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The Effect of Light Interception and Light Use Efficiency with Different Sowing Time of Faba Bean (*Vicia Faba* L.)

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Abstract

In this study, it was aimed to define the effect of light interception and light use efficiency with different sowing time of faba bean (*Vicia faba* L.). Model equation produced for light use efficiency 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 light intensity and temperature predicted light use efficiency. The light use efficiency model developed was LUE = 6.39 – ($8.93E^{-03}$ x L) – [$1.7E^{-05}$ x (T^2 x L)] + [$1.49E^{-07}$ x (T x L^2)] + [$4.69E^{-04}$ x (T x L)] where LUE is light use efficiency, L is light intensity, T is temperature. R^2 value (0.83) and standard error were found to be significant at the p<0.01 level. Radiation cut by canopy depends on the structure of canopy and is defined as light interception. When the temperature reaches 16°C and the amount of light interception is 2000 $\mu molm^{-2}s^{-1}$, light usage efficiency reaches the highest level on faba bean. In the cases on which the amount of light interception is 337.35 $\mu molm^{-2}s^{-1}$ and the temperature is low (9°C) light interception is 30%. When the amount of light interception is 817.54 $\mu molm^{-2}s^{-1}$ and the temperatures are 15°C, 18°C, 22°C, and 25°C light interception is 50% and when the amount of light interception is 1128.39 $\mu molm^{-2}s^{-1}$ and the temperature is 30°C–31°C, light interception is in the value of 90%.

Key words: Faba bean, *Vicia faba* L., *light* interception, light use efficiency

INTRODUCTION

The most important advantage of faba bean (*Vicia faba* L.) is its high potential to produce grains rich with valuable protein and its symbiotic nitrogen fixation ability [1,2]. Both the production of *Rhizobium* nodules on roots of leguminous plants and the keeping of their nitrogen fixation ability are processes which demand a high energy output from a host plant [3]. Mature faba bean grains are a good resource of protein, starch, cellulose and minerals. Therefore, it is of importance for human and animal food [4]. 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 [5]. In faba bean, water stress decreases the size and longevity of the foliage, leaf photosynthetic rate and light use efficiency, as well as pod retention and filling by reducing the availability of assimilates and distorting hormonal balance [6].

The competition amongst individual plants for PAR (Photosynthetic Active Radiation) as well as competition of them for soil nutrients is an important event. The competition among plants for PAR is controlled by direct or indirect form of photons as energy source. The most important factor for PAR is that leaves stay in a lighting position. Therefore, the plant characteristics determining the height of the structure forming the leaf canopy and growth rate are important to affect the lighting of leaf [7]. Photosynthetic speed of plants depends on the amount of the radiation intercepted by them and the degree of benefiting from that radiation. The observations have shown that canopy photosynthesis is proportionate to radiation intercepted. Hence, plant breeders tried to increase the yield by raising the photosynthetic efficiency. However, it is observed that this photosynthetic effect never exceeds 22% of light energy. Generally, 1-2% of photosynthetic active energy is stored in the plant by being converted into carbohydrates [7,8]. In a study carried out on tomatoes it was determined that the plants grown in high temperature and light reached to maximum light interception point earlier and they stayed longer in this process. When the planting time is set prior to the actual time, the plants exposed to these conditions with a certain leaf area before adverse climate conditions occur with respect to light and temperature [9]. Light interception varied in different row distance. Therefore leaf area index changed. The attitude of habitus affected the light interception remarkably according to the simulations and field measurement [10]. The interception of light (LI) by a canopy is a fundamental requirement for plants. Light interception and the relationship to crop growth have been important concepts applicable to virtually all corps. One problem is that measurements should be made when sunlight is unobstructed. That's why; light interception generally refers to measurements made close to solar noon when the sun is near its highest point above the horizon. The fraction of total solar radiation intercepted by a canopy was described as an analog of Beer's Law:

$$LI = \left[1 - e^{-(k \times LAI)}\right]$$

In this equation, two variables determine LI: light interception, k: the extinction coefficiency, LAI: leaf area index. The most common method of determining LI is to measure photosynthetic active radiation (PAR) above a canopy and beneath a canopy near solar noon when the light is unobstructed by cloud cover [11].

$$LI = \left[1 - (PAR\ \text{beneath canopy}) \times (PAR\ \text{above canopy})^{-1}\right]$$

The effect of plant density on canopy light interception and on flowering was investigated in hemp (*Cannabis sativa* L.) crop grown at initial densities of 10, 30, 90 and in 270 plants/m² field experiments in 1991 and 1992 in the Netherlands. The result presented here can be used to account for the effect of wide range of plant densities in the simulation of the course of light interception by a hemp crop [12].

In faba bean, water stress decreases the size and longevity of the foliage, leaf photosynthetic rate and light use efficiency, as well as pod retention and filling by reducing the availability of assimilates and distorting hormonal balance. In a study carried out on peanut, maize and faba bean it was determined that forming a leaf canopy which was able to intercept the light was a significant factor on affecting the yield [6,13]. Appropriate sowing distance has gained importance in agriculture. If the plants sow or plant in a large distance, the field will not be able to be used efficiently and the yield will decrease per decare [14]. Therefore for optimum photosynthesis the distance between the plants must be arranged carefully. On the other hand, according to the regions the arrangement of the sowing and planting times is important with regard to evaluating the light potential of that region. 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. The research focused on light interception and light use efficiency of faba bean. The parameters were affected by temperature and light.

MATERIAL AND METHOD

Material

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 20m, 6m and 3m at the greenhouse. Temperatures were measured in the greenhouse with a Sato Keiryoki MFG R-704 thermo hydrograph (0ºC with 50ºC±1) and soil temperature with a soil thermometer Testo 615 (0°C with 50°C±0, 4). Light measurements were performed with a Delta-T Sun Scan Canopy Analyser. Light measurements were performed 1 m high on the plants by Delta-T Sun Scan Canopy Analyser [15]. The experiment was set up in four different sowing times (October, January, April, and July) in greenhouse and field conditions, and under shaded and not shaded 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.

Method

The research was conducted as field and greenhouse experiments. The field experimental area was constructed on a land area of 280 m² (14x20 m). The field area was divided four blocks. Each block was1.5x20= 30 m². Plots were 40 rows spaced 50 cm apart and with 15 cm between plants. The seeds were sowed 15 cm x 50 cm in field and greenhouse. Each block has got 40 rows. 3 plant samples were collected every 15 days and plant dry weight was determined 80°C. 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.

Table 1. Average temperatures of shaded and not shaded areas at sowing dates.

Sowing Dates	Experiment Areas	Average Temperature of Shaded Areas	Average Temperature of not shaded Areas
October	Greenhouse	9°C	15°C
April	Greenhouse	22°C	25°C
	Field	15°C	18°C
July	Field	30°C	31°C

The distance between each sowing line was 50 cm and seeds were sown 20 cm apart in rows. Half of two blocks, which were conducted in April and July sowings, were shaded with a green net. The shading material had a 50% light transmission. The procedure followed in field experimental area was almost identically repeated in the greenhouse. The light use efficiency (Є) was calculated by equation (1), which was applied to every individual temperature at different daily mean light interception, separately.

$$Є\ (g/\mu mol) = W / J \quad (1)$$

W is the gross amount of plant dry matter produced between two different destructive harvesting and J is the amount of light energy intercepted by the plant during the same period. The data obtained from all the characteristics examined multiple regression analysis were turned into mathematical models by using Excel 2003 package program and the models obtained were turned into three dimension graphics through slide Write

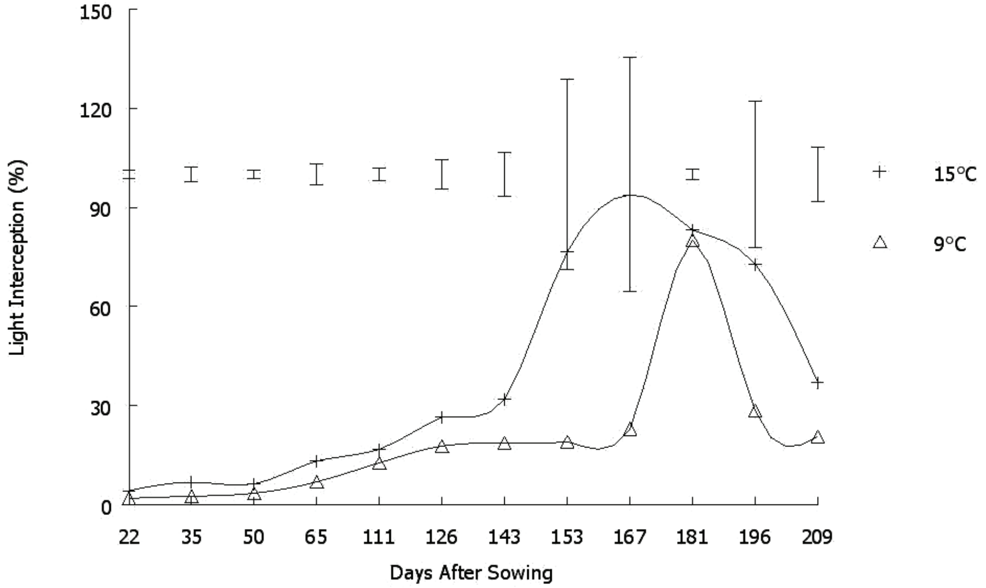

Figure 1. Changes in light interception (%) in faba bean under daily mean light interception 337.35 µmol $m^{-2}s^{-1}$ and temperatures of 9°C - 15°C. Error bars represent standard error of means.

2.0 package program. The effects of all characteristics examined were explained depending on light and temperature by using these graphics.

RESULT AND DISCUSSION

Plant Light Interception

Light interception and dry matter accumulation are based on certain essentials with regard to developing a new form of plant growth analyses.

The major factor is light interception. According to the days after sowing, the effects of increasing light and temperature on light interception were shown in Figure.1, 2 and 3. Light interception 30% was realized low light 337.35 µmol$m^{-2}s^{-1}$ and low temperatures (9°C ve 15°C).

Light interception 50% was carried out high light 817.54 µmol$m^{-2}s^{-1}$ and optimum temperatures (15°C, 18°C, 22°C and 25°C). Light interception 90% was realized high light 1128.39 µmol$m^{-2}s^{-1}$ and high temperatures.

When the figure 1 was examined, the average light intensity was 337.35µmol$m^{-2}s^{-1}$. The rise in the light interception began to increase on the 22nd day when the plant started to come into leaf.

This increase continued until 143rd day at the low level. At the temperature of 15 from 143rd day to 167th day a rapid increase occurred in the light interception. This period occurs at the same time as the coming into leaf on the highest point.

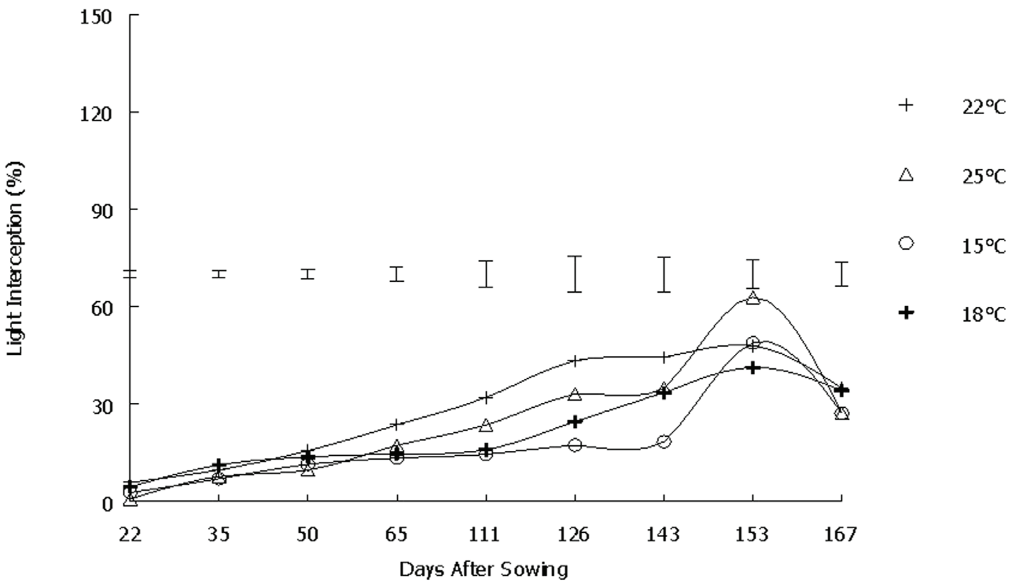

Figure 2. Changes in light interception (%) in faba bean under daily mean light interception) 817.54 µmol $m^{-2}s^{-1}$ and temperatures of 15°C, 18°C, 22°C and 25°C. Error bars represent standard error of means.

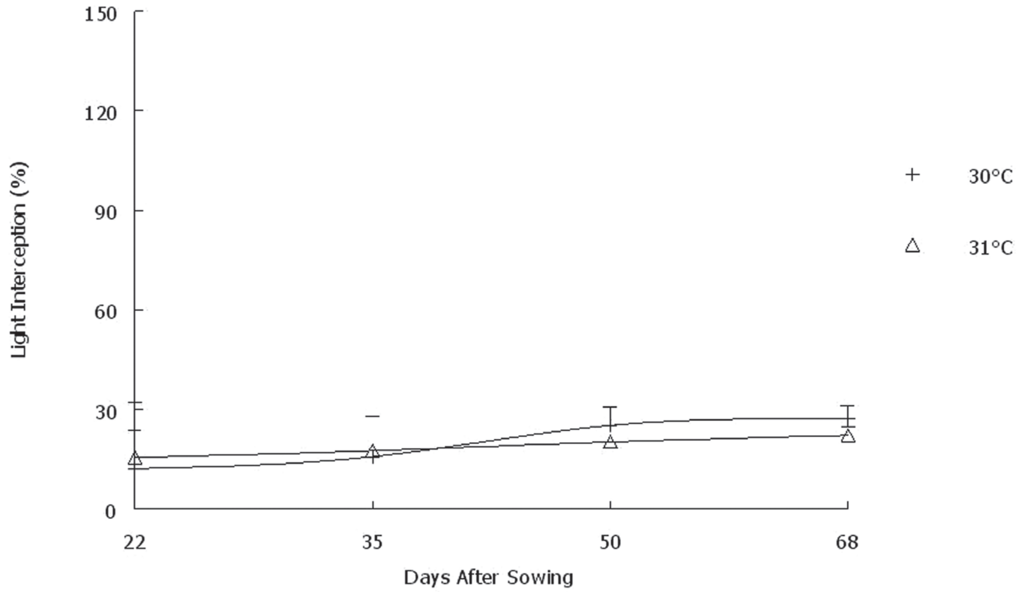

Figure 3. Changes in light interception (%) in faba bean under daily mean light interception 1128.39 µmol $m^{-2}s^{-1}$ and temperatures of 30°C, 31°C. Error bars represent standard error of means.

From 167th day when *Vicia faba* L. vegetation period started to the last stage the leaves were thrown away, so this caused decreasing of light interception. At the temperature of 9°C light interceptions from 167th day to 181st day increased rapidly and then decreased.

In the plants grown at this temperature the last stage of the vegetation period started after 181st day. Different temperatures cause the difference on the starting and the finishing days of this stage. The faba bean grown at 15 ºC matured earlier than the faba bean grown at 9ºC.

When we look at the figure 2, when the light intensity is 817.54 µmol$m^{-2}s^{-1}$ at the temperature of 15°C, 18°C, 22°C, and 25°C from 22nd day till 143rd day light interception has shown a slow increase and starting from that day till 153rd day has shown a rapid increase. The highest light interception has observed at 25ºC.

In the figure 3 when the light intensity is 1128.39 µmol$m^{-2}s^{-1}$ the high temperature (30º-31º) has almost no effect on the light interception The reason of this both of the temperature degrees are so close to each other. Consequently, as the light intensity is 337.35 µmol$m^{-2}s^{-1}$, in faba the temperature degree affecting the light interception 15ºC and as the light intensity is 817.54 µmol$m^{-2}s^{-1}$ it is 25ºC. When the light intensity is high (1128.39 µmol$m^{-2}s^{-1}$) the change in the light intensity has affected the light interception in comparison with the change in the temperature. The fact that, the light intercepted increases in time and that it becomes constant after a certain period reveals the fact that leaves velocity relatively decreases due to low temperatures. The dry material production decreases in faba which is exposed to decreasing temperature and light conditions after October in the Black Sea Region. Flower and fruit formations are also affected.

Light Use Efficiency (€)

Light Use Efficiency is described as dry material amount produced per each unit of radiation intercepted by canopy in the growth analyses. In other words, the efficiency of a plant in producing new dry material with the light energy it has intercepted is called Light Use Efficiency. The graphic provided by using the equation (2) which has been obtained as a result of the regression analysis conducted indicates, in the following the effect of light and air temperature upon Light Use Efficiency (Figure 4).

Light use efficiency is described as dry material amount produced per each unit of radiation intercepted by canopy in the growth analyses. In other words, the efficiency of a plant in producing new dry material with the light energy it has intercepted is called light use efficiency. The graphic provided by using the equation which has been obtained as a result of the regression analysis conducted indicates, in the following the effect of light and air temperature upon light use efficiency (Figure 4). Light use efficiency has been calculated by the application of the average light interception of different days to each temperature value (Figure 4).

$$LUE = 6.39 - \left(8.93E^{-03} \times L\right) - \left[1.7E^{-05} \times \left(T^2 \times L\right)\right] + \left[1,49E^{-07} \times \left(T \times L^2\right)\right] + \left[4,69E^{-04} \times \left(T \times L\right)\right] \ldots (2)$$

$$SE = 1.288{*}{*}0.0024{*}27E^{-06}{*}4.88E^{-08}{*}1.77E^{-04}{*}$$

$$r^2 = 0.83$$

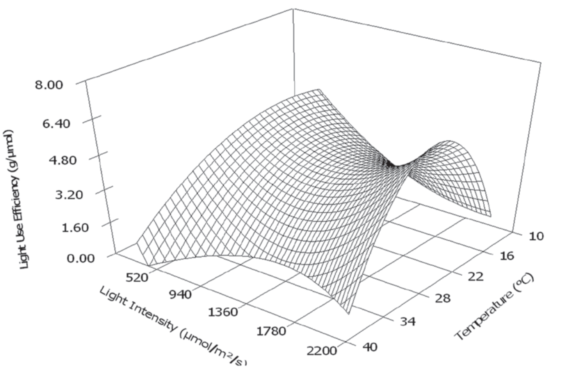

Figure 4. Changes in light use efficiency (g/µmol) of faba bean with daily mean light interception (µmol $m^{-2}s^{-1}$) and Temperature (°C).

When the figure 4 has been examined, the change in the light use efficiency at the low temperature depending on the increased light intensity has shown curve linearly decrease. As the temperature increases this decrease has continued to 1360 µmol$m^{-2}s^{-1}$, but after that it has increased. When the temperature has reached 16ºC and the light intensity is 2000 µmol$m^{-2}s^{-1}$, light use efficiency has reached to the highest level. The increasing after this value of temperature has caused decreasing the light use efficiency. When the temperature is 10 – 40 and the light intensity is 2000 µmol$m^{-2}s^{-1}$ the light use efficiency has been at the lowest level.

The temperatures in increase curve linearly decrease the light use efficiency in low amounts of light. This decrease has continued till the light intensity being up to 1360 µmol$m^{-2}s^{-1}$ and after that has increased curve linearly. The light use efficiency parallel to the increase in air temperature has decreased till the light intensity being up to 1360 µmol$m^{-2}s^{-1}$. After that value the increase in the light use efficiency has continued parallel to the increase in temperature from 10 to 16. It has been observed that air temperature has a significant effect on the light use efficiency.

CONCLUSION

In this study, we defined light interception and light use efficiency of faba bean Light use efficiency caused by the effects of temperature and light was intended to be described by a model as follows:

$$LUE = 6.39 - \left(8.93E^{-03} \times L\right) - \left[1.7E^{-05} \times \left(T^2 \times L\right)\right] + \left[1,49E^{-07} \times \left(T \times L^2\right)\right] + \left[4,69E^{-04} \times \left(T \times L\right)\right]$$

When the temperature reached 16°C and the amount of light intensity was 2000 µmol$m^{-2}s^{-1}$, light usage efficiency reached the highest level. In the cases on which the amount of light intensity was 337.35 µmol$m^{-2}s^{-1}$ and the temperature was low 9°C, light interception was 30%. When the amount of light intensity was 817.54 µmol$m^{-2}s^{-1}$ and the temperature was 15°C, 18°C, 22°C, and 25°C light interception was 50% and when the amount of light intensity was 1128.39 µmol$m^{-2}s^{-1}$ and the temperature was 30°C–31°C, light interception was in the value of 90%. The light use efficiency parallel to the increase in air temperature decreased till the light intensity, that's why air temperature had a significant effect on the light use efficiency. The best dry matter of yield was observed at not shaded field conditions on October and not shaded greenhouse conditions on April. Also, same result was seen shaded greenhouse on April. The best dates of sowing not shaded field and greenhouse conditions on October and shaded greenhouse on April. July is not good as sowing date of faba bean.

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