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THE IMPACT OF TUNNEL COVER TYPE ON GROWTH AND YIELD OF SWEET PEPPER*

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A b s t r a c t. In the years 1995-1996 investigations on modification of microclimate in tunnels covered with polyethylene (PE) and polypropylene (PP) were conducted. The tunnels were covered with PE film and non-woven PP. Both materials had either natural colour (transparent for PE and white for PP) or blue or red or green. Under these covers pepper plants of Mira cultivar were planted in early May. The transmittance of radiation through PE film and PP non-woven differed considerably. The film limited the quantity of radiation slightly but non-woven materials reduced the radiation rate remarkably, acting as an optical filter. As the result of shading and ventilation the temperature in the tunnels covered with porous non-woven PP the temperature was lower, which had a strong influence on the growth and yield of fruit. The plants under PP developed slower, produced less biomas and the ripening of fruits was delayed. The yield from the tunnels covered with PP was lower as compared to the yield from film tunnels. The highest yield was obtained under white non-woven, where the shading rate was the lowest. The small differences between fruit crops was obtained under film of various colours resulting from their high transmittance of radiation.

K e y w o r d s: fruit quality, growth, solar radiation, sweet pepper, temperature, yielding

INTRODUCTION

The high demand for sweet pepper fruit during late summer and autumn causes the search for competitive, heated growing structures. Rumpel and Grudzień [5] investigated the possibilities of direct plant covering with the use of simple plastic sheetings, such as perforated film or non-woven for the construction of low film tunnels. With the improvement of thermal conditions under non-woven tunnels early and marketable yields increased. Perforated film had a negative effect on growth and yield, which resulted from too high a temperature and air humidity. The plants developed abundant vegetative mass but fruiting was delayed. This implies that plant response to covering is affected by the physical properties of covers, especially by the transmittance of solar radiation and air as well as the capability of retaining warmth. Among the commonly applied covers, non-woven polypro-pylene creates the more favourable microclimate for plants. It transmits PAR radiation in a similar measure as polyethylene film with the additional effect of light scattering [1]. More stable thermal conditions are noted also under non-woven. Libik and Siwek [4] observed that during summer it does not cause overheating of plants and protects them from cold at night. The control of microclimate is possible also by the soil mulching with plastics. Decoteau *et al.* [2] investigated the effect of some colours of mulches on microclimate and the

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growth of sweet pepper. They found that red and black mulches reflected less radiation than white and yellow ones, causing increased soil temperature and plant faster growth. Similar results concerning plant responses to light conditions were obtained when soil was insulated with polystyrene, which confirmed the significant effect of reflected radiation on plant growth. Hatt *et al.* [3] also found that the mulch colour affected sweet pepper yields. In a warm climate the best results were obtained when soil was mulched with white film, which limited excessive temperature. Rylski *et al.* [6] indicated that sweet pepper responded considerably to shading. Light shortage and the high level of N fertilisation induced the deterioration of fruit quality. Particularly poor light conditions result in spotting and fruit discolouration.

The objective of this work was to determine the effect of microclimate conditions under low tunnels covered with PE film and non-woven PP of different colours on the growth, yield, and quality of sweet pepper fruit.

MATERIAL AND METHODS

The investigation was conducted in Mydlniki near Kraków in 1995 and 1996. Mira, the early cultivar of sweet pepper, producing yellow and conical fruits was used. Transplants were produced in a greenhouse, where seed was sown on February 20 and then seedlings with developed cotyledons were pricked off into plastic bands filled with peat-moss substrate. Transplants were set out under tunnels in the first 10 days of May. Neither pruning nor supporting of plants were applied. The tunnels 7 m long, 1.5 m wide, and 0.9 m high were covered either with polyethylene film (PE) or with non-woven polypropylene (PP) of different colours. The following covering variants were tested:

-PE film 0.15 mm colourless,
-PE film 0.15 mm green,
-PE film 0.15 mm blue,
-PE film 0.15 mm red,
-non-woven PP 50 g m^{-2} white,
-non-woven PP 50 g m^{-2} green,
-non-woven PP 50 g m^{-2} blue,
-non-woven PP 50 g m^{-2} red.

In addition a control growing without covering was applied. The experiment was established in 4 replicates with 15 plants each. The distance between plants was 50 cm x 30 cm and the plot area was 2.25 m^{-2}. Soil temperature at a depth of 10 cm was measured at 8 a.m. and 2 p.m. during 10 days in the vegetation period. On some sunny and overcast days spectral irradiance in the range of 400 - 700 nm (PAR) was measured on a radiometer, LI-COR model LI-185B, equipped with a line sensor 1 m long. The transmittance of solar radiation in the range of 300 - 1100 nm through every cover was also determined using a spectroradiometer, LI-1800 (LI-COR, USA). During the intense vegetative growth the following parameters of plants were measured: height, num-ber of leaves, and area of a leaf blade. The fruit was harvested at maturity and graded according to the norm BN-85/9137-36. The yield gathered before the end of July (the first 2-3 harvests) was assumed as an early crop. At full fruiting the dry weight of fruit (drying method according to Pijanowski), the content of sugar (Luff-Schoorl's method), and L-ascorbic acid (Tillmans's method) were estimated. The covers were kept over plants until the end of growing, i.e., the middle of October. The results were statistically analysed for the 2-factorial block design at $\alpha = 0.05$.

RESULTS

Microclimate conditions under plastic covers depend mainly on solar radiation. The laboratory measurements indicated that the transmittance of radiation within the ranges 300-1100 nm and 400-700 nm differed depending on the tested cover (Table 1.). The transmittance through PE film was 88.7-91.8% and 85.9- 90.9% in the above ranges, respectively. Among non-woven PP covers, only the white had a radiation transmittance similar to PE film (86.6% and 88.0%, respectively). The other non-woven colours limited light highly, transmitting only 49-51% and 27.9 - 41.7% of radiation in 300-1100 nm and 400-700 nm, respectively (Table 1, Fig. 1). The measurements of radiation transmittance in the field conditions gave similar results though here even higher

Table 1. Transmittance of solar radiation through PE film and non-woven PP (%)

Kind of cover	Perpendicularly to the solar quantum flux on a sunny day			
	in laboratory conditions		in field conditions	
	300-1100 nm	400-700 nm	400-700 nm sunny	400-700 nm overcast
No cover	100.0	100.0	100.0	100.0
PE film colourless	91.8	90.9	74.7	82.8
PE film green	88.7	87.6	70.8	80.1
PE film blue	90.3	89.3	73.4	78.4
PE film red	88.9	85.9	67.0	78.9
Non-woven PP white	86.6	88.0	52.2	57.3
Non-woven PP green	50.7	41.7	30.1	33.4
Non-woven PP blue	51.0	37.0	21.7	27.1
Non-woven PP red	49.0	27.9	17.6	24.0

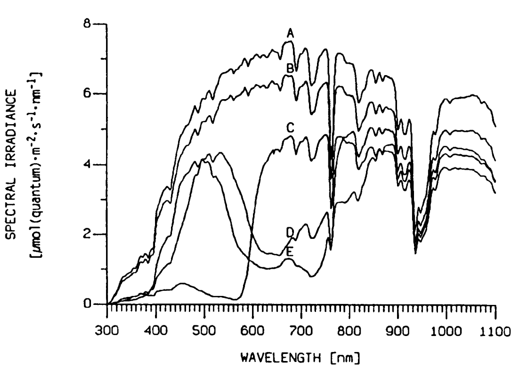

Fig. 1. Spectral irradiance in the midday hours on a sunny day in an open area (A) and transmittance of radiation through non-woven PP: B - white, C - red, D - green, E - blue.

differences occurred between co-vers and control. On a sunny day PE film transmitted 67.0 -74.7% PAR and non-woven PP 17.6-52.2%. During overcast the transmittance was 78.4 - 82.8% and 24.0 - 57.3% for PE film and non-woven PP, respectively.

The measurements of soil temperature showed differences in thermal conditions under tested covers. In the morning the temperature under tunnels covered with PE film was 3.2°C higher than outdoors. Non-woven covers protected soil from heat losses in an almost equal measure and the temperature under these tunnels was 2.1°C higher than outdoors. In midday hours these differences increased up to 3.8°C in the case of PE film but decreased down to 0.8°C in the case of non-woven. At the same time, the difference between the temperature under PE tunnels and non-woven ones was 3.0°C. No significant differences of soil temperature were noted between colours of covers both from PE and PP. The obtained results (Table 2) indicated that PE film created more favourable thermal conditions for sweet pepper growth than non-woven PP. The latter shaded the growing area considerably and its texture caused a faster air exchange.

The measurements of morphological parameters of plants showed a significant effect of covers on the vegetative growth of sweet pepper (Table 3). The growth in length was quicker under PE film and plants were higher than under non-woven. The average height of plants was 40.4 cm in the case of PE covers and 36.3 cm in the case of non-woven ones. Different radiation and thermal conditions under tested tunnels resulted in the differences of plant foliage. Under PE film the plants developed greater number of leaves (73.6 leaves per plant, on average) than under non-woven (55.5 leaves per plant, on average). The area of leaf blades did not differ significantly. Under PE tunnels the highest biomass of plants was observed when the covering PE film was colourless or blue and under PP tunnels when non-woven was white.

The microclimate conditions under tested covers affected the plant yielding significantly. The early yield under tunnels covered with PE film was considerably higher than under non-woven tunnels (Table 4). It reached 1.89 kg m^{-2}

Table 2. Soil temperature at the depth of 10 cm under tunnels covered with PE film and non-woven (°C)

Kind of cover	May 16-25, 1995		May 10-19, 1996		Mean for 1995 and 1996	
	8 a.m.	2 p.m.	8 a.m.	2 p.m.	8 a.m.	2 p.m.
No cover	10.9	14.5	12.2	16.7	11.5	15.6
PE film colourless	13,7	18.9	15.4	20.1	14.5	19.5
PE film green	14.1	18.8	15.7	20.6	14.9	19.7
PE film blue	13.9	18.2	15.5	20.6	14.7	19.4
PE film red	13.8	18.1	15.7	20.3	14.7	19.2
Non-woven PP white	13.2	15.7	14.5	18.0	13.8	16.8
Non-woven PP green	12.7	15.8	14.5	18.7	13.6	17.2
Non-woven PP blue	12.6	15.0	15.0	17.8	13.8	16.4
Non-woven PP red	12.3	14.6	14.3	16.2	13.3	15.4

Table 3. Characteristics of plant vegetative growth in tunnels covered with PE film and non-woven PP

Kind of cover	Plant height (cm)			Number of leaves			Area of a leaf blade (cm^{-2})		
	1995	1996	Mean	1995	1996	Mean	1995	1996	Mean
No cover	32.1	29.3	30.7	25.6	66.3	45.9	21.0	30.5	25.7
PE film colourless	39.3	40.2	39.7	59.2	95.8	77.5	31.9	31.6	31.7
PE film green	40.5	39.6	40.0	52.5	81.6	67.0	27.9	33.3	30.6
PE film blue	39.7	44.8	42.2	57.3	101.0	79.1	40.9	34.3	37.6
PE film red	38.5	41.0	39.7	54.2	87.7	70.9	34.8	27.9	31.3
Non-woven PP white	32.1	39.4	35.7	45.7	82.6	64.1	41.2	30.1	35.6
Non-woven PP green	34.2	42.2	38.2	47.7	69.8	58.7	39.6	31.5	35.5
Non-woven PP blue	33.5	37.9	35.7	39.3	65.6	52.4	35.1	31.5	33.3
Non-woven PP red	32.0	40.7	36.3	31.2	62.2	46.7	38.5	29.9	34.2
LDS 0.05 cover (A)	9.37	4.58		2.01	8.48		3.46	4.25	
Colour of cover (B)	0.92	3.18		1.27	10.96		2.61	3.35	
A x B	8.54	5.89		2.02	15.65		4.61	5.79	

Table 4. Fruit yield of sweet pepper cv. Mira under tunnels covered with PE film and non-woven PP (kg m^{-2})

Kind of cover	Early yield			Marketable yield			Total yield		
	1995	1996	Mean	1995	1996	Mean	1995	1996	Mean
No cover	0.61	0.56	0.58	4.07	3.63	3.85	4.30	3.74	4.02
PE film colourless	1.16	2.53	1.84	4.64	4.96	4.80	5.13	5.08	5.10
PE film green	1.15	1.87	1.51	4.77	4.02	4.39	5.23	4.18	4.70
PE film blue	1.46	3.11	2.28	4.70	5.93	5.31	5.04	6.05	5.54
PE film red	1.61	2.25	1.93	5.15	5.01	5.08	5.84	5.19	5.51
Non-woven PP white	1.38	1.38	1.38	4.02	3.74	3.88	4.22	3.95	4.08
Non-woven PP green	0.55	0.71	0.63	2.90	2.59	2.74	3.05	2.72	2.88
Non-woven PP blue	0.15	0.28	0.21	2.10	1.78	1.94	2.20	1.99	2.09
Non-woven PP red	0.51	0.67	0.59	2.05	2.37	2.21	2.11	2.50	2.30
LDS 0.05 cover (A)	0.219	0.183		0.815	0.484		1.049	0.493	
Colour of cover (B)	0.253	0.312		0.302	0.771		0.341	0.774	
A x B	0.369	0.425		0.881	1.065		1.114	1.075	

and exceeded by 170% the early yield from plants under tunnels covered with non-woven PP. The highest early yield in 1995 was noted under tunnels covered with PE film of red and blue colours. In the second year of investigations it was the highest under blue, colourless, and red PE film. The early yield under non-woven tunnels matched the yield under PE only in the case of white PP. The plants under the other non-woven tunnels gave early yields equal to or even lower than the control. Similar dependencies were found in the marketable yield. Under PE tunnels the marketable yield was 4.89 kg m^{-2}, on average, i.e., 81.8% higher than under PP ones. The highest marketable yield in 1995 was noted under red PE film and in 1996 under blue. The plants grown under PE tunnels yielded the lowest when the covering film was green. Due to shading the effect of non-woven on sweet pepper yield was unfavourable. The best result was observed in the case of white PP, though the marketable yield was the same level as the control. Under the other non-woven tunnels the yield of marketable fruit was lower by 70.0%, on average. In comparison with the marketable yield under PE tunnels this difference was 112.0%. The share of non-marketable yield in the total one was small in all cases and did not depend on the kind and colour of covers.

According to the chemical analyses of sweet pepper fruit the shading effect of non-woven covers resulted in a deterioration of fruit quality (Table 5). Dry weight was by 5.4%, on average lower than under tunnels covered with PE film. The content of total sugar, though, was similar for all tested tunnels. The one-year results of L-ascorbic content indicated that fruit under PE film gathered more of this compound (by 5.5%, on average). The highest content of sugar and L-ascorbic acid as well as dry weight were noted in the combinations where the conditions of radiation were the best, i.e., under colourless PE film and white non-woven. The latter limited direct solar radiation but at the same time caused its scattering.

DISCUSSION

The obtained results concerning microclimate showed a considerable variation in the radiation and thermal conditions under the covers of PE film and non-woven PP. PE film transmitted much more radiation in the ranges 300-1100 nm and 400-700 nm. Among non-woven covers of different colour only the white one secured plants with radiation conditions similar to those observed under PE tunnels. In addition, this cover contributed to the effect of solar flux scattering which is a favou-rable phenomenon in the case of vegetable crops [1]. The shading of soil by non-woven resulted in a decreased temperature in comparison with tunnels covered with PE film, especially in the midday hours. Similar observations were made by Libik and Siwek [4] during the covering of water melon with non-woven and PE film in dimmer. Direct plant covering with PE film caused

Table 5. Fruit dry weight and content of total sugar and L-ascorbic acid in fruit of sweet pepper cv. Mira grown in tunnels covered with PE film and non-woven PP

Kind of cover	Dry weight (%)			Total sugar (%)			L-ascorbic acid (mg%)
	1995	1996	Mean	1995	1996	Mean	1996
No cover	6.24	5.34	5.79	3.13	1.68	2.40	114.8
PE film colourless	5.98	5.91	5.94	3.11	2.55	2.83	126.5
PE film green	6.01	5.58	5.79	3.11	2.17	2.64	111.5
PE film blue	5.94	6.17	6.05	2.91	2.35	2.63	102.2
PE film red	5.56	5.65	5.60	3.14	2.43	2.78	123.1
Non-woven PP white	6.29	5.30	5.79	3.27	2.47	2.87	131.7
Non-woven PP green	5.70	5.40	5.55	2.89	2.19	2.54	107.9
Non-woven PP blue	5.35	5.18	5.26	2.88	2.08	2.48	101.4
Non-woven PP red	5.57	5.60	5.58	3.08	2.32	2.70	98.3

an increase in air temperature over 40^{0}C despite perforation. In this respect a low PE tunnel appeared to be a better cover. The plants under non-woven PP were lower, though statistical analysis showed no differences. The colourless PE film and white non-woven PP inhibited the elongation growth, but statistical differences were not observed. The number of leaves was higher under tunnels covered with PE film. With the covers of colourless PE film and white non-woven PP a higher number of leaves per plant was noted. The leaf blade area was higher under non-woven PP, but statistical differences were significant only in 1995. The limited vegetative growth of sweet pepper plants under coloured non-woven covers resulted from their low transmittance of solar radiation. Sweet pepper is a very sensitive crop to light conditions and responds strongly to its deterioration, i.e., produces poorer foliage and loses flowers and fruit sets [7]. The yield of plants expressed its response to specific microclimate conditions under tested covers. The early yield as well as the marketable and total were significantly higher under the covers of PE film. Here the radiation and thermal conditions were much better, especially in the first period of growing, and a result the early yield was higher by 170%. The growing conditions under non-woven were better in summer when the temperature was high and this was reflected in the final difference in the level of marketable yield (81.8%). A similar response for sweet pepper plants to the limitation of radiation by the tunnel covered with two- and three-layer sheetings was observed by Siwek [7] and Siwek and Libik [8]. In the light of these investigations it can be seen that tunnels giving insulation create conditions for an accelerated growth and fruiting, but only in the first period of growing. After stabilisation of thermal conditions higher yields resulted from better radiation conditions, and from more stable plant growth, under single sheeting. Statistical analysis of the effect of cover colour on yield showed that colourless PE film and white non-woven PP contributed to the highest early yield. Relative differences in total marketable yield were smaller but demonstrated the same tendency as in the early yield. The environmental conditions of the present investigation affected also the quality of sweet pepper fruit. Dry weight as well as the content of L-ascorbic acid were higher in fruit under PE film, especially colourless and under white non-woven. These covers created the most favourable light conditions: PE film due to the minimal limitation of solar radiation, and non-woven PP also due to its scattering.

CONCLUSIONS

1. Radiation and thermal conditions under tunnels covered with PE film were better than under those covered with non-woven PP. Coloured non-woven limited solar radiation considerably and reduced soil temperature.
2. The sweet pepper plants grown under tunnels developed a greater number of leaves and higher biomass.
3. The early and marketable yield of sweet pepper under the tunnels covered with PE film were significantly higher than under those covered with non-woven PP.
4. The fruit under PE film had higher dry weight and L-ascorbic acid content.

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