THE EFFECT OF DIFFERENT KIND OF POLYETHYLENE FILM USED AS A LOW TUNNEL COVER ON CELERY YIELD AND STALK QUALITY

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Summary

Earlier experiments showed that celery could be grown under different plastic covers for spring and autumn harvest. The most significant for yield quantity and quality were light conditions. In conducted studies (2005-2007) the effect of three different covers for low tunnels: transparent, white and black film (made of original and recycled polyethylene) on the growth, yield and some quality factors of celery Tango stalks was estimated. Only small differences in the length of celery stalks grown under different films were observed. In the third year of experiment stalks grown under black film were around 1cm longer than all the others. Mean values of the yield indicate that transparent film used as a cover and the control treatment increased slightly the obtained yield but the differences did not exceed several percent. Plants grown in more favourable light conditions accumulated more dry matter as well as more soluble sugars in celery stalks. No such differences were observed under original and recycled films.

key words: recycled and original film, celery, yield, soluble sugars

INTRODUCTION

Previous studies demonstrated that celery can be grown under direct covers of perforated film, in tunnels for early harvest and under non-woven fabrics for autumn harvest (Dyduch 1994, Siwek 2002). Regardless the kind of the cover, photosynthetically active radiation (PAR) is the most significant factor for the microclimate conditions, both in respect to the quantity and quality of light. In earlier studies on permeability for PAR (400-700 nm) and NIR (near infrared) (700-1100 nm) through polyethylene films and non-woven polypropylene materials used to cover low tunnels Siwek and Libik (1999) demonstrated that films in natural, blue, green and red colour transmitted 89-92%

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of PAR and 86-91% of NIR. When these results were compared to non-woven materials in same colours, it was shown that transmission was on same level only in case of natural colour non-woven (87-88%). Transmission through non-woven of other colours was 49-51% and 28-42% of PAR and NIR, respectively. Thermal conditions under covers depend on lighting conditions, but these are not always favourable for plants. In other studies it was demonstrated that in tunnels covered with thin transparent film on sunny spring days air temperature may rapidly increase, leading to plant burn (Libik & Siwek 1994, Kalisz & Cebula 1995). Attempts to limit the intensity of radiation in late spring and summer using shadings led to temperature fall which weakened the plant growth and resulted in lower yield of sweet pepper and cucumber (Siwek & Libik 1999, Siwek & Ciura 1999). In case of celery shading with various materials gave positive results in earlier experiments. Covering plants with non-woven materials in spring for 25 days from planting increased the marketable yield by 13-19% comparing to control (Jenni & Stewart 1992). Soil mulching and covering low-structure tunnels with transparent film significantly decreased bolting and led to obtain a better yield (Jenni *et al.* 2006). Covering celery plants with non-woven fabric one month before harvest resulted in the increase of the marketable yield by over 50% during autumn cultivation (Siwek 2002). In effect of covering, obtained stalks were of very good quality, however the dry matter content was lower than average. (Pressman 1997).

The aim of this study was to investigate the effect of microclimatic conditions in low tunnels with different solar radiation permeability on the growth, yield and selected quality features of stalks in the celery cultivation for early harvest.

MATERIAL AND METHODS

The experiments were carried out in 2005-2007 in the Experimental Station at Mydlniki by Krakow. It concerned medium-early celery cultivar of Tango intensively green leaves. Celery seeds were sown in the greenhouse on 4 February 2005, 6 February 2006 and 5 February 2007. Transplants were planted in the field at 30 × 25 cm spacing on 20 April in the first year, on 19 April in the second year and 17 April in the third year of conducted experiment. The experimental plots, each of 3 m² (40 plants), were established in a randomised block design with four replicates. The experiment concerned covering tunnels with low density polyethylene films (PE) which differed in respect to the material they were made of and colour: 1) without cover (control), 2) transparent from original PE; 3) transparent from recycled PE; 4) white from original PE; 5) white from recycled PE; 6) black from original PE; 7) black from recycled PE. Original films were made of Basell Orlen Polyolefins polyethylene and recycled films of high quality polyethylene originating from waste products. White (Schulman 8160) and black (Polybatch black 1850) dyes were used as colouring agents. Tunnels 10 m long, 1.5 m wide and 0.8 m high were covered with above mentioned films and stayed covered till 30 May 2005 in the first year of trial,

until 31 May 2006 in the second year and 2 June 2007 in the third year of conducted experiments. When air temperature was above 20°C tunnels were kept open. Celery was harvested only once on 6th, 13th, and 3rd July in consecutive years.

In all years of the experiment manure (35,000 kg·ha⁻¹), triple superphosphate (150 kg P₂O₅·ha⁻¹) and potash salt (200 kg K₂O·ha⁻¹) were applied in autumn. In spring, before planting, field was fertilized with nitrogen (nitrochalk) in following doses: 50 kg N·ha⁻¹ in 2005, 75 kg N·ha⁻¹ in 2006 and 50 kg N·ha⁻¹ in 2007. At the growth stage celery was fertilized with ammonium nitrate (25 kg N·ha⁻²), and 0.1% Ca(NO₃)₂ (20 dm³·m⁻²).

Used films were analyzed in respect to spectral transmission, reflection and absorption of radiation within the range of 400-1100 nm, using LI-1800-12-S (LI-COR, USA) integration sphere with standard light source, in accordance with the world standard procedure (Siwek *et al.* 2007). PAR transmission through the films was recorded with PAR Smart Sensor HOBO (Onset Comp. Corp.) on samples of all film mounted on a special tunnel-shape construction. Air temperature was recorded using HOBO Pro (Onset Comp. Corp.) during the time when celery was covered.

In order to determine the dry matter content samples of plant material were dried at 95°C. Soluble sugar content was determined by the photometric method with antrone reagent (Yemm & Wills 1954). ANOVA was used for statistical analysis of obtained results and the means were compared using Newmann-Keuls test at the P=0.05.

RESULTS

Measurements conducted on film samples demonstrated that particular colours had various effect on light conditions. Results presented in Table 1 indicate that the sum of PAR transmitted through films was: 72.2% for transparent, 48.7% for white and 23.2% for black film. Mean values of PAR under particular films during the day confirmed the results obtained for control conditions (Siwek *et al.* 2007).

Temperature under films was higher than the soil temperature and the differences were related to light permeability (Table 2). In all years of the experiment the highest daily temperature was noted under transparent film (3.7°C higher when compared to control). The minimal noted temperature was higher by 1.1°C and the maximal temperature was higher by 6.5°C comparing to control. Under less permeable white film differences comparing to control were: 1.2, 0.8 and 3.0°C, respectively. Black film modified temperature to the least degree. Under this film the mean daily temperature was higher only by 0.8°C, while the minimal and maximal temperatures by 0.1 and 1.9°C, respectively. In 2005 values of PAR and temperature under covers were lowest comparing to other years. No differences in the temperatures were observed between original and recycled films.

Table 1. Total daily PAR ($\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) under film of different colours made from original or recycled material

Treatments	Total daily PAR			Mean 2005-2007	Mean %
	20 April - 4 May 2005	19 April - 23 May 2006	20 April - 2 June 2007		
Control (without film)	8655	9811	10042	9503	100
Transparent original	6115	6776	7878	6923	72.8
Transparent recycled	5649	6862	7846	6786	71.4
Mean	5882	6819	7862	6854	72.2
White original	4702	4277	4785	4588	48.3
White recycled	4324	4567	5119	4670	49.1
Mean	4513	4422	4952	4629	48.7
Black original	1562	1638	2591	1930	20.3
Black recycled	1817	2295	3331	2481	26.1
Mean	1689	1966	2961	2205	23.2

The studies demonstrated that the colour of film had an effect on both: the length of stalks and the yield (Table 3). In 2005, the longest stalks were obtained from cultivation under black film (27.3 cm), whereas stalks obtained from under other materials were 2 cm shorter. In the following year of the experiment plants were generally smaller but stalks from cultivation under black and white film as well as the control were significantly longer than stalks of plants grown under transparent film. In the third year of the experiment the longest stalks were obtained from plants grown under transparent film (27.2 cm) whereas in case of other covers the results were similar to the control. In the third year of trial stalks of plants grown under black film were 1 cm longer than stalks of plants grown under different covers. No differences were observed between the length of stalks grown under original or recycled films.

In 2005 the highest yield of stalks was obtained from the control treatment ($5.17 \text{ kg}\cdot\text{m}^{-2}$) and from plots covered with transparent film ($4.79 \text{ kg}\cdot\text{m}^{-2}$). In the following year, the stalk yield was significantly lower than in the first year of the experiment. In comparison with the control, the highest yield was obtained from plots covered with black ($3.53 \text{ kg}\cdot\text{m}^{-2}$) and white film ($3.33 \text{ kg}\cdot\text{m}^{-2}$). However, in the third year of the experiment, the highest stalk yield was noted for plants grown under transparent film ($4.20 \text{ kg}\cdot\text{m}^{-2}$) and the yield from under control film was at the similar level. The lowest yield was obtained from plants grown under white film ($2.88 \text{ kg}\cdot\text{m}^{-2}$). Mean values of the yield from three years of the experiment indicate that better results were obtained from plants with best light conditions (control treatment and transparent film). As compared with other films of lower solar radiation permeability, the results were however minor and never exceeded several percent.

The most evident negative effect of film colours on all studied parameters was demonstrated for black film used as tunnel structure cover. Results obtained in each year of the experiment showed that celery stalks grown under black film contained the least sugars and dry matter on harvest day (Table 4).

Table 2. Air temperature (°C) in tunnels covered with polyethylene film of different colours made from original and recycled material

Treatments	Daily mean				Minimum				Maximum			
	2005	2006	2007	Mean	2005	2006	2007	Mean	2005	2006	2007	Mean
Control (without film)	10.8	14.2	14.5	13.2	3.5	5.9	6.4	5.3	18.1	24.1	23.3	21.8
Transparent original	14.4	16.3	16.6	15.8	4.2	7.0	8.0	6.4	26.9	29.2	28.0	28.0
Transparent recycled	15.0	15.9	17.0	16.0	4.3	6.9	8.1	6.4	29.0	28.2	28.6	28.6
Mean	14.7	16.1	16.8	15.9	4.2	6.9	8.0	6.4	27.9	28.7	28.3	28.3
White original	13.4	15.1	15.9	14.8	4.2	6.6	7.7	6.2	24.7	26.6	26.3	25.9
White recycled	12.1	14.6	15.4	14.0	3.9	6.6	7.5	6.0	22.2	24.7	24.6	23.8
Mean	12.7	14.8	15.6	14.4	4.0	6.6	7.6	6.1	23.4	25.6	25.4	24.8
Black original	12.9	14.8	14.1	13.9	4.2	6.3	5.9	5.5	21.4	25.9	23.9	23.7
Black recycled	13.0	14.6	14.6	14.1	4.1	6.2	6.3	5.5	20.3	25.5	25.5	23.8
Mean	12.9	14.7	14.3	14.0	4.1	6.2	6.1	5.5	20.8	25.7	24.7	23.7

Table 3. Effect of kind of polyethylene film used as a tunnel cover on the growth and yield of celery stalks

Treatments	2005			2006			2007			Mean 2005-2007		
	Mean length of stalk (cm)	Yield of stalks (kg·m ⁻²)	Mean length of stalk (cm)	Yield of stalks (kg·m ⁻²)	Mean length of stalk (cm)	Yield of stalks (kg·m ⁻²)	Mean length of stalk (cm)	Yield of stalks (kg·m ⁻²)	Length of stalk (cm)	Yield of stalks (kg·m ⁻²)	Length of stalk (cm)	Yield of stalks (kg·m ⁻²)
Control (without film)	25.5abA ²	5.17 cB	17.5aB	2.59 abA	25.3abAB	3.79 bcBC	22.8		22.8	3.85		
Transparent original	24.4 a	4.70 c	16.0 a	1.98 a	29.3 b	4.64 c	23.3		23.3	3.77		
Transparent recycled	23.7 a	4.88 c	15.5 a	2.58 ab	25.0 ab	3.77 bc	21.4		21.4	3.74		
Mean	25.0 A	4.79 B	15.7 A	2.28 A	27.2 B	4.20 C	22.6		22.6	3.75		
White original	25.6 ab	4.38 bc	18.9 a	3.07 b	24.3 a	2.56 a	22.9		22.9	3.34		
White recycled	25.1 ab	3.36 a	19.3 a	3.59 b	23.7 a	3.20 ab	22.7		22.7	3.38		
Mean	25.4 A	3.87 A	19.1 B	3.33 B	24.0 A	2.88 A	22.8		22.8	3.36		
Black original	26.6 ab	3.50 ab	18.5 a	3.47 b	24.2 a	3.06 ab	23.1		23.1	3.34		
Black recycled	28.0 b	4.31 bc	18.7 a	3.59 b	25.2 ab	3.80 bc	24.0		24.0	3.90		
Mean	27.3 B	3.90 A	18.6 B	3.53 B	24.7AB	3.43 B	23.5		23.5	3.62		
Original ¹	25.5 X	4.19 X	17.8 X	2.78 X	25.8 X	3.51 X	23.0		23.0	3.49		
Recycled ¹	25.6 X	4.18 X	17.8 X	3.09 X	24.8 X	3.64 X	22.7		22.7	3.64		

¹Means for the film material² Values with the same letters do not differ significantly at P=0.05; small letters concern interaction material x colour of film, capital letters – colour of film, X,Y – the film material

Table 4. The effect of the kind of polyethylene film used as a tunnel cover on soluble sugars and dry matter content in celery stalks

Treatments	Soluble sugars (mg·kg ⁻¹ fresh weight)					Dry matter (%)			
	2005	2006	2007	Mean for 2005-2007		2005	2006	2007	Mean for 2005-2007
Control (without film)	9.1 gD ²	15.1 eD	13.1 bB	12.4		5.57 aA	9.57 eC	7.73 bB	7.62
Transparent original	8.0 e	14.0 de	14.9 c	12.3		5.70 ab	10.08 f	8.05 c	7.95
Transparent recycled	8.5 f	13.8 de	15.0 c	12.4		6.03 d	9.10 d	9.85 e	8.33
Mean	8.2 C	13.9 C	14.9 D	12.3		5.86 B	9.57 C	8.95 D	8.14
White original	6.6 c	12.9 cd	14.6 c	11.4		6.37 e	8.79 c	8.92 d	8.02
White recycled	7.0 d	12.5 bc	14.2 c	11.2		5.89 cd	8.48 b	8.10 c	7.49
Mean	6.8 B	12.7 B	14.4 C	11.3		6.13 C	8.63 B	8.51 C	7.75
Black original	4.9 a	11.5 b	12.9 b	9.7		5.77 bc	8.52 b	7.87 b	7.38
Black recycled	6.1 b	10.0 a	12.1 a	9.4		5.69 ab	8.05 a	7.17 a	6.97
Mean	5.5 A	10.8 A	12.5 A	9.5		5.73 A	8.28 A	7.52 A	7.17
Original ¹	7.1 X	13.4 X	13.9 X	11.5		5.95 X	9.24 Y	8.19 X	7.79
Recycled ¹	7.6 Y	12.9 X	13.6 X	11.4		5.87 X	8.80 X	8.21 X	7.63

^{1,2} Note: see Table 3

In years 2006-2007 that effect was even more significant in case of black recycled film. Plants grown in the initial vegetation period under tunnels covered with transparent (original and recycled) film had the highest content of soluble sugars. The lowest level of this compound was noted in case of plant covered with white film. Only in 2005 significant differences in soluble sugars content were found depending on the material of which transparent and white films were made, indicating higher values in plants grown under films made from recycled materials. In comparison with uncovered plants, in 2007 there was a significant increase of sugars content in stalks of celery cultivated in tunnels covered with transparent and white films. Such dependences in dry matter content were demonstrated not only in the last, but also in the first year of the experiment. However, the dry matter content in stalks of plants harvested from these plots differed depending on the year of the experiment. The highest content of dry matter was noted in stalks from plants cultivated until the end of May under transparent film of original material in 2006.

DISCUSSION

Minor differences in the length of celery stalks cultivated under different films indicate that plant growth was even, regardless of different light conditions in the initial vegetation period in the field. Similar results were obtained in experiment where the effect of identical films on the yield of lettuce was studied (Siwek *et al.* 2007). In previous studies it was also confirmed that growing cucumbers in low tunnels shaded with different materials, negatively effected elongation growth of stalks and decreased the yield. This may indicate that celery plants are more tolerant to light deficiency than cucumber (Siwek & Ciura 1999). Significant growth limitation and lower yield were also obtained in case of sweet pepper as a result of covering low tunnels with polypropylene non-woven fabric in different colours and with strong plant-shading properties (Siwek & Libik 1999). The experiment proved that in case of strong light absorption by shades the amount of light reaching plants had greater effect than the light's spectral composition. The results of this study indicate a great tolerance of celery plants to solar radiation deficiency which may be important finding for horticultural practice.

The obtained results indicate that films used as a cover for low tunnels can significantly modify the level of soluble sugars and dry matter content in stalks. In this case plant cultivation in tunnels covered with transparent films was the most favourable due to the fact that transparent film (regardless of the origin of the material) transmits the most light. Plants cultivated in more favourable light conditions (under control treatment and under transparent film) during the whole period under cover generally accumulated more sugars in stalk yield than plants from under different materials. In celery leaves saccharose and mannitol are the biggest share in all soluble sugars. Both compounds are products of photosynthesis and are important in transport, with mannitol serving also as a storage compound (Davies *et al.* 1988). Due to the fact that limited access to

light for assimilating parts of plants can lead to a decrease of assimilates also a decrease of foil permeability for PAR causes that the amount of sugars accumulated in stalks decreases. In the experiment concerning celery stalks shaded with various materials, soluble sugars and dry matter contents were the lowest in blades and stalks covered with black non-woven fabric for 14 days prior to harvest (Wojciechowska & Siwek 2006).

However, it is interesting that in this experiment the yield from plants covered with black film (which average PAR transmission of 36.2%), were satisfactory and in 2006 it was even higher than that obtained from plants grown in tunnels covered with transparent film. Presented results also indicate that celery plants often produce longer stalks in worse light conditions. This dependency may result from the fact that light, apart from the direct stimulating effect on photosynthesis, indirectly affects the morphological phenomena. The inverse effect of light and auxins on cell elongation process is well-known thus at conditions of light deficiency plants contain higher amount of auxins and their growth is more intensive than at normal light conditions (Kraepiel *et al.* 2001). Earlier studies also demonstrated that plants may form a bigger assimilation surface when the shading is stronger (Siwek & Libik 1996). This may be connected with a lower water loss due to transpiration as a positive water balancing factor necessary for cell growth (Xu *et al.* 1994). Moreover, earlier studies showed that plants adapt to particular lighting conditions and very often maximal photosynthetic rate occurred in the irradiance to which the plants were adapted (Krug 1997). When black film shading period was over and plants were grown at normal light conditions for over a month, celery biomass was still increasing, however it was more hydrated and contained less soluble sugars.

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PLON SELERÓW NACIOWYCH I ICH JAKOŚĆ W TUNELACH POKRYTYCH RÓŻNYMI RODZAJAMI FOLII POLIETYLENOWEJ

Streszczenie

Wcześniejsze eksperymenty wykazały, że seler naciowy może być z powodzeniem uprawiany na zbiór wiosenny i jesienny pod osłonami wykonanymi z różnych folii, a czynnikiem w największym stopniu modyfikującym wielkość i jakość plonu były warunki świetlne. W trzyletnich doświadczeniach oceniano wpływ bezbarwnej, białej i czarnej folii polietylenowej wykonanej z surowców oryginalnych i recyklingowych na tunelach niskich na wzrost, plon i wybrane parametry jakości ogonków liściowych selerów naciowych odmiany Tango. Pomędzy poszczególnymi rodzajami folii nie stwierdzono różnic we wzroście elongacyjnym roślin. Jedynie pod folią czarną długość ogonków była o 1 cm większa niż w pozostałych obiektach. Plon ogonków liściowych był o kilka procent większy w przypadku stosowania folii bezbarwnej i w obiekcie kontrolnym. W lepszych warunkach świetlnych rośliny akumulowały więcej suchej masy i cukrów rozpuszczalnych. Stwierdzono, że większy wpływ na rośliny wykazała ilość promieniowania przepuszczanego przez folie niż jego skład spektralny. Nie obserwowano różnic pod wpływem folii oryginalnej i recyklingowej.