growing season (on 13th Aug., 28th Aug., 10th Sept., 25th Sept., 7th Oct. 2002; on 7th Aug., 14th Aug., 25th Aug., 3rd Sept., 17th Sept., 2nd Oct. 2003). At every harvest time weight and number of fruits per plot were recorded. Early marketable yield (harvests in August) and total marketable yield were determined.

All data were analysed using analysis of variance with LSD test at $p<0.05$ for mean separation.

## Results

### *Soil temperature*

Examining the whole growing season mulched treatments increased the soil temperature both years significantly, by 1.4–2.9 °C compared to the un-mulched treatment (Table 1). The colour of the soil mulch determined the degree of soil warming. Light-coloured mulches (clear, light green, violet) maintained highest values of soil temperature. Dark coloured mulches (black, dark green, red) warmed the soil at a lower rate than the light ones. Using violet and light green mulches in 2002 the soil temperature was 2.5–2.8 °C higher than in the un-mulched treatment, the dark ones caused 1.4–1.9 °C soil temperature increase compared to the un-mulched control. In 2003, soil temperature under clear and violet mulches was 2.6–2.9 °C higher than in the un-mulched treatment, under dark coloured mulches the difference was 1.4–2.1 °C compared to un-mulched control.

In case of black plastic mulch DÍAZ-PÉREZ and DEAN BATAL (2002) got similar result as we observed

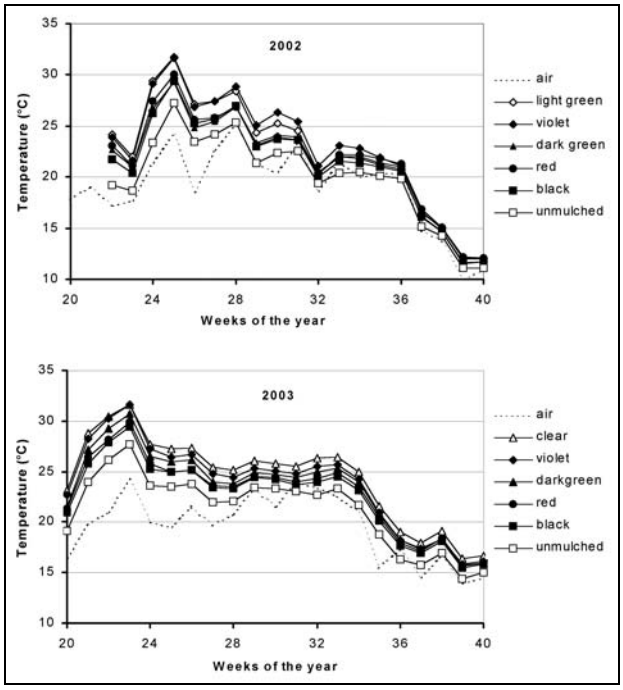



Fig. 1. Seasonal trend of root-zone and air temperature during growing season in 2002 and 2003. Each symbol represents the weekly mean roots zone temperature in case of each treatment.

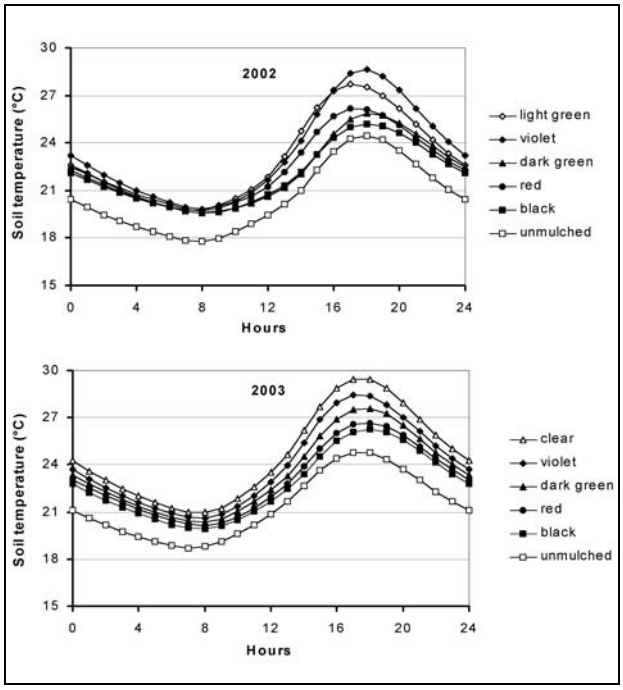



Fig. 2. Effect of coloured mulches on diurnal trends in soil temperatures in the average of the whole growing season in 2002 and 2003.

in our trial, they measured 1.2 and 1.4 °C soil temperature increase in two different years in depth of 10 cm compared to bare soil. According to LAMONT (1993) soil temperature increase in 10 cm depth during the daytime is usually 1.7 °C in case of black mulch and 3.3–5.0 °C in case of clear mulch. In case of other mulch colours comparison with the literature is difficult because mulches with the same colour differed in their light reflecting properties and therefore they differed in their soil-warming ability (DÍAZ-PÉREZ and DEAN BATAL 2002).

In 2003, the soil temperature was 1.3 °C higher than in 2002 without mulching. This was caused by different weather, higher air temperature and solar radiation. Therefore plastic mulches warmed up the soil also to a higher degree, they caused 1.1–1.7 °C higher soil temperature than in the first year. The increase of soil temperature caused by certain mulches was about the same in both years.

Seasonal fluctuations of soil and air temperatures are shown in Table 1 and Fig. 1. The highest temperature occurred in both years in different time. At the beginning of the growing season (20–25$^{th}$ weeks of the year) when the plants did not cover the mulches considerably, the soil warmed up to a higher degree than later in the growing season in spite of lower air temperature. With the progress of the season we must calculate on the shading effect of the plants by other crops, too. This phenomenon was noticed by ROMIC et al. (2003) in case of watermelon and by FARIAS-LARIOS et al. (1994) in case of cucumber. The degree of the difference between the certain treatments was determined by air temperature, solar radiation and shading effect of the plants. The difference between the treatments was the highest at the beginning of the growing season then by the increase of the shading effect of the plants and by the decrease of air temperature and solar radiation decreased this difference.

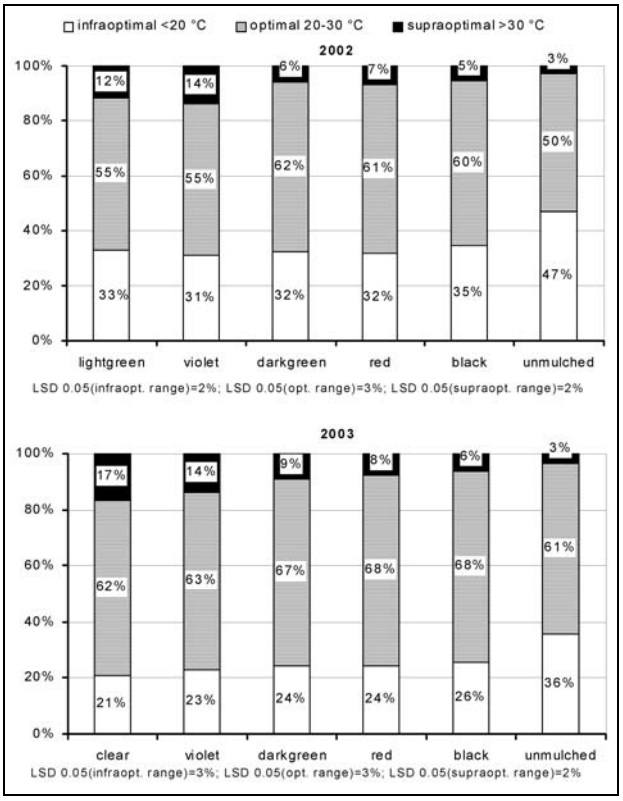



Fig. 3. The percentage distribution of optimal, infra-optimal, and supra-optimal soil temperature values for sweet pepper under different coloured mulches in 2002 and 2003.

On the basis of diurnal fluctuation of soil temperature the maximum temperature values occurred on the west side of the beds in both years between 17 and 19 o'clock and the minimum was reached between 7 and 8 o'clock (Fig. 2). Soil night-time temperatures were higher in the mulched treatments than in the un-mulched treatment. The reasons are the following: mulched treatments were warmed up to a higher degree during daytime and from this higher temperature cooled they down; the air gap between the mulch and the soil reduces convective heat transfer; plastic traps a portion of the outgoing long wave radiation emitted from the soil (HAM et al. 1993). Among the mulched treatments considerable difference occurred during daytime. The cooling of soil temperature during night-time was not influenced by the colour of the mulches or only to a very little degree. In 2002, the cooling of the soil under the mulches was the same during night-time. In 2003, only maximum 1 °C difference occurred, the soil was the warmest under the clear mulch during night-time.

We divided the soil temperature data measured trough the whole growing season into 3 temperature-ranges (Fig. 3). Based on data from the literature (GOSSELIN and TRUDEL 1986; ZATYKÓ 1993) we set the optimal soil temperature range between 20 and 30 °C. In 2002, the highest ratio of optimal temperature data occurred in case of dark green, red and black mulches, significantly higher than in case of the other treatments. The most infra-optimal data occurred in case of un-mulched treatments. The rate of supra-optimal values was in case of light green and violet mulches significantly higher than in case of the other treatments. Likewise in 2002, in 2003 the rate of optimal values was in case of dark green, red and black mulches significantly higher than those of used in the other treatments. Similarly to year 2002, the most infra-optimal values occurred in 2003 in the un-mulched treatment. Using clear and violet mulches the rate of supra-optimal values was significantly higher than in other treatments. So optimal soil temperature requirements of sweet pepper were met to the highest degree in case of the dark-coloured mulches. In 2003, the rate of optimal values was in case of all treatments higher than in 2002. In the warmer second year the increase of optimal temperature values was the highest (11 %) in case of un-mulched treatment, higher than in case of mulched treatments. This means that in cooler years mulching has a better effect.

*Plant growth*

Examining both the plant height and stem diameter the mulched treatments showed significantly stronger vegetative growth in both years than the un-mulched treatment except the clear mulch in 2003 those plant height was similar to that of the un-mulched treatment (Table 2). The stronger vegetative growth of the mulched treatments can be explained with more favourable soil temperature and with better soil mois-

Table 2. Effect of coloured mulches on plant height and stem diameter of sweet pepper in 2002 and 2003.

| | Plant height (m) | | Stem diameter (mm) | |
|---|---|---|---|---|
| | 2002 2 Aug | 2003 24 July | 2002 31 July | 2003 23 July |
| Clear | – | 0.54 | – | 11.9 |
| Light green | 0.71 | – | 12.9 | – |
| Violet | 0.71 | 0.61 | 12.6 | 12.7 |
| Dark green | 0.74 | 0.62 | 13.1 | 13.1 |
| Red | 0.75 | 0.62 | 12.7 | 13.1 |
| Black | 0.71 | 0.63 | 13.5 | 13.0 |
| Un-mulched | 0.66 | 0.55 | 11.5 | 11.3 |
| LSD 0.05 | 0.04 | 0.03 | 0.6 | 0.6 |

Table 3. Effect of coloured mulches on early and total marketable yield of sweet pepper in 2002 and 2003.

| Treatment | 2002 Early yield (kg m$^{-2}$) | 2002 Total yield (kg m$^{-2}$) | 2003 Early yield (kg m$^{-2}$) | 2003 Total yield (kg m$^{-2}$) |
|---|---|---|---|---|
| Clear | – | – | 3.33 | 4.73 |
| Light green | 3.01 | 5.25 | – | – |
| Violet | 3.45 | 5.41 | 3.15 | 5.23 |
| Dark green | 3.16 | 5.49 | 3.47 | 5.88 |
| Red | 3.12 | 5.41 | 3.57 | 5.61 |
| Black | 3.08 | 5.42 | 3.44 | 5.63 |
| Un-mulched | 2.27 | 4.48 | 2.88 | 4.95 |
| LSD 0.05 | 0.55 | 0.41 | 0.50 | 0.65 |

ture conditions (WIEN and MINOTTI 1993; FARIAS-LARIOS et al. 1994). In 2003, vegetative growth of the clear mulch was similar to the un-mulched treatments. It can be explained by that the soil temperature was too high for the sweet pepper under the clear mulch. Too high soil temperature can have harmful effects on the vegetative growth of the plants (DÍAZ PÉREZ and DEAN BATAL 2002).

*Yield*

In case of all treatments yields were between 4.5 and 6 kg m$^{-2}$ in both years which means an outstanding result under Hungarian open-field conditions for this variety. In 2002, mulched treatments produced significantly higher yields in early season (harvests in August) than the un-mulched treatment (Table 3). The violet plastic mulch resulted in the highest early yield, although the difference compared to the other mulched treatments was not significant. Examining the whole growing season mulched treatments also produced significantly higher total yield compared to the un-mulched treatment. The yield difference among the mulched treatments was negligible. We observed different trend in 2003. Dark mulches again produced significantly higher early yield than the un-mulched treatment but the clear and the violet mulch did not produce significantly different yield compared to the un-mulched treatment. Total yields of dark mulches were significantly higher than in case of the control treatment. Clear mulch produced the lowest yield, significantly lower than in case of dark mulches. The violet mulch also produced lower yield compared to dark mulches.

The different trends of the two years can be explained with the different weather conditions. The difference between the yields of mulched and un-mulched treatments was higher in 2002 than in 2003. It shows that the increase of soil temperature above a certain level cannot result in such a high yield increase.

## Discussions

The results of the trial show that coloured mulches had an effect on soil temperature, which influenced the early and total yield through the vegetative growth of the plants.

The degree of soil temperature increase was determined by the colour of the mulches and in relation to this, by the amount of light they transmitted. It follows that considerable difference occurred among mulched treatments during the daytime, the cooling of the soil under the mulches was the same during the night-time. Soil mulches used in the trial were divided into two groups on the basis of soil-warming ability. Highest soil temperature occurred under light coloured mulches (clear and nearly clear violet and light green). The reason for it is that clear mulch transmits 85–95 % of solar radiation. The inner surface of clear mulch is usually covered with condensed water droplets. This water is transparent to incoming short-wave radiation, but it retains outgoing long-wave radiation emitted from the soil (LAMONT 1993). In case of light-coloured mulches the rate of soil temperature values optimal for sweet pepper, depending on weather conditions, was 1–5 % higher than in the un-mulched treatment (Fig. 3).

Dark coloured mulches (black, dark green and red) had a lower soil-warming ability than light coloured ones. Black mulch absorbs most of incoming solar radiation and the absorbed energy can be transferred to the soil by conduction. Improving the contact between mulch and soil surface can increase soil-warming ability of black mulch (LAMONT 1993; TARARA 2000). Although the dark green and the red mulch transmit a portion of incoming solar radiation, their soil-warming ability is similar to that of the black mulch. In case of dark-coloured mulches the rate of soil temperature values optimal for sweet pepper, depending on weather conditions, was 6–12 % higher than in the un-mulched treatment (Fig. 3).

Due to the more favourable soil temperature the plants showed stronger (more intensive) vegetative growth in mulched treatments than plants in the un-mulched treatment except using clear mulch when soil temperature was too high for sweet pepper and it had a harmful effect on vegetative growth. From the aspect of vegetative growth the first weeks of the growing season are determinant and the highest soil temperatures occurred in both years during this early period.

The highest soil temperature provided by the violet mulch produced the highest early yield in 2002. In case of the total yield did not occur considerable difference

among the mulched treatments. However, in 2003 the use of clear and violet mulches with the highest soil-warming ability resulted in lower early and total yield, than in case of dark mulches. In case of clear mulch total yield was even lower than in the un-mulched treatment. In a Canadian study (WATERER 2000) adverse results were observed. In their case yields of pepper increased with clear mulch compared to black and wavelength selective mulches and bare soil.

We considered that due to the warmer weather in 2003 soil warmed up under the clear mulch extremely and also to a certain degree under the violet mulch (the most supra-optimal temperature values occurred in their case). This extremely high soil temperature was reached at the beginning of the growing season when the roots of the plants were located in the upper layer of the soil. High soil temperatures can have a drastic effect on vegetative growth, fruiting, water and nutrient uptake and root respiration (TINDALL et al. 1990; DODD et al. 2000). In case of tomato (DÍAZ-PÉREZ and DEAN BATAL 2002) plant growth and yield can be reduced drastically even when plants are exposed to a soil temperature only slightly higher than the optimal. Dark coloured mulches ensured optimal soil temperature for sweet pepper even in the warmer weather in 2003, the most optimal temperature values occurred in their case.

Consequently, our results show that the relationship between average soil temperature and yield is not linear. The optimal soil temperature for the whole growing season is about 23–23.5 °C. However, between the rate of optimal temperature values for sweet pepper and yield the relationship is nearly linear (Fig. 4).

Based on these results we concluded that in the examined region the use of clear and light coloured mulches cannot be suggested in warmer years because the soil can warm up to an extremely high temperature under this mulches and can have a harmful effect on growth and through this on yield of sweet pepper. The use of dark coloured mulches is the safest solution because even in case of high air temperature and solar radiation the soil does not warm to a harmful degree therefore among the mulches examined they can meet the soil temperature demands of sweet pepper to the highest degree.

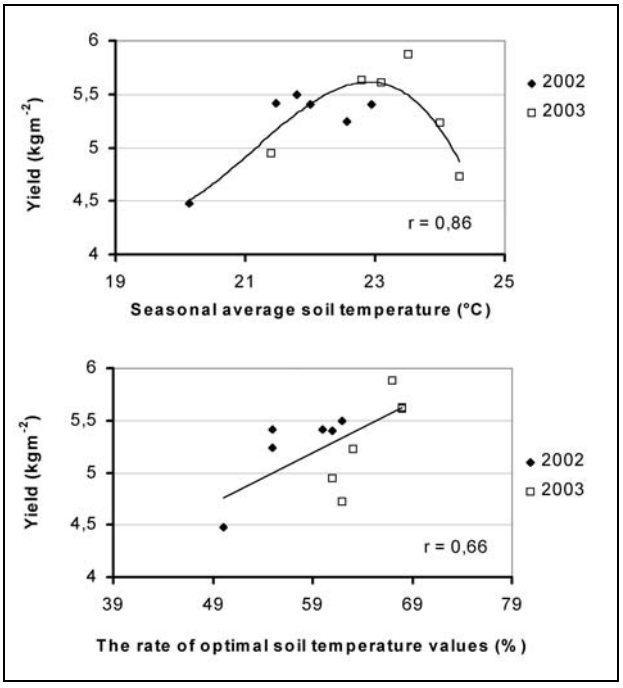



Fig. 4. The relationship between seasonal average soil temperature and yield and between the rate of optimal soil temperature values for sweet pepper and yield.

## Acknowledgements

The authors are grateful the No. OM-00127/2001 project of the Hungarian Ministry of Education for funding the study.

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Received April 28, 2004 / Accepted February 23, 2005

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