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The type of polyethylene mulch impacts vegetative growth, yield, and aphid populations in watermelon production

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Abstract

Polyethylene (PE) films are widely applied as mulches by commercial producers of watermelon. During the last decade the industry has developed a variety of new mulch PE film formulations with numerous positive effects on watermelon production. In order to define the influence of mulching on growth and yield of watermelon and on aphid populations landing in the crop, we carried out field experiments at two locations (Pula and Opuzen) in the Mediterranean part of Croatia. Watermelon was grown on black, brown, clear, green, and white PE films. During the first 60 days after planting (DAP) the highest soil temperatures, at 5 cm depth, were recorded under the clear PE film. Positive correlation of vine length, branch number and early and total yield was found to both sum and average soil temperatures during the first 60 DAP in three of the total of five experiments. Clear PE films had generally positive effects on vegetative growth and early yield while the trend for white PE films was quite the opposite. For the majority of the observed traits we found no difference between semi-transparent (brown and green) mulches. The effects of semi-transparent films (brown and green) on watermelon vegetative growth and yield were similar to each other. During two years in Opuzen, we recorded 70 species of Aphididae of 48 genera, with 11 species making up more than 1% in each year. *Toxoptera aurantii* (Boyer de Fonscolombe) and *Aphis gossypii* Glover were the most dominant species in 2004. The number of winged aphids was consistently lower under clear and black PE films. According to our results, clear PE film could be recommended for an early spring planting under conditions of the Mediterranean climate.

Key words: Aphididae, *Citrullus lanatus*, Cucurbitaceae, fruit, PE film, soil temperature, virus vectors.

Introduction

Watermelon [*Citrullus lanatus* (Thumb.) Matsum et Nakai] is among the most widely cultivated crops in the world and the acreage under it has been increased in the past years [1]. The region for commercial production of watermelon is limited to areas with long growing season. In less suitable regions, the harvest could be delayed and yield reduced by low air and soil temperatures during night, following spring and early summer planting [2]. Development of new technologies and especially application of PE films as mulch have shortened growing season and enhanced earliness and yield [3-6]. Nowadays, usage of PE films and fertigation are widely adopted by commercial producers of watermelon [4, 6, 7].

Earlier harvest is among the most important advantages of PE mulch application [8] and the most commonly used PE mulch in vegetable production is black PE film of low density [9]. However, during the last decade the industry has developed a variety of new formulations of colored, transparent, photo-degradable and photo-selective PE films for mulches [10]. The type of PE mulch considerably affects soil temperature at 5 cm depth depending on the mode of mulch heating and heat transferring [2, 7, 10, 11]. The soil temperature can be higher up to 7°C under clear mulch compared to bare soil [10]. Under semitransparent and photo-selective PE mulches (brown and green) soil temperature is increased approximately 4.5°C compared to bare soil, under nontransparent (black) around 2.5°C, and under reflective ones (white on black) around 0.7°C [2, 7, 10]. Besides beneficial effect on earliness, PE film as a mulch can enhance plant growth and development, increase yield, decrease soil evaporation and nutrient leaching, reduce incidence of pests and weeds, and improve fruit cleanliness and quality [10, 12-17]. However, the impact on previously listed traits will depend on mulch type [12].

The quantity and quality of light reflected from the mulch surface back to leaves affect not only plant growth and development but the behaviour of insects visiting plants [10, 18]. A number of aphid species have been recorded as Cucurbitaceae crops feeders [19-21]. Some of them transmit one or more virus diseases affecting cucurbits [22-24]. Mulch can attract or repel insects depending on the type and color. Compared to the bare soil, aphid number is reduced by use of clear, black and white PE mulches [12, 13, 20], while silver reflective mulch reduces aphid number more efficiently than white, yellow or black mulch with yellow edges [25]. However, the effect of mulch color on insect population is very complex and closely related to the influence on growth of the plant canopy [11].

The variety of positive effects of PE mulch makes it highly suitable for sustainable vegetable production aiming at reduction of nutrient and pesticides use [26]. Since, in Croatia the main growing areas of watermelon are in sensitive karst region, prone to leaching of pests and nutrients, the ways of environmental protection are of high importance. Black polyethylene mulch is the most often used cover in Croatia. The aim of the study was to compare the effect of standard black PE mulch with available range of PE film colors on soil temperature, vegetative growth and yield components of watermelon, as well as aphid number in the Mediterranean macro-region of Croatia.

Material and Methods

Experimental sites and treatments: Field experiments with watermelon [*Citrullus lanatus* (Thunb.) Matsum & Nakai], cv. Fantasy (Known-You Seed Co., Ltd., Taiwan) were conducted at Pula (44°51′N, 13°51′E, 10 m elevation) and Opuzen (43°00′N, 17°34′E, 3 m elevation) both located in the Mediterranean area of Croatia.

At Pula location, the location, the experiments were carried in 2003, 2004 and 2005 on Terra rossa, a type of red clay soil produced by the weathering of limestone and dolomites. An average annual rainfall at Pula is 816 mm and the mean air temperature 14.1°C.

Opuzen is situated in the delta of the river Neretva, which represents the most important watermelon-growing area in Croatia. The trials were carried out during 2004 and 2005 on hydromeliorated allomorphic soil of filthy clay loaded on the fluvial deposits of the river. An average annual rainfall at Opuzen is 1232 mm and the mean air temperature 15.7°C.

The treatments (five differently colored polyethylene mulches) were arranged in a randomized complete block design with three replications. Black (non-transparent), brown and green (semitransparent) PE films were 0.02 mm thick and 120 cm width (Ginegar Plastics Products Ltd., Kibbutz Ginegar, Israel), clear (reflective) was 0.04 mm thick and 120 cm width (Brković d.o.o., Sveta Nedjelja, Croatia). The white on black (non-transparent) mulch was 0.07 mm thick and 120 cm width (Eiffel Plastics Industry-Bernardi Paride, Fontanellato Ltd. - Parma, Italy) and it was applied only in 2005.

Field preparation and cultural practice: Cultural practice was the same for both sites unless described otherwise. A month before planting fields were ploughed at 25-30 cm and preplant fertilizer NPK at 1000 kg ha^{-1} was broadcast applied and cultivated to a 20 cm depth. Organic manure (40 t ha^{-1}) was ploughed only in 2003. The herbicide Devrinol 45 FL (napropamid, Pinus TKI d.d., Rače, Slovenia) at 4 L ha^{-1}, was incorporated with fertilizer. Additional water soluble fertilizers Kristalon™ (Hydro Agri Rotterdam B.V. Rotterdam, Norway), at 100 kg ha^{-1} per irrigation, were fertilized during season as follows: NPK 13-40-13 (seven days after planting-7 DAP), NPK 17-6-18 + 3MgO (17 and 27 DAP) and NPK 13-5-26 + 3MgO (37 and 47 DAP). In total, N was fertigated at rate 143 kg ha^{-1}.

The transplants were grown in a heated greenhouse. The sowing was in the first week of April and in the second half of February in trays of cell volume 20 cm^3, filled with the commercial substrate Brill (Gebr. Brill Substrate GmbH & Co. KG, Georgsdorf, Germany). After 15-20 days, the seedlings were transferred into trays of cell volume 100 cm^3. Seedlings were irrigated every day and fertilized once a week with a soluble fertilizer Folifertil-T (Veterina d.d., Zagreb, Croatia).

Planting was done at the stage of two to three true leaves at both locations. Planting was done on 25 May 2003, 23 May 2004 and 22 May 2005, and on 27 April 2004 and 19 April 2005. Taking into account the more southern position of Opuzen, temperatures of soil and air are generally higher there than for the same period in the season. Therefore, it is possible to plant watermelon as early as about mid-April when soil temperature usually reaches 15°C.

Planting beds were 1.0 wide and 0.1 m high and covered with PE films. The rows were 2.0 m apart and in-row plant spacing was 1.5 m. Experimental plot was single row 100 m long, except 2005 where each plot consisted of three rows 21 m long.

The drip irrigation tape (T-Systems International, San Diego, California, USA) with emitters spaced every 20 cm and a capacity of 4 L h^{-1} was installed near the centre of the bed. Soil insecticide Volaton G5 (foksim, Pinus TKI d.d., Rače, Slovenia) at rate of 3 kg ha^{-1} was incorporated in holes during planting. Weeds between rows were removed by hand if necessary, while diseases and pests were controlled according to common practices in commercial production.

Measurements: Soil temperature at 5 cm depth was recorded daily at 07:00, 14:00, and 21:00 HR during May and June by soil thermometers (Tlos d.d., Zagreb, Croatia) inserted between two plants in the middle of the plot. The average daily temperatures were calculated as follows: 7:00+14:00+(21:00*2)/4.

The number of branches thicker than 5 mm, and the length, diameter and number of leaves of the most developed vines were recorded from 15 plants in the middle of the each plot. Measurements were done on 22nd, 29th, and 19th DAP in 2003, 2004, and 2005, respectively, and on 29th and 36th DAP in 2004 and 2005, respectively.

Watermelons were harvested as fruits ripened and fruit from the first harvest were considered early. Watermelons at each individual site were harvested three times each year. All fruits were counted and weighed and fruits smaller than 3 kg, misshaped and damaged were taken as non-marketable.

Aphid sampling at Opuzen: Aphids were sampled in both 2004 and 2005. Winged aphids were caught into yellow water pan trap. The pans were placed in the middle of the plot. Depending on environmental conditions water was added to the pans during the week. There were 12 traps in 2004 and 15 in 2005. Insect samples were collected once a week from the planting until mulch was covered by canopy closure.

Collected material was examined and aphids separated using a stereomicroscope (Zeiss, Stemi 2000). Aphid specimens were preserved in 70% ethanol until identification. Species composition was determined according to following taxonomy keys [27-29] and those constituting more than 1% were considered dominant. Due to missing insect parts, some specimens were identified only up to the genus level.

Statistical analysis: General linear model procedure [30] was used for statistical analyses. Data were tested for normality of distribution and homogeneity of variance and transformed when necessary. Due to significant interactions between year and location for the most of growth and yield parameters data were analyzed separately for each year and location and the mean separation was done by LSD test at $P \leq 0.05$. Simple linear regression was utilized to determine relationship between the total and averaged soil temperature during the first 60 DAP and for the growth and yield data.

The number of winged aphids per trap was transformed using the arcsine square root transformation and data were analyzed by a repeated-measures analysis of variance (ANOVA) with date of measurement as the repeated factor. Since the interaction between mulch and date of measurement was significant, data were analyzed separately for each date and the mean separation was done by LSD test at $P \leq 0.05$.

Results and Discussion

Soil temperature: Soil temperatures measured below the PE films at 5 cm depth showed regularity at both locations and in both years (Table 1). During the first 60 DAP the soil temperature was highest under clear PE film. The soil under white mulch was on the average 6.5°C colder than that under the clear ones and it was constantly colder compared to other mulch colors as well. Generally, the soil temperature was lower under black compared to brown and green PE films for which similar temperatures were measured during the first 60 DAP (Table 1). The changes in soil temperature below tested PE films could be attributed to different manners of heating and heat transfer to soil, and also to heat accumulation during day and loss during night [2, 10, 31, 32].

Opuzen is warmer location and therefore suitable for early planting. However, as consequence of later planting, soil temperatures during the first 60 DAP were higher compared to Opuzen (Table 1). If we compare soil temperatures for the same period at both locations, it is evident that they are higher for Pula, because the PE film was covered by plant canopy earlier in the season as a result of an early planting. Therefore, the effect of PE film color is more evident at early stages of plant growth when the mulch is not shaded by plant canopy [33]. Locher *at al*. [34] observed growth depression caused by high soil temperatures under clear and semitransparent mulches due to the lack of canopy closure in pepper.

Vegetative growth: Observed parameters of vegetative growth were differently affected by PE film color, but the effects were dependent on the interaction of the year and location (Table 2). The main vine length was longer at clear than at black PE film during three years, and we found no difference between black and green mulches (Table 2). In 2004, there was no difference in vine length regarding film color, while in 2005 vines at green (91.9 cm) were almost twice as long as those on white (45.7 cm) films.

Like for the vine length, vine diameter was always lower at black than on clear PE film, and except in 2005, there was no difference between black, green and brown films (Table 2). We found no difference in vine diameters, except in 2005 when vines were narrower at white compared to clear PE film.

The main vine leaf number and number of branches were similar at brown, green and clear PE films in both 2003 and 2004 and in

Table 1. Average ten-days soil temperatures at 5 cm depth during first 60 days after planting under colored mulch at Pula and Opuzen in 2003, 2004, and 2005.

PE-film	May			June			July			AVR
	1-10	11-20	21-31	1-10	11-20	21-30	1-10	11-20	21-31	
	Location and planting date									
	Pula, 25 May 2003									
			Last 6 days[1]						First 4 days[2]	
Black			28.5 d	32.2 d	33.3 d	33.0 d	32.9 d	31.8 d	30.2 d	31.7 c
Brown			30.3 b	33.2 b	34.0 b	33.7 b	33.5 b	32.8 b	30.7 b	32.6 b
Clear			31.3 a	34.1 a	36.1 a	35.9 a	34.5 a	33.9 a	31.1 a	33.8 a
Green			29.2 c	32.9 c	33.7 c	33.5 c	33.3 c	32.4 c	30.5 c	32.2 bc
	Pula, 23 May 2004									
			Last 8 days						First 2 days	
Black			22.7 c	26.0 c	27.1 d	28.3 d	28.3 c	28.1 c	31.8 b	27.5 c
Brown			24.7 b	27.7 b	28.4 b	29.0 b	28.9 b	28.5 b	32.1 ab	28.5 b
Clear			27.5 a	28.2 a	28.9 a	32.3 a	31.8 a	30.3 a	32.7 a	30.2 a
Green			25.1 b	27.8 b	28.0 c	28.9 c	28.9 b	28.1 c	31.8 b	28.4 b
	Pula, 22 May 2005									
			Last 9 days						First 1 day	
Black			27.3 c	25.3 d	27.5 d	32.1 c	26.1 c	27.4 c	29.3 b	27.9 b
Brown			27.5 b	25.9 c	28.7 b	32.2 c	26.4 b	27.4 b	29.4 b	28.2 b
Clear			30.4 a	28.0 a	30.2 a	34.1 a	28.0 a	28.6 a	30.6 a	30.0 a
Green			27.3 c	27.0 b	28.3 c	32.4 b	26.3 b	27.0 b	29.5 b	28.3 b
	Opuzen, 27 April 2004[3]									
						First 6 days				
Black	20.3 c	22.5 c	23.4 c	23.9 d	27.2 b	25.4 b				23.8 c
Brown	21.3 b	23.9 b	25.7 b	26.0 b	28.8 a	25.3 b				25.2 b
Clear	23.5 a	27.0 a	28.4 a	27.0 a	28.2 a	26.5 a				26.8 a
Green	21.4 b	24.6 b	26.1 b	24.9 c	26.8 b	24.9 b				24.8 b
	Opuzen, 19 April 2005									
					First 8 days					
Black	21.0 c	23.8 c	25.3 c	23.3 b	22.8 b					23.2 c
Brown	22.4 b	25.8 b	27.4 ab	24.5 b	24.9 a					25.0 b
Clear	24.6 a	27.2 a	28.6 a	26.2 a	25.3 a					26.4 a
Green	22.8 b	25.2 b	26.2 bc	24.2 b	24.3 ab					24.5 b
White	17.6 d	20.4 d	22.9 d	20.5 c	18.2 c					19.9 d

[1] The temperatures are average of the last 6 days of the ten-day period or as listed in the rest of the table. [2] The temperatures are average of the first 4 days of the ten-day period or as listed in the rest of the table.

Table 2. Length, diameter and leaf number of the main vine, and number of branches of watermelon grown on colored mulch at Pula and Opuzen in 2003, 2004, and 2005.

Mulch color	Main vine length, cm	Main vine diameter, mm	Main vine leaf no.	No. of branches
		Pula		
		2003 (17 DAP[1])		
Black	31.7 b[2]	5.2 b	10.7 a	2.8 b
Brown	35.8 ab	5.4 b	10.6 a	3.1 ab
Clear	41.5 a	6.5 a	11.7 a	4.0 a
Green	37.9 ab	5.6 ab	11.0 a	3.3 ab
		2004 (29 DAP)		
Black	63.1 b	5.2 b	12.6 b	5.2 b
Brown	83.5 a	6.2 a	15.2 a	6.7 a
Clear	90.7 a	6.3 a	16.4 a	7.1 a
Green	83.2 a	6.3 a	14.9 a	6.6 a
		2005 (19 DAP)		
Black	32.6 c	4.2 b	9.6 b	3.2 b
Brown	34.0 bc	4.2 b	9.9 b	3.1 b
Clear	44.6 a	5.1 a	12.3 a	4.3 a
Green	39.2 ab	4.3 b	11.9 a	3.5 b
		Opuzen		
		2004 (29 DAP)		
Black	36.0 a	4.8 a	10.5 b	2.2 a
Brown	36.3 a	4.7 a	11.0 ab	2.2 a
Clear	38.3 a	4.8 a	11.6 a	2.2 a
Green	34.1 a	4.5 a	10.5 b	2.4 a
		2005 (36 DAP)		
Black	71.9 b	6.5 ab	18.9 a	4.1 b
Brown	86.9 ab	7.0 ab	20.4 a	4.6 ab
Clear	89.6 ab	7.2 a	20.9 a	4.5 ab
Green	91.9 a	6.9 ab	20.4 a	4.8 a
White	45.7 c	6.3 b	15.8 b	3.3 c
		Significance[3]		
Location (L)	NS	0.001	0.001	0.001
Year (Y)	0.001	0.001	0.001	0.001
Mulch (M)	0.001	0.001	0.001	0.001
L*Y	0.001	0.001	0.001	0.001
L*M	NS	0.035	0.043	NS
Y*M	NS	NS	NS	NS
L*Y*M	NS	0.024	NS	NS

[1]Days after planting. [2]Means within column for each location and year followed by the same letter are not significantly different according to *LSD*-test at $P \leq 0.05$. [3]Effects were insignificant (NS, $P > 0.05$) or significant at reported *P* value.

2004 (Table 2). More leaves were observed on clear compared to black film in both 2004 and 2005, and in 2004, while for the branch number the same was true only for Pula for both years.

Generally, brown and green PE films had similar effect on vegetative growth regardless of the location or year, whereas plants were better developed at clear compared to black PE film. The white film was used only in 2005, but compared to other films it highly depressed all growth parameters except vine diameter. Vegetative growth of watermelon is directly related to air and soil temperature, and as in other crops, it will be enhanced if temperatures are close to an optimum for growth [2, 32].

Although we observed similar effects of PE film colors on soil temperature for both locations (Table 1), the effect of PE film on vegetative growth parameters was less marked (Table 2). That was the most pronounced during the first 15 DAP (data not shown) when vegetative growth was poor regardless of the PE film color. Therefore, measurements were carried out later during the season (29 and 36 DAP) as compared to Pula (17, 29, and 10 DAP). The lack of response is probably related to soil temperatures. They were lower than optimum for vegetative growth of watermelon under all PE films at Opuzen.

Early marketable yield and yield components: Early yield of watermelon (t/ha) was affected by PE film color and dependent on the interaction between PE films, location, and year (Table 3). The early yield was higher at clear compared to green and black PE films, in four and three out of five experiments, respectively (Table 3). There was no difference in early yield between brown and clear mulch except in 2005. Due to less vegetative developed plants on white PE film (Table 2) and probably later flowering and fruit set, we found no fruit on white mulch in the first harvest (Table 3).

Similar response to PE film color was found for fruit number per area and plant, and they were more affected by film color and year than by location (Table 3). The fruit number per area and plant were affected by film color almost in the same manner as an early yield, except at Opuzen in 2005 where no fruit was obtained at white PE film in the first harvest.

Table 3. Early and total yield of watermelon grown on colored mulch at Pula and Opuzen in 2003, 2004 and 2005.

	Early yield				Total yield			
Mulch color	t/ha	no/ha	no/plant	kg/fruit	t/ha	no/ha	no/plant	kg/fruit
Pula, 2003								
Black	37.1 a[1]	3973 a	1.2 a	9.4 a	74.9 a	8266 a	2.5 a	8.0 a
Brown	35.5 a	3872 a	1.2 a	9.2 a	67.0 ab	7374 b	2.2 b	9.1 a
Clear	36.2 a	3703 a	1.1 a	9.9 a	62.2 b	6499 c	2.0 c	9.5 a
Green	26.6 b	2727 b	0.8 b	9.7 a	60.3 b	6617 c	2.0 c	9.1 a
Pula, 2004								
Black	19.9 c	2576 b	0.8 b	7.8 a	42.4 b	5943 c	1.8 c	7.2 ab
Brown	26.2 ab	3821 a	1.1 a	6.9 a	47.7 b	7105 ab	2.1 ab	6.7 b
Clear	31.3 a	4175 a	1.3 a	7.5 a	59.2 a	8014 a	2.4 a	7.4 a
Green	24.4 bc	3283 ab	1.0 ab	7.6 a	46.9 b	6650 bc	2.0 bc	7.0 ab
Pula, 2005								
Black	12.1 c	1616 c	0.5 c	7.6 a	35.1 c	5084 c	1.5 c	6.9 a
Brown	15.2 b	2104 b	0.6 b	7.3 a	43.5 b	6162 b	1.9 b	7.1 a
Clear	20.7 a	2609 a	0.8 a	8.0 a	57.7 a	7795 a	2.3 a	7.4 a
Green	15.6 b	2138 b	0.6 b	7.3 a	38.8 bc	5606 bc	1.7 bc	6.9 a
Opuzen, 2004								
Black	34.8 b	3333 b	1.0 b	10.2 a	78.0 a	8045 a	2.4 a	9.7 a
Brown	47.7 a	5124 a	1.5 a	9.3 a	79.5 a	8539 a	2.6 a	9.3 ab
Clear	39.9 ab	4033 b	1.2 b	10.5 a	79.0 a	8313 a	2.5 a	9.5 ab
Green	7.9 c	823 c	0.2 c	10.0 a	81.5 a	8951 a	2.7 a	9.1 b
Opuzen, 2005								
Black	13.7 b	1852 a	0.6 a	7.4 c	36.4 bc	4550 bc	1.4 bc	8.0 b
Brown	18.4 ab	2143 a	0.6 a	8.6 ab	46.3 a	5291 ab	1.6 ab	8.7 a
Clear	21.1 a	2328 a	0.7 a	9.0 a	49.9 a	5741 a	1.7 a	8.7 a
Green	17.9 ab	2222 a	0.7 a	8.1 bc	42.5 ab	5000 ab	1.5 ab	8.5 ab
White	0.0 c	0 b	0.0 b	0.0 d	29.2 c	3730 c	1.1 c	7.9 b
Significance[2]								
Location (L)	0.001	NS	NS	0.001	0.001	NS	NS	0.001
Year (Y)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Mulch (M)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
L*Y	0.013	NS	NS	0.001	0.001	0.001	0.001	0.001
L*M	0.001	0.001	0.001	NS	0.016	0.002	0.002	NS
Y*M	0.001	0.001	0.001	NS	0.001	0.001	0.001	NS
L*Y*M	0.001	0.001	0.001	NS	NS	NS	NS	NS

[1]Means within column for each location and year followed by the same letter are not significantly different according to *LSD*-test at $P \leq 0.05$. [2] Effects were insignificant (NS, $P > 0.05$) or significant at reported *P* value.

The significant effect of PE film color on fruit weight was found only at Opuzen in 2005, when fruit weight was enhanced on clear (9.0 kg/fruit) and brown (8.6 kg/fruit) compared to black (7.4 kg/fruit) PE films (Table 3). It seems that fruit weight is more affected by genotype than PE film color [35, 36]. Since PE film affected the number of fruit per plant rather that fruit weight, we may assume that early yield is more determined by number of fruit per plant than by fruit weight. Beneficial effect of PE mulch on the increase of the early yield was also found for watermelon [7], zucchini [13], tomato [11, 17, 37, 38] and pepper [17].

Total marketable yields and yield components: The color of PE film, location and year all affected total yield of watermelon (Table 3). The total yield was influenced by PE film color in the similar manner as early yield which confirms results of Soltani *et al*. [2]. The total yield was higher at clear compared to other PE film colors at Pula in 2004 (59.2 t/ha) and 2005 (57.7 t/ha), whereas there was no difference among brown and green films probably due to their similar effects on soil temperature. The total yield at black PE film (74.9 t/ha) was higher than at clear one (62.2 t/ha) at Pula 2003, while it was lower at Pula in 2004 and 2005 as well as at Opuzen in 2005. In 2005, lower yield was obtained at Opuzen, at white and black PE films compared to other colors. Generally, obtained yields were similar to those achieved in other studies [3, 6, 7].

The total number of fruit per area and plant was dependent on year and PE film color, and similar trend was found for both traits regarding mulch color (Table 3). More fruit were harvested at black mulch compared to other colors at Pula in 2004 and at clear film at Pula in 2005. Except at Pula in 2004, there was no difference in number of fruit per area or per plant between green, black and brown PE films.

Significant effects of location, year and PE film color on fruit weight were also observed (Table 3). The fruit weight was higher at Opuzen compared to Pula ($P \leq 0.001$), where fruit weight decreased each year due to the planting on the same field. The color of PE film effected fruit weight at Pula in 2004 and at Opuzen in both years, even though not steady. Andino and Motsenbocker [36] found no effect of mulch color on fruit weight.

The depression of early and total yield and their components with each subsequent year of planting was obvious at both locations confirming sensitivity of watermelon on the lack of crop rotation (Table 3). The problem could be alleviated by adoption of some new, more tolerant cultivars [39] or usage of colored PE mulches like in tomatoes [40].

***Relation of soil temperature and vegetative growth and yield*:** The relation between soil temperature and vegetative growth and yield was dependent on location and year of the study (Table 4). At Pula in 2003, the soil temperatures were optimum for the growth of watermelon under all PE films, whereas at Opuzen in 2004 the trend was quite the opposite, that is, with the soil temperatures lower than optimum at the early stages of growth. In both cases we found the lack of correlation between soil temperature and all observed growth and yield parameters (Table 4). Except for two previously mentioned cases, we observed significant relation of vine length, branch number, early and total yield to both sum and average soil temperatures during the first 60 DAP (Table 4).

Aphid species composition: The aphid flight in watermelon field at Opuzen started at the beginning of May with maximum at the end of the first decade in June in both years (data not shown). The study of aphid population, captured in watermelon field at Opuzen, showed a total of 70 species in 48 genera, with 63 species in 42 genera identified in 2004 and 44 species in 31 genera identified in 2005. All the species belonged to the Aphididae. Because of the injuries, 10% of the total observed aphid specimens were not identified in 2004 and 11% in 2005. Eleven species and *Aphis* sp. were represent by more than 1% dominant criteria in each year and constituted 90% of the total examined material in 2004 and 91% in 2005 (Table 5).

Aphis sp. was not treated as an individual species because several species of these genera were determined, with predominance of *Aphis gossypii* Glover. *Toxoptera aurantii* (Boyer de Fonscolombe) (34%) and *A.* gossy*pii* (15%) were the most dominant species in 2004. These two species were consistently predominant in 2005 when *A. gossypii* (24%) was the most dominant species, followed by *T. aurantii* (23%). The large number of citrus orchards surrounding the vegetable fields in the area is responsible for the black citrus aphid *T. aurantii* predominance. Although, aphid borne viruses of cucurbits were not the subject of the study, the presence of *A. pisum*, *Aphis craccivora* Koch, *A. gossypii* and *Myzus persicae* (Sulzer), recorded in the area during the experimental periods, could be important factor in cucurbit viruses spreading.

***Aphids number*:** Number of winged aphids on colored PE films was not significantly different among four treatments in 2004 (df = 3, F = 1.89, P = 0.145) with respect to the each individual sampling date (Fig. 1A-B). However, it was significantly different among dates (df = 5, F = 77.26, $P \leq 0.0001$) and the interaction of treatment and date (df = 15, F =1.93, P = 0.046). The number of aphids captured during the sampling was too variable to detect the differences between the mulches. Overall seasonal aphid number in 2004, based on six assessments that year, was highest at brown mulch (Fig. 1B) with peak observed on 9 June.

Number of winged aphids on colored mulches was significantly different among five treatments (df = 4, F = 4.88, P = 0.002) and dates in 2005 (df = 5, F = 172.69, $P \leq 0.0001$). The overall seasonal average number of aphids, assessed form six samplings in 2005, was higher at green and white mulches compared to other mulches (Fig. 2B). Similar trend was observed during the experimental period (Fig. 2A-B).

Contrary to 2004, we observed differences among PE films depending on date of sampling for four out of six sampling

Table 4. Coefficient of determination (r^2) between vegetative growth parameters, early and total yield and sum of temperatures (Sum) or average daily temperatures (Avg) measured in root zone during the first 60 days after planting of watermelon grown on colored PE films at Pula and Opuzen in 2003, 2004, and 2005.

Location	Year	Vine length		Vine diameter		Leaf number		Branch number		Early yield		Total yield	
		Sum	Avg	Sum	Avg	Sum	Avg	Sum	Avg	Sum	Avg	Sum	Avg
		Coefficient of determination (r^2)											
Pula	2003	0.78^{ns}	0.79^{ns}	0.79^{ns}	0.79^{ns}	0.57^{ns}	0.56^{ns}	0.82^{ns}	0.82^{ns}	0.03^{ns}	0.03^{ns}	0.38^{ns}	0.39^{ns}
	2004	0.95^{*}	0.96^{*}	0.79^{ns}	0.81^{ns}	0.98^{**}	0.99^{**}	0.93^{*}	0.94^{*}	0.96^{*}	0.95^{*}	0.85^{*}	0.84^{*}
	2005	0.92^{*}	0.91^{*}	0.96^{*}	0.97^{*}	0.70^{ns}	0.68^{ns}	0.95^{*}	0.95^{*}	0.95^{*}	0.95^{*}	0.88^{*}	0.89^{*}
Opuzen	2004	0.33^{ns}	0.33^{ns}	0.00^{ns}	0.00^{ns}	0.74^{ns}	0.73^{ns}	0.00^{ns}	0.00^{ns}	0.01^{ns}	0.01^{ns}	0.05^{ns}	0.05^{ns}
	2005	0.89^{*}	0.88^{*}	0.93^{**}	0.93^{**}	0.94^{**}	0.93^{**}	0.78^{*}	0.78^{*}	0.95^{**}	0.94^{**}	0.96^{**}	0.96^{**}

Significant linear regressions are denoted as: ns, *, **, ***, insignificant or significant at $P \leq 0.05$, 0.01, 0.001, respectively.

dates in 2005 (Fig. 2A-B). The aphid number was higher at white and brown PE films compared to black one on 12 May. One week later, on 19 May, aphids were more numerous on white than on clear mulch. Green mulch was more attractive to aphid population than brown and clear PE films on 26 May. Sampling on 9 June showed that white mulch attracted more aphids than clear. The lowest aphid number was most often trapped on clear mulch what corresponded to the seasonal average.

In relation to seasonal average, less winged aphids were consistently found on black and clear PE films compared to other mulches in both years. A beneficial effect of clear mulch on reduction of aphid population was recorded by Farias-Larios and Orozco-Santos [12, 20]. The effect of green and brown mulches on aphid population was not consistent in two seasons. Black mulch attracted less aphids compared to white at one assessment and as overall seasonal average in 2005 confirming the results of Walters [13]. Mulch color not only affects the total number of aphids which populate crops, but also the presence of individual species [41].

Conclusions

The soil temperature under clear PE film was higher compared to semitransparent (brown and green), non-transparent (black) and reflective (white) PE films regardless of the location or year of the experiment. Significant relation of vine length, branch number and early and total yield to both sum and average soil temperatures during the first 60 DAP was found in three out of five combinations of year and location. Generally, clear film had positive effect on vegetative growth and early yield while an opposite trend was found for the white one. Semitransparent films (brown and green) had similar effect to each other on watermelon vegetative growth and yield. The number of winged aphids was consistently lower at clear and black mulch in both years at Opuzen. Thus we can recommend clear film for early watermelon planting under the Mediterranean conditions.

Table 5. Percentage of aphid species with the dominance greater than 1% of the total catch in the watermelon field at Opuzen 2004 and 2005.

Year 2004		Year 2005	
Aphid species (%)			
Toxoptera aurantii	34.05	*Aphis gossypii*	23.92
Aphis gossypii	14.51	*Toxoptera aurantii*	22.74
Aphis sp.	7.20	*Hyperomysus lactucae*	11.02
Acyrtosiphon pisum	6.66	*Myzus persicae*	6.02
Hyalopterus pruni	5.48	*Aphis* sp.	5.72
Aphis craccivora	4.90	*Brevicoryne brassicae*	5.60
Aphis fabae	4.67	*Hyperomyzus lampsane*	4.45
Hyperomyzus lactucae	4.29	*Aphis craccivora*	3.86
Aulacorthum solani	4.03	*Aphis fabae*	3.80
Myzus persicae	1.94	*Hyperomyzus picridis*	1.48
Macrosiphum euphorbiae	1.68	*Macrosiphum euphorbiae*	1.36
Brevicoryne brassicae	1.27	*Acyrtosiphon pisum*	1.02
Other species[1]	9.32	Other species	8.99
Total	100.00	Total	100.00

[1] Fifty- two species in 2004 and 33 species in 2005 each making up < 1.0 % of the total examined material in each year were grouped as other species and considered as rare.

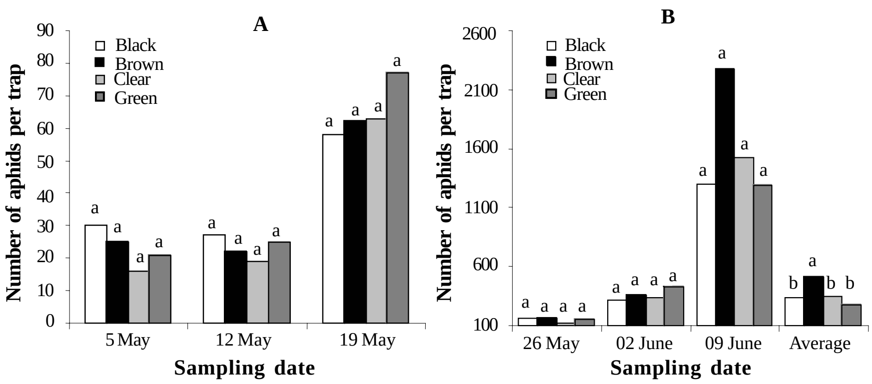

Figure 1. The number of winged aphids caught in yellow water traps on different colored polyethylene mulches in watermelon field at Opuzen, 2004.

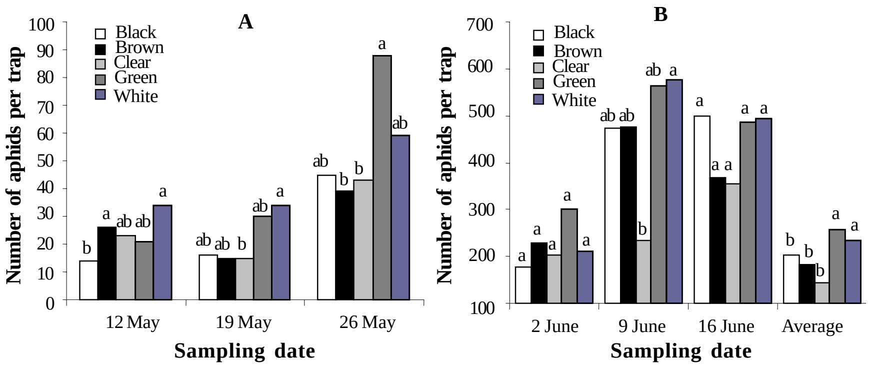

Figure 2. The number of winged aphids caught in yellow water traps on different colored polyethylene mulches in watermelon field at Opuzen, 2005.

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