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Original scientific article

SHADING EFFECT ON PERFORMANCES OF CROP GROWTH AND YIELD PARAMETERS OF VINING PEA AT DIFFERENT DEVELOPMENTAL STAGES

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In the paper, the effect of different shading treatments (full sunlight, light shading: 40%, medium shading: 75%, and heavy shading: 90%) on yield and crop growth parameters of vining pea was investigated. The experiment was conducted at Dicle University, Faculty of Agriculture, in Diyarbakir, Türkiye during the 2023 spring season under field conditions. The experiment was arranged Randomized Complete Blocks design with three replications. In study, some observations were investigated such as plant height, number of internodes per plant, leaf area per plant, number of leaves per plant, dry matter, SPAD value, soil moisture, number of pods per plant, fresh pod weight, pod width, pod length, number of seeds per pod and dry pod weight and some growth parameters were calculated. For this purpose, plants were harvested six times at 10-day intervals and measured for growth and yield parameters. Consequently, shading treatments increased fresh pod weight, pod width, and pod length compared to full sunlight, while heavy shading (90%) significantly reduced plant height. The crop growth rate tended downward under the shading conditions at the blooming and podding stages. However, crop growth rate was apparently higher under low light intensity (light shading; 6.46 g m^{-2} day^{-1} and heavy shading; 5.14 g m^{-2} day^{-1}) than at full sunlight (3.35 g m^{-2} day^{-1}) at the podding stage. Full sunlight was the most sensitive treatment to environmental conditions, therefore, the relative growth rate drastically reduced during the crop growth stages. In conclusion, the relative growth rate of crops grown under full sunlight was significantly

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lower than that of crops grown under other treatments. In summary, light and temperature accelerated crop development under full sunlight, while shade applications extended crop development duration. As a result, medium and low-level shading is thought to extend crop vegetation duration, especially in the arid and semi-arid climate areas exposed to water scarcity and high heat.

Keywords: pea**,** shade intensity, crop growth, yield, Pearson's correlation.

INTRODUCTION

Renewable crop proteins have achieved importance due to changes in world population and dietary habits. Humans have used legume crops for diets for about 10,000 years (MUDRYJ *et al.*, 2014). Pea is one of the legume crops including crucial protein sources for human and animal diets between plant-based proteins. Plant-based proteins are preferred to minimize threats to the environment, human and animal health, especially in recent years (CHOUDHURY *et al.*, 2020; BOUKID *et al.*, 2021).

Pea (*Pisum sativum* L.) are produced in over 95 countries worldwide, with an annual production of around 15.7 million tons (FAO, 2023). Pea is a cost-effective and high-yield protein source among legumes and the demand for this plant has been enhanced in the last years (GE *et al.*, 2020). Indeed, pea is commonly grown in temperate countries such as the Mediterranean or South West Asia. Pea cultivation is restricted by various reasons such as climate, temperature, crop cultivation techniques, etc. (PARIHAR *et al.*, 2022). Additionally, climate change may reduce pea yield due to high temperatures, lack of moisture and heat stress particularly in arid and semi-arid regions (FALCONNIER *et al.*, 2020; LAMICHANEY *et al.*, 2021; KOSEV *et al.*, 2023). Indeed, pea production is high in relatively cool weather and resists low temperatures during the growth and development stages (ANITHA and HANUMANTHARAYA, 2022). Especially, temperatures above 30°C may severely decrease pea yield during the developmental stage (BUECKERT *et al.*, 2015). Therefore, it is essential to minimize the factors that reduce pea yield as much as possible. For this purpose, pea production is increase by cultivating high-yielding varieties at appropriate planting density (PRUSIŃSKI and BOROWSKA, 2022), intercropping system (PANKOU *et al.*, 2022) and combining other agricultural practices (TOBIASZ-SALACH *et al.*, 2023). Although the light controls the growth rate, development and structure of crops, full sunlight conditions can cause some stress factors in crops such as heat, drought, low soil moisture, etc. Therefore, the shading methods can also be effective to increase light absorption, chlorophyll and photosynthesis rate and increase the final yield by proving advantages for plants to cope with stress factors (TOPNO and RAI, 2024). (NAVEED *et al.*, 2024).

Many researchers reported that shading treatments could reduce the negative effects of temperature, drought, light intensity etc. on some legume crops yield and growth parameters (CHEN *et al.*, 2019; WANG *et al.*, 2021; LAKIĆ *et al.*, 2019). There is a certain requirement for shading to enhance the photosynthetic efficiency of plants (DONGYU *et al.*, 2024). Shading prevents plants from being exposed to excessive sunlight, optimizing the photosynthesis process and reducing heat stress (WIDARYANTO *et al.*, 2023; AHMED *et al.*, 2024). Additionally, shading regulates the water usage of plants and decreases the impact of harmful insects. Therefore, the use of appropriate shading techniques by taking into account shade intensity, color of the shade materials, and the treatment duration can encourage healthy growth of crops and finally increase productivity (ZHANG *et al.*, 2021; ACAY and BICER, 2024). Indeed, plant productivity is directly related to the amount of light in the environment and the adaptation of crops to the environment (MANOJ *et al*., 2021).

This study aimed to address questions included the responses of yield and yield-related parameters of pea to different shading treatments (i), the calculation of some growth parameters including crop growth rate, relative growth rate, leaf area index, net assimilation rate, leaf area ratio, relative leaf area, specific leaf area, proportional leaf weight, proportional stem weight and absolute growth rate (ii) and the determination of soil moisture changes under different shade intensity (iii).

MATERIAL AND METHOD

The research was conducted as a field experiment during the early spring growing season of 2023 at the Dicle University Faculty of Agriculture in Diyarbakır, Turkey (37°53' N, 40°16'E, 675 m.a.s.l). The image of the experimental area and the experimental design was given in Figure 1. The soil of the experimental area was clay-loam textured, and its pH value was 8.15. It was low in organic matter, nitrogen and phosphorus ratio; however, it was quite rich in iron and calcium ratio.

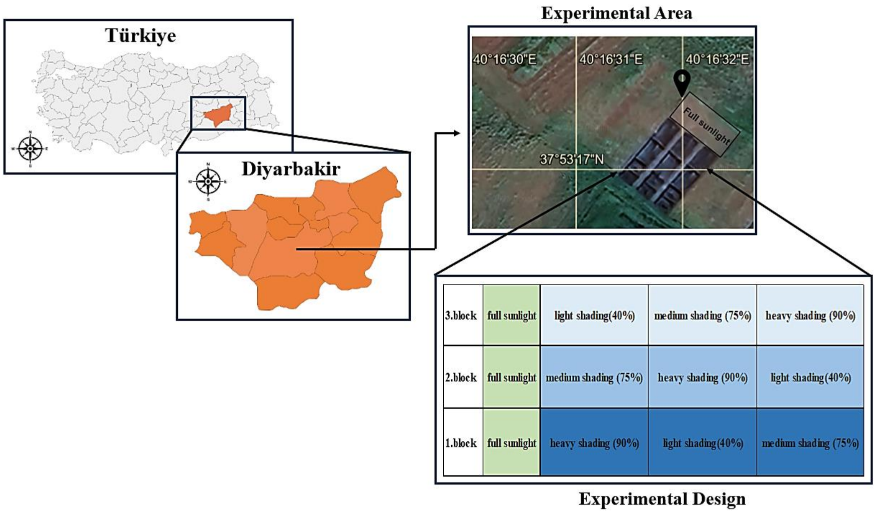

Figure 1. The schematic representation of the experimental area and design

The total rainfall recorded as 398 mm during the experiment period (February-June). The rainfall was high in February, March, and April, however low in May. The average temperature recorded in the same month was 17.57°C. Relative humidity demonstrated a decreasing tendency from January to June. The experimental site has been experienced intense evapotranspiration in June. In the first week of April, sharp decreases occurred in night temperature (Figure 2).

The study used four shade intensities including full sunlight, light shading (40%), medium shading (75%), and heavy shading (95%) (Figure 3). The experiment set out a randomized block design with three replications. The plots consisted of 4 rows, 4 m, and 0.45 m intervals. The seeds were sown on February 22, 2023. The shading treatments determined the directions of sunrise, sunset, the experimental area and direction of the shading. Before the sowing, non-flexible shading poles were erected by digging holes in the experimental site. These poles were designed to withstand environmental factors such as rain and wind while supporting the shading material. The shading poles were maintained at a height of 2.0 m.

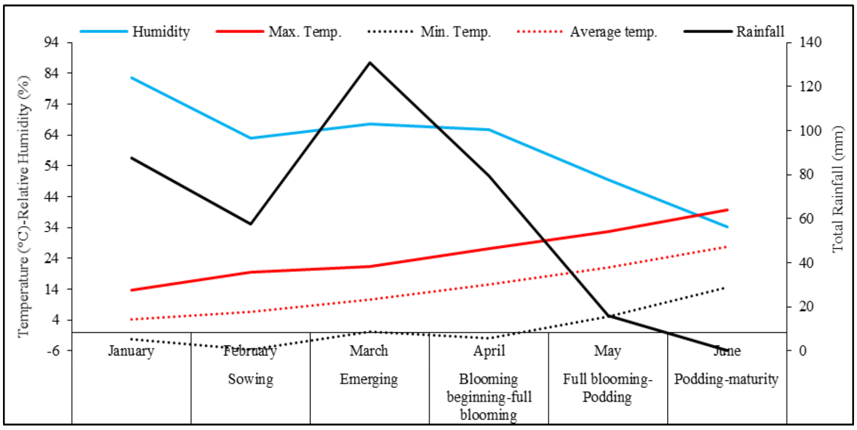

Figure 2. Meteorological data of experimental site (Diyarbakir Meteorological Service, 2023)

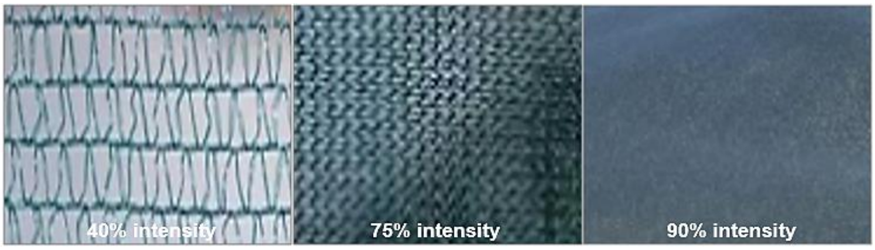

Figure 3. The intensity of the used shade materials in the experimental field

Plants were not irrigated and weed control realized manually twice during the vegetation period. The plants were harvested six times, each time at ten-day intervals from 30 DAE, and plant samples washed in tap running water to remove soil from the stem and root. The plant samples were separated into branches, leaves, and stems. The dry weight of each sample was kept at 70°C for 24 hours (WOOD and ROPER, 2000). Leaf area was measured using the 'HP Scanjet 3400C' device. Leaf chlorophyll content (SPAD) was determined before blooming, full blooming and podding stages by using SPAD-502.

Plant height, number of internodes per plant, leaf area per plant, number of leaves per plant, dry matter, SPAD value, soil moisture, number of pods per plant, fresh pod weight, pod width, pod length, number of seeds per pod, dry pod weight and growth parameters were investigated. Growth parameters and soil moisture were calculated by formulas (Table 1).

Soil samples taken from a depth of 30 cm were measured for soil moisture in pre-weighed containers six times every ten days from 30 DAE. Then, soil samples were keeping the container in the oven for 24 hours. The samples were dried at 105°C until a constant weight was reached.

Table 1. Calculations of CGR, RGR, NAR, AGR, SLW, SLA, LAI, LAR, PLW, PRW and PSW

Calculations	Units	References
$Crop\ Growth\ Rate\ (CGR) = \frac{W2-W1}{t2-t1}$	g m^{-2} day^{-1}	Watson, 1956
$Relative\ Growth\ Rate\ (RGR) = \frac{(\log_e W2 - \log_e W1)}{(t2-t1)}$	g $g^{-1}day^{-1}$	Williams, 1946
$Net\ Asimilation\ Rate\ (NAR) = \frac{(W2-W1)}{(t2-t1)} \times \frac{(\log_e L2 - \log_e L1)}{(L2-L1)}$	g $g^{-1}day^{-1}$	Williams, 1946
$Absolute\ Growth\ Rate\ (AGR) = \frac{h2-h1}{t2-t1}$	cm day^{-1}	Benbi, 2011
$Specific\ Leaf\ Weight\ (SLW) = \frac{leaf\ weight}{leaf\ area}$	g cm^{-2}	Pearce *et al*., 1968
Specific Leaf Area$(SLA) = \frac{leaf\ area}{leaf\ weight}$	cm^2 g^{-1}	Kvet *et al*. 1971
$Leaf\ Area\ Index\ (LAI) = \frac{leaf\ area}{plant\ area}$		Williams, 1946
$Leaf\ Area\ Ratio\ (LAR) = \frac{Leaf\ area}{dry\ weight\ per\ plant}$	cm^{-2} g^{-1}	Radford, 1967
$Proportional\ leaf\ weight\ (PLW) = \frac{Total\ leaf\ weight}{Total\ plant\ weight}$	g $plant^{-1}$	Uzun, 1997
$Proportional\ root\ weight\ (PRW) = \frac{Total\ root\ weight}{Total\ plant\ weight}$	g $plant^{-1}$	Uzun, 1997
$Proportional\ stem\ weight\ (PSW) = \frac{Total\ stem\ weight}{Total\ plant\ weight}$	g $plant^{-1}$	Uzun, 1997
$W_{H2O} = \frac{w1 - w2}{w2 - w0} \times 100$		(https://uta.pressbooks.pub/soilmechanics/chapter/chapte).

Abbreviations: W_2 *and* W_1 = plant dry weights, which were measured at time 2 and 1, *H2-H1*= plant height, which were measured at time 2 and 1, *T1 and T2*= duration, which were measured at time 2 and 1, respectively. Wo: Container weight, W1: Wet soil weight, and W2: Dry soil weight.

Statistics

The data were analysed by using JumpPro-17 software (SAS INSTITUTE, 2002). Analysis of variance (ANOVA) was performed on randomized block design, and the difference between means was compared by student t test (0.05). Pearson's correlation analysis was performed to determine the linear relationship between the growth parameters by coding within R software 4.4.2 (R Xposit 2024) in the metan package using "the corr()" function. In this package, Pearson's correlation coefficient was calculated by the following equation:

$$r = \frac{\sum(Xi-X)((Yi-Y)}{\sqrt{\sum(Xi-X)^2}.\sqrt{\sum(Yi-Y)^2}}$$ (PEARSON, 1895).

In this equation, Pearson's correlation coefficient was obtained by dividing the covariance by the standard deviations of both variables.

$$r = \frac{Cov\ (X,Y)}{\sigma X\ .\ \sigma Y}$$

where *Cov*(X, Y) is covariance of X and Y, σX is standard deviation of variable X and σY is standard deviation of variable Y.

RESULTS

Results of growth parameters included plant height, number of internodes per plant, leaf area per plant, number of leaves per plant, dry matter, SPAD value, soil moisture, number of pods per plant, fresh pod weight, pod width, pod length, number of seeds per pod and dry pod weight were given in Figure 4 and Table 2.

Yield Parameters

Plant height

Significant differences were found within all the development stages except for 60th day observation for plant height between the full sunlight and other shading treatments. Plant height was significantly decreased by heavy shading (90%) (11.3 cm), and it increased in full sunlight (19.0) with increased light density on the 30th day. At the end of generative stage (on the 80th day), plant height peaked in full sunlight (92.0 cm) and all other shade treatments (light shading: 76.3 cm, medium shading: 58.7 cm, and heavy shading: 57.3 cm). There was a general reducing tendency for increased shading treatments for plant height. The similarity between the growth curve for plant height of the heavy and medium shading treatments strongly revealed that increasing shading treatments reduced plant height at the vegetative stage. The rapidly increase in plant height was apparent in both full sunlight and light shading treatment (Figure 4).

Number of nodes per plant

The increase in plant height was related to a basic increase in the number of nodes per plant. In this study, significant differences were found on the 30th, 40th and 50th day observations for number of nodes (P≤0.01; Figure 3). However, no significant differences were in other observation days. The number of nodes almost tripled under full sunlight, light shading and heavy shading treatments, while it doubled under medium shading on the 30th day. At the end of generative stage (on the 80th day), number of nodes peaked in all treatments (full sunlight; 15.0, light shading; 12.7, medium shading; 15.0 and heavy shading; 14.7). The first response to shading in a plant is to extend its stem to arrive over the canopy, thus the number of nodes increases (Figure 4).

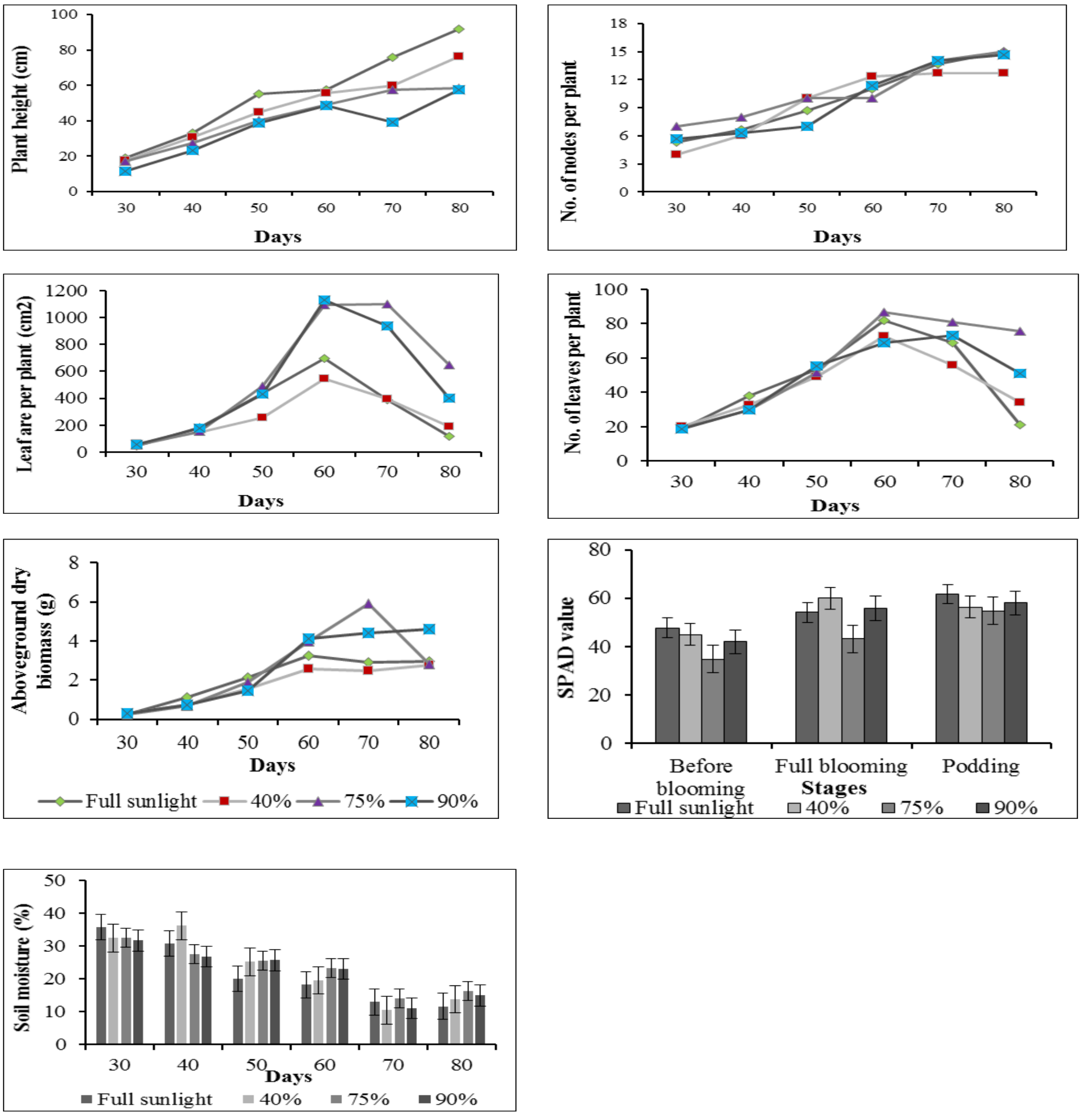

Figure 4. Plant height, number of internodes, leaf area per plant, number of leaves per plant, dry matter, SPAD value of *Pisum sativum* and soil moisture under full sunlight and shading conditions at 10-day intervals.

Leaf area per plant

Significant differences were found within all development stages for leaf area per plant increasing shading treatments. The number of leaf and leaf area per plant were closely linked, thus an increase in leaf area could be attributed to leaf number. Under high shading conditions, remarkable changes in leaf morphology happen. This change was most occurred by medium shading (1096.6 and 1101.3 cm^2) on the 60th day and heavy shading (1129.2 and 935.50 cm^2) on the 70th day and reduced as the pea matured. Under light shading a drastic reduction in leaf area was recorded with 693.9 cm^2 on the 60th day, which was the end of blooming and the beginning of podding stages, compared to medium and heavy shading conditions (Figure 4).

Number of leaves per plant

Significant differences were not found within all development stages for the number of leaves per plant. The leaf number on the 30th day was observed at 18.7 and 20.0, and the shading treatments were close to each other. The medium shading occurred more leaves on the 60th day compared to other treatments. At the generative stage (on the 60th day), number of leaves per plant peaked in all treatments (full sunlight; 81.67, light shading; 72.67, medium shading; 86.67) except for heavy shading. Heavy shading reached peak on the 70th day (69.00). The decrease in leaf occurred with increased light intensity and a drastic reduction was observed. Summarily, leaf area increased under shading as apparent by the increased leaf number. The growth curve showed that the number of leaves per plant in increasing tendency in the generative stages. Conversely, reducing a tendency at the end of generative stage (on the 80th day) was apparent, since photosynthesis was limited and the leaf abscission enhanced (Figure 4).

Aboveground dry biomass

The pea showed different responses to shading treatments at different growth and development stages for aboveground dry biomass. Aboveground dry biomass significantly increased under shading on the 40th, 60th and 70th days. This increase was most apparent in heavy shading (4.13 g) on the 60th day. The growth curve showed that reducing light intensity increased aboveground dry biomass at the vegetative stage (on the 60th day). The rapid increase was apparent in full sunlight on 60th day and under light shading and heavy shading on 80th day and medium shading on 70th day (Figure 4).

Leaf chlorophyll content (SPAD)

Significant differences were found under shading treatments for the leaf chlorophyll content (SPAD) during the before blooming, full blooming and podding stages of pea. SPAD tended to be enhanced in high light intensity. It decreased progressively with reducing light intensity and the highest value was noted in full sunlight at the podding (61.50) and before blooming stages (47.7). SPAD was inconsistent under shading conditions and the highest value was recorded under light shading (59.87) at full blooming stage (Figure 4).

The effect of shading on the number of pods per plant and number of seeds per pod was no significant. Compared to full sunlight, shading treatments were positively increased in fresh pod weight, pod width and pod length, however; shading was decreased in dry pod weight (Table

2). These results proved that there was a strong relationship between light intensity and pod traits such as number of pods, pod size, and pod weight under shading conditions.

Table 2. Effect of shade on traits after podding stage (70 DAS)

Treatments	No. of pods per plant	Fresh pod weight (g)	Pod width (cm)	Pod length	No. of seeds per pod	Dry pod weight (g)
Full sunlight	6.3	15.4 d	1.8 b	6.2 c	5.3	6.4 a
40% density	5.3	18.6 c	1.7 c	7.2 b	6.3	6.1 a
75% density	5.3	22.3 b	2.0 a	7.5 b	6.0	6.6 a
90% density	5.7	29.8 a	2.0 a	9.0 a	6.0	2.4 b
Average	5.67	21.5	1.7	7.45	5.91	5.14
LSD (0.05)	ns	3.70**	0.09**	0.60**	ns	0.99**

**; P≤0.01 significant level, ns: non-significant. Levels not connected by same letter are significantly different

Soil moisture

Significant differences were found under shading treatments for the soil moisture all observation days, except on the 30th day. Soil moisture was high due to rainfall and relative humidity on the 30th day, however decreased the end of the growing season. The soil moisture in the full sunlight was lower than in the other treatments throughout the vegetation period, except for on 30th day. Soil moisture was maintained on the 80th day under medium and heavy shading conditions. Generally, soil water content is preserved under shading conditions (Figure 4).

Crop Growth Parameters

Responses shading treatments of pea including CGR, RGR, LAI, NAR, LAR, RLA, SLA, PLW, PRW, PSW and AGR were presented with graphs in Figure 5 and Figure 6.

Crop growth rate (CGR)

Shading had a beneficial effect on CGR at the decreased light intensity. CGR was apparently higher under low light intensity (light shading; 6.46 g m^{-2} day^{-1} and heavy shading; 5.14 g m^{-2} day^{-1}) than at full sunlight (3.35 g m^{-2} day^{-1}) on 60th day (at the podding stage). Medium shading showed a stable development throughout the growing season (Figure 5). The shading had a downward trend in CGR during the blooming and podding stages, thus growth was delayed. Moreover, light and temperature accelerated development in full sunlight, and shading treatments extended the developmental period of the crops.

Relative growth rate (RGR)

The RGR of crops grown under full sunlight was notably lower than other treatments, particularly at the early development stage (on the 30th day) and generative stage (on the 70th day).

RGR and varied between 0.09 g g^{-1} and -0.02 g g^{-1} day^{-1}, respectively. The full sunlight was the most sensitive treatment to environmental conditions, thus drastically reduced RGR compared to the other shading treatments through crop growth stage. Medium shading, which remained stable throughout the growing season, was the least affected by environmental conditions.

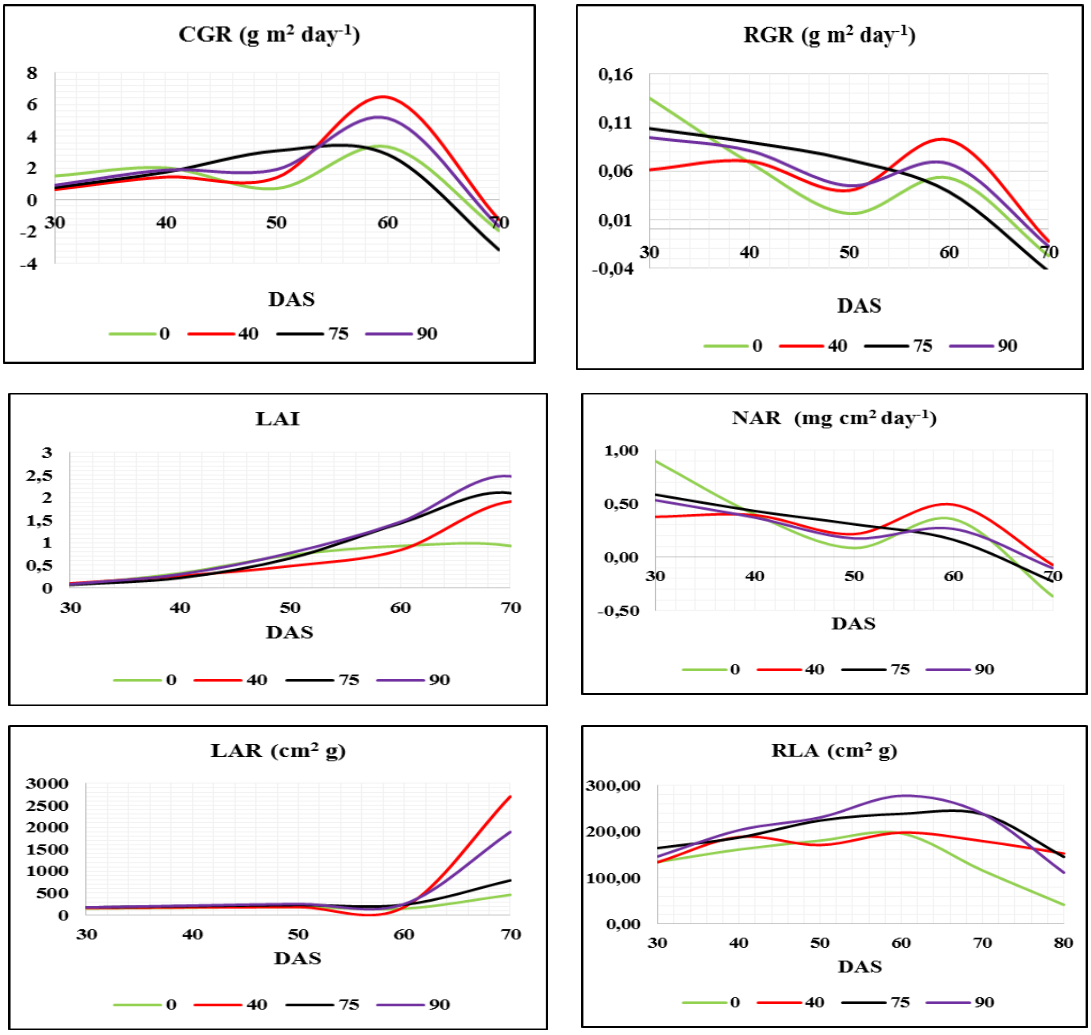

Figure 5. Effect of shading on crop growth rate (CGR), relative growth rate (RGR), leaf area index (LAI), net assimilatory rate (NAR), leaf area ratio (LAR), relative leaf area (RLA).

Leaf area index (LAI)

Medium and high light intensity (0.07 m^2/m^2) decreased LAI on 30^{th} day. Light shading (0.10 m^2/m^2) rise to this observation day illustrated beneficial effect on LAI. Heavy shading

(2.47 m^2/m^2) had an upward trend and reached a peak on 70th day. During the blooming and podding stages, LAI suddenly decreased in light shading treatments, however, increased under full sunlight, medium and heavy shading conditions (Figure 5).

Net assimilation rate (NAR)

Shading treatments caused a sharp reduction in the NAR. Under medium shading, NAR showed a regular trend at the beginning of growth until the end of crop growth stage. However, NAR was irregular in full sunlight, light shading and heavy shading conditions, respectively. Light changes under full sunlight treatments could cause this irregular growth and negatively affect NAR during the beginning blooming (on 40-50th days). Light shading had downward tendency through vegetative stage. Moreover, NAR reached a peak under full sunlight, light (0.49 mg cm^2 day^{-1}) and heavy shading (0.27 mg cm^2 day^{-1}) conditions at the end of generative stages (Figure 5).

Leaf area ratio (LAR)

Shading had an upward tendency in LAR at low-temperature and light limitation conditions during the different crop development stages. LAR increased on the 50th day, however, drastically showed a downward tendency on the 60th day. It had more growth in light shading (2704.58 cm^2 g) occurred low light limitation. However, there was no observed increase in LAR in full sunlight presented high light and temperature on the 70th day (464.32 cm^2 g).

Relative leaf area (RLA)

Light shading caused a drastic reduction in RLA (133.97 cm^2 g^{-1}). However, RLA positively affected on medium shading (164.56 cm^2 g^{-1}) at the early vegetative stage (on the 30th day). RLA had a regular increasing tendency in full sunlight, medium and heavy shading presented different light and temperature at the generative stage (on the 60th day). Additionally, RLA showed a downward trend at the end of the crop growth stage (70th and 80th days) (Figure 5).

Specific leaf area (SLA)

Shading had no negative effect on leaves due to the compensative effect of SLA under shading conditions presenting low light and temperature. Medium shading exhibited an upward tendency in SLA (75%: 260.73 cm^{-2} g^{-1}), however, full sunlight was downward tendency (219.34) at the early vegetative stage (on 30th day). SLA was regularly increased in both the full sunlight and all shading treatments until generative stage. Light shading had a relative reduction on the 50th day. All treatments reached peak on the 60th day, and heavy shading was the highest SLA. However, this performance decreased on the 70th and 80th days. Generally, under shaded crops constructed leaves with larger surface areas and higher SLA over full sunlight crops (Figure 6).

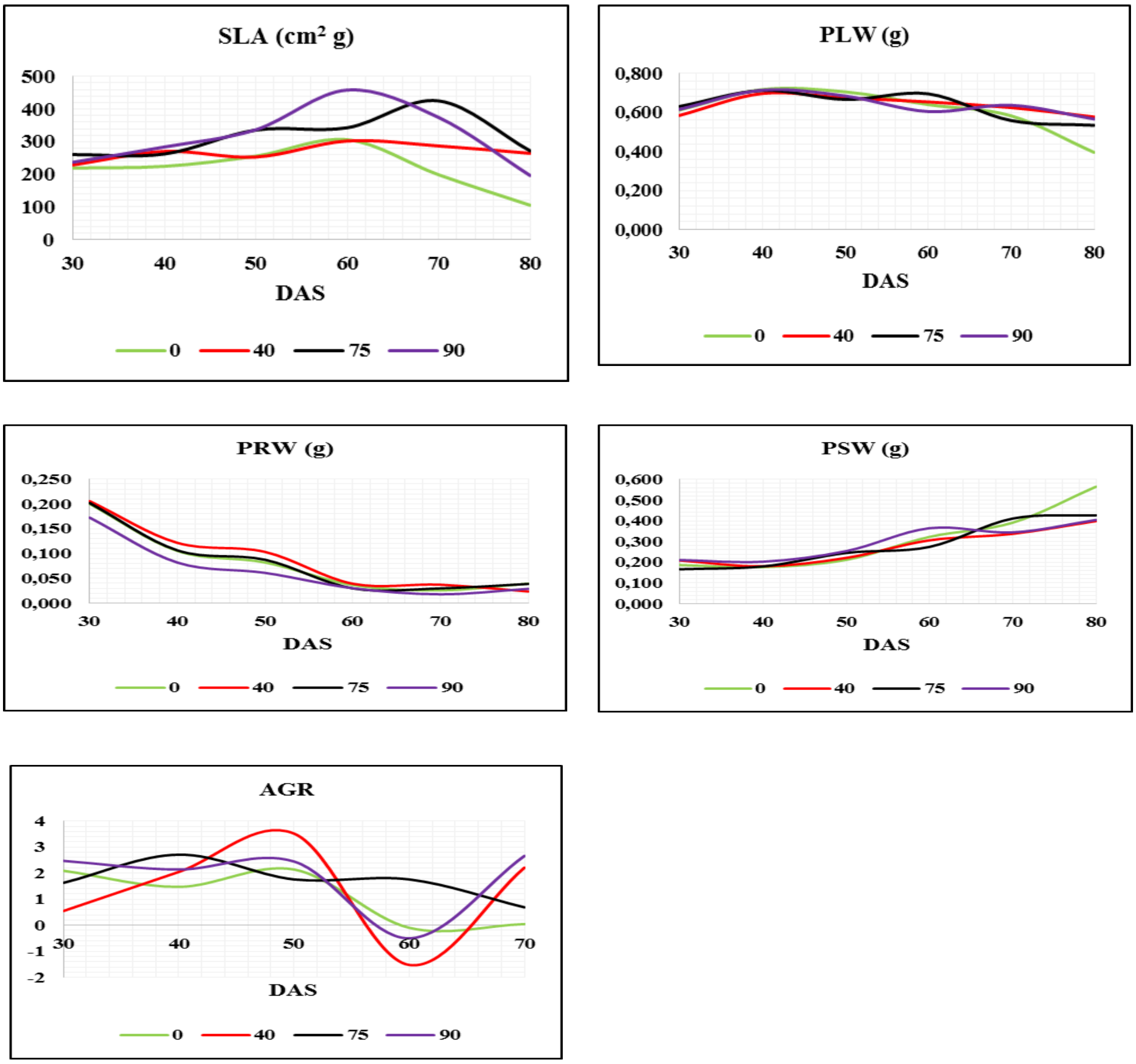

Figure 6. Effect of shading on specific leaf area, (SLA) proportional leaf weight (PLW), relative growth speed (RGS), proportional root weight (PRW), proportional stem weight (PSW) and absolute growth rate (AGR).

Proportional leaf weight (PLW)

Shading treatments had a positive effect on PLW. Medium shading reached a peak in PLW with 0.631 g. Light shading and full sunlight presented upward tendency in PLW at the end of vegetative stage (on the 40th day). However, PLW exhibited a downward trend in full sunlight, light and heavy shading conditions presented different light and temperature. The limited light could provide more leaf tissue in the unit leaf area. Medium shading increased at the generative stage (0.667-0.696 g), but later decreased. PLW had drastic reduction in all treatments on the 70th and 80th days (Figure 6).

Proportional root weight (PRW)

Shading had a detrimental effect on PRW and there was more damage marked under heavy shading. PRW performed consistent tendency in full sunlight, light and medium shading conditions (0.20 g) due to high light and suitable temperature at the early vegetative stage (on the 30th day). Besides, PRW had a drastic reduction in heavy shading (0.17 g). Despite the expectation that RGW would develop rapidly in dry and hot conditions, it showed a decreasing tendency in shadings as plant development progressed (Figure 6).

Proportional stem weight (PSW)

Shading had an upward tendency in PSW (0.17-0.21 g) at the early vegetative stage (on the 30th day). PSW regularly increased in full sunlight presented low light limitation at the early generative stage (on the 40th day). There was irregular reduction under light shading at the generative stage (on 60th day). However, PSW performed an upward tendency and reached a peak at the end of the growth stage (on the 70th and 80th days) because high dry matter accumulation occurred under suitable temperatures and low light limitation (Figure 6).

Absolute growth rate (AGR)

AGR performed a drastic reduction under decreased shading, while upward trended under heavy shading (90%: 2.47) at the early vegetative stage (on the 30th day). Plant growth was more fasted under full sunlight (1.47) and medium shading (2.71) than other conditions at the early vegetative stage (on the 40th day). However, plant growth reached a peak (3.52) under light shading at the generative stage (on the 50th day). Additionally, medium shading similarly performed at this stage (1.76) (Figure 6).

Pearson's correlation for crop growth parameters in shaded and unshaded plants

There were positive and very strong relationships between NAR and RLA (r^2=0.98***), PSW with LAI (r^2=0.91***) and SLA (r^2=0.82***), and SLA and RLA (r^2=0.93***). There were negative and very strong relationships between NAR with LAI (r^2=-0.86***) and PSW (r^2=-0.78***) in shaded plants. Additionally, PRW showed negative and strong relationship with RLA (r^2=-0.82***) and PSW (r^2=-0.78***). NAR showed a positive and direct relationship with RGR (r^2=0.99***) in unshaded plants. There were positive and significant relationships between SLA and RLA, RLA and CGR, PRW and LAI. Consequently, the relationship between growth parameters of shaded plants was stronger compared to unshaded plants. As can be seen from the correlation diagram, the growth parameters were affected by shading treatments, and plant growth was better in the shaded plants (Figure 7).

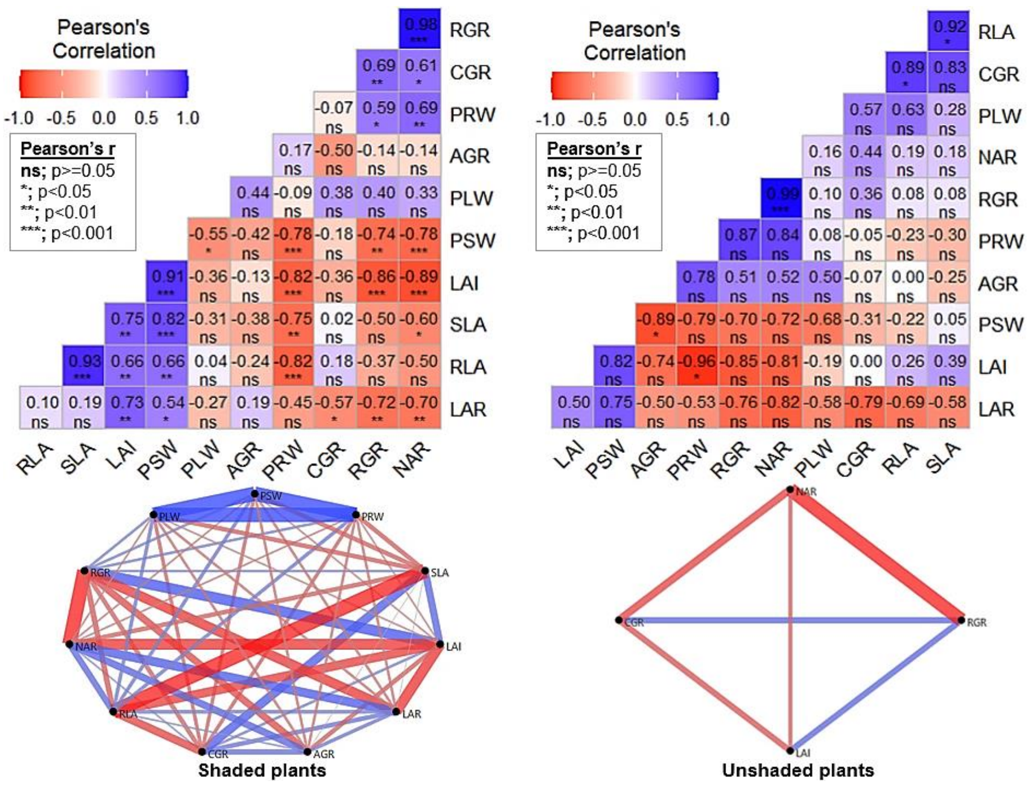

Figure 7. Pearson's correlation and correlation diagram show the relationships between the growth parameters of shaded and unshaded plants. The correlation diagram shows the relationship between two growth parameters by considering the p values in Pearson's correlation, where thick networks indicate strong relationship and thin networks indicate weak relationships. CGR= crop growth rate, RGR= relative growth rate, LAI= leaf area index, NAR= net assimilation rate, LAR= leaf area ratio, RLA= relative leaf area, SLA= specific leaf area, PLW= proportional leaf weight, PRW= proportional root weight, PSW= proportional stem weight and AGR= absolute growth rate, respectively.

DISCUSSION

The examined yield and yield-related parameters and calculated growth parameters differed under different shading intensity and full sunlight conditions. Reduced light decreases crop productivity; however, the degree of reduction varies depending on the crop species, used varieties, shade material, shade color, shade thickness, the duration of crop remaining under shade, etc (ZHANG *et al.*, 2021). Crops grown in shaded conditions tend to decrease their plant height at the vegetative stage, probably because of insufficient light under shade. Indeed, plants grown in shade conditions realize more in the synthesis and maintenance of light harvest than those grown in open area (TESFAYE *et al*., 2006). MISHRA *et al.* (2020) stated that plant height was the principal physiological response and increased under shading conditions. The first response to shading in a plant is to extend its stem to arrive over the canopy for capturing light, thus the number of nodes increases. In the study, it was recorded that a higher number of nodes under medium (75% intensity) shading conditions. This activity is firstly affected by the change in red: far red ratio under shading treatments, and indeed red: far red ratio reduces under shading and supplies the extension by triggering phytochrome. The different shade intensities can also alter certain conditions of the environment and suitable microclimates, realizing variation in plant height under different shade conditions (TOPNO and RAI, 2024). The notably changes occurred in the number of leaves and leaf area under high shading conditions compared light shading and full sunlight conditions. Some researchers reported that leaf area, thickness, and length under sunlight conditions may vary depending on daily temperature (ANGMO *et al.*, 2021), while shade treatments mitigate the adverse effects of solar radiation, heat, temperature, wind, and drought on plants (DONGYU *et al.*, 2024). AL MAJDI *et al.* (2020) stated that the number of leaves per plant in pea was enhanced by reducing the light density, and BALLARE (2004) declared that the leaf area increased under shading conditions to compensate for the low photosynthesis due to low light, and enhanced photosynthesis in the later development stage of crops. Similarly, AKHTER *et al.* (2009) noted that the leaf area of pea could be increased in reduced light intensity because of adaptation to light. The pea showed different responses to shading treatments at different growth and development stages for aboveground dry biomass, and the rapid increase was apparent under full sunlight on 60th day and light shading and heavy shading on 80th day and medium shading on 70th day. Indeed, the light may be influenced plant morphology, photosynthetic and physiological activity, dry matter and yield of crops (CHEN *et al.*, 2019), however, some factors such as variety, shading density, duration and degree also affected on these (WANG *et al.*, 2021). The highest SPAD value was recorded under light shading during full blooming due to sustained leaf development under light shade. This case may be attributed to leaf in full sunlight being thicker and richer for chlorophyll than leaves under shading conditions (POLTHANEE *et al.*, 2011; MANOJ *et al.*, 2021). However, NAGASUGA and UMEZAKI (2022) also stated that shading treatments were not significantly affected on SPAD. Light intensity and pod traits such as number of pods, pod size, and pod weight under shading conditions were in a strong relationship, and the vegetative part of crops reduced in shading conditions. These findings showed similarity with findings reported by some researchers (NASRULLAHZADEH *et al.*, 2007; MISHRA *et al.*, 2020; TOPNO and RAI, 2024). LAKE *et al.*, (2019) reported that the number of seeds per pod tended to drastic reduction in full sunlight, however, tended to increase in shading conditions. Growth parameters of pea were changed under different shading conditions. Plants grown in shaded conditions tended to increase their CGR during the blooming and podding stages. Therefore, crop growth was delayed, probably because light and temperature accelerated development in full sunlight, and shading treatments extended the developmental period of the crops. Many researchers reported that shading conditions impacted on CGR (TAMIRAT *et al.*, 2021; WANG *et al.*, 2024). BOARD and KAHLON, (2011) recorded that CGR upward trend was maximum at the start of the seed-filling stage. Similarly, AHMEED *et al.* (2024) reported that the crop growth rate enhanced by 35.06% under 30% shading intensities. RGR, which gives information about the rate of enhancement in crop mass, drastically reduced under sunlight conditions compared to shading treatments, probably due to its sensitivity to the environmental conditions and photo-assimilate sources (MISHRA *et al.*, 2020). Plants grown in heavy shading (90%) conditions tended to increase their LAI, probably because of greater leaf longevity and maintained active leaf growth. Young leaves of crops give high LAI due to high absorption of light and CO_2 assimilation (WIDARYANTO *et al.*, 2023), similarly, LAI showed a downward trend with maturity (on the 80th day) in full sunlight. ZHANG *et al.* (2021) reported that LAI increased at the blooming and pod-filling stages; however, there was a downward trend depending on light intensity. Additionally, MISHRA *et al.* (2020) reported that NAR had a downward tendency under changed light intensity and increased temperature. Similarly, leaves of crops grown in shading conditions are thinner and cover more area to reach light compared to those grown in sunlight (DÍAZ-PÉREZ, 2013) and finally, the LAR, RLA and SLA values also increased (OZTURK and DEMIRSOY, 2013; MENSAH *et al.*, 2022). PLW and PRW reduced in shading conditions as plant development progressed, probably a decrease of tissue in a unit leaf area and increased the susceptibility of crops to light restriction (AKHTER *et al.*, 2009). However, PSW peaked at the end of the growth stage because of higher accumulation of dry matter (ZHANG *et al.*, 2021). With the increase of dry mass, the amount of photoassimilation starts to decrease and plants need more photoassimilations, therefore, if plants cannot meet their required photoassimilations, AGR tends to decrease (ZEIST *et al.*, 2021). The translocation of photoassimilates, which are necessary for plant growth, development, and metabolic processes (sucrose, glucose, starch, etc.) occurs, finally the transition to physiological maturity begins (SCHEMES *et al.*, 2024). In the current study, crop growth was higher in shaded plants compared to unshaded crops, and crop growth parameters were related to each other. These findings were similar to the findings reported by NEUGSCHWANDTNER *et al.*, (2025).

CONCLUSION

This study examined the impact of shading intensities and sunlight on the vining pea growth and yield at the different development stages. In the current study, the growth and yield parameters increased due to the increase of the aboveground dry biomass under the tested medium shading. Sınce sunlight exposed the crops to environmental stresses such as temperature, drought, wind, etc., the fluctuations in growth parameters of vining pea occurred. However, the shading treatments protected crops from environmental stresses, and shaded crops grew better than crops grown in sunlight. Therefore, shading treatments can be an effective agricultural practice to protect crops from these stresses. In the future, evaluation of different shade colors, shade application duration, etc. will be effective in pea cultivation as well as the intensity of shading.

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UTICAJ ZASENJIVANJA NA PERFORMANSE RASTA USEVA I PARAMETRE PRINOSA VINOVE LOZE U RAZLIČITIM FAZAMA RAZVOJA

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Izvod

U radu je ispitan uticaj različitih tretmana senčenja (puno sunčevo svetlo, blago senčenje: 40%, srednje senčenje: 75% i jako senčenje: 90%) na prinos i parametre rasta useva vinove loze. Eksperiment je sproveden na Univerzitetu Didžle, Poljoprivrednom fakultetu, u Dijarbakiru, Turska, tokom prolećne sezone 2023. godine u poljskim uslovima. Eksperiment je organizovan po randomizovanom kompletnom blok dizajnu sa tri ponavljanja. U studiji su ispitane neke osobine kao što su visina biljke, broj internodija po biljci, površina lista po biljci, broj listova po biljci, suva materija, SPAD vrednost, vlažnost zemljišta, broj mahuna po biljci, težina svežeg ploda, širina ploda, dužina grozda, a izračunati su i neki parametri rasta. U tu svrhu, biljke su ubrane šest puta u intervalima od 10 dana i mereni su parametri rasta i prinosa. Shodno tome, tretmani senčenjem su povećali težinu svežih plodova, širinu i dužinu ploda u poređenju sa punim sunčevim svetlom, dok je jako senčenje (90%) značajno smanjilo visinu biljke. Stopa rasta useva je imala tendenciju da se smanji u uslovima senčenja u fazama cvetanja i stvaranja ploda. Međutim, stopa rasta useva je očigledno bila veća pri slabom intenzitetu svetlosti (lagano senčenje; 6,46 g m-2 dan-1 i jako senčenje; 5,14 g m-2 dan-1) nego pri punoj sunčevoj svetlosti (3,35 g m-2 dan-1) u fazi stvaranja ploda. Puna sunčeva svetlost je bila najosetljiviji tretman na uslove okoline, stoga je relativna stopa rasta drastično smanjena tokom faza rasta useva. Zaključno, relativna stopa rasta useva gajenih pod punom sunčevom svetlošću bila je značajno niža nego kod useva gajenih pod drugim tretmanima. Ukratko, svetlost i temperatura su ubrzali razvoj useva pod punom sunčevom svetlošću, dok je primena senke produžila trajanje razvoja useva. Kao rezultat toga, smatra se da srednji i nizak nivo senčenja produžavati trajanje vegetacije useva, posebno u sušnim i polusušnim klimatskim područjima izloženim nestašici vode i visokim temperaturama.

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