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ORIGINAL PAPER

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A MODEL TO DETERMINE QUANTITATIVE EFFECTS OF LIGHT AND TEMPERATURE ON ORGANIC TOMATO SEEDLINGS

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ABSTRACT

The present study was conducted to determine the quantitative effects of light and temperature on growth and development of organic tomato (*Solanum lycopersicum* L.) seedlings in a glasshouse under ecological conditions of Samsun Province of Turkey. Seedlings were grown in four different periods (seeds sown on 29 September for 1st period; 2 December for 2nd period; 18 March for 3rd period and 6 July for 4th period). In order to create different light intensities, shading material having a shading capacity of 50% in 1, 2 and 3 layers was used in each period after seeding. The effects of light and temperature on plant growth and development (leaf area, stomatal conductivity, leaf chlorophyll content, plant height, stem diameter and total plant vegetative dry weight) and the number of days from sowing to plantation of seedlings, were investigated. Obtained results revealed decreasing number of days from sowing to seedling plantation with increasing light intensities. Finally, the number of days from sowing to seedling plantation to be used in organic tomato seedling production was modeled based on the variations in temperature and light intensity ($r^2 = 0.92$).

Key words: *Solanum lycopersicum*, light, temperature, modelling, greenhouse

INTRODUCTION

Environmental conditions play significant roles in seedlings production in greenhouses. Therefore, optimum environmental conditions (temperature, light, humidity) should be provided based on plant cultivar and species. Besides environmental conditions, insufficient cultural practices, cultivar mixtures, disease and pests also result in significant decreases in both the quantity and quality of saplings [Demir 2004]. In organic vegetable culture, seedlings production is one of the most significant cultivation steps. Plant growth and development in organic seedlings production may differ from standard conventional seedlings production, since different growth mediums, nutrient treatments and environmental conditions (temperature, light, humidity and etc.) are applied in organic vegetable cultivation [Uzun 2001]. Organic seedlings are almost unavailable in markets, just because of difficulties experienced in seedling growth and development in organic seedlings production. In this case, the need for organic saplings most of the time is supplied by the producers themselves [Tüzel et al. 2015]. Effects of environmental factors on plant growth and development greenhouse production systems may vary based on plant species and cultivars. Light and temperature are the most significant factors for basic physiological processes in plants. A control over these factors in greenhouse production systems may provide a control also over plant growth and development [Uzun 2001].

In recent years, mathematical models have been used in developed countries to express plant growth and development. Plant growth models have been employed to express the variations in plant growth and

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development with environmental conditions (light, temperature, water, soil temperature and etc.) and to elucidate the relationships between plant growth and yield [Heuvelink 1995, Uzun 1996, Maddonni et al. 2001]. A model representing a real system accurately and sufficiently encompasses the parameters considered in the system to be modeled. However, the model is not necessarily expected to include entire parameters, otherwise it will be the actual system, which is impossible [Pearson et al. 1994, Heuvelink 1995, Uzun 1996]. Environmental control in plant production is mostly and widely implemented in the greenhouses. The greenhouses allow the producers to arrange light, temperature, humidity and CO_2 at optimum levels all year long. However, the whole year long control on climate factors increases the production costs in greenhouses [Topçu and Baytorun 1999]. With those growth models, the best proper growing periods are identified and thus producers are able to make production planning. Such plans then create a chain between the producer and the marketer, create a mutual thrust between them and allow the marketing of products without any losses of value [Uzun 1997].

There are several models worldwide developed by different researchers. These models have commonly been developed to elucidate the relationships of plant growth, development, yield and quality with environmental conditions [Wolf et al. 1986, Dayan et al. 1993, Uzun 1996, Beyhan et al. 2008, Shirvani et al. 2015, Saraçoğlu and Özarslan 2015]. Such models on plant growth should be widespread and new ones should be developed to serve for specific purposes.

The present study was conducted to determine the effects of temperature and light on organic tomato seedling quality, to determine the number of days from sowing to seedling emergence and the number of days from sowing to seedlings plantation. The ultimate goal was to plan seedling production stages in organic tomato seedling production in greenhouses.

MATERIAL AND METHODS

The present research was conducted in a glasshouse located at Research and Implementation Center of Ondokuz Mayıs University Agricultural Faculty (41°22'3.7272" and 36°11'53.9448" and 137 m altitude) in the years 2010–2011. One of the greenhouse partitions (13 × 13 m) was unheated as to represent the control treatment and the other two partitions were heated as to have an indoor temperature over 15°C. Shading material was placed 1 m above the transplant production benches (4 × 2 m). Green shading nets with 50% shading capacity were used for shading treatments. For each growing period, shading material was arranged as 1 layer (50%), 2 layers (50 + 50%), 3 layers (50 + 50 + 50%) and without shading material for control treatment.

Tomato (*Solanum lycopersicum* L. cv. 'Sümela F1') sowing was performed on 29 September, 2 December, 18 March and 6 July. A plastic viol with 345 cells each having 2.2 × 2.2 cm dimensions and filled with soil + composted manure (decomposed for 6 months) mixture (2 : 1 ratio), was used for sowing. A total of 50 seeds were sown for each sowing period and for each chamber. Seedlings with the first true leaf were transplanted into 9 × 8 cm pots filled with 2 : 1 composted manure: soil mixture. Irrigations were performed through monitoring soil moisture levels. Fertilizer and chemical treatments were not performed throughout growing period.

During the production period, from sowing until the 4th true leaf plant growth stage of the transplants,

Table 1. Mean light intensity (MJ m^{-2} day^{-1}) and temperature (°C) values of experimental treatments

Treatments		Light intensity (MJ m^{-2} day^{-1})				Temperature (°C)			
		1st p.	2nd p.	3rd p.	4th p.	1st p.	2nd p.	3rd p.	4th p.
Shading	Control	8.91	2.42	8.87	12.03	17.85	17.67	20.74	27.07
	1 layer	6.86	1.86	6.83	9.26	17.88	17.52	20.06	26.30
	2 layers	4.27	1.16	4.25	5.77	17.79	16.87	19.45	24.63
	3 layers	3.20	0.87	3.09	4.33	17.80	16.94	19.47	23.82

light (lux) and temperature (°C) values were recorded with data loggers (KT100, Kimo, France) at one-hour intervals in each of the treatments (Tab. 1). The obtained lux values were converted to PAR using the conversion factor (1 PAR, MJ m^{-2} d^{-1} = 2400.16 lux) according to Sarıbaş et al. [2017].

To determine seedling quality, stomatal conductivity (mmol m^{-2} s^{-1}) and chlorophyll content (CCL) measurements were performed on 15 seedlings when the seedlings have reached the planting stage (with 4 true leaves). Leaf stomatal conductivity was measured with a stomatal conductivity device (SC-1, Decogon Devices, Pullman, USA) between the hours 10.00 and 11.00 from all leaves of the seedlings and expressed as mmol m^{-2} s^{-1}. Leaf chlorophyll content was measured as leaf chlorophyll index (CCI) also between 10.00 and 11.00 from all leaves of the seedlings using a chlorophyll meter (CCM-200, Opti-Sciences, Hudson, USA).

Seedlings (10 seedlings of each replication) were removed from the soil and separated into root, stem and leaves. Roots were flashed with tap water to remove all the soil particles over them. Plant height (cm) was measured with a tape measure and stem diameter (mm) was measured with a digital caliper. Width and length of tomato leaves (head, left and right leaflet) were measured and leaf areas were calculated according to Beyhan et al. [2008]. Leaves, stems and roots were separately placed into small paper bags and dried in an oven (Venticell 55, Ecocell, MMM group, Germany) at 80°C for 48 h. Weight change method was used to determine whether or not the drying is complete. Fully dried leaf, stem and root samples were weighed with a digital scale (±0.01 g, MW-II, CAS, Korea).

Experiments were conducted in randomized blocks design with 3 replications and 10 plants in each replication. Data were analyzed with Microsoft Excel 2010 and two-dimensional graphs were drawn in Excel and Slide Write 7.0 software. Multiple regressions were also performed in Excel and the resultant models were converted into 3-D graphs in Slide Write software.

RESULTS AND DISCUSSION

The relations of leaf area (cm^2) with temperature (°C) and light intensity (MJm^{-2} day^{-1}) of tomato seedlings were identified as:

$$LA = 36.48 + 63.29*L - 2.96*T*L - 10.51*L2 + 0.68*T*L2 + 0.18*T2 - 0.01*T2*L2 \quad (1)$$

$$SE \;\; (17.9)^{*} \; (13.91)^{***} \; (0.72)^{***} \; (2.7)^{***} \; (0.21)^{**} \; (0.052)^{**} \; (0.004)^{**}$$

$$r^2 = 0.92^{***}$$

where: LA – leaf area (cm^2), T – daily mean temperature (°C), L – daily average light intensity (MJm^{-2} day^{-1}), SE – standard errors.

While the leaf area reached the greatest value under low light conditions and at high temperature, leaf area decreased curvilinearly with light intensity (Fig. 1). Leaf area increased in high temperature conditions with increasing the light intensity and decreased with decreasing light intensity. The temperature, at which leaf area started to decrease under high light conditions was identified as 20–22°C. Significantly high relationship was observed between the number of days obtained in this study with regard to actual leaf area of tomato seedlings (cm^2) and the estimated leaf area (cm^2) with Equation 1 ($P < 0.001$). It was reported in previous studies that leaf surface areas were larger in low light intensity than in high light intensity, leaf areas increased under low light and high temperature conditions and leaf areas positively correlated with temperature [Kürklü 1994, Leskovar and Daniel 1994, Uzun 1996, Kandemir 2005]. Current findings on leaf areas were similar to those of other studies.

Multi-regression analyses for relationships of stomatal conductivity (SC) with temperature (°C) and light intensity (MJ m^{-2} day^{-1}) revealed the following equation:

$$SC = 14.49 + 1.6*L + 0.008*L*T2 - 0.00088*T2*L2 \quad (2)$$

$$SE \; (1.69)^{***} \; (0.4)^{***} \; (0.001)^{***} \; (0.0001)^{***}$$

$$r^2 = 0.69^{***}$$

where: SC – stomatal conductivity (mmol m^{-2} s^{-1}), T – daily mean temperature (°C), L – daily average light intensity (MJ m^{-2} day^{-1}), SE – standard errors.

A curvilinear increase was observed in stomatal conductivity (SC) with increasing temperature and light intensity. A curvilinear decrease was observed in

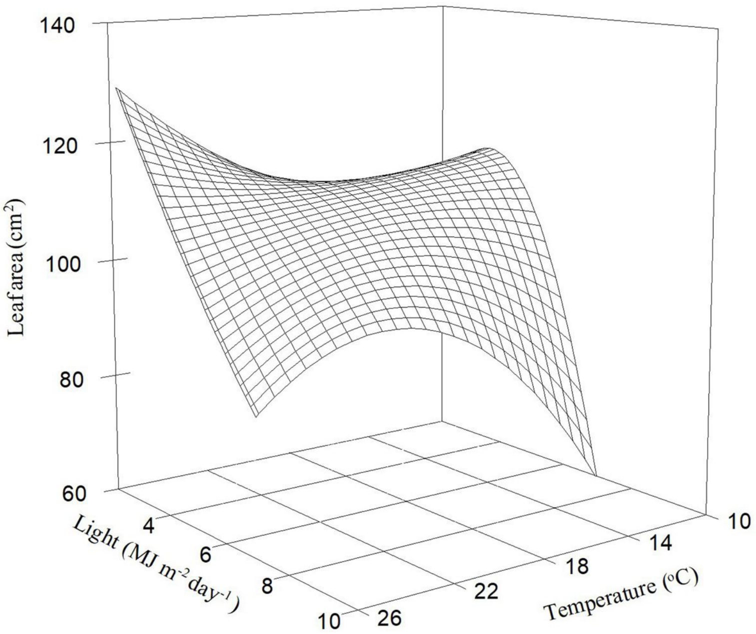

Fig. 1. Relations of leaf area of tomato seedlings (cm^2) with temperature (°C) and light intensity (MJ m^{-2} day^{-1}). The graph was drawn with the aid of Equation 1

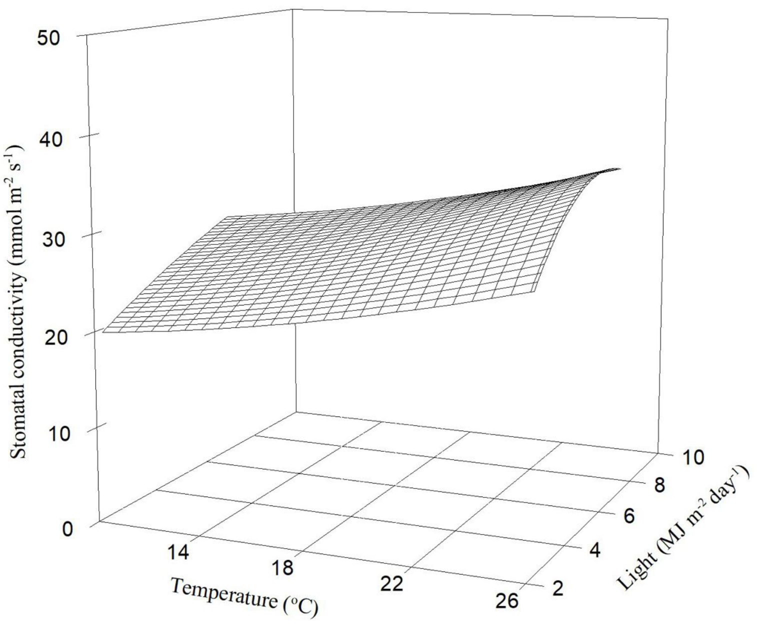

Fig. 2. Relations of stomatal conductivity (mmol $m^{-2}s^{-1}$) of tomato seedlings with temperature (°C) and light intensity (MJ m^{-2} day^{-1}). The graph was drawn with the aid of Equation 2

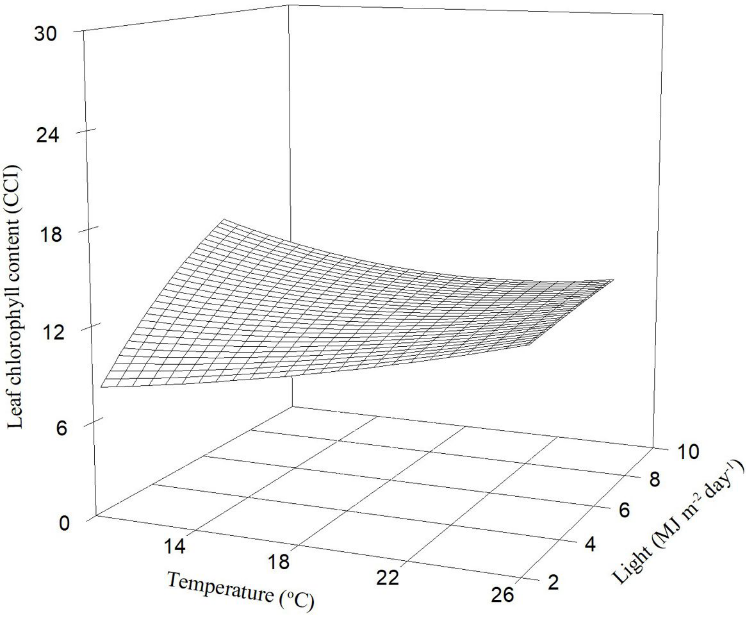

Fig. 3. Relations of leaf chlorophyll content (CCI) of tomato seedlings with temperature (°C) and light intensity (MJ m^{-2} day^{-1}). The graph was drawn with the aid of Equation 3

SC values over light intensity of 8 MJm^{-2} day^{-1} under high temperature conditions. Stomatal conductivity curvilinearly increased in every light intensity under low temperature conditions. SC reached the greatest level under high temperature and high light intensity conditions. Significantly high relationship was observed between the number of days obtained in this study with regard to actual stomal conductivity of tomato seedlings and the estimated stomatal conductivity with Equation 2 ($P < 0.001$) (Fig. 2). It was reported in previous studies that several factors were effective in stomal actions in plants. These factors alone or together have significant impacts on stomal actions [Elad et al. 2007, Kılıc et al. 2010, Ozturk et al. 2014]. Light intensity and quality, temperature, relative humidity and cell inner CO_2 concentrations are detected by guard cells in stomas. Light is a significant environmental signal for stomal actions. Stomas open with increasing the light intensity over the leaf surface and close with decreasing light intensities [Taiz and Zeiger 2008]. However, increased stomatal conductivity was reported for tomato with shading under high light intensity conditions [Özer 2017]. Current findings were complying with the results of earlier studies on stomatal conductivity.

The following equation was obtained from the multi-regression analyses for the relationships of leaf chlorophyll content (LCC) with temperature and light intensity (MJ m^{-2} day^{-1}):

$$LCC = -4.87 + 5.59{*}L + 0.67{*}T - 0.29{*}T{*}L - 0.23{*}L2 + 0.008{*}T{*}L2 + 0.003{*}L{*}T2 \quad (3)$$

$$SE\ \ (2.47)^{*}\ (1.09)^{***}\ (0.1)^{***}\ (0.08)^{***}\ (0.07)^{**}\ (0.003)^{*}\ (0.001)^{*}$$

$$r^2 = 0.86^{***}$$

where: LCC – leaf chlorophyll content (CCI), T – daily mean temperature (°C), L – daily average light intensity (MJ m^{-2} day^{-1}), SE – standard errors.

A curvilinear increase was observed in leaf chlorophyll content with increasing temperatures within the light intensity range of 2–4 MJ m^{-2} day^{-1}. Significantly high relationship was observed between the number of days obtained in this study with regard to actu-

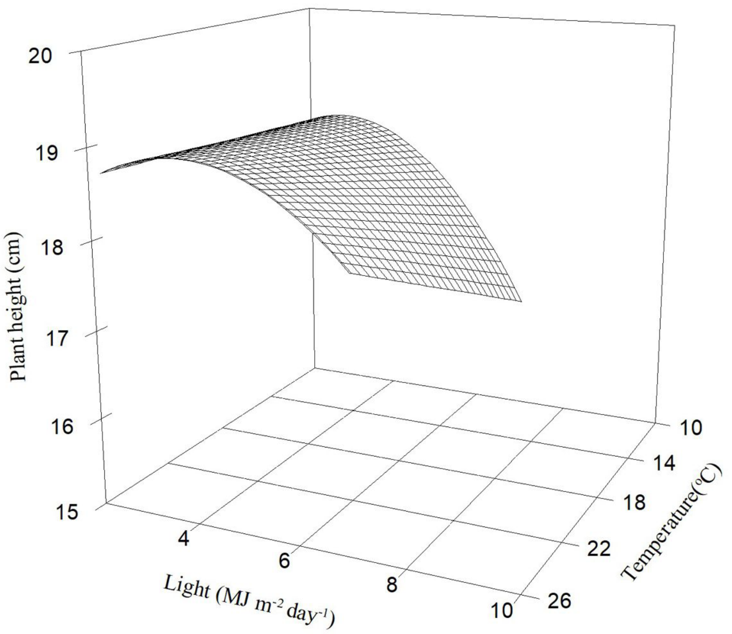

Fig. 4. Relations of plant height of tomato seedlings (cm) with temperature (°C) and light intensity (MJ m^{-2} day^{-1}). The graph was drawn with the aid of Equation 4

al leaf chlorophyll content of tomato seedlings and the estimated chlorophyll contents with Equation 3 ($P < 0.001$) (Fig. 3).

Excessive light energy may damage the photosynthesis systems. Significant changes are observed in physiology of the plants exposed to high light intensities. One of these changes is related to chlorophyll content. An increase in light intensity after a threshold value may reduce leaf chlorophyll contents [Kılınç and Kutbay 2008, Taiz and Zeiger 2008, Özer 2017]. In this study, leaf chlorophyll contents decreased curvilinearly with increasing temperatures above a light intensity of 4 MJ m^{-2} $gün^{-1}$. However, a curvilinear decrease was observed in leaf chlorophyll contents at temperatures above 18°C.

Multi-regression analyses for relationships of plant height (cm) with temperature (°C) and light intensity (MJ m^{-2} day^{-1}) revealed the following equation:

$$PH = 17.58 + 0.73*L - 0.15*L2 + 0.00212*T*L2 \quad (4)$$

$$SE \quad (0.62)^{***} \; (0.25)^{**} \; (0.03)^{***} \; (0.00084)^{**}$$

$$r^2 = 0.77^{***}$$

where: PH – plant height (cm), T – daily mean temperature (°C), L – daily average light intensity (MJ m^{-2} day^{-1}), SE – standard errors.

A rapid curvilinear increase was observed in plant height with temperatures above 10°C at light intensities between 4–6 MJ m^{-2} day^{-1}. Slight curvilinear decrease was observed in plant height with light intensities after a certain temperature. A rapid curvilinear decrease was observed in plant height with light intensities above 2 MJ m^{-2} day^{-1} under low temperature conditions. Such a decrease was more distinctive than high temperature conditions. Significantly high relationship was observed between the number of days obtained in this study with regard to actual plant heights (cm) of tomato seedlings and the estimated plant heights with Equation 4 ($P < 0.001$) (Fig. 4).

Decreasing the light intensities may result in higher cell and plant heights, weaker stems and brighter plants. A linear relationship was reported in several plants between temperature and plant height and it was also reported that increasing temperatures (up to 32°C) increased plant heights, but such increases recessed with the plant age [Kürklü

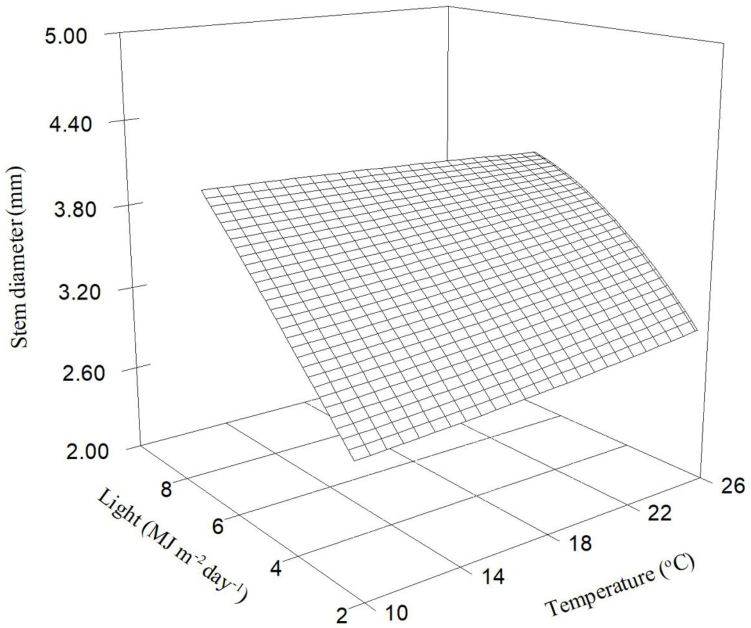

Fig. 5. Relations of stem diameter of tomato seedlings (mm) with temperature (°C) and light intensity (MJ m^{-2} day^{-1}). The graph was drawn with the aid of Equation 5

1994, Kandemir 2005]. Uzun [1996] obtained the greatest plant height in tomato and aubergine under low light intensity and high temperature conditions. Uzun [2001] also indicated that temperature and light intensity had significant interactive impacts on plant heights in tomato and reported the greatest plant height under low light intensity and high temperature conditions. Current findings on plant height were parallel to those reported by previous researchers.

The following equation was obtained from the multi-regression analyses for the relationships of stem diameter (mm) of tomato seedlings with temperature (°C) and light intensity (MJ m^{-2} day^{-1}):

$$SD = 2.186 + 0.276*L + 0.00024*L*T2 - 0.000038*T2*L2 \quad (5)$$

$$SE \ (0.086)^{***} \ (0.022)^{***} \ (0.000067)^{***} \ (0.0000058)^{***}$$

$$r^2 = 0.91^{***}$$

where: SD – stem diameter (mm), T – daily mean temperature (°C), L –daily average light intensity (MJ m^{-2} day^{-1}), SE – standard errors.

At temperatures above 15°C, a rapid curvilinear increase was observed in stem diameter (SD) with increasing light intensity. The SD values reached to the highest level under high light-low temperature and high light-high temperature conditions. Under light intensities equal to and above 5 MJ m^{-2} day^{-1}, a curvilinear decrease was observed in stem diameters with increasing temperatures. Such an increase was less distinctive in high light conditions. Significantly high relationship was observed between the number of days obtained in this study with regard to actual stem diameters (mm) of tomato seedlings and the estimated stem diameters with Equation 5 ($P < 0.001$) (Fig. 5).

Plant stem diameter is negatively correlated with plant height. It can be stated that plant develop less heights under high temperature-high light conditions and thus accumulation of dry matter produced through photosynthesis in stems was higher [Kandemir 2005].

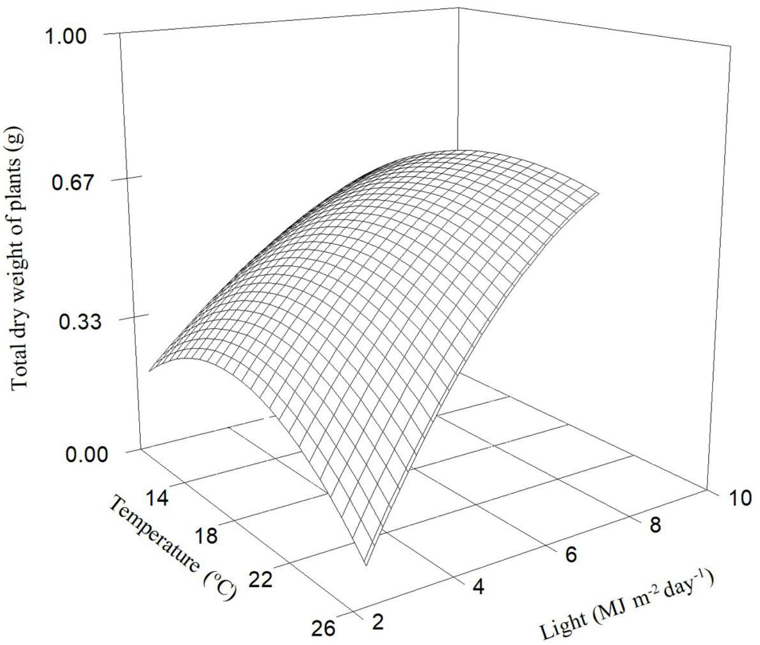

Fig. 6. Relations of total plant dry weight of tomato seedlings (g) with temperature (°C) and light intensity (MJ m^{-2} day^{-1}). The graph was drawn with the aid of Equation 6

It was reported in previous studies that increasing the light intensities reduced plant heights and thus increased stem diameters; there was a positive curvilinear relationship between stem diameter and temperature and a positive linear relationship between stem diameter and light intensity in tomato; and low light intensities yielded thinner stems [Uzun 2001, Kandemir 2005]. Current findings were similar to ones reported by those researchers. In order to obtain high yield, it is necessary to start production with seedlings of sufficient plant height and high stem diameter [Özer and Kandemir 2016, Özer 2018]. In our study, the significant effects of the balanced relationship between light and temperature on seedling quality were determined. As a result, the seedling will be estimated with the model we have obtained and the producers will start production with high-quality seedlings.

Multi-regression analyses for the relationships of plant total dry weights (g) with temperature (°C) and light intensity (MJ m^{-2} day^{-1}) revealed the following equation:

$$TDWP = -0.695 + 0.114{*}L + 0.092{*}S - 0.0032{*}T2 - 0.0006{*}T{*}L2 + 0.00026{*}L{*}T2 \quad (6)$$

$$SE \quad (0.349)^{*}\ (0.02)^{***}\ (0.045)^{*}\ (0.0015)^{*}\ (0.00015)^{***}\ (0.0001)^{**}$$

$$r^2 = 0.81^{***}$$

where: TDWP – total dry weight of plant (g), T – daily mean temperature (°C), L – daily average light intensity (MJ m^{-2} day^{-1}), SE – standard errors.

Total dry weight of the plants (TDWP) was at the lowest level under high temperature-low light intensity conditions. A curvilinear increase was observed in TDWP values with increasing temperatures and light intensities. However, a rapid curvilinear decrease was observed at temperatures above 18°C. The curvilinear increase was observed in TDWP values with increasing light and decreasing temperature values. A significantly high relationship was observed between the number of days obtained in this study with regard to total dry weight (g) of tomato seed-

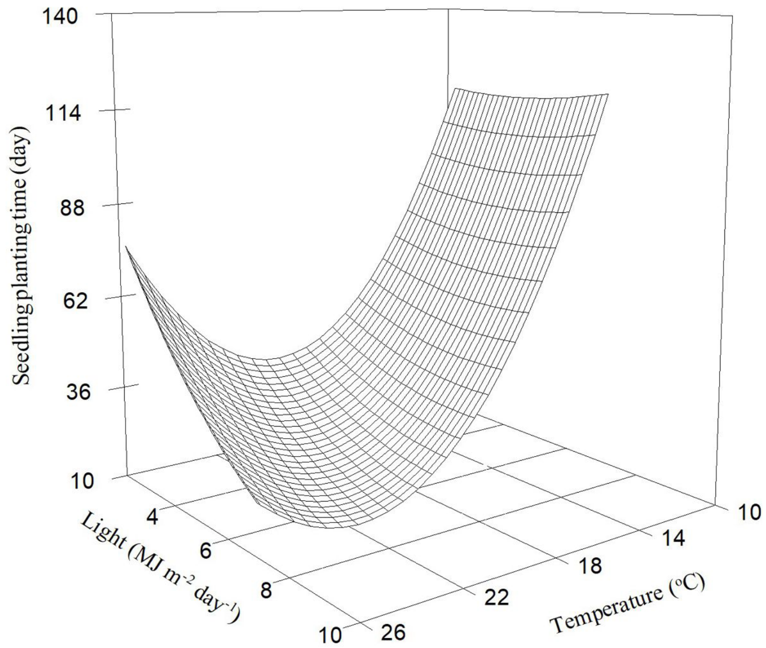

Fig. 7. Relations of number of days from sowing to plantation of tomato seedlings (SPT : seedling planting time) with temperature (°C) and light intensity (MJ m^{-2} day^{-1}). The graph was drawn with the aid of Equation 7

lings and the estimated total dry weight of plants with Equation 6 ($P < 0.001$) (Fig. 6).

Light has important effects on photosynthesis and plant morphology. Less dry matter accumulations under low light intensity conditions were reported by several researchers [Cockshull et al. 1992, Uzun 1996, Kandemir 2005]. Photosynthetic efficiency is influenced by air temperature and there is an optimum temperature for each plant species. Grimstadt and Frimanslund [1993] reported increased dry matter accumulation in tomato and cucumber plants with the increase of temperature from 17°C to 27°C. Kürklü [1994] reported that temperature increase between 14–32°C intensifies the dry matter accumulation in aubergine curvilinearly. Similar results were observed in current study. A relationship was observed in this study between temperature and light. It was also observed that a balanced increase in temperature and light intensity significantly increased total plant dry weights.

To determine the number of days from sowing to seedling plantation (seedling planting time – SPT), the model developed by Uzun et al. [2001] calculating the number of days from sowing to seedling emergence

$$(D = a - b*T + c*T^2) \text{ was used}$$

where: D – seedling emergence time (day), T – daily mean temperature (°C), A – fixed value for tomato (62.42), B – fixed value for tomato (3.97), C – fixed value for tomato (0.068).

The number of days calculated with this model should be added to the number of days from emergence to seedling plantation (the stage with four true leaves) determined with the current models. The following equation (Equation 7) was obtained for tomato in this study:

$$SPT = [(62.42 - 3.97*T + 0.068*T2) + \\ + (370.82 - 34.7*T + 0.96*T2 - \\ - 0.03*L*T2 + 0.038*T*L2)] \quad (7)$$

$$r^2 = 0.92***$$

where: SPT – seedling planting time (day), T – daily mean temperature (°C), L – daily average light intensity (MJ m^{-2} day^{-1}), SE – standard errors.

Under different light intensities, a curvilinear decrease was observed in SPT values with increasing temperatures until a certain temperature and subsequent increase was observed after a certain temperature based on light intensity. The temperatures, at which SPT started to increase was between 18 and 22°C under low light intensity conditions and between 22 and 26°C under high light intensity conditions. Significantly high relationship was observed between the number of days obtained in this study with regard to the number of days from sowing of tomato seedlings to the plantation and the estimated number of days with Equation 7 ($P < 0.001$) (Fig. 7).

CONCLUSIONS

Current findings were used to determine and model the number of days from sowing to seedling plantation (SPT) to be used in organic tomato seedlings production based on variations in temperature and light intensity. These models may provide significant contributions in organic seedling production planning of seedling producers.

Mathematical expressions of the relationships between seedling quality parameters and environmental conditions (temperature and light) may provide significant advantages in quality seedling production. Because of good balance between temperature and light, it was determined that seedlings increased their total dry weight, stomatal conductivity and leaf chlorophyll content. With the use of quality seedlings, higher quality productions will be possible and resultant plants will be more resistant to pests and diseases.

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REFERENCES

Beyhan, M.A., Uzun, S., Kandemir, D., Özer, H., Demirsoy, M. (2008). A model for predicting leaf area in young and old leaves of greenhouse type tomato (*Lycopersicon esculentum*, Mill.) by linear measurements. J. Agric. Fac. OMU, 23(3), 154–157.

Cockshull, K.E., Graves, C.J., Carol, R.J. (1992). The influence of shading on yield of glasshouse tomatoes. J. Hort. Sci., 67(1), 11–24.

Dayan, E., Keulen, H.V., Jones, J.W., Vipori, I., Shmuel, D., Challa, H. (1993). TOMGRO – A greenhouse-tomato simulation model. Simulation Report 29, CABO-DLO, Wageningen.

Demir, K. (2004). Fide yetiştiriciliği. Türk-Koop Ekin Dergisi, Aralık, 6–14.

Elad, Y., Messika, Y., Brand, M., David, D.R., Sztejberg, A. (2007). Effect of Colored Shade Nets on Pepper Powdery Mildew (*Leveillula taurica*). Phytoparasitica, 35(3), 285–299.

Grimstadt, S.O., Frimanslund, E. (1993). The effect of different day and night regimes on greenhouse cucumber young plant production, flower bud formation and early yield. Sci. Hortic., 53, 191–204.

Heuvelink, E. (1995). Growth, development and yield of a tomato crop: Periodic destructive measurements in a greenhouse. Sci. Hortic., 61, 77–99.

Kandemir, D. (2005). The quantitative effects of temperature and light environment on the growth, development and yield of pepper (*Capsicum annuum* L.) grown in greenhouses. PhD thesis. Institute of Natural and Applied Sciences, Ondokuz Mayıs University, Samsun (unpublished).

Kılıc, S., Karatas, A., Cavusoglu, K., Unlu, H., Ozdamar, H., Padem, H. (2010). Effects of different light treatments on the stomata movements of tomato (*Lycopersicon esculentum* Mill. cv. Joker) seeedlings. J. Anim. Vet. Adv., 9(1), 131–135.

Kılınç, M., Kutbay, G.H. (2008). Plant Ecology. Palme Yayıncılık, Ankara, 490.

Kürklü, A. (1994). Energy Management in Greenhouses Using Phase Change Materials (PCMS). PhD Thesis. The University of Reading, England (unpublished).

Leskovar, D.I., Daniel, J.C. (1994). Transplant production systems influence growth and yield of fresh-market tomatoes. J. Amer. Soc. Hort. Sci., 119(4), 662–668.

Maddonni, G.A., Otegui, M.E., Cirilo, A.G. (2001). Plant population density, row spacing, and hybrid effects on maize canopy architecture and light interception. Field Crops Res., 71, 183–193.

Özer, H., Kandemir, D. (2016). Evaluatıon of the performance of greenhouse tomato seedlıngs grown wıth dıfferent cultıvatıon technıques. Bangladesh J. Bot., 45(1), 203–209.

Özer, H. (2017). Effects of shading and organic fertilizers on tomato yield and quality. Pakistan J. Bot., 49(5), 1849–1855.

Özer, H. (2018). The effects of different seedling production systems on quality of tomato plantlets. Acta Sci. Pol., Hortorum Cultus, 17(5), 15–21.

Ozturk, A., Umit, S., Gürgör, P.N., Korkmaz, A. (2014). The effect of different nursery conditions on some of the leaf and stomata characteristics in Chestnuts. J. Appl. Bot. Food Qual., 87, 190–195.

Pearson, S., Hadley, P., Wheldon, A.E. (1994). A model of the effects of temperature on the growth and development of cauliflower (*Brasssica oleracea* L. *botrytis*). Sci. Hortic., 59, 91–106.

Saraçoğlu, T., Özarslan, C. (2015). Kiraz domatesi meyvesinin kütle ve hacminin matematiksel modellemesi. J. Adnan Menderes Univ. Agric. Fac., 12(1), 103–108.

Sarıbaş, H.Ş., Saka, A.K., Özer, H. (2018). Mathematical growth model for organically grown pepper transplants. Biol. Agric. Hortic., 34(1), 10–17.

Shirvani, A., Moradi, F., Moosavi, A.A. (2015). Time series modelling of increased soil temperature anomalies during long period. Int. Agrophys., 29, 509–515.

Taiz, L., Zeiger, E. (2008). Plant physiology. Palme Yayıncılık, Ankara, 690 pp.

Topçu, S., Baytorun, A.N. (1999). Evaluation of the greenhouse tomato growth model TOMGRO under Çukurova protected cultivation conditions. J. Agric. For., 23(3), 749–755.

Tüzel, Y., Gül, A., Daşgan, H.Y., Öztekin, G.B., Engindemiz, S., Boyacı, H.F. (2015). Örtüaltı yetiştiriciliğinde değişimler ve yeni arayışlar. Türkiye Ziraat Mühendisliği VIII. Teknik kongresi, Bildiriler Kitabı-I, 12–16 Ocak, Ankara, 685–709.

Uzun, S. (1996). The Quantitative Effects of Temperature and Light Environment on the Growth, Development and Yield of Tomato and Aubergine. PhD Thesis. The Univ. of Reading, England (unpublished).

Uzun, S. (1997). Sıcaklık ve ışığın bitki büyüme, gelişme ve verimine etkisi (I. Büyüme). J. Fac. Agric. OMU, 12(1), 147–156.

Uzun, S. (2001). The relationships between some growth and yield parameters of greenhouse grown tomatoes and aubergine and temperature and light intensity. 6. Ulusal Seracılık Sempozyumu, 5–7 Eylül, Fethiye-Muğla, 97–102.

Uzun, S., Marangoz, D., Özkaraman, F., (2001). Modelling the time elapsing from seed sowing to emergence in some vegetable crops. Pak. J. Biol. Sci., 4(4), 442–445.

Wolfi, S., Rudich, J., Marani, A., Rekah, Y. (1986). Predicting harvesting date processing tomatoes by a simulation model. J. Am. Soc. Hortic. Sci., 111(1), 11–16.