Europ.J.Hort.Sci., **70** (1). S. 16–22, 2005, ISSN 1611-4426.

Effects of Greenhouse Covers on Growth and Yield of Aubergine

B. Cemek[1)], Y. Demir[1)] and S. Uzun[2)]
([1)]Agricultural Structures and Irrigation Department and [2)]Department of Horticulture, Faculty of Agriculture University of Ondokuz Mayis, Kurupelit-Samsun, Turkey)

Summary

In this study, effects of PE-UV (UV stabilised polyethylene), PE-IR (IR absorbers polyethylene), D-PE (double layer polyethylene) and PE (polyethylene) used as greenhouse covers, on growth, development and yield of aubergine were investigated over three spring seasons (1999, 2000, 2001). The greenhouse covered with PE had the highest light transmission, followed by PE-UV, PE-IR and D-PE, respectively. Based on the results, covering materials were ranked as D-PE, PE-IR, PE-UV and PE in terms of temperature in the greenhouses. Vapour pressure deficit was highest in PE, and followed by PE-IR, PE-UV and D-PE covered greenhouses. Plant growth in D-PE houses was faster than that of the plants in PE-UV, PE-IR, PE covered greenhouses. Some parameters regarding plant growth in D-PE and PE-IR covered greenhouses were found to be similar. The highest yield was obtained from the greenhouses covered with D-PE and this was followed by PE-UV, PE-IR and PE covered greenhouses. These results showed that D-PE was superior to the other covering materials for optimal plant growth and earliness of aubergine yield under the studied experimental conditions.

Zusammenfassung

Wirkung von Gewächshausabdeckungen auf Wachstum und Erntemenge von Auberginen.

Es wurde die Wirkung von Gewächshausabdeckungen aus PE-UV (UV stabilisiertem Polyethylen), PE-IR (IR absorbierendem Polyethylen), D-PE (doppellagigem Polyethylen) und PE (Polyethylen) auf das Wachstum, die Entwicklung und die Erntemenge von Auberginen bei Frühjahrskulturen (1999, 2000, 2001) untersucht. Das PE gedeckte Gewächshaus wies die höchste Lichtdurchlässigkeit auf, gefolgt von PE-UV, PE-IR bzw. D-PE. Hinsichtlich des Faktors Gewächshaustemperatur ergab sich folgende Reihung: D-PE, PE-IR, PE-UV und PE. Das Dampfdruckdefizit war bei Gewächshausabdeckungen aus PE am höchsten, gefolgt von PE-IR, PE-UV and D-PE. Das Pflanzenwachstum war in D-PE Häusern stärker als in PE-UV, PE-IR, PE Gewächshäusern. Einige Wachstumsparameter waren in D-PE und PE-IR Häusern sehr ähnlich. Die höchste Erntemenge wurde in D-PE Häusern gefolgt von PE-UV, PE-IR und PE erzielt. Diese Ergebnisse zeigen, dass unter den gewählten Bedingungen D-PE als Gewächshausabdeckung hinsichtlich Wachstum und Frühzeitigkeit der Auberginen den anderen untersuchten Materialien überlegen ist.

Key words. polyethylene – greenhouse covers – plant growth – yield

Introduction

During the two last decades, productivity and efficiency of horticultural production have received particular attention and the key concept was to accelerate plant growth. This stresses farmers to use production factors, such as land, water etc. more effective. The main objective is to reach maximum yield per unit area. Protected cultivation makes it possible to obtain increased crop productivity by maintaining a favourable environment for plants. Therefore, production in greenhouses becomes more popular than in the past.

Increasing popularity of covering materials led to focus on relationship between climate conditions in greenhouses and the growth, development and productivity of crops. The effects of greenhouse environment on growth, development and productivity of crops have been studied by many researchers (CHALLA and SCHAPENDONK 1984; BAKKER et al. 1987; ELLIS et al. 1990; PEARSON 1992).

Greenhouse cover materials and their effects on the greenhouse environment draw particular attention due to the high level of fuel costs. NOBLE and HOLDER (1989) stated that the high fuel costs during the 1970's and early 1980's led to an increased interest in greenhouse cover materials that were more energy efficient than glass. Thus, many researches have been concentrated on the effects of cover materials on greenhouse environment as well as growth, development and productivity of crops (BLOM and INGRATTA 1985; BOULARD et al. 1989; COCKSHULL et al. 1992; PAPADOPOULOS and HAO 1997a).

To reduce fuel costs in recent years, Turkish growers have tended to grow tomato, aubergine, pepper, and cucumber outside the cold winter months by changing crop schedules. Therefore, an understanding of the effect of temperature and light on the growth of aubergine is of great importance to such growers (UZUN 1996). Crop yields have been reported to depend on the responses of plants to environmental influences (ELLIS et al. 1990), for example, temperature has a considerable

influence on crop timing and yield (PEARSON 1992) and, of course, light is a primary determinant of crop growth.

Greenhouse air temperature, humidity, and plant leaf temperature are in turn affected by the light transmission of the cover material. The improvements in insulation of double layered polyethylene and acrylic greenhouses have resulted in increased humidity in the greenhouse (BLOM and INGRATTA 1985; BOULARD et al. 1989).

Changes in greenhouse microclimates may have significant effects on the growth, development and productivity of crops. Photosynthetic rates are reduced at low PAR integrals and it is generally assumed that the loss of light will lead to a proportional loss in yield (CHALLA and SCHAPENDONK 1984). Photosynthetic rates may increase at high humidity (ACOCK et al. 1976; BUNCE 1984). Cucumber vegetative growth was enhanced by either high day or night humidity, and final total yield was closely related to daytime humidity (BAKKER et al. 1987). The major concern regarding high humidity is that it may encourage plant diseases and cause physiological disorders such as calcium deficiency (HAND 1988).

High temperature stimulates plant growth and increases early yield of various greenhouse fruit vegetables. Little attention has been paid to the interaction of environmental factors. Therefore, it is impossible to predict crop responses to different cover materials realistically only based on the effects of individual greenhouse environmental factors (BLOM and INGRATTA 1985; COCKSHULL et al. 1992). Experiments under simulated commercial conditions may lead to a better understanding of the responses of greenhouse crops to the commercial use of various cover materials (PAPADOPOULOS and HAO 1997b).

Most of the experiments on the effects of cover materials on greenhouse crops have been performed without replication, because of the high cost of the cover materials. This lack of replication has made it impossible to quantify the effects of the cover materials on the greenhouse environment, energy use and crop productivity with any statistical certainty (PAPADOPOULOS and HAO 1997a). The study reported in this article was conducted in eight mini-greenhouses covered with PE-UV(UV stabilised polyethylene), PE-IR(IR absorbers polyethylene), D-PE(double layer polyethylene) or PE (polyethylene), with two replications to determine the effects of these four cover materials on aubergine growth and yield.

Materials and Methods

The experiment was carried out in the spring 1999, 2000, 2001 in eight independent mini-greenhouses of the same size (9x3x2.5 m, LxWxH) and shape oriented East-West (Fig. 1) at Samsun (42 °N), Turkey. This allowed a replication in a randomised complete block experimental design.

The cover materials of the greenhouses were PE-UV, PE-IR, D-PE and PE with a thickness of 150 μm. Ni quenchers were used as UV stabilizers in UV stabilised polyethylene and IR was used as absorbers to prevent long wave-radiation heat exchange in IR absorbers polyethylene. According to the commercial description, light transmissions of the used covering materials were 89–92 %, 86–92 %, and 92–93 % for PE-UV, PE-IR, and PE, respectively. On the other hand, transmission of 5000–14000 nm wavelenght radiation of the covering materials were 56 %, 33 % and 54 % for PE-UV, PE-IR and PE, respectively. Seeds of aubergine ('Valentine' F_1) were sown in mini pots. Sowing and planting dates for each experiment are given in Table 1. Pots were filled with peat based compost. The plants were planted in growing bags (0,4 x 1 m, W x L), containing a peat compost. Three plants were placed in each growing bag. The 16 growing bags, each with 35 litres of volume were placed in each greenhouse with a sum of 48 plants/greenhouse. The treatments were set up as a randomised complete block experimental design, comprising 6 test plants in each greenhouse. Totally 48 plants were used as a sample in this study.

Temperature and relative humidity in each greenhouse and outside were recorded simultaneously by using thermohygrographs (Sato Keiryoki, R-704) and measurements were taken 1 m above the ground in the middle of the greenhouses. Mean day and night temperatures were recorded by the thermohygrographs and a microclimate station near the experimental area.

Photosynthetically active radiation (PAR) was measured daily with a sun scan canopy analyser (Delta-T de-

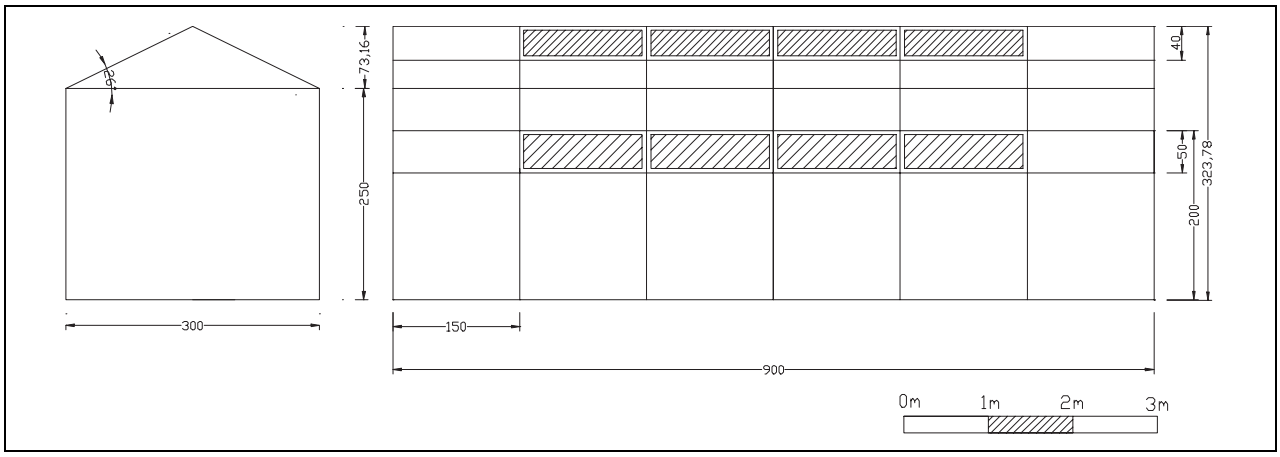


Fig. 1. Description of the dimensions of the greenhouses (Solid areas represent side and roof ventilation gaps)

Table 1. Sowing, planting, early yield and total yield dates of aubergine for 1999, 2000, 2001 in different greenhouse covers.

Year	Date of sowing	Date of planting	Early harvest	Total harvest
1999	4 April	10 May	14 June	18 August
2000	28 April	23 May	23 June	27 August
2001	4 May	28 May	26 June	30 August

Table 2. Explanation of the growth parameters used in the present study.

Growth parameters	Explanation of the growth parameter models
Leaf area ratio (LAR)	The total leaf area of the plant (cm^2) / The total dry weight of the plant (g)
Specific leaf area (SLA)	The leaf area of the plant (cm^2) / The total leaf area dry weight of the plant (g)
Leaf weight ratio (LWR)	The total leaf area dry weight of the plant (g)/ The total dry weight of the plant (g)
Net assimilation rate (NAR)	$(1/A)dA/dt$ (g cm^{-2} day^{-1})*
Relative growth rate (RGR)	Net assimilation rate (NAR) x Leaf area ratio (LAR)[day^{-1}]

*Where A is the total area of the plant. W is dry weight and t is time.

vices type SS1) at the centre of each greenhouse from 1:00 to 2:00 pm inside and outside greenhouses. The measurements were made at 50 cm intervals from 0 to 200 cm at four levels. The daily light transmission of greenhouses was measured with sun scan canopy analyser.

Two plants for each replication in each greenhouse were retained until the end of each experimental period in order to study the relationships between plant growth parameters. Plant fresh weight was determined and leaf area of each plant was measured with a (Placom) digital planimeter. Plant growth and development and growth-determining crop characteristics, such as plant height, leaf number, stem diameter, net assimilation rate (NAR), relative growth rate (RGR), leaf area ratio (LAR), specific leaf area (SLA) and leaf weight ratio (LWR) were also quantified (Table 2). Leaf number was counted when leaves were greater than 2-3 mm. Vernier Callipers were used to measure stem diameter 5 cm above the ground level.

Dry matter partitioning between different plant organs, namely leaf, stem, root, and fruit, was also examined. Destructive harvesting started from fifteenth day after planting and continued at fifteen-day intervals until the end of each experimental period. Plant dry weight was determined after oven drying at 80 °C, specific leaf area was calculated as unit leaf area per dry weight (UZUN 1996).

Statistical analysis on the crop variables studied was performed by Anova-Two-Factor analysis of variance (GOMEZ and GOMEZ 1984). Mean separation within growth and yield parameters using Duncan's Multiple Range Test was performed.

Results

The mean air temperature in D-PE and PE-IR houses were found to be higher than those of PE-UV and PE houses (Fig. 2, Table 3). Duncan multiple test was applied to the data obtained from all the greenhouses during the spring of the years 1999, 2000 and 2001, and the results were given in Fig. 2.

As seen in Fig. 2a, the difference between PE-UV and PE-IR in terms of temperature is insignificant.

In the same way, mean vapour pressure deficit values for three years were compared and presented in Fig. 2b. The highest vapour pressure deficit was observed in PE covered-greenhouse and it was followed by PE-IR, PE-UV and D-PE covered-greenhouses, respectively. When vapour pressure deficit in all the greenhouses were compared statistically, a $P<0.05$ significance was obtained. When light intensity values in the greenhouses were compared, the highest light intensity was in PE covered greenhouse and found to be significant at the level of $P<0.05$ (Fig. 2c).

The plants grown in D-PE and PE-IR covered-greenhouses showed faster growth, such as plants heights and stem diameter were higher in these greenhouses, than those of the plants grown in PE-UV and PE covered greenhouses. Plant height and stem diameter of the plants from PE-UV covered greenhouses showed values between D-PE and PE houses (Fig. 3a and b). However, plants from PE covered greenhouses had smaller stem diameters apart from the plants grown in other greenhouses.

The highest net assimilation rate was obtained from the plants in PE covered greenhouses (Table 4). This was followed by D-PE, PE-IR and PE-UV covered greenhouses, respectively. The highest leaf weight ratio was obtained from the plants grown in D-PE covered greenhouses and there were significant differences amongst different covering materials. There was no significant difference between D-PE and PE-IR covered-greenhouses regarding specific leaf area whereas the plants in PE-UV and PE covered-greenhouses differed from the others (Table 4).

To obtain a general picture of effects of greenhouses with different covering materials growth parameters and total yields pair-wise correlation coefficients were calculated (NILWIK 1981; HEUVELINK 1989) at about 75 DAS for aubergine.

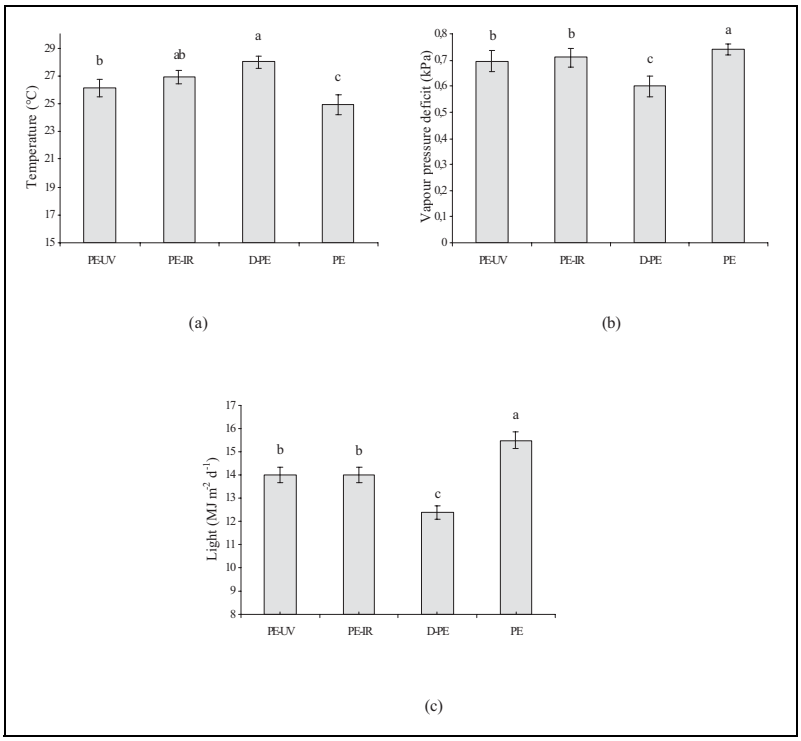


Fig. 2. Changes in (a) temperature (°C), (b) vapour pressure deficit (kPa) and (c) light intensity ($MJm^{-2}d^{-1}$) in the greenhouses covered with different covering materials (PE-UV, PE-IR, D-PE and PE). Error bars indicate the $P<0.05$ confidence intervals around the means according to Duncan's Multiple Range Test. Values with different letters are significantly different ($P<0.05$).

Table 3. Average of day and night air temperature and vapour pressure deficit outside and inside greenhouses covered with four different cover materials, 1999, 2000, 2001 (May, June, July, August)

		Outside		PE-UV		PE-IR		D-PE		PE	
		Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
	Temperature (°C)	26.5	19.7	28.2	23.8	29.1	24.8	29.7	25.6	27.6	21.5
1999	**Vapour pressure deficit (kPa)**	**1.13**	**0.41**	**0.82**	**0.4**	**1.03**	**0.34**	**0.91**	**0.22**	**1.09**	**0.37**
	Light intensity ($MJ\ m^{-2}d^{-1}$)	16.4		13.1		13		11.3		14.6	
	Temperature (°C)	26.2	20.6	29.4	23.4	29.8	24.6	30.8	25.4	27.6	21.4
2000	**Vapour pressure deficit (kPa)**	**1.41**	**0.43**	**0.96**	**0.36**	**1.15**	**0.33**	**0.88**	**0.26**	**0.88**	**0.31**
	Light intensity ($MJ\ m^{-2}d^{-1}$)	15.6		12.6		12.3		11.2		13.8	
	Temperature (°C)	25.8	18.8	29.8	24.5	30.4	25.1	31.2	26	28.1	20.3
2001	**Vapour pressure deficit (kPa)**	**0.93**	**0.34**	**1.16**	**0.5**	**0.95**	**0.43**	**1.08**	**0.28**	**1.13**	**0.22**
	Light intensity ($MJ\ m^{-2}d^{-1}$)	16.4		13.4		13.1		10.8		14.1	
	Temperature (°C)	26.2	19.7	29.1	23.9	29.8	24.8	30.6	25.7	27.8	21.1
Mean	**Vapour pressure deficit (kPa)**	**1.16**	**0.39**	**0.97**	**0.42**	**1.05**	**0.37**	**0.95**	**0.25**	**1.04**	**0.44**
	Light intensity ($MJ\ m^{-2}d^{-1}$)	16.1		13.0		12.8		11.1		14.2	

As seen in Table 5, the correlation between RGR and NAR was positive although it was negative between RGR and LAR. As indicated previously in Table 4, increasing light intensity increased NAR and decreased LAR. As a result of decline in NAR with increasing LAR reflected this negative relationship between RGR and NAR in each greenhouse.

The highest yield was obtained from the greenhouses covered with D-PE and this was followed by PE-UV, PE-IR and PE covered greenhouses. The earliest yield was obtained from D-PE greenhouses (Fig. 4).

Discussion

Several studies on the effect of covering materials on growth and yield of different species plants have indicated that the climate conditions of location have great importance in terms of the effectiveness of cover materials (REIERSON and SEBESTA 1981; WINDEN et al. 1984; PAPODOPOULOS and HAO 1997a).

The results of the present study were found to be in agreement with the results of PAPODOPOULOS and HAO (1997a) because of the similar latitude of the locations.

Table 4. Effects of greenhouses with different covering materials on mean values of growth parameters (RGR, NAR, LAR, SLA, and LWR) of aubergine

	PE-UV	**PE-IR**	**D-PE**	**PE**
Relative growth rate (RGR) (day^{-1})	0.26 b	0.48 a	0.48 a	0.34 b
Standard Error	0.034	0.055	0.049	0.040
Net assimilation rate (NAR) (mg $cm^{-2}day^{-1}$)	0.37 b	0.45 b	0.46 b	0.51 a
Standard Error	0.001	0.001	0.001	0.001
Leaf area ratio (LAR) (cm^2g^{-1})	94.4 bc	130.4 ab	143.4 a	80.0 c
Standard Error	11.16	13.99	18.56	9.61
Leaf weight ratio (LWR)	0.60 ab	0.56 bc	0.65 a	0.50 c
Standard Error	0.026	0.026	0.026	0.026
Specific leaf area (SLA)(cm^2g^{-1})	142 c	202 ab	229 a	158 bc
Standard Error	12.4	20.6	19.0	16.7

Different letters in the same row indicate significant difference (P<0.01). according to Duncan's Multiple Range Test .The data presented are means of 48 plants per three years

Table 5. Correlation between RGR, NAR, LAR, SLA, LWR, and TY at 75 DAS of aubergine in greenhouses with different covering materials

Cover materials	Growth parameters	NAR	LAR	LWR	SLA	TY
	RGR	0.940***	-0.107	-0.955***	-0.294*	0.444**
	NAR		-0.391*	-0.998***	-0.469**	0.687***
	LAR			0.357*	0.862***	-0.721***
PE-UV	LWR				0.450**	-0.666***
	SLA					-0.464***
	RGR	0.724***	-0.444**	-0.955***	-0.269	0.456***
	NAR		-0.799***	-0.787***	-0.705***	0.600***
	LAR			0.583***	0.981***	-0.522***
PE-IR	LWR				0.415**	-0.677***
	SLA					-0.423***
	RGR	0.477**	-0.235	-0.524***	-0.083	0.501***
	NAR		-0.792***	-0.585*	-0.709***	0.481***
	LAR			0.551***	0.958***	-0.501***
D-PE	LWR				0.292*	-0.689***
	SLA					-0.306*
	RGR	0.492***	-0.073	-0.948	-0.326*	0.420**
	NAR		-0.764***	-0.594***	-0.764***	0.624***
	LAR			0.325*	0.894***	-0.666***
PE	LWR				0.499***	-0.663***
	SLA					-0.500***

*P<0.05; **P<0.01; P<0.001*** (DAS: days after sowing)

It could be suggested that D-PE greenhouses would provide advantages in terms of early yield in early spring growing season in Samsun and nearby towns.

Many researchers indicated that temperature and relative humidity in D-PE greenhouses were higher than standard polyethylene greenhouses resulting in higher plant yield. Results from the present study comply with (ACOCK et al. 1976; BUNCE et al. 1984; STROMME et al. 1986; BAKKER et al. 1987; PAPADOPOULOS and HAO 1997a).

UZUN (2001) found that there was a positive relationship between light intensity and plant stem diame-

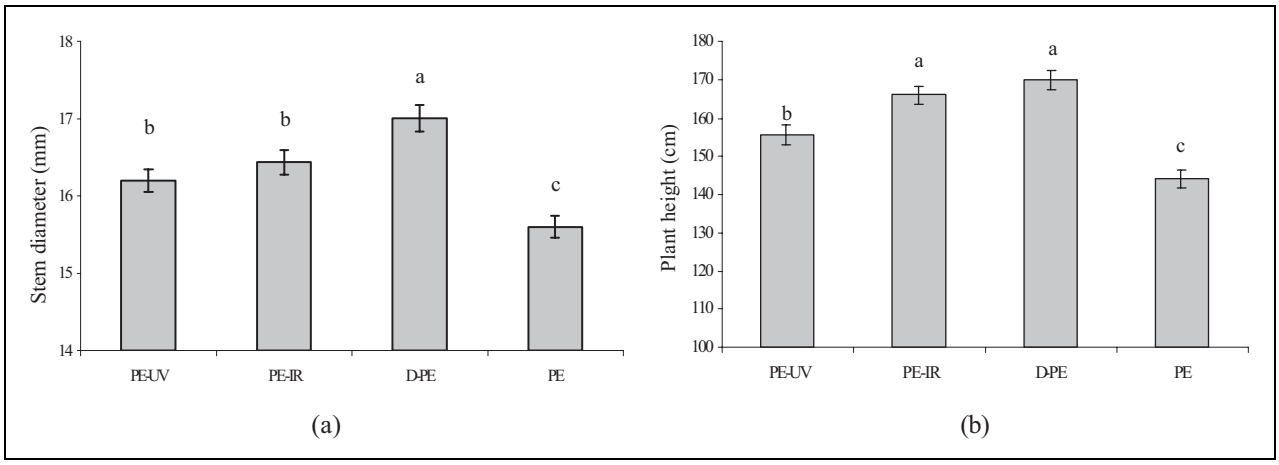


Fig. 3. Changes in (a) stem diameter (mm) and (b) plant height (cm) in the greenhouses covered with different covering materials (PE-UV, PE-IR, D-PE, and PE). Error bars indicate the $P<0.05$ confidence intervals around the means according to Duncan's Multiple Range Test. (Values with different letters are significantly different ($P<0.05$). Means presented are the averages of 20 observations in each of four greenhouses with the same cover).

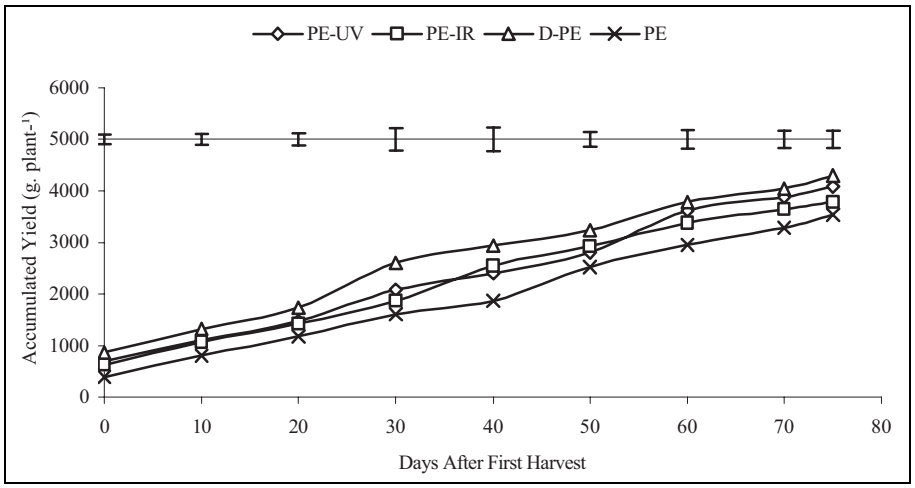


Fig. 4. Changes in accumulated yield (g plant^{-1}) with days after first harvest with different covering materials (PE-UV, PE-IR, D-PE, and PE). Error bars indicate the $P<0.05$ confidence intervals around the means.

ter in both tomato and aubergine. It was also found that stem diameter in tomato and aubergine increased curvi-linearly with increasing temperatures as well as an interactive effect of temperature and light intensity on stem diameter.

It was also found that an increase in temperature from 10 to 32 °C would result in increasing plant height in tomato and aubergine (ATHERTON and HARRIS 1986; COCKSHULL et al. 1992; PEARSON 1992; KURKLU 1994; UZUN 1996; CEMEK 2002).

CEMEK (2002) indicated that the greenhouses covered with D-PE had higher temperatures and induced plant height in cucumber. In the present study, the highest plant height was obtained from the aubergine plants grown in D-PE covered greenhouses and this was followed by PE-UV, PE-IR and PE covered-greenhouses.

There was a positive correlation between RGR and NAR in each greenhouse. Thus, the ontogenetic drift on RGR appeared to be due to the decline in both NAR and LAR during growing period of aubergine in each greenhouse. On the other hand, increase in RGR during the early stage of development was determined primarily by the positive relationship of NAR. There appeared to be a strong positive relationship between LAR and SLA in each greenhouse. Thus, an increase in daily mean light integral caused a decline in both SLA and LAR as the effect of decreasing temperature. It was also observed that the changes in RGR with the lowest daily mean light integral was related to changes in LAR of aubergine rather than by NAR, whereas changes in RGR of the aubergine grown with higher daily mean light integral (PE) was determined mainly by NAR but also by LAR. This is in good agreement with HEUVELINK (1989) and UZUN (1996), who showed that changes in RGR due to temperature regime are mainly caused by the changes in LAR. When considering changes in RGR due to daily mean light integral, BRUGGINK (1992) reported that there was a negative correlation of LAR with NAR at different light levels. In the present study, it was also observed that the relationships between NAR and either LAR or LWR were negatively related for aubergine. It could be suggested that the decline in LAR, SLA and LWR with increasing light

levels and the increase in NAR with the same light integrals caused the negative relationship between NAR and either LAR or LWR in each greenhouses.

Many studies have shown that SLA increases linearly with increasing temperatures and declines with increasing light intensities (PEARSON 1992; UZUN 1996; CEMEK 2002).

When considering the results obtained from the present study, the highest SLA value was obtained from the plants grown in D-PE greenhouses. D-PE greenhouses had higher temperatures and lower light intensities than the other greenhouses. As a result of this, higher SLA values were obtained from the plants grown in D-PE greenhouses.

Conclusions

The selection of the greenhouse cover material depends on many factors, such as initial investment, maintenance costs, its effects on greenhouse crop productivity, local climate and technological support and developments (PAPADOPOULOS and HAO 1997a, b).

The results obtained from the present study for growth and yield of aubergine have shown that the most convenient results were obtained from D-PE greenhouses when compared to IR absorbers PE, UV stabilised PE and PE covered-greenhouses. It could be suggested that D-PE greenhouses would provide the growers with early yield of aubergine in spring season in Samsun, in the Black Sea Region.

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Received July 27, 2003 / Accepted January 24, 2005

Addresses of authors: Dr. Bilal Cemek (corresponding author) and Yusuf Demir, Agricultural Structures and Irrigation Department and Sezgin Uzun, Department of Horticulture, Faculty of Agriculture University of Ondokuz Mayis, Kurupelit-Samsun, Turkey, e-mail: bcemek@omu.edu.tr.