

## EFFECTS OF TEMPERATURE AND LIGHT INTENSITY ON GROWTH OF FODDER BEET (*BETA VULGARIS* L. VAR. *CRASSA* MANSF.)

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*Key words:* Fodder beet, Growth, Light intensity, Temperature, Modeling

### Abstract

Changes in plant growth *viz.* leaf area, leaf weight ratio, root weight ratio, dry leaf weight, dry root weight, total plant dry weight, specific leaf area, leaf thickness, leaf area ratio, net assimilation rate and relative growth rate due to the effects of environmental conditions such as temperature and light intensity were described by plant growth models. All equations produced for growth parameters were affected by light intensity and temperature. From multi-regression analysis, close relationships were found between actual and predicted growth parameters. The regression coefficients ( $r^2$ ) of the equations for growth parameters varied from 0.95 to 0.99 for cultivar Ecdogelb and 0.83 to 0.99 for cultivar Ecdorot, respectively.

### Introduction

Fodder beet is successively grown as a fodder crop in the coastal regions of many European countries. The crop is used as a valuable source of food for cattle (Niazi *et al.* 2000). Due to its higher water and sugar contents, it increases milk production and is a suitable forage for dairy cows. The fodder beet is usually fed as chopped and mixed with straw. Environmental factors such as climate and soil 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), since 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). Leaf weight ratio is the ratio of total leaf weight to total plant weight. Slow growing species may accumulate considerable amounts of secondary compounds like lignin and phenolics, which increase the dry weight of the leaves. The higher the specific leaf area, the thicker the leaf (Coughenour *et al.* 1984, Opitz von Boberfeld 1994). Specific leaf area was negatively correlated with high light intensity and positively with temperature (Evans 1989). Light intensity affects dry matter contents of the plants, and increasing light intensity decreases leaf area ratio (Picken *et al.* 1986). 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). Relative growth rate means the dry weight increase in a time interval in relation to initial weight (Gardner *et al.* 1994). Plant species may differ considerably in relative growth rate. This may be caused by habitat-related variation in abiotic factors, like temperature, water, light and nutrients, or by biotic factors like competition and diseases (Poorter 1989). Warmer temperatures accelerate development and early growth but have a negative effect on final biomass, probably due to canopy senescence and increase in maintenance respiration (Demmers-Derks *et al.* 1998).

To date, there have been a few attempts to describe the relationship between fodder beet growth, temperature and light intensity. Additionally those studies were carried out under limited ranges of temperature and light intensity. Therefore, this research quantitatively examined the effects of temperature and light on fodder beet growth, using a wide range of temperature and light intensity.

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## Materials and Methods

Fodder beet (*Beta vulgaris* var. *crassa* Mansf.) cultivars (Ecdogelb and Ecdorot which are diploid fodder beet cultivars bred at Saaten Union, Germany in 1953) were used as experimental material. Ecdogelb having wide leaf width, middle leaf length and semi erect leaf attitude, is diploid and multigerm variety. Leaf blade of Ecdogelb cultivar (width compared to length) is wide. It has also short root length and middle root width. Roots having cylindrical character are yellow. Ecdorot having wide leaf width, long leaf length and semi erect leaf attitude, is diploid and multigerm variety. Leaf blade of Ecdorot cultivar is wide. It has also short root length and wide root width. Roots having cylindrical character are red. Roots of Ecdogelb and Ecdorot cultivars grow close to surface.

Field experiments were carried out in Bafra (41°35' N, 35°56' E, and 15 m elevation), Osmancik (40°58' N, 34°5' E, and 449 m elevation), Suluova (40°47' N, 35°4' E, and 484 m elevation), Gumushacikoy (40°52' N, 35°14' E, and 785 m elevation) and Ladik (40°56' N, 35°54' E, and 920 m elevation) in Middle Black Sea Region, Turkey, started on 8-11 April, 2004 and were carried out throughout the vegetation periods of the selected locations. Soil types of Bafra, Suluova and Gumushacikoy are clay loam, of Osmancik and Ladik are silty clay loam.

The usual growing season precipitation (April through September) is 445 mm at Bafra, 298 mm at Osmancik, 282.3 mm at Suluova, 281.8 mm at Gumushacikoy and 145 mm at Ladik. Normal mean temperatures and light intensities during this period are 18.28, 19.58, 18.26, 17.61 and 14.1°C, and 428, 449, 471, 509 and 513 kcal cm<sup>-2</sup> at Bafra, Osmancik, Suluova, Gumushacikoy and Ladik, respectively. Temperature readings were continuously recorded over a 24 hour period using a thermograph. The temperature was recorded over 30 minutes from which an average hourly temperature was obtained. Twenty four hourly averages were used to attain an average daily temperature. Light intensity was measured and calculated everyday from nine o'clock in the evening until nine o'clock the following (next day) evening using an actinography at hourly intervals. Hourly actinography values were added up and a total daily light intensity was obtained and measured in kcal cm<sup>2</sup>. In this way a figure for the average daily light intensity was also obtained. The actinography was placed 1.5 m above the ground and it measured light intensity from dusk until dawn.

The experimental design was a randomized complete block design with three replications. Seeding rates were 30 kg/ha. Individual plot size was 10 m<sup>2</sup> (2 × 5 m). Four fodder beet plants in each plot were harvested in five different locations and at five different periods. Dates were June 3-5, June 21-23 June, July 11-13, August 5-7 and August 27-29 in 2004. Growth parameters were calculated as follows:

*Leaf area (LA)*: The total area of the leaf per plant (cm<sup>2</sup>) was measured by a Placom Digital Planimeter. *Leaf weight ratio (LWR)*: It is the ratio of total leaf weight (g) to total plant weight (g). *Root weight ratio (RWR)*: It is the ratio of total root weight (g) to total plant weight (g). *Dry leaf weight (DLW)*: Fresh leaf samples were dried in ovens at 70°C to a constant weight for the estimation of dry matter content. *Dry root weight (DRW)*: Fresh root samples were dried in ovens at 70°C to a constant weight for dry matter content. *Total plant dry weight (TDW)*: It is the sum of dry leaf weight and dry root weight. *Specific leaf area (SLA)*: It is the ratio of leaf area (cm<sup>2</sup>) per plant to leaf dry weight. *Leaf thickness (LT)*: It is the 1/ SLA. *Leaf area ratio (LAR)*: The leaf area of the plant (cm<sup>2</sup>) is divided to its total dry weight (g). *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 can be calculated as:  $NAR (g/cm^2/d) = (1/LA) dW/dt$ . In this equation, LA: total leaf area (cm<sup>2</sup>); *dw*, total plant dry weight and *t* is time. *Relative growth rate (RGR)*: The variation in the RGR can be partitioned into an assimilatory component, net assimilation rate (NAR), and a

morphological component, leaf area ratio (LAR). Therefore, RGR was calculated as :  $RGR (g/g d^{-1}) = NAR \times LAR$ .

Regression analysis was performed separately for each location and each cultivar. For each cultivar, regression analysis was performed in each location with 5 different destructive harvests by taking a single average. In this way, an average of five locations  $\times$  three replications = 15 data set was used for regression analysis. Regression analysis was performed with the "Forward Selection Method" (Gomez and Gomez 1984).

Multiple regression analysis was performed on the cultivars separately. A search for the best model for predicting growth parameters was conducted with various subsets of the independent variables, namely temperature (T), light intensity (L), temperature square ( $T^2$ ), light intensity square ( $L^2$ ), temperature  $\times$  light intensity ( $T \times L$ ), temperature square  $\times$  light intensity ( $T^2 \times L$ ), temperature  $\times$  light intensity square ( $T \times L^2$ ) and temperature square  $\times$  light intensity square ( $T^2 \times L^2$ ). For regression analysis, the MICROSOFT-EXCEL 7.0 pocket program was used. Curve fitting processes were continued until the least sum of squares of residuals was obtained. Three-D graphics were drawn in SlideWrite 2.0 package programme.

## Results and Discussion

As light intensity decreased from 520 to 420 kcal cm<sup>-2</sup>, LA showed a dramatic linear increase from 750 to 2000 cm<sup>-2</sup>. The effect of both temperature and light intensity on LA was evident in cv. Ecdorot. Light intensity had no significant effect on LA at high temperature (20.0°C). However, at low temperature (16.0°C), decreasing light intensity resulted in a linear increase in LA. At any given light intensity, increasing temperature resulted in an increased LA. Fig. 1, shows that the highest LA was obtained from low light intensity and high temperature in both cvs. Ecdogelb and Ecdorot (Tables 1 and 2)

The effect of the temperature on LWR was more than that of light intensity in Ecdogelb. Decreasing temperature from 18.50 to 14.90°C increased LWR linearly. Light intensity showed interactive effect at the low and high temperatures in Ecdorot. While increasing light intensity reduced LWR at low temperature (15.2°C), increasing light intensity increased LWR at high temperature (20.0°C) in Ecdorot. Especially, decreasing temperature increased LWR at low light intensity (450 kcal cm<sup>-2</sup>). However, at high light intensity (520 kcal cm<sup>-2</sup>) LWR did not result in a significant variation. The highest LWR was obtained from high light intensity and low temperature in both Ecdogelb and Ecdorot (Fig. 1).

Fig. 1 shows that decreasing light intensity resulted in an increased RWR in Ecdogelb. Especially, the effect of the light intensity was significant at low temperature (14°C). Temperature had significant effect on RWR. At any given light intensity, increasing temperature resulted in a sharp increase in RWR. Decreasing light intensity from 490 to 420 kcal cm<sup>-2</sup> increased RWR at high temperature (20°C) in Ecdorot. Decreasing light intensity resulted in a reduced RWR at low temperature (16°C). Effect of the light intensity was more significant at high temperature. Increasing temperature increased RWR in Ecdorot. However, temperature had no significant effect on RWR at high light intensity. The highest RWR was obtained from high temperature and low light intensity in both Ecdogelb and Ecdorot.

The effect of the light intensity on DLW was more than that of temperature in Ecdogelb. Decreasing light intensity from 410 to 492 kcal cm<sup>-2</sup> increased DLW linearly. At any given temperature, decreasing light intensity increased DLW linearly. Increasing temperature at 400 kcal cm<sup>-2</sup> light intensity increased DLW linearly in Ecdorot. Decreasing light intensity at 19.6°C temperature resulted in an increased DLW. The effect of temperature at low light intensity (400 kcal cm<sup>-2</sup>) on DLW was not significant. The highest dry leaf weight was determined on low light intensity and high temperature in both Ecdogelb and Ecdorot (Fig. 2).

**Table 1. The models and regression equations of growth parameters in cultivar Ecdogelb.**

Parameters	The models of growth parameters	$r^2$
LA	$(9295.01) - (16.95 \times L) + [2.47E^{-06} \times (T^2 \times L^2)]$	0.98
SE	869** 1.63** 5.09E <sup>-06*</sup>	
LWR	$(0.195) + (1.4E^{-3} \times L) - [3.4E^{-06} \times (T^2 \times L)]$	0.99
SE	0.0049*** 8.21E <sup>-06****</sup> 1.13E <sup>-08****</sup>	
RWR	$(0.805) - (1.4E^{-3} \times L) - [3.42E^{-06} \times (T^2 \times L)]$	0.99
SE	0.049*** 8.2E <sup>-06****</sup> 1.13E <sup>-08****</sup>	
DLW	$(-36.74) + (5.913 \times T) - [3.8E^{-4} \times (T^2 \times L)]$	0.99
SE	2.96** 0.39** 2.96E <sup>-05**</sup>	
DRW	$(-3379.89) + (198.29 \times T) + (6.497 \times L) - [0.379 \times (T \times L)]$	0.99
SE	175.8* 9.55* 0.348* 0.019*	
TDW	$(-772.25) + (5.11 \times T^2) + (2.9E^{-3} \times L^2) - [9.7E^{-3} \times (T^2 \times L)]$	0.99
SE	57.4* 0.31* 6E <sup>-4*</sup> 2.2E <sup>-4*</sup>	
SLA	$(57.36) + (0.492 \times T^2) - [5.4E^{-4} \times (T^2 \times L)]$	0.98
SE	10.02* 0.09* 0.00024*	
LT	$(0.013) - (1.8E^{-5} \times T^2) + (6.7E^{-09} \times L^2)$	0.97
SE	0.0026* 3.6E <sup>-06*</sup> 7.1E <sup>-9*</sup>	
LAR	$(73.74) - (0.054 \times T^2) - (1.4E^{-05} \times L^2)$	0.95
SE	7.63* 0.011* 2.12E <sup>-05*</sup>	
NAR	$(-0.0706) + (4E^{-4} \times T^2) + (2.67E^{-07} \times L^2) - [7.7E^{-07} \times (T^2 \times L)]$	0.99
SE	0.003* 1.7E <sup>-05*</sup> 1.2E <sup>-08*</sup> 3.4E <sup>-08*</sup>	
RGR	$(-0.553) + (3.7E^{-3} \times T^2) + (2.2E^{-06} \times L^2) - [7E^{-06} \times (T^2 \times L)]$	0.99
SE	0.033* 1.8E <sup>-4*</sup> 1.27E <sup>-07*</sup> 3.5E <sup>-07*</sup>	

SE = Standard error. \* =  $p < 0.05$ ; \*\* =  $p < 0.01$ ; \*\*\* =  $p < 0.0001$ ; \*\*\*\* =  $p < 0.00001$ .

**Table 2. The models and regression equations of growth parameters in cultivar Ecdorot.**

Parameters	The models of growth parameters	$r^2$
LA	$(16472.13) - (1691.75 \times T) + (54.96 \times T^2) - (5.807 \times L)$	0.99
SE	1066.82* 132.11* 0.49* 4.01*	
LWR	$(5.592) - (0.290 \times T) - (1.9E^{-05} \times L^2) + [1.1E^{-06} \times (T \times L^2)]$	0.98
SE	0.88* 0.07* 3.4E <sup>-06*</sup> 1.9E <sup>-07*</sup>	
RWR	$(-9.098) + (0.541 \times T) + (0.019 \times L) - [1.19E^{-3} \times (T \times L)]$	0.99
SE	1.58* 0.09* 0.003* 0.00017*	
DLW	$(102.74) + (0.435 \times T^2) - [0.056 \times (T \times L)] + [5.9E^{-05} \times (T \times L^2)]$	0.99
SE	2.15* 0.009* 0.0012* 1.3E <sup>-06*</sup>	
DRW	$(-1091.64) + (3.45 \times T^2) + (3.79 \times L) - [0.211 \times (T \times L)]$	0.99
SE	57.73* 0.16* 0.010* 0.194*	
TDW	$(-1271.08) + (7.287 \times T^2) + (4.89E^{-3} \times L) - [0.014 \times (T^2 \times L)]$	0.99
SE	75.19* 0.41* 2.99E <sup>-4*</sup> 8.19E <sup>-4*</sup>	
SLA	$(273.50) - (7.9E^{-4} \times L^2) + [1.9E^{-4} \times (T^2 \times L)]$	0.95
SE	55.74* 0.00016* 0.0002*	
LT	$(-0.0055) - (1.6E^{-07} \times L^2) - [4.9E^{-09} \times (T \times L^2)]$	0.96
SE	0.0057* 2.2E <sup>-08*</sup> 1.7E <sup>-9*</sup>	
LAR	$(115.17) - (2.89E^{-4} \times L^2) - [3.2E^{-08} \times (T^2 \times L^2)]$	0.83
SE	27.88* 8.7E <sup>-05*</sup> 2.6E <sup>-07*</sup>	
NAR	$(-0.174) + (9.9E^{-3} \times T) + (3.49E^{-4} \times L) - [1.9E^{-05} \times (T \times L)]$	0.99
SE	0.013* 0.00073* 2.6E <sup>-05*</sup> 1.4E <sup>-6*</sup>	
RGR	$(-1.635) + (0.0548 \times T) + (0.00322 \times L) - [2E^{-07} \times (T \times L^2)]$	0.99
SE	0.062* 0.0018* 0.00012* 7.2E <sup>-09*</sup>	

SE = Standard error. \* =  $p < 0.05$ ; \*\* =  $p < 0.01$ ; \*\*\* =  $p < 0.0001$ ; \*\*\*\* =  $p < 0.00001$ .

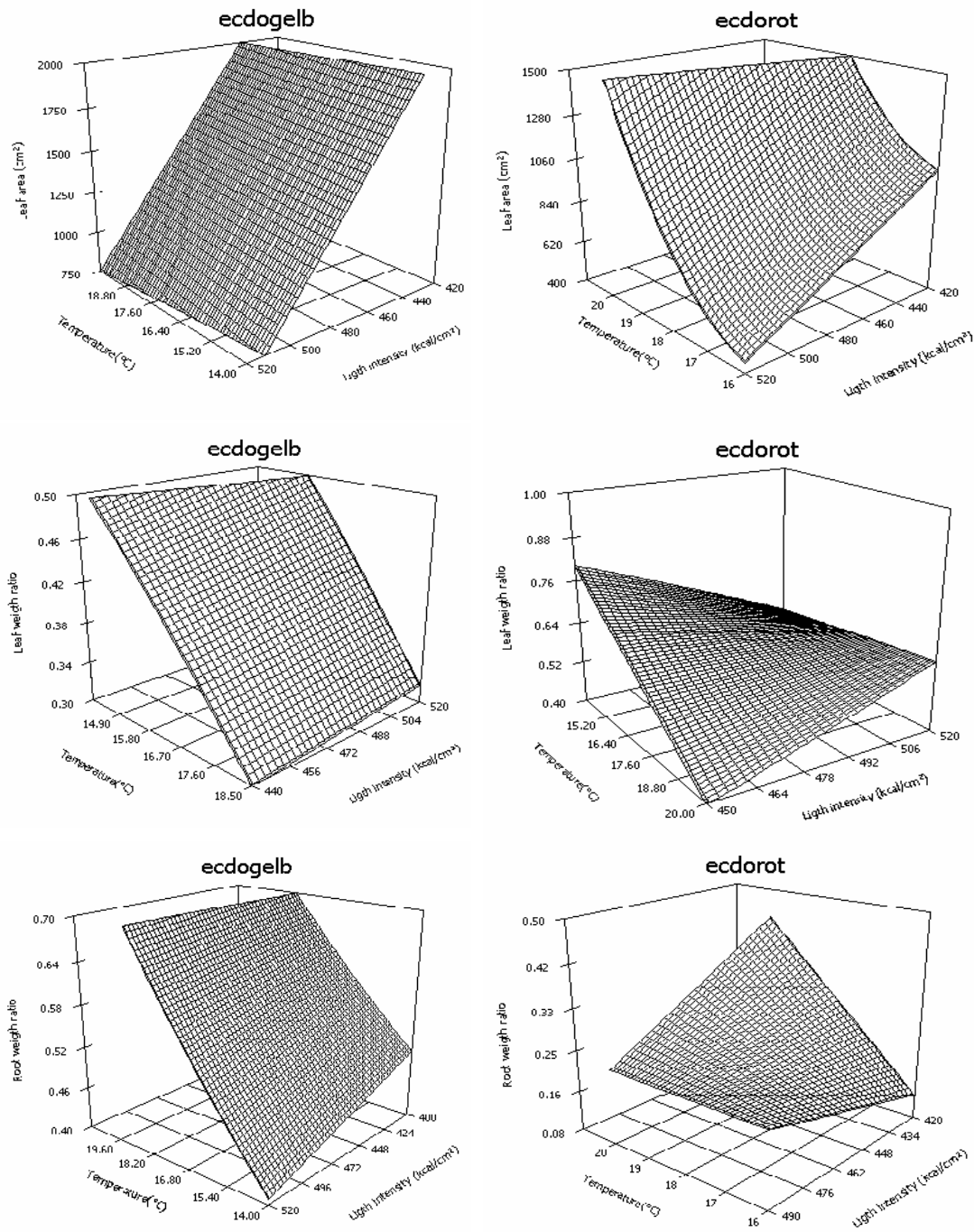


Fig. 1. Changes in leaf area, leaf weight ratio and root weight ratio for Ecdogelb and Ecdorot against daily mean light intensity (kcal/cm²) and temperature (°C).

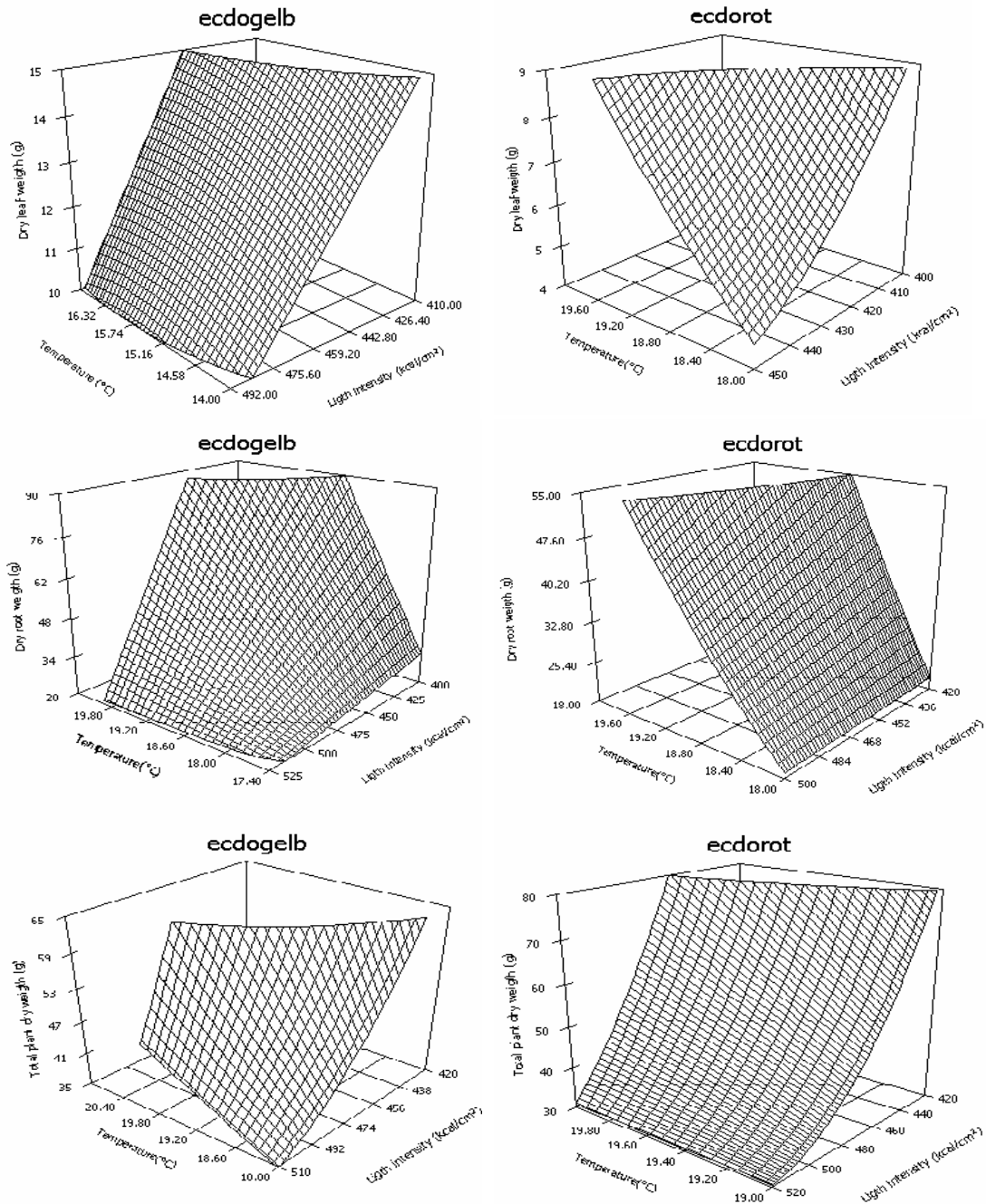


Fig. 2. Changes in dry leaf weight, dry root weight and total plant dry weight for Ecdogelb and Ecdorot against daily mean light intensity (kcal/cm<sup>2</sup>) and temperature (°C).

Decreasing light intensity at high temperature (19.8°C) increased DRW. Increasing temperature at low light intensity (400 kcal cm<sup>-2</sup>) increased DRW linearly. The effect of the

temperature on dry root weight (DRW) was more than that of light intensity in Ecdorot. At any given light intensity, increasing temperature increased DRW linearly. Increasing temperature from 18.0 to 19.6 °C increased DRW from 18.0 to 55.0 g. The highest dry root weight was obtained from low light intensity and high temperature in both Ecdogelb and Ecdorot (Fig. 2).

The effect of the light intensity on TDW was more than that of temperature in Ecdogelb. Decreasing light intensity from 510 to 420 kcal cm<sup>-2</sup> increased TDW. Increasing temperature from 18.0 to 20.4°C at high light intensity (510 kcal cm<sup>-2</sup>) resulted in an increased TDW from 35.0 to 41.0 g. The effect of the light intensity on TDW was more than that of temperature in Ecdorot due to the narrow temperature regimes (19.0 - 19.8°C). At any given temperature, decreasing light intensity from 520 to 420 kcal cm<sup>-2</sup> resulted in an increased TDW. The highest total plant dry weight was obtained from low light intensity and high temperature in both Ecdogelb and Ecdorot (Fig. 2).

*Specific leaf area:* The result of multi-regression analysis showed that increasing temperature from 14 to 19.6°C increased SLA. At any given light intensity, increasing temperature resulted in an increased SLA. The effect of the light intensity on SLA was more than that of temperature in Ecdorot. Decreasing light intensity from 520 to 420 kcal cm<sup>-2</sup> reduced SLA rapidly. At any given light intensity, increasing temperature resulted in a slight increase in SLA. The highest SLA was obtained from high temperature and low light intensity in both Ecdogelb and Ecdorot.

Decreasing temperature from 19.5 to 15.1°C increased LT in Ecdogelb. At any given light intensity, decreasing temperature resulted in increased LT sharply. Increasing light intensity from 420 to 520 kcal cm<sup>-2</sup> caused an increase in LT of Ecdorot. Decreasing temperature from 17.0 to 14.6°C reduced LT. The leaf thickness increased by high light intensity and low temperature in both Ecdogelb and Ecdorot (Fig. 3).

A sharp increase can be seen in leaf area ratio (LAR) with decreasing temperature from 19 to 14°C in Ecdogelb. Decreasing light intensity resulted in a slight increase in LAR. The effect of the light intensity on LAR was more than that of temperature in Ecdorot. At any given temperature, decreasing light intensity from 520 to 420 kcal cm<sup>-2</sup> resulted in a sharp increase in LAR. The highest LAR was obtained from low temperature and low light intensity in both Ecdogelb and Ecdorot (Tables 1 and 2).

Increasing temperature from 17.7 to 18.74°C resulted in an increase in net assimilation rate (NAR) in Ecdogelb. Especially, increasing temperature at the low light intensity (400 kcal cm<sup>-2</sup>) increased NAR. Decreasing light intensity at high temperature (19.6°C) increased NAR in Ecdorot. The highest NAR obtained from 420 kcal cm<sup>-2</sup> light intensity and 19.6°C temperature. Increasing temperature at 420 kcal cm<sup>-2</sup> light intensity increased NAR, decreasing light intensity at 19.6°C temperature resulted in an increase in NAR in Ecdorot. The highest NAR was obtained from low light intensity and high temperature in both Ecdogelb and Ecdorot (Tables 1 and 2).

The effect of the temperature on RGR was more than that of light intensity in Ecdogelb. At any given light intensity, increasing temperature from 17.5 to 20.3°C increased RGR linearly. The effect of the light intensity on RGR was more than that of temperature in Ecdorot. The effect of temperature on RGR significant only at low light intensity (460 kcal cm<sup>-2</sup>). Increasing temperature increased RGR at low light intensity. At any given temperature, decreasing light intensity curvilinearly increased RGR. This increase at high temperature was sharp. The highest RGR was obtained from low intensity and high temperature in both Ecdogelb and Ecdorot (Fig. 4)

In the present study, low light intensities and high temperatures enhanced leaf area in both Ecdogelb and Ecdorot. It was reported that LA varies depending on a number of factors including seasonal climate temperature and light intensity, water and nitrogen availability (Drake *et al.* 1997, Ewert and Pleijel 1999, Hartz-Rubin and DeLucia 2001, Kimball *et al.* 2002, Cowling and Field 2003). In high light intensity, cell membrane and cuticle get thicker, cells and stomas decrease in

size and get closer. Leaf veins get thinner leaf becomes narrower and erected resulting in a lower LA. The decreased LA in high light intensity in our experiment confirm the findings of Eser (1986).

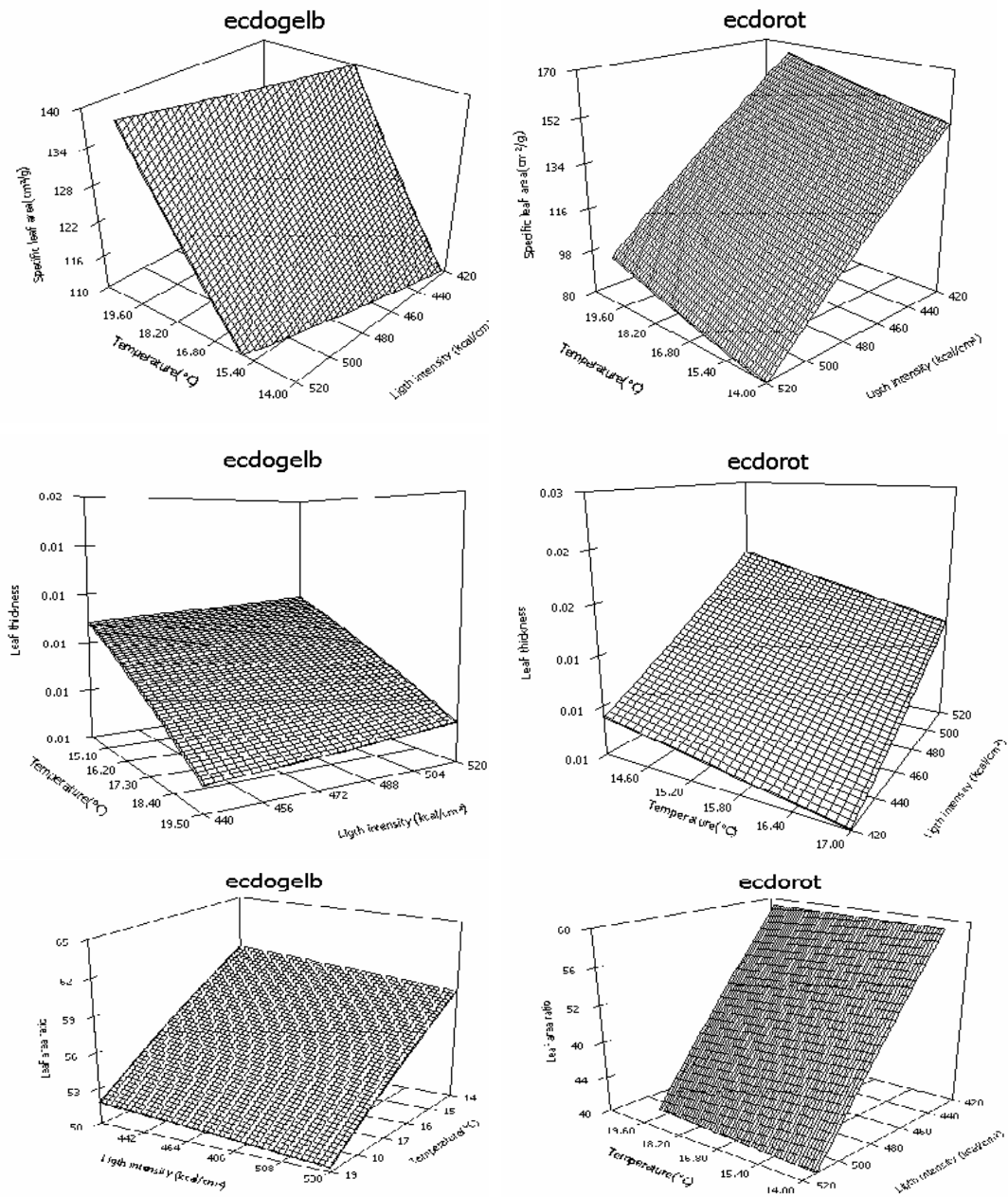


Fig. 3. Changes in specific leaf area, leaf thickness and leaf area ratio for Ecdogelb and Ecdorot against daily mean light intensity (kcal/cm<sup>2</sup>) and temperature (°C).



The change in LWR occurred in both Ecdogelb and Ecdorot with the effect of temperature rather than light intensity. The highest LWR was obtained from high light intensity and low temperature in both the cultivars. In high light intensity and low temperature, because the plant continued to grow for a longer period, the leaf may have remained green longer and hence LWR might have been increased.

The highest RWR was determined on high temperature and low light intensity in both cultivars Ecdogelb and Ecdorot. Warm conditions generally stimulate growth of root crops: a 1°C increase in soil temperature increases biomass of carrots by 37% at maximum leaf area index (Wheeler *et al.* 1994). This is consistent with the finding of present study.

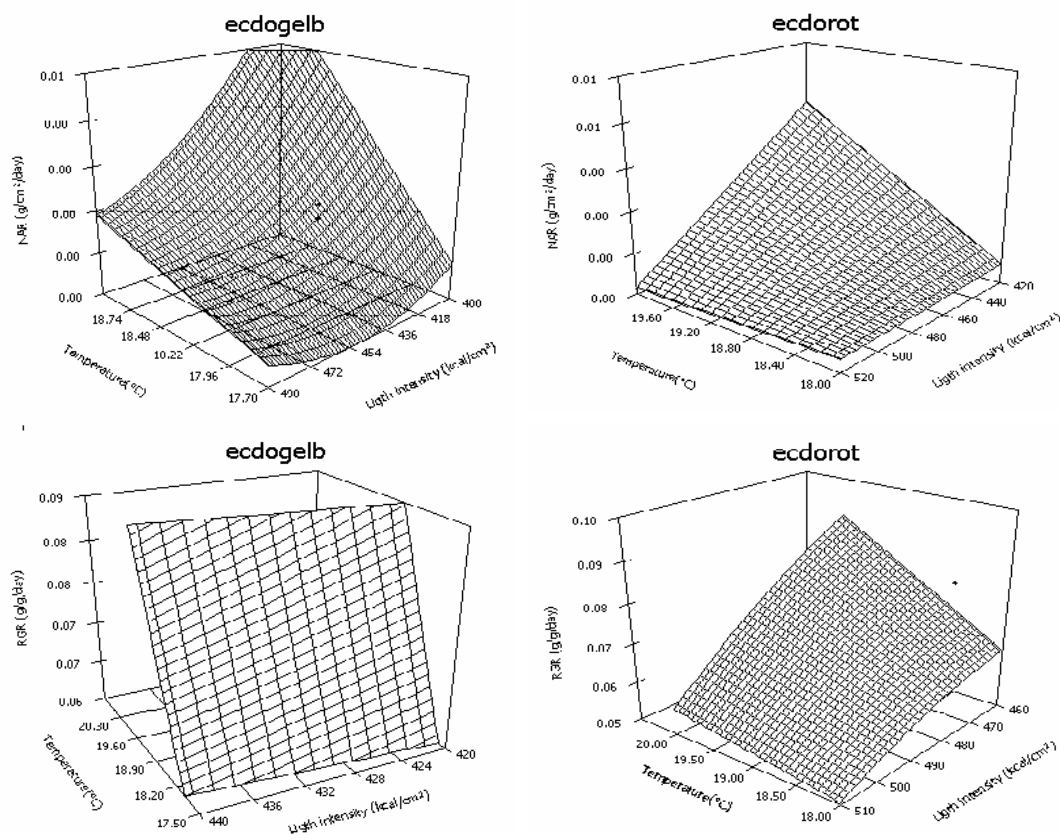


Fig. 4. Changes in NAR and RGR for Ecdogelb and Ecdorot against daily mean light intensity (kcal/cm<sup>2</sup>) and temperature (°C).

The highest DLW, DRW and TDW were obtained from low light intensity and high temperature in both Ecdogelb and Ecdorot. Freckleton *et al.* (1999) reported that both rain and temperature have a significant effect on sugar beet yield, however the effect of light is less, probably because intercepted radiation (i.e. the product of canopy area and total radiation) rather than total radiation determines growth. The amount of chlorophyll on the surface of leaf increases with a decrease in light intensity. However, if this decrease in light intensity continues, the amount of chlorophyll on the surface of leaf decrease instead of increasing. Low light intensity causes the blocking of stomatal pores. Additionally, it adversely affects photosynthesis by preventing enough

CO<sub>2</sub> entrance into the plant. Similarly, high light intensity causes an increase in transpiration in most plants. This in turn results in a decrease in the amount of water and hence in a decreased photosynthesis in leaf cells (Kacar, 1989). Warm conditions generally stimulate growth of root crops: a 1°C increase in soil temperature increased biomass of carrots by 37% at maximum leaf area index (Wheeler *et al.* 1994). However, early warmth accelerates development of sugar beet, a plant with supposedly intermediate root storage of carbohydrates, but decreases growth later (Demmers-Derks *et al.* 1998). This is similar to the response of a determinate seed storage plant such as wheat (Mitchell *et al.* 1995, Wheeler *et al.* 1996). Warmer temperatures accelerated development and early growth but had a negative effect on final biomass, probably due to canopy senescence and increase in maintenance respiration (Demmers-Derks *et al.* 1998).

The highest SLA was obtained from high temperature and low light intensity. However, the LT increased under low temperature and high light intensity in both Ecdogelb and Ecdorot. SLA represents the mean leaf area per unit of leaf weight, or in other words it measures leaf density or relative thickness (Hunt 1982). LT is measured as 1/SLA. The higher the SLA, the thinner the leaf is (Coughenour *et al.* 1984, Opitz von Boberfeld, 1994). SLA area can change markedly 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, Rebetzke *et al.* 2004). SLA is slower when plants are grown at higher light intensities than when plants are grown at low light intensities (Uzun 1996). Hughes and Evans (1962) observed that deep shade caused an increase in SLA. SLA generally decreases with leaf age (Uzun 1996, Reich *et al.* 1999, Wilson *et al.* 2000). Evans (1989) observed that SLA was negatively correlated with high light intensity and positively with temperature. Eser (1986) reported that increasing light intensity increased LT. Our results are consistent with these observations.

The highest LAR was obtained from low temperature and light intensity in both Ecdogelb and Ecdorot. The decrease in LAR occurred in plants grown under 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 LAR decreases as the plant gets older (Charles-Edwards *et al.* 1986). Picken *et al.* (1986) reported that light intensity affects dry matter contents of plants and increasing light intensity decreases LAR. Our results confirm the finding of Picken *et al.* (1986) for LAR.

NAR is the net gain of assimilates per unit leaf area and time (Gardner *et al.* 1994). In the present study, the highest NAR was obtained from low light intensity and high temperature in both Ecdogelb and Ecdorot. In a study carried out in eggplant it was observed that NAR increased as the temperature rose and declined with time. However, this increase in the plant grown at 30°C reached the maximum value of 0.15 g cm<sup>-2</sup> day<sup>-1</sup> and then as the temperature decreased to 16°C it reached the value of 0.03 g cm<sup>-2</sup> day<sup>-1</sup> (Heuvelink 1989). Both in this study and in other similar studies, the increased NAR depending on time in the first periods of plant growth was slower at low temperature than at high temperature. Consequently, a general evaluation of NAR revealed the fact that rapid increases in the NAR leads to rapid decreases in the later stages and thus this feature being closely related with plant growth rate. 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.

In the present study, the highest RGR was obtained from low intensity and high temperature in both Ecdogelb and Ecdorot. Plant species may differ considerably in RGR. This may be caused by habitat-related variation in abiotic factors, like temperature, water, light and nutrients, or by biotic factors like competition and diseases (Poorter 1989). Due to the fact that plant growth is quite rapid in the early stage of plant life, the RGR continuously changes and generally decreases

in time. With respect to the total plant weight, the decrease in meristem tissues was considered as the major cause of the decrease in RGR (Uzun 1997).

The highest leaf area, root weight ratio, dry leaf weight, dry root weight, total plant dry weight, specific leaf area, net assimilation rate and relative growth rate were obtained from low light intensity (average 416.2 kcal cm<sup>-2</sup>) and high temperature (average 19.48°C). However, the highest leaf weight ratio and leaf thickness were determined in high light intensity (average 520 kcal cm<sup>-2</sup>) and low temperature (average 14.95°C). Ecdogelb and Ecdorot had the highest leaf area ratio at low light intensity (average 431 kcal cm<sup>-2</sup>) and low temperature (average 14°C). The regression coefficients of the new produced equations for growth parameters varied from 0.95 to 0.99 for Ecdogelb and 0.83 to 0.99 for Ecdorot. The results from the present study showed that the produced submodels could be used for predicting growth habits of fodder beet. Moreover, in choosing most suitable growing areas of fodder beet, these models can be evaluated for producing the overall growth models of fodder beet.

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