The Journal of Animal & Plant Sciences, 26(1): 2016, Page: 139-148
ISSN: 1018-7081

GROWTH RESPONSE OF CUCUMBER UNDER GREENHOUSES COVERED WITH PLASTIC FILMS

A. A. Alsadon*[1], I. M. Al-Helal[2], A. A. Ibrahim[1], A. M. Abdel-Ghany[2], S. M. Al-Zaharani[3] and S. K. H. Gulrez[3]

[1] Plant Production Department, and [2] Agricultural Engineering Department College of Food and Agricultural Sciences, King Saud University, P.O. Box 2460,Riyadh 11451, Saudi Arabia. [3] Chemical Engineering Department, College of Engineering, King Saud University, P.O. Box 800 Riyadh 11421, Saudi Arabia.
Corresponding author: alsadon@ksu.edu.sa

ABSTRACT

Greenhouse overheating in summer is a major challenge that greenhouse growers face in arid regions. In comparison with two commercial plastic films, a new NIR-reflective plastic film was tested for effectiveness in reflecting some of the NIR radiation and transmitting most of the PAR into the greenhouse. Three identical greenhouses were built and covered by one of these films. Cucumbers (cv. Sovana F1) were grown in each greenhouse in 30 cm diameter pots with plant density of 2.5 plants m^{-2}. Vegetative, fruit and yield traits were measured at 15 days intervals. The growth indices were calculated such as leaf area index (LAI), leaf area duration (LAD), leaf weight ratio (LWR), stem weight ratio (SWR), specific leaf area (SLA), leaf area ratio (LAR), unit leaf area (ULR), relative growth rate (RGR), and crop growth rate (CGR). Plants grown under the new plastic film gave the highest values for vegetative, growth indices, fruit and yield traits as compared with the commercial plastic films. In addition, they showed highly significant correlations between growth indices. It can be concluded that growth indices can be used as tools to explain morphological and/or functional plant responses under greenhouse conditions.

Keywords: arid region, greenhouse, plastic cover, growth indices, cucumber, covering materials, solar radiation, PAR, RGR.

INTRODUCTION

Plant growth analysis is a mathematical approach of interpreting plant development. Growth analysis tools can explain plant function and its dependence on genotype and environment (Lambers *et al*., 1989). Growth analysis has been identified as best and appropriate tools for evaluating the performances of plant species in any cropping conditions. Plants adapt to their surrounding environment via morphological or functional plant adaptations (Tedeschi *et al*., 2011). Morphological adaptations include traits such as reduction in leaf area and LAD while functional adaptations include traits such as reductions in ULR. The reduction in plant growth under abiotic stress can be evaluated by measuring RGR (Hunt, 1982). Xu *et al*., (2010) presented a model for predicting LAI of five greenhouse crops (cucumber, sweet pepper, chrysanthemum, tulip and lilium) based on the quantification of morphological traits affected by temperature and radiation. They concluded that LAI is an important variable highly correlated with canopy photosynthesis. Bruggink and Heuvelink (1987) studied the effect of light on RGR, Net assimilation rate (NAR) and LAR of young tomato, cucumber and sweet pepper plants grown in the greenhouse. They reported that RGR for cucumber and tomato were about the same while RGR for sweet pepper was about 25% lower due to its lower LAR value, caused by the fact that it has thicker leaves than cucumber and tomato. They also found that NAR was almost the same for all three species.

Greenhouses provide better environmental conditions for plant growth and productivity. Solar radiation of a given region is the first climatic factor to be considered before starting a protected cultivation project (Castilla, 2013). Kittas *et al*., (1999) noticed that the quality of the radiation allowed by covering materials to enter the greenhouse is important for evaluating its influence on plant's growth and development. Papadopoulos and Hao (1997) studied the effect of single-glass (glass), double inflated polyethylene film (D-poly) and a rigid twin acrylic (acrylic) panel, as greenhouse covers, on seedless cucumber growth and productivity. They found that plants in D-poly houses might have acclimated to the low light conditions by reducing Specific leaf weight (SLW) and increasing their light interception efficiency. Abdel-Ghany *et al*., (2012) reviewed the effects of greenhouse cover type on the transmittance of photosynthetically active radiation (PAR), the reflectance or absorbance of NIR and the greenhouse air temperature. They concluded that NIR-reflecting plastic films seem to be the most suitable, low cost and simple cover for greenhouses under arid conditions. The most common plastic materials used as agricultural films include low density polyethylene (LDPE), the copolymer of ethylene and vinyl-acetate (EVA) and plyvinyl chloride (PVC) (Castilla, 2013).

Polyethylene films are flexible, transparent to thermal radiation and have been used extensively as greenhouse covering materials in many regions. Cemek *et al*., (2006) studied the effects of various polyethylene films as greenhouse covers on aubergine growth and productivity. They reported that plants under double layers of polyethylene showed faster growth and development with higher yield than plants under UV stabilised polyethylene, IR absorbers polyethylene and single layer of polyethylene. When selecting a particular greenhouse cover, some considerations should be considered; cover degradation, economic aspects, light distribution patterns in the greenhouse and the relationship between green-house microclimate and cover material (Lamnatou and Chemisana, 2013).

Overheating problem of the greenhouse air is the major challenge that greenhouse industry faces in Saudi Arabia. A greenhouse cover that can reduce solar irradiance on crops by enhancing the NIR reflectivity power would be ideal for sustainable agricultural production in such regions. This can be accomplished using a radiation-filtering cover that can reflect a portion of the NIR radiation and transmit the PAR to the crops. In previous work (Al- Helal, *et al*., 2013), a novel strategy was established to develop NIR-reflective film able to prevent the heat from entering the greenhouse by absorbing the UV, transmitting the PAR and reflecting-out the NIR radiations.

Cucumber (*Cucumis sativus* L.) is a popular vegetable crop grown under protected cultivation worldwide. Cucumber is the fourth most cultivated vegetable crop in the world and it is the second crop grown in Saudi Arabia. The total greenhouse production of cucumber in Saudi Arabia was 229963 ton from an area of 2664 hectares (MOA, 2013). Cucumbers are known to be one of the best foods for overall health. The aim of this work was to evaluate the effect of three greenhouse plastic films: a newly produced plastic film and two commercial plastic films on the vegetative, fruit and yield traits of cucumber plants. Growth analysis was used as a tool to identify the changes in cucumber growth and development in responses to these films.

MATERIALS AND METHODS

The greenhouse covering materials: Three plastic films, each with 200 μm thickness, were selected for the study. The three films were: (i) NIR-reflective film (designated as P1) produced at pilot scale at SABIC Polymer Research Center, College of Engineering, King Saud University for the purpose of reflecting some of the NIR radiation and transmitting most of the PAR into the greenhouse, and (ii) two commercial films (designated as P2 and P3) were selected from the local market of Saudi Arabia (P2) and Kuwait (P3), respectively. Detailed description, the chemical formulations and the production procedures for the newly developed NIR-reflective film (P1) have been reported by Gulrez *et al*., (2013).

The radiation properties: The spectral reflectance (Fig. 1) and transmittance (Fig. 2) for the three films were measured, at the Agricultural Engineering laboratories, College of Food and Agricultural Sciences, King Saud University at normal incidence in the wavelength range of 200-1100 nm. Average transmittance, reflectance values in various spectral regions (UV, PAR, and NIR), the blue-red ratios and red-far red ratios are summarized in Table 1.

Table 1. Average values for transmittance (T) and reflectance (R) in UV, PAR and NIR regions and the blue-red (B-R) and red-far red (R-FR) ratios for the new film (P1) and commercial films (P2 and P3)

Film Sample	T (%) UV	T (%) PAR	T (%) NIR	R (%) NIR	B-R	R-FR
P1	3.18	45.04	46.75	25.76	0.73	0.96
P2	2.79	50.59	70.47	9.22	0.72	0.91
P3	5.56	42.17	56.43	7.86	0.43	0.85

Wavelength ranges: blue (400-500 nm), red (600-700 nm), far red (700-800 nm), blue-red (400-500 nm/600-700) and red-far red (600-700/700-800 nm).

Greenhouses: Three identical greenhouses (Fig. 3) were built; each with an area of 48 m^2, oriented in a N-S direction and with wet-pad and fan cooling system. The greenhouses were located at the Educational Farm, King Saud University (Riyadh, Saudi Arabia, 46º 47` E, longitude and 24º 39` N, latitude) during winter and spring season 2012/2013.

Plant materials: Cucumber seeds (*Cucumis sativus* L. cv. Sovana F1, Rijk Zwaan; The Netherlands) were sown on 15 February 2013 in Jiffy 7 pellets in controlled environment (24ºC ±1day/18ºC ±1) night temperatures. On 1 March 2013 (at three true-leaf stage), seedlings were transplanted in the three greenhouses into 30 cm diameter pot containing a mixture of peat, sand and vermiculite (1:1:1) w/w. Fertilization and other cultural practices were applied as recommended in commercial cucumber production.

Data recoded: Fifteen days after transplanting**,** three plants from each greenhouse were randomly selected at 15 days interval for the measurement of growth traits. Vegetative growth parameters (number of leaves, leaf area, plant height, leaves fresh and dry weight, stem fresh and dry weight and stem diameter per plant) were measured. Fruit and yield traits (Fruit number, length and dry weight, total dry biomass and total yield) were recorded at each harvest time. Plant parts were chopped into small pieces to enable drying. They were oven dried at 80 ºC to a constant weight and then oven dry weight of stem along with leaf was recorded. The average of the three plants was then used to determine the growth indices reported in Table 2 according to equations reported in (Hunt1982; Tedeschi *et al.,* 2011). As reported by Matsuda *et al*., (2011). CGR was computed from shoot DW, leaf DW and harvested fruits between two harvesting dates.

The environmental parameters were measured outside and inside the three greenhouses; recorded at 1-minute intervals, averaged every 10 minutes, and then every one hour and saved in a data logger (CR3000 Micrologger®, Campbell Scientific Inc. These parameters were: (i) air temperatures (Fig. 4) and relative humidity (Fig. 5) inside and outside the greenhouses were measured using aspirated psychrometers, and (ii) global solar radiation flux by using CMP3 pyranometer (Kipp & Zonen, USA), The daily average (over 24-h period) of air temperature and relative humidity under P1, P2 and P3 covers were measured during the period from 25 to 85 days from transplanting. This period covered vegetative, flowering, and fruiting stages.

Experimental design and analysis: Randomized complete block design was applied with four replications. Each greenhouse was divided into 4 rows; distance between rows was 1 m, and the space between the containers in rows was 0.4 m. Plant density was 2.5 plants m^{-2}. Analysis of variance and correlation coefficients were calculated using SAS version 8.1 computer program (SAS 2008).

Table 2. Growth parameters used in this study (symbols, formulas and the units). LA is the plant leaf area; p is the surface occupied by a plant; t is the time; LW is the leaf dry weight; SW is the stem dry weight; and W is the shoot dry weight

Definition	Symbol	Formula	Unit
Leaf area index	LAI	LA/P	-
Leaf area duration	LAD	$\sum^{tn}_{t1} (LA_1 t_1)$	m^2d
Leaf weight ratio	LWR	$(LW_2-LW_1)\times(\ln W_2-\ln W_1)/(\ln LW_2-\ln LW_1)\times(W_2-W_1)$	gg^{-1}
Stem weight ratio	SWR	$(SW_2 - SW_1)\times(\ln W_2 - \ln W_1)/(\ln SW_2 - \ln SW_1)\times(W_2 - W_1)$	$g\ g^{-1}$
Specific leaf area	SLA	$(LA_2 - LA_1) \times (\ln LW_2 - \ln LW_1)/(\ln LA_2 - \ln LA_1) \times (LW_2 - LW_1)$	cm^2g^{-1}
Leaf area ratio	LAR	$(LA_2 - LA_1) \times (\ln W_2 - \ln W_1)/(\ln LA_2 - \ln LA_1) \times (W_2 - W_1)$	cm^2g^{-1}
Unit leaf area	ULR	$(\ln LA_2 - \ln LA_1) \times (W_2 - W_1)/(LA_2 - LA_1) \times (t_2 - t_1)$	$g\ m^{-2}\ d^{-1}$
Relative growth rate	RGR	$(Ln\ W_2 - \ln W_1) / (t_2 - t_1)$	$g\ g^{-1}d^{-1}$
Crop growth rate	CGR	LAI x ULR	$g\ m^2\ d^{-1}$

RESULTS

Laboratory tests showed that the three films (P1, P2 and P3) block the UV radiations. However, the new film P1 showed higher NIR-reflectance than P2 and P3 (Fig. 1). Therefore, P1 film was able to reduce the heating load in the greenhouse better than P2 and P3. In addition, the low transmittance profiles of P1 and P3 (in Fig. 2) make them with high potential in reducing the solar radiation load on the crops inside the greenhouses.

The radiative properties of the new NIR-reflective film (P1) improved the microclimate inside the greenhouse. The air temperature under (P1) was lower than those under P2 and P3 during the production period (Fig. 4). Because the three greenhouses were evaporatively cooled (using wet pads and fans systems), the effect of the three films covers (P1, P2 and P3) on the relative humidity in the greenhouses was not clearly evident (Fig. 5).

Vegetative, fruit growth and yield traits: The highest vegetative growth values (number of leaves, leaf area, plant height, leaf weight, stem weight and diameter) were clearly found for plants grown under the new plastic film (P1) and the lowest values observed from plants grown under (P3) film. Plants grown under (P2) film had intermediate growth response (Table 3). Fruit number, length and dry weight increased for plants grown under P1 film with significant differences from both P2 and P2 covered plants (Table 4). Total dry biomass and yield followed similar manner. In general, the results indicated that vegetative, fruit and yield traits increased under P1 followed by P2 and then by P3 films. Daily transmission of solar radiation and temperature has been optimal for cucumber growth and development under P1 cover as compared to P2 and P3 film.

Table 3. Vegetative growth traits of cucumber plants grown under different plastic films (Data taken at 60 days from transplanting)

Type of Plastic film	Leaf No.	Leaf area (cm^2)	Height (cm)	FW leaves (g)	DW leaves (g)	FW stem (g)	DW stem (g)	Stem diameter (cm)
P1	29.38 a	6878.9 a	182.6 a	245.2 a	23.40 a	175.68 a	25.41 a	0.88 a
P2	25.79 b	5807.7 b	161.6 b	180.5 b	19.11 b	147.25 b	21.27 b	0.75 b
P3	24.58 c	5495.1 c	155.1 c	166.4 c	17.35 c	139.68 c	19.11 c	0.75 b
LSD at 0.05	0.44	30.36	1.66	1.73	0.29	1.37	0.199	0.049

Means in each column followed by different letters are significantly different (LSD at 0.05). FW: fresh weight, DW: dry weight.

Table 4. Fruit and yield traits of cucumber plants grown under different plastic films (Data taken at 60 days from transplanting)

Type of Plastic film	No fruits/plant	Fruit length (cm)	DW fruits(g)	Total dry biomass (g)	Yield /plant (g)	Yield/m2 (g)
P1	49.89 a	16.7 a	236.67 a	285.23 a	6383 a	15958 a
P2	45.98 b	15.6 b	201.35 b	241.48 b	5501 b	13753 b
P3	44.67 c	14.5 c	194.57 c	230.78 c	5137 c	12842 c
LSD at 0.05	1.05	0.79	4.26	6.981	104.5	259.7

Means in each column followed by different letters are significantly different (LSD at 0.05). Total biomass represent dry weight of leaves, shoots and fruits).

Plant growth analysis: Growth analysis data (Table 5) showed significant differences in growth indices between cucumber plants under different plastic films. Leaf area index (LAI) increased with time under all plastic films. The significant differences in LAI values started at 30 days from transplanting (Fig. 6). Plants grown under P1 film consistently have the highest LAI followed by plants grown in P2 film and then by plants grown under P3 film. The leaf area duration (LAD) for cucumber plants under the three plastic films was almost similar in the beginning of the growing season although significant differences were noticed at 30 days from transplanting (Fig. 6). LAD values increased steadily toward the end of the growing season. The significant differences were clearly shown at 105 and 120 days from transplanting. Plants grown under P1 film consistently have the highest LAD followed by plants grown in P2 film and then by plants grown under P3 film. In all treatments, the leaf weight ratio (LWR) decreased as growing season progressed (Fig. 6). Being the highest under P1 film (Table 2), the LWR decreased as growing season progressed. Plants grown under P1 film have highest LWR followed by plants grown under P2 cover and then by plants grown under P3 film.

Table 5. Average values of growth indices for cucumber plants grown under different plastic films throughout the growing season

Type of Plastic film	LAI	LAD (m^2d)	LWR (gg^{-1})	SWR (gg^{-1})	SLA ($cm^2\ g^{-1}$)	LAR ($cm^2\ g^{-1}$)	ULR ($gm^{-2}\ d^{-1}$)	RGR ($gg^{-1}d^{-1}$)	CGR ($g\ m^2\ d^{-1)}$)
P1	1.72 a	48.09 a	0.152 a	0.145 a	307.45 a	48.52a	6.90 a	0.0575 a	9.43 a
P2	1.45 b	44.00 b	0.144b	0.134 b	294.51 b	46.03 b	6.38 b	0.0538 b	7.29 b
P3	1.73 c	41.38 c	0.136 c	0.119 c	283.78 c	43.29 c	5.84 c	0.0506 c	6.07 c
LSD at 0.05	0.008	0.057	0.00113	0.0011	0.391	0.136	0.028	0.0005	0.087

Means in each column followed by different letters are significantly different (LSD at 0.05). For abbreviation refer to Table 2.

Continuous decrease in stem weight ratio (SWR) was noticed as season progressed (Fig. 6). Plants grown under P1 film have the highest SWR followed by plants grown under P2 film and then by plants grown under P3 film. The specific leaf area (SLA) increased from the beginning of the study, being highest at 45 days from transplanting and then decreased (Fig. 6). Plants grown under P1 film have the maximum SLA followed by plants grown under P2 film and then by plants grown under P3 film. Generally, leaf area ratio (LAR) declined fast from the initiation of the study in all treatments (Fig. 6). However, the rate of decline was slow starting at 45 day from transplanting. Minimal significant differences in LAR were found under the three plastic films.

For the three greenhouses, the Unit leaf area (ULR) increased up to the 45 days period and declined thereafter (Fig. 6). The relative growth rate (RGR) decreased with plant age for all treatments (Fig. 6). Plants grown under P1 film have the highest RGR followed by plants grown under P2 film and then by plants grown under P3 film. Throughout the growing season, crop growth rate (CGR) was the higher for plants grown under P1 cover followed by plants grown under P2 and P3 covers, respectively. CGR increased from the beginning of the study, being the highest at 45 days from transplanting and decreased thereafter (Fig. 6).

Correlation coefficients: In this study, correlation coefficients were high or very high among most growth indices (Table 6). Among the significant and highly significant correlations were LAR, SLA, LWR and SWR with all growth indices. The highly significant and negative correlations included LAI with LAD, LWR with SWR, SLA, LAR, ULR and RGR, SWR with SLA, LAR, ULR and RGR, SLA with LAR, ULR, RGR and CGR. Both LAI and LAD had negative correlations with other growth indices. Non significant correlations were only found between CGR and LAI, LAD and RGR.

Table 6. Correlation coefficients among studied growth indices of cucumber plants grown under different plastic films. *, **, *, NS: r^2 significant at 0.001 level, at 0.01 level, at .05 level and not significant, respectively**

	Total biomass	LAI	LAD	LWR	SWR	SLA	LAR	ULR	RGR	CGR
Total biomass	1	0.9644***	0.9340***	-0.7574***	-0.8575***	-0.7172***	-0.8179***	-0.7383***	-0.9454***	-0.0837(NS)
LAI		1	0.9122***	-0.8776***	-0.9269***	-0.5773***	-0.9172***	-0.5621***	-0.9564***	0.1368(NS)
LAD			1	-0.7435***	-0.8477***	-0.8317***	-0.7829***	-0.7334***	-0.8754***	-0.1922(NS)
LWR				1	0.9516***	0.3186**	0.9897***	0.2610*	0.8792***	-0.3690**
SWR					1	0.4830***	0.9794***	0.4060***	0.9580***	-0.5219*
SLA						1	0.3670**	0.9259***	0.5833**	0.6865***
LAR							1	0.32105**	0.93007***	-0.34798**
ULR								1	0.5886***	0.7117***
RGR									1	-0.1048(NS)
CGR										1

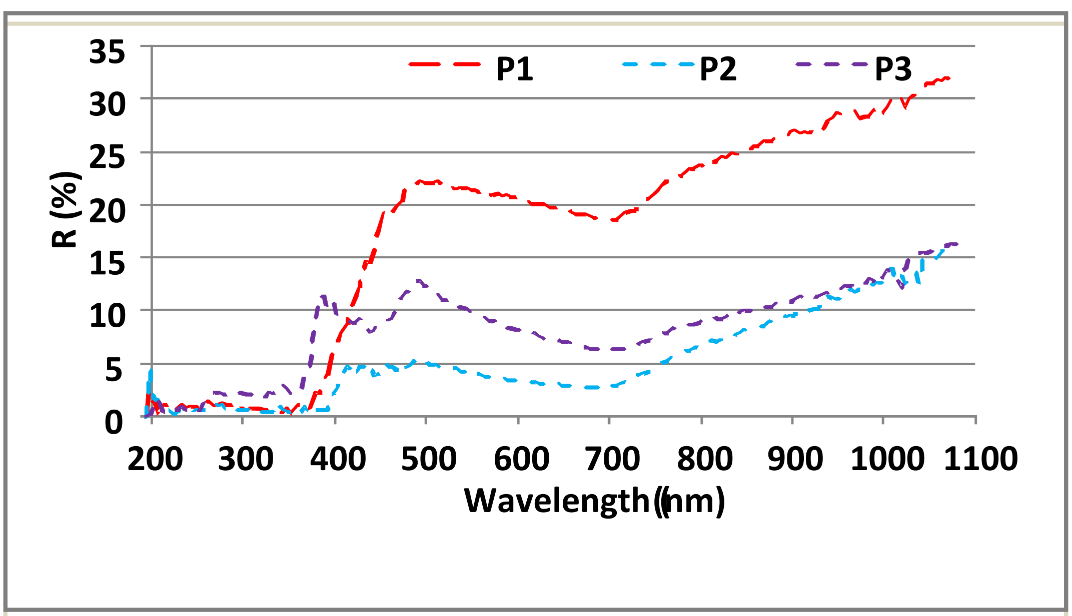

Figure 1: Spectral reflectance of the newly developed NIR-reflective film (P1) and the commercial films (P2 and P3).

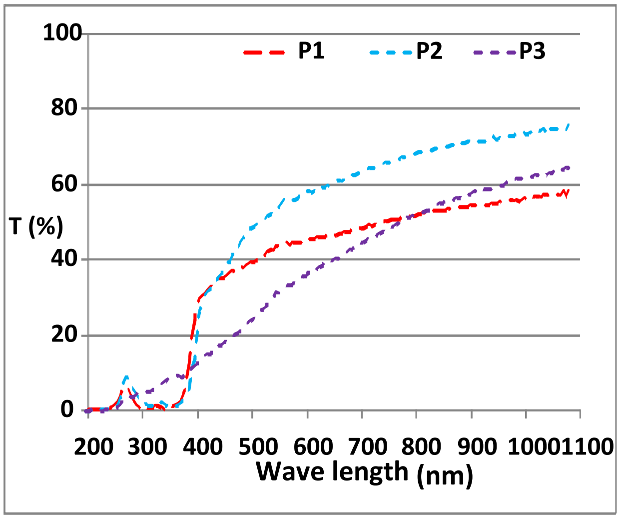

Figure 2: Spectral transmittance of the newly developed NIR-reflective film (P1) and commercial films (P2 and P3)

Fig.3 The three greenhouses covered with P2, P1 and P3 plastic films.

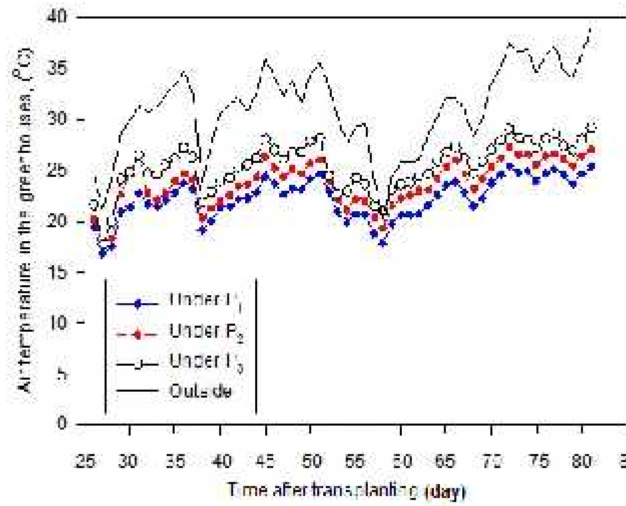

Figure 4: Daily average (over 24-h period) for the air temperature inside the three greenhouses and at the outside during vegetative, flowering, and fruiting stages

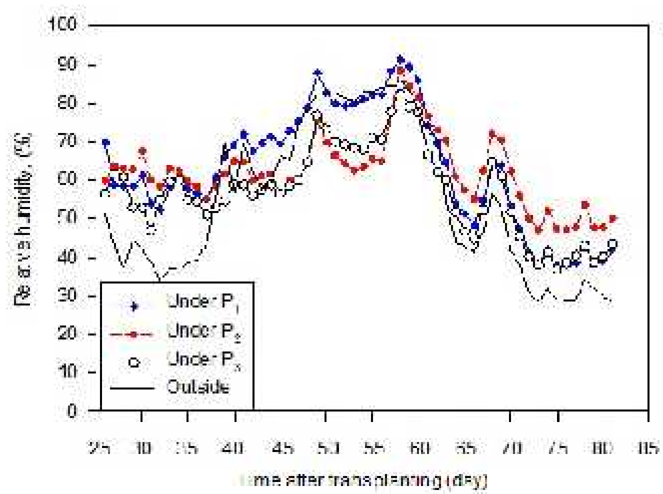

Figure 5: Daily average (over 24-h period) for the relative humidity inside the three greenhouses and at the outside during vegetative, flowering, and fruiting stages.

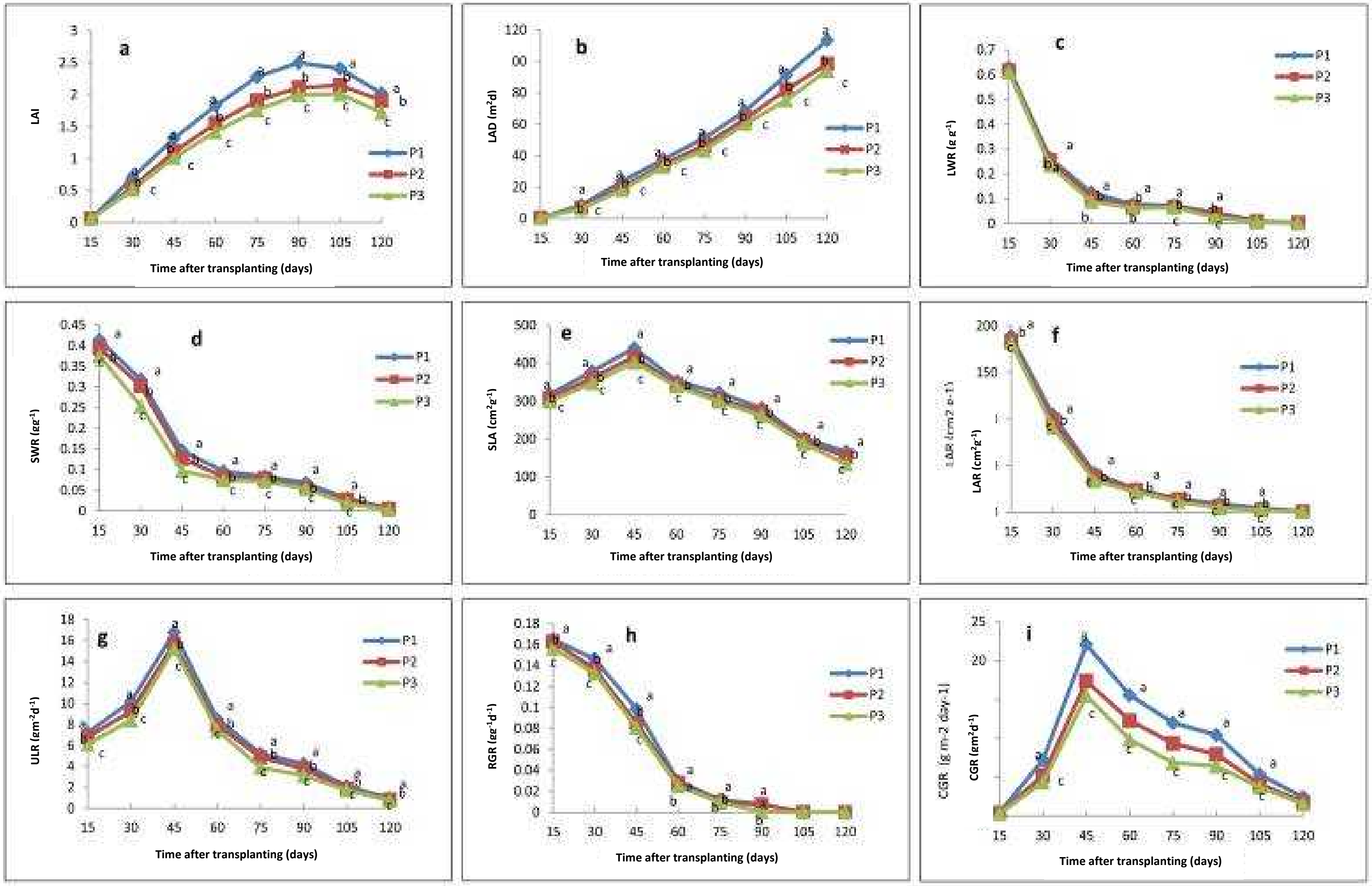

Fig. 6. Growth analysis indices of cucumber plants under P1, P2 and P3 plastic covers: (a) LAI, (b) LAD, (c) LWR, (d) SWR, (e) SLA, (f) LAR, (g) ULR, (h) RGR and (i) CGR. Different letters at each time interval indicate significant difference between treatments (LSD at 0.05).

DISCUSSION

PAR and air temperature in the greenhouse are the most important environmental factors that can be affected by the transmittance of the covering material and its insulating properties (Papadopoulus and Hao, 1997). Daily transmission of solar radiation and temperature has been strongly affected by the type of covering material (Abdel-Ghany *et al*., 2012). The daily average of the PAR transmitted under P1, P2 and P3 covers were measured during the production period to be in the ranges 95-105 (W m^{-2}), 105-125 (W m^{-2}) and 100-120 (W m^{-2}), respectively. According to Abdel-Ghany *et al*., (2012), the optimum PAR for cucumber crop growth is 36-60 (W m^{-2}). Therefore, enough amounts of PAR were available under the three films that can fulfil the cucumber growth requirements during the production period.

As a result, vegetative, fruit and yield traits increased under new plastic film (P1) followed by plastic film (P2) and then by (P3) plastic film covering materials. The improved vegetative (Table 3) and fruit (Table 4) growth evidenced by many growth indices for cucumber plants grown under new plastic film cover (P1) may be due to the favourable weather condition, especially temperature, and light irradiance in comparison with the two commercial plastic films (Al-Helal *et al*., 2013).The increase in accumulated biomass of a plant is the combined result of net photosynthetic activity and growth of vegetative and reproductive organs (Camargoa et al., 2015).

Plant Growth analysis: The highest growth analysis values were clearly seen for plants under P1 film and the lowest values were found in plants grown under P3film. Plants grown under P2film had intermediate growth response. Therefore, it can be concluded that rate and duration of growth for cucumber plants under the newly developed film (P1) were consistently higher than that of P2 and P3 films. In General, significant differences in cucumber growth indices under different plastic covering were found throughout the season while absence of significant differences was recorded only for some indices at the end of the season (Fig. 6).

The highest and significant leaf number of cucumber plants grown under P1 film (Table 3) was associated with the highest leaf area of same plants. The data reported here coincide with previous study on cucumber plants (Alsadon *et al*., 2006).The significant increase in leaf area (Table 3) of P1 covered plants resulted in significantly high LAI and high LAD values (Fig. 6) as compared to P2 and P3 covered plants. These conditions are considered as morphological plant adaptation to the growing conditions (Tedeschi *et al*., 2011).

The LWR is the fraction of the total plant biomass allocated to the leaves (Lambers *et al*., 1989). Difference in cucumber growth parameters under the three plastic covers diminished toward the end of the growing season (Fig. 6) due to the reduction in plant vegetative growth. Demural *et al*., (2005) suggested that the decreasing values of LWR are associated with increasing distribution of dry matter to other plant organs as plants grow. Tedeschi *et al*., (2011) studied allocation of biomass among the different melon plants under saline-sodic conditions plant organs. They reported that SWR increased significantly with increasing salinity and that SWR decreased as season progressed. Similarly, our study showed a gradual decline in SWR as season progressed.

The SLA is a measure of density, because it measures leaf areas in relation to the DW of leaves (Fig. 6). SLA was highest at 45 days from transplanting and then decreased. Miranda *et al*., (2010) reported that SLA of cape gooseberry (*Physalis peruviana* L.) was the highest at day 55 for plants treated with 30 mM NaCl.

Leaf Area Ratio (LAR) was defined as the ratio of leaf area to unit dry weight (Hunt *et al*., (2002). LAR is the amount of LA per unit total plant mass and a function of the SLA and LWR (Lambers *et al*., 1989). Miranda *et al*., (2010) reported that the reduction of LAR was primarily caused by a decrease in the SLA, which played an important role in determining the RGR of the treated plants. Hunt (1990) characterized LAR as a measure of the balance between potentially photosynthesizing and potentially respiring components of the plant. Poorter and Remkes (1990) conducted growth analysis of 24 perennial and annual species. They indicated that LWR and SLA contribute significantly to the positive correlation of LAR and RGR.

Unit leaf area (ULR) or net assimilation rate (NAR) indicate dry matter accumulation rate of the whole plant per unit of leaf area at any instant during crop growth. It is computed from NAR = RGR/LAR (gm^2day^{-1}). NAR is a measure of the average photosynthetic efficiency of the leaves of plants or in a crop stand (Hunt, 1990; Lambers *et al*., 1989). NAR is the most important parameter explaining variation in RGR within plants of the same genus or species and even between closely related plant species (Hunt, 1982). Basically, the relative growth rate (RGR) depends upon the net assimilation rate (NAR), which is a measure of the efficiency of leaves to produce new materials as the assimilatory organ of the plant, and upon leaf area ration (LAR) which is a measure of the leafiness of the plant (Hunt, 1982 and Hunt, 1990). This suggests that the differences in the initial RGR may be due to the instability of its components (NAR and LAR).

Plant relative growth rate (RGR) is determined by their genetic background and by environmental conditions (Rafael *et al*. 2005). De Swart *et al*., (2007) reported that variation in the reduction of RGR under lowered temperatures was due to changes in both (NAR) and (LAR). They concluded that NAR was the most important factor to explain variations in RGR in plants of the same genus or species, and even between closely-related plant species. Miranda *et al*., (2010) reported in the case of the cape gooseberry, that the LAR, but not the ULR, is highly related to the RGR. Bruggink and Heuvelink (1987) studied the relationship between RGR of tomato, cucumber and sweet pepper and the mean daily light integral (PAR incoming per unit ground area) under greenhouse conditions. They reported that RGR for cucumber and tomato plants were about the same; while RGR for sweet pepper plants was about 25% lower.

Crop Growth Rate (CGR) was defined as the increase in plant dry weight per unit time (Hunt, 1982, 1990and Hunt et al., 2002). It is a measure of dry matter production and estimated as CGR = NAR x LAI (g m2 day-1). Yarami and Sepaskhah (2015) reported that maximum CGR decreased significantly as about 26% for saffron plants irrigated with the highest water salinity level. Miranda *et al*., (2010) indicated that in cape gooseberry (*Physalis peruviana* L.) plants affected by salinity, maximum CGR generally coincided with the flowering differentiation stage (approximately at day 55) and then decreased as the plant matured due to the cessation of vegetative growth and the loss of mature leaves.

Correlations of growth indices: Results of this study are in agreement of other studies on plant growth analysis. Ziaf *et al*., (2009) reported that all growth traits were positively correlated with RGR. Tedeschi *et al*., (2011) reported a highly significant positive correlation between RGR and LAR ($r^2 = 0.9847^{***}$) and between RGR and ULR ($r^2 = 0.6808^{***}$). The RGR is a function of the ULR which is an index of the photosynthetic-assimilatory capacity of the plant per unit leaf area, and the LAR which is an index of the leafiness of the plant (Hunt, 1990). Poorter and Remkes (1990) conducted a pathway analysis to study further the relative contribution of RGR, NAR and LAR. They reported that the effect of NAR on RGR was 0.51 ($P < 0.001$) and the effect of LAR was 0.96 ($P < 0.001$). LAR is a composed parameter of LWR and SLA which both contribute significantly to the positive correlation of LAR and RGR (Poorter and Remkes, 1990). Saied *et al*., 2005 found a positive correlation between RGR and ULR and explained the RGR reduction by reduction in ULR but not in LAR. RGR is a composite index: RGR = LAR ×ULR; the LAR is also a composite index: LAR = LWR ×SLA. Lambers *et al*., (1989) indicated that RGR integrate net assimilation rate (NAR) and leaf area ratio (LAR), which represent its “morphological” “physiological” basic components. Similar findings were reported by Saied *et al*., 2005. Matsuda *et al.*, (2011) indicated that the inverse relationship between NAR and LAI can be interpreted as the result of changes in light interception per unit leaf area, which is positively correlated with NAR.

Conclusion: Cucumbers grown under P1 plastic film were superior to those under either P2 or P3 films due to the favourable environmental conditions and consequent morphological responses and physiological processes. The value and significant levels of correlation coefficients indicated comprehensive relationships between the growth indices.

Acknowledgments: The project was funded by the National Plan for Science, Technology and Innovation, (MAARIFAH), King Abdulaziz City for Science and Technology, Kingdom of Saudi Arabia, Award Number (09-DV914-02).

REFERENCES

Abdel-Ghany A.M., I. M. Al-Helal, S. M. Alzahrani, A. A. Alsadon, I. M. Ali and R. M. Elleithy (2012). Covering materials incorporating radiation-preventing techniques to meet greenhouse cooling challenges in arid regions: A Review. The Scientific World J., Article ID 906360, 11 pages. http://dx. doi.org/ 10.1155/2014/349319.

Al-Helal I. M., A. A. Alsadon, A. M. Abdel-Ghany, S. M. Al-Zaharani and S. K. H. Gulrez (2013). Development and evaluation of polyethylene film for covering greenhouses in arid regions. Final report. Project No. 09-ADV914-02. King Abdulaziz City for Science and Technology. Riyadh, Saudi Arabia.

Alsadon A.A., M.A. Wahb-allah and S.O. Khalil (2006). Growth, yield and quality of three greenhouse cucumber cultivars in relation two types of water applied at different growth stage. J. King Sand Univ. Agric. Sci. 18(2): 89–102.

Bruggink G.T. and E. Heuvelink (1987). Influence of light on the growth of young tomato, cucumber and sweet pepper plants in the greenhouse: Effects on relative growth rate, net assimilation rate and leaf area ratio. Scientia Horticulturae. 31(3–4):161–174.

Camargo, D. C., F. Montoya, J. I. Córcoles and J. F. Ortega (2015). Modelling the impacts of irrigation treatments on potato growth and development. Agricultural Water Management. 150: 119–128

Castilla N. (2013). Greenhouse Technology and Management, 2nd Edition. (Translated by E. J. Baeza). CABI. Croydon, UK. 335p.

Cemek B., Y. Demir, S. Uzun and V. Ceyhan (2006). The effets of different greenhouse covering materials on energy requirement, growth and yield of aubergine. Energy. 31:1780–1788.doi:10.1016/j. energy.2005.08.004.

Demural M. A., M. Aydin and A. Yorulmaz (2005). Effect of salinity on growth chemical composition and antioxidative enzyme activity of two malting barley (*Hordeum vulgare* L.) cultivars. Turk. J. Biol. 29:117-123. doi:10.3906/biy-1305-54.

De Swart E.A.M., L.F.M. Marcelis and R .E. Voorrips (2007). Variation in relative growth rate and growth traits in wild and cultivated *Capsicum* accessions grown under different temperatures. The J. of Horticultural Science & Biotechnology. 81(6):1029-1037.

Gulrez S. K. H., A. M. Abdel-Ghany, I. M. Al-Helal, S. M. Al-Zaharani and A. A. Alsadon (2013). Evaluation of PE films having NIR-reflective additives for greenhouse applications in arid rgions. Advances in Materials Science and Engineering. Volume 2013, Article ID 575081, 8 pages. http://dx.doi.org/10.1155/2013/575081.

Hunt R. (1982). Plant Growth Curves. An Introduction to the Functional Approach to Plant Growth Analysis. Edward Arnold, London. 248p.

Hunt R. (1990). Basic growth analysis. University of Sheffield, Sheffield, UK. 112 pp.

Hunt R., D. R. Causton, B. Shipley and A. P. Askey (2002). A modern tool for classical plant growth analysis. Annals of Botany. 90:485-488. doi:10.1093/aob/mcf214, www.aob.oupJ.s.org.

Kittas C., A. Baille and P. Giaglaras (1999). Influence of covering material and shading on the spectral distribution of light in greenhouses. J. agric. Eng. Res. 73:341-351.doi: 10.1006/ jaer. 2001.0755, http://www.idealibrary.com.

Lambers H., N. Freijsen, H., A T. Poorter Hirose and Van der Werf (1989). Analyses of growth based on net assimilation rate and nitrogen productivity. Their physiological background. PP 1–17. In: Causes and Consequences of Variation in Growth Rate and Productivity of Higher Plants. Ed. H. Lambers, SPB. Academic Publishing bv., The Hague, The Netherlands.

Lamnatou, C. and D. Chemisana (2013). Solar radiation manipulations and their role in greenhouse claddings: Fluorescent solar concentrators, photo selective and other materials. Renewable and Sustainable Energy Reviews. 27:175-190.

Matsuda R., K. Suzuki, A. Nakano, T. Higashide and M. Takaichi (2011). Response of leaf photosynthesis and plant growth to altered source-sink balance in a Japanese and Dutch tomato cultivar. Sci. Hort. 127:520-527. doi: 10.1016/j.scienta.2010.12.008.

MOA (2013). Agricultural Statistical Year Book. Vol. 26. Ministry of Agriculture, Riyadh, Kingdom Saudi Arabia. 133p.

Miranda L. D., G. Fischer and C. Ulrichs (2010). Growth of Cape gooseberry (*Physalis peruviana* L.) plants affected by salinity. J. Applied Botany and Food Quality. 83:175 – 181.

Papadopoulos A. P. and X. Hao (1997). Effect of the greenhouse covers on seedless cucumber growth, productivity and energy use. Scientia Horticulturae. 68:113-123.

Poorter H. and C. Remkes (1990). Leaf area ratio and net assimilation rate of 24 wild species differing in relative growth rate. Oecologia 83:553-559.

Rafael V., M. Teodoro, L. Q. José, P. Pilar, A. Francisco and L. Hans (2005). Variation in relative growth rate of 20 *Aegilops* species (Poaceae) in the field: The importance of net assimilation rate or specific leaf area depends on the time scale. Plant and Soil 272: 11-27.DOI 10.1007/s11104-004-3846-8.

Saied A. S., A. J. Keutgen and G. Noga (2005). The influence of NaCl salinity on growth, yield and fruit quality of strawberry cvs. "Elsant" and "Korona". Scientia Horticulturae103:289-303. doi:10.1016/j.scienta.2004.06.015.

SAS (2008). Statistical Analysis System. SAS Institute, Inc., Cary ,NC., USA.

Tedeschi A., M. Riccardi and M. Menenti (2011). Melon crops (*Cucumis melo* L., cv. Tendral) grown in a Mediterranean environment under saline–sodic conditions: Part II. Growth analysis. Agricultural Water Management 98:1339– 1348. doi:10.1016/j.agwat.2011.04.008.

Xu R., J. Dai, W. Luo, X. Yin, Y. Li, X. Tai, L. Han, Y. Chen, L. Lin, G. Li, C. Zou, W. Du and M. Diao (2010). A photothermal model of leaf area index for greenhouse crops. Agricultural and Forest Meteorology. 150: 541–552. doi:10.1016/ j. agrformet. 2010.01.019.

Yarami, N. and A.R. Sepaskhah (2015). Physiological growth and gas exchange response of saffron (*Crocus sativus* L.) to irrigation water salinity, manure application and planting method. Agricultural Water Management. 154: 43–51.

Ziaf, K., M. Amjad, M. A. Pervez, Q. Iqbal, I. A. Rajwana and M. Ayyub (2009). Evaluation of different growth and physiological traits as indices of salt tolerance in hot pepper (*Capsicum annuum* L.). Pakistan J. Bot. 41(4):1797-1809.