Relationship between flowering, fruit setting and environmental factors on consecutive clusters in greenhouse tomato *(Lycopersicon lycopersicum* (L) *Karsten)*

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Summary: The main season of greenhouse tomato begins late winter or early spring in the northern Temperate Zone. During this period decisive environmental factors affect flowering and fruit setting.
In the present experiments, progress and dynamics of greenhouse tomato flowering and fruit set were examined in 1999 and 2001 spring. The beginning and the end of flowering and fruit set, the number of flowers and fruits set in each cluster were recorded. Flowering and fruit set characteristics were analysed with respect to the accumulated PAR and temperature were calculated for each cluster. One flower required 31.3 mol m^{-2} of accumulated PAR and 38 °C of sum temperature as an average for anthesis. One fruit required 27.9 mol m^{-2} of accumulated PAR and 33.3 °C of sum temperature as an average for fruit setting.

Key words: Irradiance; PAR; Flower; Fruit set; Cluster; Tomato

Introduction

The main target of greenhouse tomato growing is to develop intensive flower formation, fruit set and fruit growth, and to achieve a balance between vegetative and reproductive growth.

Flowering and fruit setting are important developmental stages, which have considerable influence on the dynamics of fruit growth and the quantity and quality of harvested fruits *(Helyes* et al., 2000).

Greenhouse tomatoes are usually sown in November or December in northern Europe, as to achieve reasonable high prices in early spring *(Helyes & Pék,* 2001).

Light is one of the most important environmental factors, which affects flowering. Short days and low light intensity are suboptimal conditions for flowering and fruit set. These winter conditions can seriously delay flowering, resulting in malformed ovaries *(Rylski* et al. 1994).

The numbers of leaves preceding first inflorescence (NLPI) *(Dieleman & Heuvelink* 1992), days to flower bud appearance *(Lohar & Peat,* 1998) and days to anthesis *(Klapwijk,* 1986; *Calvert,* 1957) can characterize the earliness of tomato yield.

Many studies are concerned to NLPI, because it is an input of the simulation model of tomato growing *(Chiu* et al. 1996; *Heuvelink & Bertin,* 1994; *Heuvelink,* 1999).

The latter clusters appear to be controlled in the same way, although the influences of environmental factors are less. *Saito* (1986) found varietals differences in flowering and fruiting of tomato among upper clusters.

The continuous growth or inflorescence can characterize the rate of appearance of consecutive clusters *(Heuvelink,* 1995; *Dumas* et al. 1993; *De Koning,* 1989; *Abreau* et al. 2000).

The higher the temperature is, the earlier the opening of the flowers is *(Hurd & Cooper,* 1970; *Abreau* et al. 2000; *Pék & Helyes,* 2003).

The onset of red fruit production is correlated negatively with the accumulated PAR during the seedling stage *(Janes & McAvoy,* 1991).

Yield is correlated positively with the accumulated radiation received by the crop in long season *(Cockshull* et al., 1992) and in single-cluster tomatoes as well *(Janes & McAvoy,* 1991).

Other environmental factors, such as water availability, nutrition, CO_2 concentration of the air, appear to be less important *(Dieleman & Heuvelink,* 1992; *Helyes* et al., 2000).

Studying environmental factors and the dynamics of flowering and fruit set can be justified, that they are related to accumulated PAR and temperature in greenhouse tomato especially in spring. Creating and evaluating an index, is characterized the processing of flowering and fruit set.

Material and method

Glasshouse experiments were conducted to quantify the effect of daily temperature and PAR on spring tomato development, in two years (1999 and 2001). Experiments were conducted all with four replicates (compartments) per variety. Data logger was used for data acquisition. Temperature and PAR were measured every ten minute by Skye micrometeorological instrument that registered only the hourly average value of each parameter, and these were later used to obtain the daily averages used in. Sensors were positioned centrally in the compartment at the level of flowering clusters on tomato plants. Plants were planted in single rows with a plant density of 2.1 plants m^{-2} and the growing techniques were the usual for greenhouse tomatoes in Hungary; culture on soil, irrigated with a standard nutrient solution by means of a drip irrigation system, plant training to one stem, according to a high wire system, greenhouse soil additionally covered with a highly reflective white PE film.

The stage when the first fruit primordia could be seen was considered to be the beginning of set. Clusters were recorded on three occasions each week for each plant and averaged per experimental plot. By interpolation in the averaged recordings of flowering, the moment of a particular cluster started to flower were estimated. Then, for each cluster, the growth period and average temperature over this period were calculated.

In 1999, we tested candidate hybrid RX958 planted at 27^{th} of January 1999 and the last harvest was made at 22^{nd} of July 1999.

In 2001, we tested the cultivar Daniela F_1 planted at 27^{th} of March 2001 and the last harvest was made at 13^{th} of August 2001.

The top of the plants was cut by the second leaf above the 10^{th} cluster all years. All the cultivars are continuonsky growing and of round fruit type. All axillary shoots were removed as they appeared. Leaves were removed from below the cluster as the fruit reached the mature-green stage, and the fruits were picked when ripe.

In 1999, the plant data were obtained from a sample of 24 plants (6 plants from each of the 4 plots) and in 2001, plant data were obtained from a sample of 20 plants (5 plants from each of the 4 plots).

Both experiments were executed in four replicates and the results were expressed as the average plus/minus the standard deviation. Differences between results were evaluated using variance analysis and were considered statistically different at $P = 0.05$.

Results

Flowering

The basis of the evaluation of flowering was the number of flowers per cluster *(Table 1)*. From the first inflorescence to the fifth cluster the flowering intervals were continuously shorter in 1999, because the average daily PAR increased continuously during flowering, but it was alternating in 2001 *(Table 1)*. The average flowering time of clusters overlapped continuously. The shorter the flowering time, the less the

Table 1 The average values of flowers and environmental factors per cluster, during the flowering period in 1999 and 2001 (RX958 F_1: n=24 in 1999 and Daniela F_1: n=20 in 2001)

Cluster	Number of flowers (a)		Days from sowing to first anthesis		Days of flowering (b)		Index of flowering (a/b)		Accumulated PAR/flower (mol m^{-2}/a)		Accumulated temperature/ flower (°C/a)	
	1999	2001	1999	2001	1999	2001	1999	2001	1999	2001	1999	2001
1.	6.4	8.6	83	79	17.4	15.6	0.40	0.60	34.5	29.1	63.0	37.6
2.	7.4	7.7	90	88	15.6	14.0	0.54	0.60	27.7	30.9	48.0	39.8
3.	7.9	10.0	95	94	14.2	16.0	0.60	0.64	27.0	32.2	39.8	34.2
4.	7.2	9.3	101	101	13.7	14.0	0.55	0.71	29.5	31.9	40.8	30.9
5.	7.2	8.3	109	107	11.3	12.6	0.68	0.67	24.6	33.3	35.9	32.3
6.	7.0	7.5	115	118	11.7	11.5	0.62	0.69	27.3	32.9	27.3	32.4
7.	8.4	7.2	121	125	10.7	11.9	0.83	0.69	23.3	38.5	32.4	36.0
8.	7.2	6.9	126	131	11.0	11.6	0.70	0.62	28.3	39.4	37.5	36.4
9.	7.1	6.1	133	138	10.5	10.2	0.70	0.65	25.2	35.4	34.9	35.3
10.	5.6	6.1	141	147	12.9	10.5	0.51	0.65	44.6	29.2	50.6	34.5
	7.1	7.8			12.9	12.8	0.61	0.65	29.2	33.3	41.0	34.9
d	1.00	1.24	1.25	2.75	2.06	2.74	0.09	0.12	5.20	7.54	6.63	7.46
SE												
1.	±0.25	±0.52	±0.73	±0.66	±1.37	±1.42	±0.027	±0.047	±2.51	±2.46	±4.17	±3.09
2.	±0.34	±0.51	±0.37	±0.91	±1.40	±1.81	±0.045	±0.045	±2.52	±3.01	±3.76	±2.52
3.	±0.33	±0.70	±0.38	±0.93	±1.06	±1.49	±0.044	±0.045	±1.80	±2.24	±2.36	±2.06
4.	±0.20	±0.43	±0.45	±1.28	±0.71	±1.70	±0.025	±0.048	±1.47	±2.82	±2.29	±2.50
5.	±0.21	±0.37	±0.49	±1.30	±0.95	±1.21	±0.038	±0.028	±1.53	±1.33	±2.44	±1.18
6.	±0.26	±0.26	±0.54	±1.11	±0.91	±1.32	±0.031	±0.038	±1.65	±2.08	±1.65	±1.87
7.	±0.69	±0.41	±0.53	±1.09	±0.97	±1.79	±0.062	±0.050	±1.64	±5.31	±2.26	±4.95
8.	±0.68	±0.32	±0.68	±1.06	±1.07	±1.28	±0.052	±0.034	±2.14	±2.18	±2.83	±2.04
9.	±0.45	±0.43	±0.57	±1.15	±0.82	±1.19	±0.044	±0.043	±1.49	±2.00	±2.05	±2.22
10.	±0.22	±0.60	±0.83	±1.61	±1.54	±1.44	±0.047	±0.044	±4.88	±1.86	±4.95	±2.25

d= significant differences of averages at $P<0.05$

clusters overlap. We calculated the amount of average daily PAR for each cluster. Average daily PAR required for one flower was 29.2 and 33.3 mol/m^2, respectively. Adding average daily temperatures the temperature required of flowering were: 41 °C and 34.9 °C per flower.

To evaluate the process of flowering we calculated the number of flowers per day *(Table 1)*. This index, which shows the interval which a flower needs to start blooming, can be also seen. In 1999, the seventh cluster produced the most intensive flowering and in 2001 it was the fourth, which produced it. An average of 0.83 and 0.71 flower per day is the flowering rate, respectively.

There were close correlation between accumulated PAR and sum temperature and flowering index *(Table 2, Figure 1)* concerning each cluster of all plants.

Fruit set

The different clusters showed the same characteristics as in flowering, but the indices (fruit set per setting period) of different clusters were alternating *(Table 3)*.

Studying the length of fruit set we came to analogous conclusion. Fruit set required shorter time (in average 15%) than flowering on each cluster.

The required average daily irradiance was 23.2 mol m^{-2} and 32.5 mol m^{-2}, respectively, for one fruit to set. The total sum of average daily temperature was calculated as well. Adding average daily temperatures the required time of setting is, 32.7 °C per fruit in 1999 and 34 °C per fruit in 2001 *(Table 3)*.

Fruit set index, which shows the time which a fruit needs to set, can be also seen in *Table 3*. The seventh cluster had the most intensive fruit set in 1999 and the second had in 2001. It was an average of 1.13 and 0.94 fruit per day the fruit set rate, respectively. *Table 4* and *Figure 2* show the correlation between the intensity of setting and accumulated PAR and temperature concerning each cluster.

Examining the different parameters, we tried to find the correlation among them.

There was no correlation between the number of flowers per cluster and the length of flowering (days) or the index of flowering (flower/day).

Table 2 Relationship between flowering index and environmental factors (RX958 F_1 in 1999 and Daniela F_1 in 2001

parameters	Index of all clusters in relation of accumulatedíper flower		Index of all clusters in relation of sum temperature per flower	
	1999	2001	1999	2001
N	240	200	240	200
Regr. function	$y = 12.531x^{-0.9372}$	$y= 9.0443x^{-0.7756}$	$y = 17.417x^{-0.9408}$	$y= 18.779x^{-0.9709}$
R^2	0.87	0.77	0.91	0.97

P<0.001

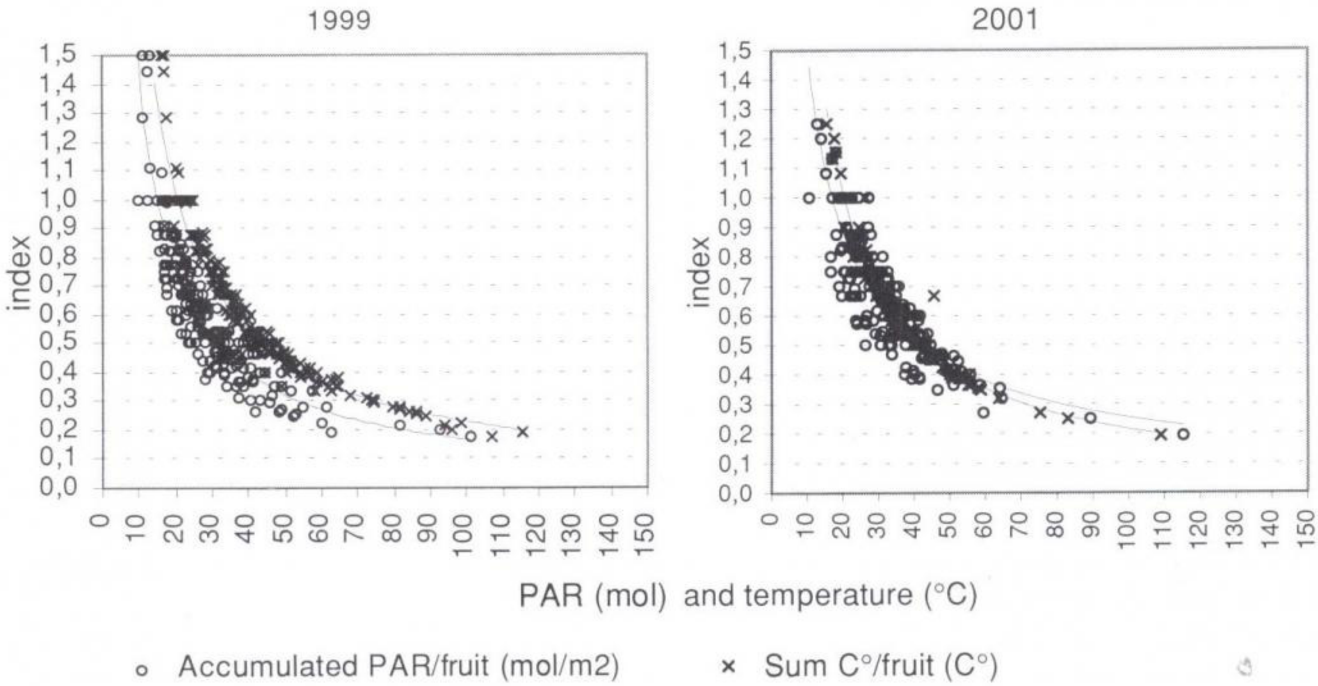

Figure 1 Flowering index and regression functions in relation of irradiance and temperature on the first ten clusters (RX958 F_1: n=24 in 1999 and Daniela F_1: n=20 in 2001)

Table 3 The average values of fruit set and environmental factors per cluster, during the fruit set period (RX958 F_1: n=24 in 1999 and Daniela F_1: n=20 in 2001)

Cluster	Number of set fruits		Number of days from sowing to first fruit set		Whole fruit set (days)		Index of fruit set (fruit/day)		Accumulated PAR/set fruit (mol m^{-2})		Accumulated temperature (°C/set fruit)	
	1999	2001	1999	2001	1999	2001	1999	2001	1999	2001	1999	2001
1.	5.8	8.5	89	88	12.5	17.5	0.49	0.54	29.7	34.8	52.1	43.2
2.	7.2	7.6	95	98	12.1	10.7	0.77	0.94	23.8	28.8	36.5	30.4
3.	7.5	9.5	99	101	11.0	13.7	0.76	0.77	22.2	31.3	31.3	30.2
4.	7.3	8.7	105	107	10.3	14.8	0.75	0.70	22.2	38.1	30.5	35.9
5.	7.0	8.2	113	116	8.5	11.7	0.94	0.74	18.9	29.1	29.2	29.0
6.	7.0	7.3	118	124	9.5	11.1	0.78	0.78	23.0	33.2	33.6	31.4
7.	8.4	6.9	124	131	8.1	10.7	1.13	0.79	17.2	37.2	24.0	35.2
8.	7.2	6.6	130	138	8.3	10.4	0.98	0.76	20.8	34.9	27.6	34.9
9.	7.1	5.8	137	145	7.2	9.2	1.00	0.67	17.7	30.7	23.8	35.0
10.	5.6	5.7	145	153	9.9	9.2	0.74	0.74	36.4	26.9	38.2	34.4
	7.0	7.5			9.8	11.9	0.84	0.74	23.2	32.5	32.7	34.0
d	1.01	1.29	1.42	2.86	2.12	3.30	0.17	0.23	5.45	8.54	6.87	8.74
SE												
1.	±0.34	±0.50	±0.94	±0.83	±1.35	±2.03	±0.035	±0.036	±2.80	±3.00	±4.48	±3.08
2.	±0.31	±0.54	±0.48	±0.94	±1.39	±1.81	±0.087	±0.127	±2.64	±3.84	±3.61	±3.88
3.	±0.29	±0.62	±0.50	±1.04	±1.06	±1.17	±0.062	±0.077	±1.66	±2.62	±2.33	±2.61
4.	±0.19	±0.47	±0.63	±1.21	±0.71	±1.93	±0.037	±0.081	±1.20	±3.90	±1.68	±3.72
5.	±0.27	±0.37	±0.66	±1.02	±0.92	±1.28	±0.085	±0.042	±1.79	±1.78	±2.66	±1.66
6.	±0.26	±0.25	±0.62	±1.20	±0.91	±1.47	±0.042	±0.075	±1.63	±3.27	±2.09	±3.08
7.	±0.69	±0.47	±0.48	±1.02	±0.97	±1.96	±0.079	±0.083	±1.46	±4.92	±1.87	±5.25
8.	±0.68	±0.40	±0.77	±1.00	±1.06	±1.37	±0.090	±0.127	±2.19	±2.87	±2.59	±2.96
9.	±0.45	±0.46	±0.79	±1.49	±0.82	±1.38	±0.048	±0.048	±0.99	±1.90	±1.14	±2.63
10.	±0.22	±0.66	±0.78	±1.68	±1.53	±1.32	±0.079	±0.103	±4.87	±2.84	±4.82	±3.74

d= significant differences of averages at $P<0.05$

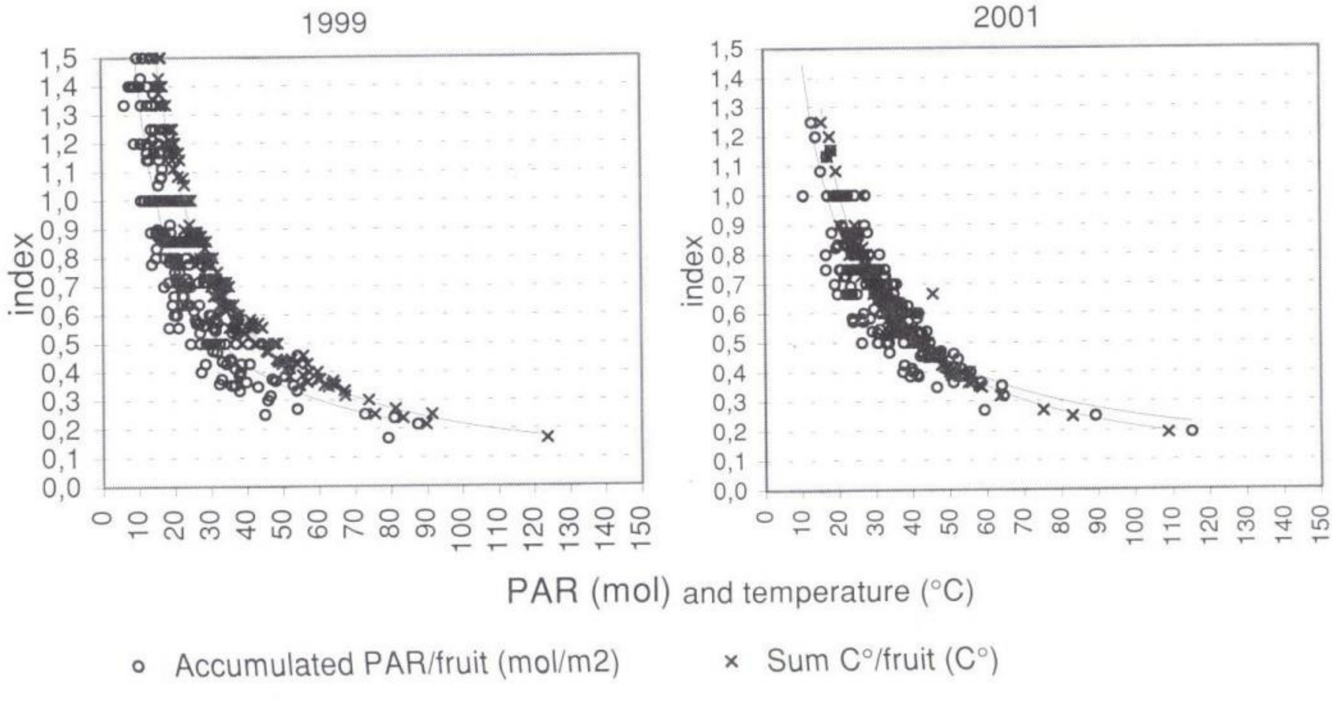

Figure 2 Fruit set index and regression functions in relation of irradiance and temperature on the first ten clusters in (RX958 F_1: n=24 in 1999 and Daniela F_1: n=20 in 2001)

Table 4 Relationship between fruit set index and environmental factors (RX958 F_1 in 1999 and Daniela F_1 in 2001

parameters	Index of all clusters in relation of accumulated PAR per flower		Index of all clusters in relation of sum temperature per fruit	
	1999	2001	1999	2001
N	240	200	240	200
Regr. Function	$y = 10.494x^{-0.8699}$	$y= 13.967x^{-0.8971}$	$y = 25.02x^{-1.0324}$	$y = 17.925x^{-0.9592}$
R^2	0.86	0.86	0.98	0.97

P<0.001

Table 5 The significant differences of flowering and fruit set between cultivars, clusters, and cultivar × cluster (RX958 F_1: n=24 in 1999 and Daniela F_1: n=20 in 2001)

Factors	Number of flowers		Length of flowering (day)		Index of flowering (flower/day)		Number of set fruits		Length of fruit set (day)		Index of fruit set (fruit/day)	
	1999	2001	1999	2001	1999	2001	1999	2001	1999	2001	1999	2001
Cultivar	P<0.05	P>0.05	P<0.05	P<0.05	P<0.05	P>0.05	P<0.05	P>0.05	P<0.05	P>0.05	P<0.05	P<0.05
Cluster	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P>0.05	P<0.05	P<0.05	P<0.05	P<0.05
Interaction (cultivar × cluster)	P>0.05	P<0.05	P>0.05	P>0.05	P<0.05	P>0.05	P<0.05	P>0.05	P>0.05	P<0.05	P>0.05	P>0.05

(200 degree of freedom in 1999, 160 degree of freedom in 2001)

Table 6 Relationship between flowering index of first and seventh cluster and PAR (RX958 F_1 in 1999 and Daniela F_1 in 2001)

parameters	Index of all clusters in relation of accumulated PAR per flower		Index of all clusters in relation of sum temperature per fruit	
	1. cluster	7. cluster	1. cluster	7. cluster
N	44	44	44	44
Regr. function	$y = 14.728x^{-1.0231}$	$y= 10.643x^{-0.8196}$	$y = 8.0749x^{-0.8283}$	$y = 13.433x^{-0.8853}$
R^2	0.89	0.90	0.78	0.88

P<0.001

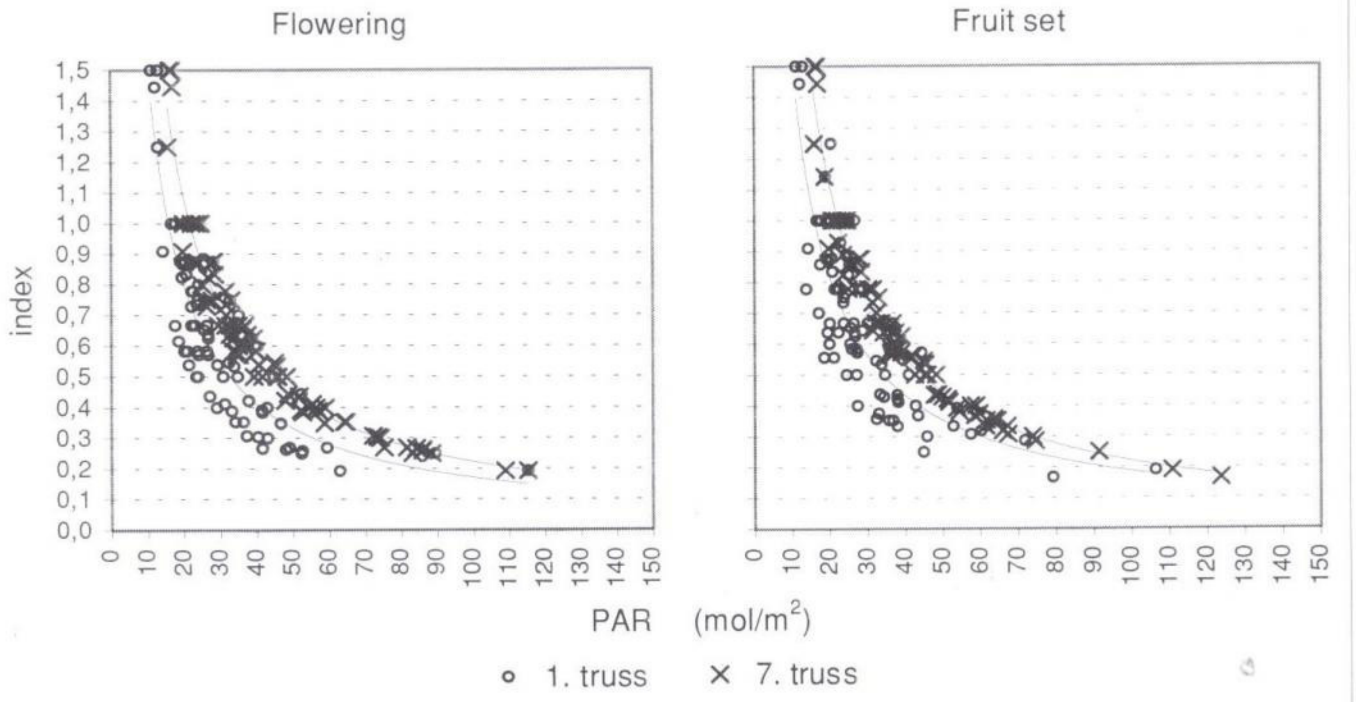

Figure 3 Relationship between flowering and fruit set index and regression functions in relation of PAR on first and seventh cluster in 44 plants in (RX958 F_1 in 1999 and Daniela F_1 in 2001)

In the case of number of flowers and set fruits; length of flowering and fruit set; index of flowering and fruit set there were significant differences between the cultivars in 1999, but there was none in 2001. It is important to mention, that we used candidate cultivar in the experiments in 1999, but hybrids in commercial sale were used in 2001.

In the case of number of flowers and set fruits; length of flowering and fruit set there were significant differences between the clusters in both years, only the indexes showed no difference *(Table 5)*.

The light conditions were suboptimal for the first four clusters in 1999 and caused lower effectiveness of flowering, than in 2001. The flowering index shows this difference in *Table 1*. Nevertheless flowering-index shows difference concerned clusters in both years. The difference was significant ($P<0.01$), comparing the first (lowest index) and the seventh (highest index) cluster in 1999. *Table 6* and *Figure 5* shows the relationship between the index of first and seventh cluster and PAR added both years. The same difference was between fruit set of seventh clusters and PAR *(Table 6, Figure 5)*. But the difference was not significant in the case of temperature.

Conclusions

Comparing the indexes of cultivars, the difference was also remarkable. There are cultivars, which are able to use light more effectively than the others *(Saito,* 1986). This character makes cultivars suitable for growing in winter conditions without the decrease of flowering and fruit set. Calculation of indexes is an easy method of choosing the best cultivar for lower light conditions.

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