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# The Quantitative Effects of Temperature and Light on Growth, Development and Yield of Faba Bean (*Vicia faba* L.): I. Growth

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**Abstract:** In this study, it was aimed to define the relationships between temperature, light intensity and growth parameters for faba bean (*Vicia faba* L.) namely leaf area, leaf weight ratio, specific leaf area, leaf area ratio, net assimilation rate and relative growth rate. Changes in plant growth caused by the effects of environmental conditions such as temperature and light intensity were intended to be described by plant growth models. All equations produced for growth parameters were derived as affected by light intensity and temperature. As a result of multi-regression analysis, it was found that there was close relationship between actual and predicted growth parameters. The regression coefficients ($R^2$) of the produced equations for growth parameters changed from $R^2$: 0.73 (leaf weight ratio) to $R^2$: 0.94 (leaf area ratio).

**Key words:** Faba bean, *Vicia faba* L., growth, light, temperature, modeling

## INTRODUCTION

Although there are more than 80 different types of faba bean in the world, only eighteen of them are being cultivated widely. Mature faba bean grains are a good resource of protein, starch, cellulose and minerals. Therefore, it is of importance for human and animal food (Haciseferogullari *et al*., 2003). High yield, smaller grains, less antinutritional factors, high adaptation ability to modern agriculture will make this plant more attractive for farmers, feed and food manufacturers (Duc, 1997).

Environmental factors such as climate and soil factors affect plant growth and development. It will be useful to know minimum, optimum and maximum temperatures and light intensity required for plant growth and development (Arechiga and Carlos, 2000; Hakansson *et al*., 2002). These factors determine plant species which will be grown productively in a region.

Leaf area is an important determinant of plant growth rate during early phases of development (Brown and Byrd, 1996). Plant growth can be defined as the increase of dry material in plant or the increase of plant parts numerically. One of the most useful indices of plant growth is the Relative Growth Rate (RGR). It assumes that new growth is related to existing biomass and is therefore exponential. In other words, the bigger the plant is the greater the absolute growth increment will be (Uzun, 1997).

Relative growth rate increased with increasing light intensity on tomatoes and eggplants. It was determined that the optimum temperatures of the eggplant and tomato for relative growth rate were 25 and 26°C, respectively (Heuvelink, 1989; Uzun, 1997). Relative growth rate can be regarded as the product of Net Assimilation Rate (NAR) and Leaf Area Ratio (LAR). It was determined that net assimilation rate of eggplant increased with temperature and time. Optimum temperatures of eggplant

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and tomato for net assimilation rate were 22 and 23°C, respectively. At low light intensities, the NAR of tomato plants responded the most strongly to changes in light intensity. It was also reported that the lower relative growth rate for sweet pepper was due to its lower LAR value, caused by the fact that it has thicker leaves than cucumber and tomato (Bruggink and Heuvelink, 1987).

To date, there have been a few attempts to describe the relationship between faba bean growth, temperature and light intensity but with no wide temperature and light ranges. Therefore, this research quantitatively examined the effects of temperature and light on faba bean growth, using a wide range of temperature and light intensity.

## MATERIALS AND METHODS

### Materials

The research was conducted as field and greenhouse experiments. The field experimental area was constructed on a land area of 280 $m^2$ (14×20 m). The field area was divided four blocks. Each block was 1.5×20 = 30 $m^2$. Plots were 40 rows spaced 50 cm apart and with 15 cm between plants.

The seeds were sowed 15×50 cm in field and greenhouse. Each block has got 40 rows. Three plant samples were collected every 15 days and plant dry weight was determined 80°C.

The cultivar of Lara was used in the study. The soil used in the research was loamy-clay and had a pH value of 5.7. The same soil was used in the Polyethylene (PE) greenhouse. Length, width and height were separately 20, 6 and 3 m at the greenhouse.

Temperatures were measured in the greenhouse with a Sato Keiryoki MFG R-704 thermo hydrograph (0 with 50°C±1) and soil temperature with a soil thermometer Testo 615 (0 with 50°C±0, 4). Light measurements were performed with a Delta-T Sun Scan Canopy Analyzer. Light measurements were performed 1 m high on the plants by Delta-T Sun Scan Canopy Analyzer (Cemek, 2002) (Table 1).

The experiment was set up in four different sowing times (October, January, April and July) in greenhouse and field conditions and under shaded and unshaded conditions, however, 50% transparent polyethylene cover was used for shading seeds. The effects of light and temperature on the plant development (emergence, bloom and plant height and stem diameter and leaf number) and growing characteristics of faba bean and yield (fresh yield, fresh pod yield and dry pod yield) were determined. As for quantitative characteristics (relatives of root, stem, leaf weight also relative leaf area, net assimilation rate, relative growth rate, leaf thickness, stem diameter, plant height, plant leaf number) were evaluated. The data obtained from all the characteristics examined multiple regression analysis

Table 1: Different planting times the presentation of temperature, humidity, light intensity and rain data during the growing period (Anonymous, 2003)

| | Temperature (°C) | | Humidity rate (%) | | Total rain | | Light intensity (cal) | |
|---|---|---|---|---|---|---|---|---|
| Months | 2001 | 2002 | 2001 | 2002 | 2001 | 2002 | 2001 | 2002 |
| January | 9.1 | 4.5 | 69.3 | 60.8 | 63.1 | 93.0 | 146.78 | 135.76 |
| February | 8.1 | 6.4 | 70.6 | 57.3 | 46.2 | 100.4 | 170.53 | 204.43 |
| March | 11.9 | 7.7 | 69.0 | 66.0 | 47.3 | 76.3 | 280.48 | 330.35 |
| April | 11.6 | 13.5 | 83.1 | 77.3 | 54.7 | 27.3 | 352.74 | 346.41 |
| May | 15.0 | 15.3 | 78.0 | 75.3 | 83.9 | 37.4 | 446.36 | 490.05 |
| June | 19.9 | 19.5 | 78.3 | 76.6 | 16.3 | 118.5 | 558.84 | 544.01 |
| July | 25.8 | 23.8 | 74.0 | 73.5 | 0.0 | 0.0 | 551.71 | 587.82 |
| August | 26.2 | 24.0 | 74.0 | 72.6 | 11.2 | 27.8 | 476.62 | 468.88 |
| September | 22.4 | 20.5 | 78.0 | 78.8 | 32.3 | 49.1 | 381.90 | 350.49 |
| October | 16.0 | 15.9 | 78.8 | 80.3 | 61.6 | 35.7 | 237.80 | 256.93 |
| November | 12.5 | 12.8 | 68.8 | 69.2 | 94.0 | 11.3 | 160.77 | 192.39 |
| December | 8.0 | 10.2 | 74.5 | 68.1 | 138.1 | 48.6 | 91.59 | 121.18 |

were turned into mathematical models by using Excel 2003 package program and the models obtained were turned into three dimension graphics through slide Write 2.0 package program. The effects of all characteristics examined were explained depending on light and temperature by using these graphics.

### Methods

As the research focused on growth of faba bean, the parameters examining growth were analyzed as affected by temperature and light intensity.

The field experiment area was divided into four blocks of $1.5\times20 = 30$ m$^2$. A similar arrangement was also applied to the greenhouse. Each block was then divided into three replications. Destructive harvest measurement and observation were carried out for each replication. Each measurement was repeated ten times starting from early plant growth stage to the harvest. In order to obtain a wide variation in the growth trend of faba bean for each replication, October the 15th, January the 15th, April the 15th and July the 15th were determined as sowing times. The seeds were sown by hand in drills. The distance between each sowing line was 50 cm and seeds were sown 20 cm apart in rows. Half of two blocks, in which April and July sowings were conducted, were shaded with a green net file. The shading material had a 50% light transmission. The procedure followed in field experimental area was almost identically repeated in the greenhouse. The growth parameters were calculated as follows:

### Leaf Area (LA)

The total area of the leaf per plant (cm$^2$) was measured by a Placom Digital Planimeter.

### Leaf Weight Ratio (LWR)

Leaf weight ratio is the ratio of total leaf weight (g) to total plant weight (g).

### Specific Leaf Area (SLA)

Specific leaf area is the ratio of leaf area (cm$^2$) per plant to leaf dry weight (g).

### Leaf Area Ratio (LAR)

The leaf area of the plant (cm$^2$) divided to its total dry weight (g), is called the leaf area ratio (cm$^2$ g$^{-1}$).

### Net Assimilation Rate (NAR)

The net assimilation rate of a plant is defined as its growth rate per unit leaf area for any given time period (day). It is usually denoted by NAR and can be calculated as:

$$\text{NAR (g cm}^{-2}\text{ day}^{-1}) = (1/\text{LA})\ dW/dt$$

In this equation, LA: total leaf area (cm$^2$); W, total plant dry weight and t is time.

### Relative Growth Rate (RGR)

The variation in the Relative Growth Rate (RGR) can be separated into an assimilatory component, Net Assimilation Rate (NAR) and a morphological component, Leaf Area Ratio (LAR), as they are related as follows:

$$\text{RGR (g cm}^{-2}\text{ day}^{-1}) = \text{NAR} \times \text{LAR}$$

## RESULTS

### Leaf Area (LA)

In order to produce a general picture of the effect of temperature and light intensity on leaf area multi-regression analysis were carried out by plotting Leaf Area (LA) against Temperature (T), Light intensity (L) and the following Eq. 1 was obtained. It was found that most of the variation (98%) in leaf area was explained by Temperature (T) and Light intensity (L).

$$LA = (-5.87) + (2.76\times T) + (1.11\times L) + (0.04\times L^2) + [0.05\times (L \times T^2)]$$
$$SE = 0.37^{***}\ 0.11^{***}\ 0.13^{***}\ 0.01^{***}\ 0.0018^{***} \quad (1)$$
$$R^2 = 0.98$$

Utilising Eq. 1, the combined effect of temperature and light intensity on leaf area of faba bean was shown in Fig. 1. As seen in the Fig. 1, at any given light intensity, increasing temperatures resulted in reduced leaf area. Increasing light intensities also reduced leaf area of faba bean. The highest leaf area was obtained with low light intensity (350 Mmol $m^{-2}$ $sec^{-1}$) and low temperatures. The lowest leaf area was obtained from high light intensity (600 Mmol $m^{-2}$ $sec^{-1}$) and high temperatures (Fig. 1).

### Leaf Weight Ratio (LWR)

A relationship between leaf weight ratio, temperature and light intensity was obtained by mean of multi-regression analysis and the equation below (Eq. 2) was produced. Most of the variation (73%) in LWR was explained by the selected parameters, namely Temperature (T) and Light intensity (L).

$$LWR = (3.81) - (1.12\times T) - (0.009\times T^2) - [0.38\times (\text{In } T\times L)]$$
$$SE = 1.06^{*}\ 0.33^{*}\ 0.0025^{*}\ 0.11^{*} \quad (2)$$
$$R^2 = 0.73$$

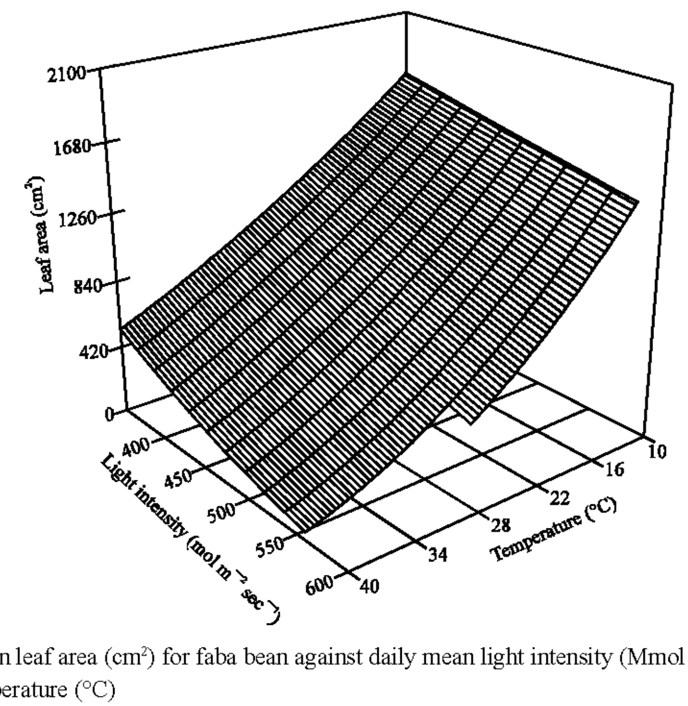


Fig. 1: Changes in leaf area ($cm^2$) for faba bean against daily mean light intensity (Mmol $m^{-1}$ $sec^{-2}$) and Temperature (°C)

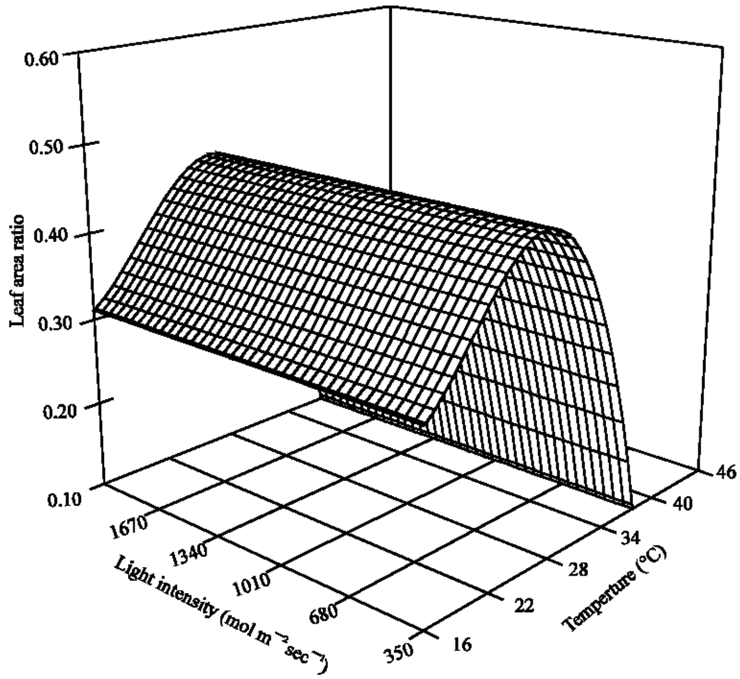


Fig. 2: Changes in leaf weight ratio for faba bean against daily mean light intensity (Mmol $m^{-1}$ $sec^{-2}$) and temperature (°C)

As seen in Fig. 2, increasing light intensity had no significant effect on leaf weight ratio at any given temperature regimes. With all light intensities examined, leaf weight ratio increased with temperature up to 28°C and declined thereafter (Fig. 2).

**Specific Leaf Area (SLA)**

The result of multi-regression analysis showed that there was a significant relationship between leaf weight ratio, temperature and light intensity. As a result of this relationship Eq. 3 was obtained. Most of the variation (93%) in Specific Leaf Area (SLA) was explained by temperature and light intensity.

$$\text{SLA} = (855.97) + [1.04\text{E}^{-07} \times (\text{T}^2 \times \text{L}] - (17.61 \times \text{T}) - (0.29 \times \text{L})$$
$$\text{SE} = 84.75^{**}\ 3.74\text{E}^{-08*}\ 2.60^{***}\ 0.062^{**} \quad (3)$$
$$R^2 = 0.93$$

As seen in Fig. 3, increasing light intensity reduced the specific leaf area linearly. Increasing temperature also reduced specific leaf area. The highest specific leaf area was obtained with low light intensities and low temperatures. The lowest specific leaf area was obtained from high light intensity and low temperatures (Fig. 3).

**Leaf Area Ratio (LAR)**

The effects of temperature and light intensity on leaf area ratio of faba bean, multi-regression analysis were carried out by plotting Leaf Area Ratio (LAR) against Temperature (T) and Light intensity (L) and the following equation (Eq. 4) was obtained. Most of the variation (94%) in Leaf Area Ratio (LAR) was explained by Temperature (T) and Light intensity (L) (Fig. 4).

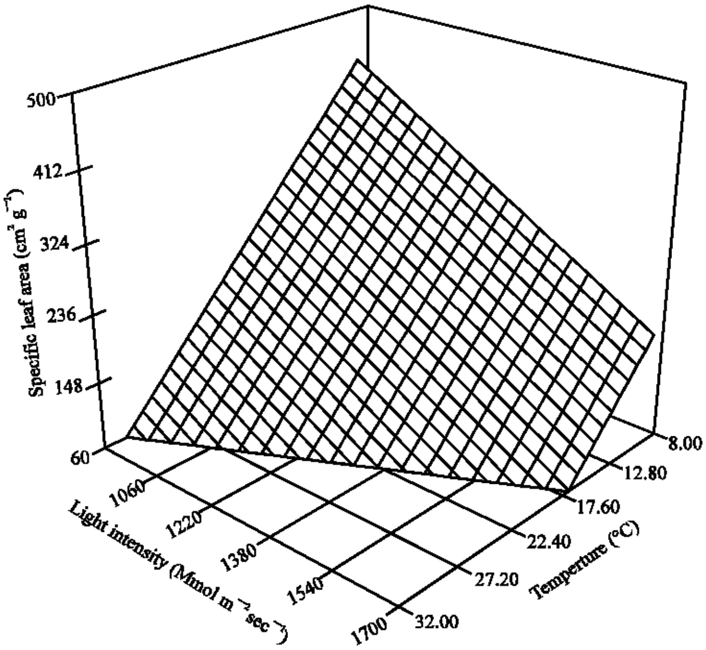


Fig. 3: Changes in specific leaf area (cm$^2$ g$^{-1}$) for faba bean against daily mean light intensity (Mmol m$^{-1}$ sec$^{-1}$) and Temperature (°C)

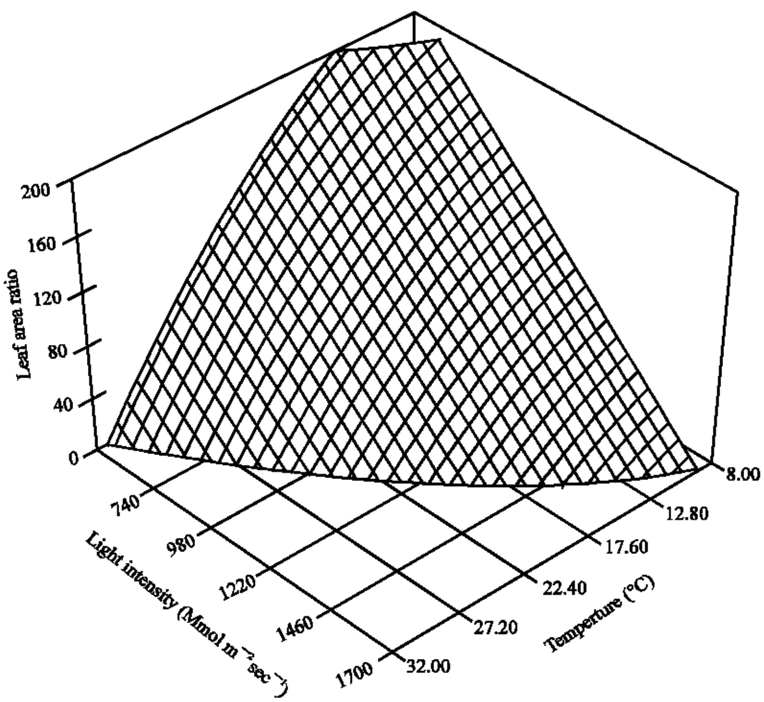


Fig. 4: Changes in leaf area ratio for faba bean against daily mean light intensity (Mmol m$^{-1}$ sec$^{-2}$) and Temperature (°C)

$$\begin{aligned} LAR &= (344.12) - (0.26\times T^2) + [1.49E^{-04} \times (T\times L)] - (0.19\times L) \\ SE &= 31.82^{***}\ 0.04^{***}\ 4.17E^{-05*}\ 0.03^{***} \\ R^2 &= 0.94 \end{aligned} \quad (4)$$

Utilising Eq. 4, the combined effect of temperature and light intensity on leaf area ratio of faba bean was determined. As seen in Fig. 4, at any given light intensity, increasing temperatures results in reduced leaf area ratio. Increasing light intensities also reduced leaf area of faba bean. The highest leaf area was obtained with low light intensity and low temperatures. The lowest leaf area ratio was obtained from high light intensity and high temperatures (Fig. 4).

**Net Assimilation Rate (NAR)**

According to the results of multi-regression analysis for net assimilation rate in faba bean, it was found that net assimilation rate was affected by temperature and light intensity significantly. The following equation was obtained as a result of the analysis (Eq. 5).

$$\begin{aligned} NAR &= (0.018) + (1.49E^{-08} \times L^2) - [1.51E^{-08} \times (T^2 \times L)] \\ SE &= 0.003^{***}\ 2.5E^{-09***}\ 5.26E^{-09*} \\ R^2 &= 0.84 \end{aligned} \quad (5)$$

It was found that most of the variation (84%) in NAR was explained by Temperature (T) and light intensity (L) (Fig. 5).

When the Fig. 5 was examined, it was seen that there was a sharp increase in net assimilation rate with increasing light intensity at low temperatures. The rate of this increase declined curvilinearily as the temperature increased up to 40°C. Even though increasing light intensity increased net assimilation

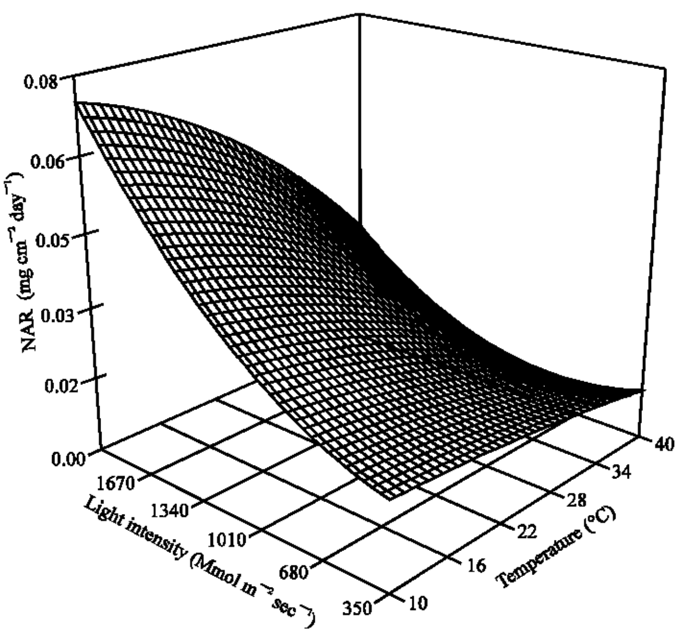


Fig. 5: Changes in net assimilation rate (mg cm$^{-2}$ day$^{-1}$) for faba bean against daily mean light intensity (Mmol m$^{-1}$ sec$^{-2}$) and Temperature (°C)

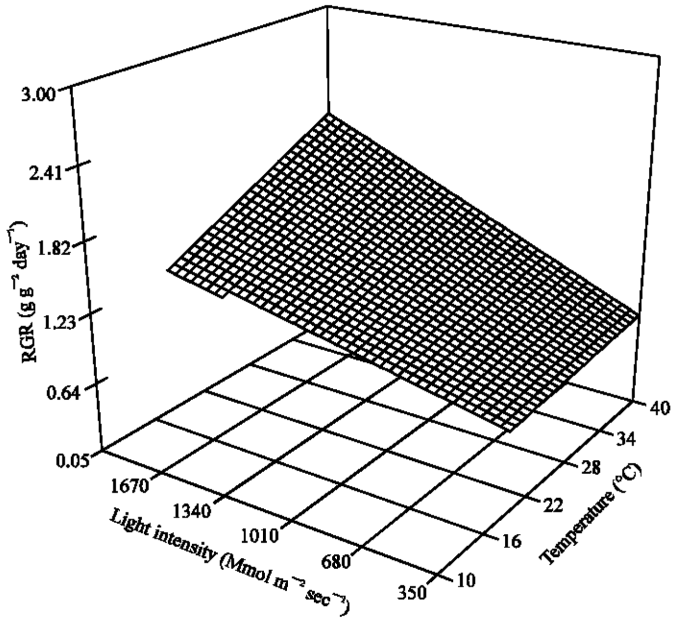


Fig. 6: Changes in relative growth rate (g $g^{-1}$ $day^{-1}$) for faba bean against daily mean light intensity (Mmol $m^{-1}$ $sec^{-2}$) and Temperature (°C)

rate curvilinearly at high temperatures, this increase was marked more at lower temperatures. The highest net assimilation rate was obtained with high light intensity and low temperatures. The lowest net assimilation rate was obtained from low light intensity and high temperatures (Fig. 5).

**Relative Growth Rate (RGR)**

As a result of multi-regression analysis of relative growth rate in faba bean, the effects of light intensity and temperature were found to be significant. The equation below was derived from this relationship (Eq. 6). As seen from the equation, most of the variation (87%) in RGR was explained by temperature (T) and light intensity (L).

$$\begin{array}{c} \text{PGR} = (0.679) - (6.8\text{E}^{-04} \times T^2) + [1.91\text{E}^{-05} \times (T \times L)] \\ \text{SE} = 0.064^{***}\ 1.07\text{E}^{-04***}\ 3.03\text{E}^{-06***} \\ R^2 = 0.87 \end{array} \quad (6)$$

When Fig. 6 was examined, it was seen that at low temperatures, increasing light intensity linearly increased relative growth rate. This increase continued to 40°C. The highest relative growth rate was obtained with high light intensity and high temperatures. The lowest relative growth rate was obtained from low light intensity and low temperatures (Fig. 6).

## DISCUSSION

Data obtained from the present study showed that the change in the leaf area was caused by the effect of temperature rather than light intensity. For maize, it was reported that date of appearance and expansion duration of leaves were critical parameters for calculating leaf area of a canopy (Stewart and Dwyer, 1994).

The change in leaf weight ratio occurred in faba bean with the effect of temperature rather than light integral. While the highest leaf weight ratio was obtained at 28°C, the lowest leaf weight ratio occurred at 34°C. Leaf weight ratio can be regarded as a reflection of the plants own ability to protect its normal growth characteristics (Fitter and Hay, 1987). Due to the fact that plant growth is quite rapid with the early stages of plant life, the relative growth rate continuously changes and generally decreases with time. With respect to the total plant weight, the decrease in meristemic tissues production was considered as the major cause of the decrease in relative growth rate.

Specific leaf area can change with the environment under which the plant develops. A number of environmental factors are known to influence SLA including light intensity, air temperature and soil factors (Friend, 1966; Casal *et al*., 1987; Andrade *et al*., 1993; Rebetzke *et al*., 2004). Specific leaf area was slower when plants were grown at higher light intensities than plants were grown at low light intensities (Uzun, 1996). Increasing light intensity linearly reduced the specific leaf area. This decline continued linearly with the increase of temperature up to 17°C. The highest specific leaf area was measured under low light intensity and in temperature 16°C. The lowest specific leaf area was measured under high light intensity and in temperature 10°C. The changes in temperature and light integral did not affect the specific leaf area afterwards.

The decrease in leaf area ratio occurred with low light intensity much quicker than those of plants grown under higher light intensities. It is because the period of plant's growth is long and at the end of this period plant is older. It was stated that the leaf area decreased as the plant got old (Charles-Edwards *et al*., 1986). Because leaf area is a function of leaf area ratio and leaf weight, a decrease or an increase in leaf area leads to a change in the leaf area ratio. The decrease in the leaf weight in time following the emergence is completely reflected in leaf area. Many researchers have stated that the increase in temperature increases the leaf area (Hunt *et al*., 1984; Picken *et al*., 1986; Heuvelink, 1989; Uzun, 1996).

Increasing temperature up to 40°C at low light intensity led a decrease in the net assimilation rate. The highest net assimilation rate was obtained at high light intensity and low temperatures conditions. The lowest net assimilation rate was found at low light intensity and high temperatures. Net assimilation rate is one of the most important growth parameters. This describes the net production efficiency of the assimilatory apparatus (Bruggink and Heuvelink, 1987). In a study carried out in eggplant it was observed that net assimilation rate was increased as the temperature rose in time. However, this increase in the plant grown at 30°C reached the maximum value of 0.15 g $cm^{-2}$ $day^{-1}$ and then as the temperature decreased to 16°C, it reached the value of 0.03 g $cm^{-2}$ $day^{-1}$ (Heuvelink, 1989). Both in this study and in other similar studies, net assimilation rate increased depending on time. In the first periods, plant growth was slower at low temperature than at high temperature. Consequently, a general evaluation of net assimilation rate revealed the fact that rapid increases in the net assimilation rate led to rapid decreases in the latter stages and thus this feature being closely related with plant growth rate, the vegetation period was shortened. A significant advantage is acquired by expanding the vegetation period of the plant and accordingly increasing the dry material accumulation at a certain temperature when the net assimilation rate becomes the highest. That's why NAR is a useful growth index which has been used for many years.

At high temperature increasing light integrally increased relative growth rate linearly. At the low light intensity, increasing temperature up to 40°C did not lead to a significant change in the relative growth rate. The highest relative growth rate was found at high light intensity and high temperatures. Such as the optimum temperature was found to be 28°C for the relative growth rate the lowest relative growth rate was found at low light intensity and low temperatures. Maximum crop growth rate (Cm), which was generally the best estimation of the parameters, increased with increased light density ranging from 15 to 30 g $m^{-2}$ $day^{-1}$ for faba bean (Ishag and Dennett, 1998).

## CONCLUSIONS

In this study, we defined the relationships between faba bean growth parameters (Leaf area, Leaf weight ratio, Specific leaf area, Leaf Area ratio, net assimilation rate and relative growth rate), temperature and light. Changes in plant growth caused by the effects of environmental conditions (temperature, light, moisture etc.) have been intended to be described by plant growth models. The models of growth parameters are respectively $LA = -5{,}8741 + (2{,}761655 \times W) + (1{,}11006 \times L) + (0.037175 \times L^2) + [0.049112 \times (L \times W^2)]$; $LWR = 3.810501 - (1.11774 \times T) - (0.00941 \times T^2) + (0.378563 \times [\ln(T) \times L)]$; $SLA = 855.9723 + (1.04E^{-07} \times (T^2 \times L) - (17.6117 \times T) - (0.29189 \times L)$; $LAR = 344.1226 - (0.2559 \times T^2) + [0.000149 \times (T \times L)] - (0.19234 \times L)$; $NAR = 0.018308922 + (1.48843E^{-08} \times L^2) - [1.51322E^{-08} \times (T^2 \times L)]$; $RGR = 0.679446 - (0.00068 \times T^2) + [1.91E^{-05} \times (T \times L)]$. The regression coefficients of the new produced equations for growth parameters for faba bean changed between 0.73 (Leaf weight ratio) and 0.94 (Leaf area ratio).

Using multiple regression equations it is very much likely to predict the variation in plant growth as related to temperature and light intensity with high probability.

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