Rit LbhÍ nr. 40

„Effects of lighting time and light intensity on growth, yield and quality of greenhouse tomato“

FINAL REPORT

Christina Stadler

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Landbúnaðarháskóli Íslands

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Final report of the research project
„Effects of lighting time and light intensity on growth, yield and quality of greenhouse tomato“

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Abbreviations

DM	dry matter yield
DS	dry substance
E.C.	electrical conductivity
H_2O	water
HPS	high-pressure vapour sodium lamps
HSD	honestly significant difference
J	Joule
KCl	potassium chloride
kWh	kilo Watt hour
M	mole
N	nitrogen
$p \leq 0,05$	5 % probability level
pH	potential of hydrogen
ppm	parts per million
W	Watt
Wh	Watt hours
Zn	zinc

Other abbreviations are explained in the text.

1 SUMMARY

In Iceland, winter production of greenhouse crops is totally dependent on supplementary lighting and has the potential to extend seasonal limits and replace imports during the winter months. Adequate guidelines for the most adequate lighting strategy (timing of lighting and light intensity) are not yet in place for tomato production and need to be developed.

An experiment with tomato (*Lycopersicon esculentum* Mill. cv. Encore, 2,5 plants/m^2) was conducted from 13.09.2010-16.03.2011 in the experimental greenhouse of the Agricultural University of Iceland at Reykir. Plants in four replicates were grown under HPS lamps for top lighting with 300 W/m^2 in one cabinet and with 240 W/m^2 in three cabinets. Light was provided for max. 18 hours. During the time of high electrical costs for time dependent tariffs (November - February) one cabinet with the lower light intensity got supplemental light during the night as well during the whole weekend, whereas during the other months it was uniformly provided from 04-22 h as in the other cabinets, all the time. One cabinet received a daily integral of 100 J/cm^2/plant and in addition per cluster 100 J/cm^2 with 240 W/m^2 supplemental light and natural light.

Temperature was kept at 22-23 ° C / 18-19 ° C (day / night) for cabinets with 240 W/m^2, but 24-25 ° C / 20 ° C (day / night) for the cabinet with 300 W/m^2. Carbon dioxide was provided (800 ppm CO_2). Tomatoes received standard nutrition through drip irrigation.

The influence of light intensity and of lighting at cheaper times on growth, yield and quality of tomato was tested and the profit margin calculated.

At the end of 2010 plants showed zinc deficiency. It was decided to shorten the growth period from the cabinet with the highest light intensity.

The accumulated marketable yield of tomatoes that received light during nights and weekends was lower compared to the normal lighting time. Also, when normal lighting time had been restored, the yield did not approach the yield obtained at normal lighting time with final yields amounting to about 15 % less yield. The yield decrease was mainly attributed to less fruits. Less light at the early stage of transplanting and lighting according to solar irradiation resulted in yield that was comparable to the traditional lighting system.

Marketable yield was 94-97 % of total yield and was lower with the highest light intensity due to a high amount of cracked fruits. It seems that fruits with blossom end rot were increased at the highest light intensity and at lighting during nights and weekends.

There was no influence of the lighting regime on height, number of clusters, distance between internodes, DM yield of leaves, cumulative DM yield (yield of fruits, leaves, shoots) and N uptake by plants. However, if results from the cabinet with the higher light intensity were also included, the distance between internodes was there tendentially decreased and dry substance of fruits tendentially increased compared to the other cabinets.

The energy costs could be only slightly decreased with supplemental light during nights and weekends, whereas lighting according to the number of clusters and solar irradiation saved about 6 % of the energy costs. This resulted in an about 9 % higher profit compared to the traditional lighting system, while the profit with light during nights and weekends was about 18 % lower compared to normal lighting times. Possible recommendations for saving costs other than lowering the electricity costs are discussed.

From the economic side it seems to be recommended to provide light at normal lighting times and not during nights and weekends. Energy costs could be decreased, when lights would be turned on for fewer hours at the early stage after transplanting and if supplemental lighting is done in accordance with the solar irradiation.

2 INTRODUCTION

The extremely low natural light level is the major limiting factor for winter greenhouse production in Iceland and other northern regions. Therefore, supplementary lighting is essential to maintain year-round vegetable production. This could replace imports from lower latitudes during the winter months and make domestic vegetables even more valuable for the consumer market.

The positive influence of artificial lighting on plant growth, yield and quality of tomatoes (*Demers* et al., 1998a), cucumbers (*Hao* & *Papadopoulos*, 1999) and sweet pepper (*Demers* et al., 1998b) has been well studied. It is often assumed that an increment in light intensity results in the same yield increase. Indeed, yield of sweet pepper in the experimental greenhouse of the Agricultural University of Iceland at Reykir increased with light intensity (*Stadler* et al., 2010a). However, at high natural light level, no yield differences on marketable yield were observed most likely because environmental conditions (temperature, illuminance) did nearly not differ within cabinets due to high solar irradiation. Therefore, assuming that tomatoes react similarly as sweet pepper to the natural light level, the present tomato experiment ends before the high light level starts.

Tomato plants vary in their number of clusters, posing the question, if the number of clusters and consequential yield may be influenced by the lighting regime. According to recent experiments it was estimated that 100 J/cm^2/cluster and 100 J/cm^2 for plant maintenance should be provided (*Dorais*, 2003). That means, for seven clusters, a total of 800 J/cm^2 is needed (*Stijge,* without year).

The costs for lighting are high, especially when growers are using electricity during the day and not during the night. Due to this “time dependent” tariffs, the idea was developed to lighten in cheaper times to decrease electricity costs. The sale for the energy is cheapest from 21.00-07.00 as well as on weekends and the distribution is lowest from 23.00-07.00 as well as on weekends. The energy is highest from 01.11-01.03 from 09.00-21.00 in sale and from 07.00-23.00 in distribution. Therefore, to lower the energy costs it would be appropriate to lighten in the cheapest time, which is from 23.00-07.00 during weekdays and during weekends. Sweet pepper was able to deal with lighting times during the whole weekend and light during night instead of during day. However, the yield was lower (about 10 %), when uncommon lighting times were used (*Stadler* et al., 2010b). In a preliminary experiment observed

Gunnlaugsson & Aðalsteinsson (2003) the effect of timing strategies in tomatoes and measured the highest yield with lighting hours from 04.00-22.00 compared to 23.00-17.00. Electricity costs were 11 % higher for lighting at the usual time but since the yield increased accordingly (12 %) it compensates for higher electricity costs. The authors concluded that therefore it is not necessary to adapt lighting hours for tomatoes to the tariffs for electricity. *Dorais* (2003) reported leaf chlorosis after several days with more than 17 h or even continuous supplemental light. However, under almost 24 h of natural solar light in Finland, tomato plants do not show negative symptoms.

New aspects of lighting with special emphasis on a range of measurements providing additional results are observed in the present experiment, giving among others answers, if also tomatoes are able to deal with uncommon lighting times and if they respond in growth, yield and quality in the same way, as at the usual lighting time (04.00-22.00). Hence, the main aim of this study is to test if there is a possibility to decrease lighting costs by lighting at cheaper times without a negative response of tomato plants.

Incorporating lighting into a production strategy is an economic decision involving added costs versus potential returns. Therefore, the question arises whether different timings of lighting to decrease lighting costs are reflected in an appropriate yield of fruits and in a better energy use efficiency. Different lighting regimes will be considered with respect to the profit margin of the horticultural crop.

The objective of this study was to test if (1) different lighting times and light intensities are affecting growth, yield and quality of tomatoes and the N uptake of the plant, (2) decreasing energy costs by lighting at cheaper times are going along with an appropriate yield, (3) a higher light intensity is converted efficiently into yield and (4) the profit margin can be improved by lighting times and light intensities. This study should enable to strengthen the knowledge on the lighting regime and give vegetable growers advice how to improve their tomato production by modifying the efficiency of electricity consumption in lighting.

3 MATERIALS AND METHODS

3.1 Greenhouse experiment

An experiment with tomatoes (*Lycopersicon esculentum* Mill. cv. Encore) and different lighting times and two light intensities was conducted in four cabinets at the Agricultural University of Iceland at Reykir. Seeds of tomatoes were sown on 09.08.2010 in rock wool plugs. Seedlings were transplanted to rock wool cubes on 20.08.2010. On 13.09.2010 three plants were transplanted in 12 l Bato-buckets filled with pumice stones and transferred to the cabinets with different lighting regimes. Tomatoes were transplanted in rows in four 70 cm high beds (A, B, C, D; Fig. 1) with 2,5 plants/m^2. Beds were equipped with 8 pots, respectively 24 plants. Four replicates, one replicate in each bed consisting of four pots (12 plants) acted as subplots for measurements. Other pots were not measured. Do to the weekly hanging down, all plants were at least once at the end of the bed.

Wires were placed in about 3,56 m height from the floor with each 90 cm distance between floors and beds. Bumblebees were used for pollination and hives were open from 11.00-14.00 (but from 09.00-14.00 from November to end of February for the cabinet that received light during nights and whole weekends).

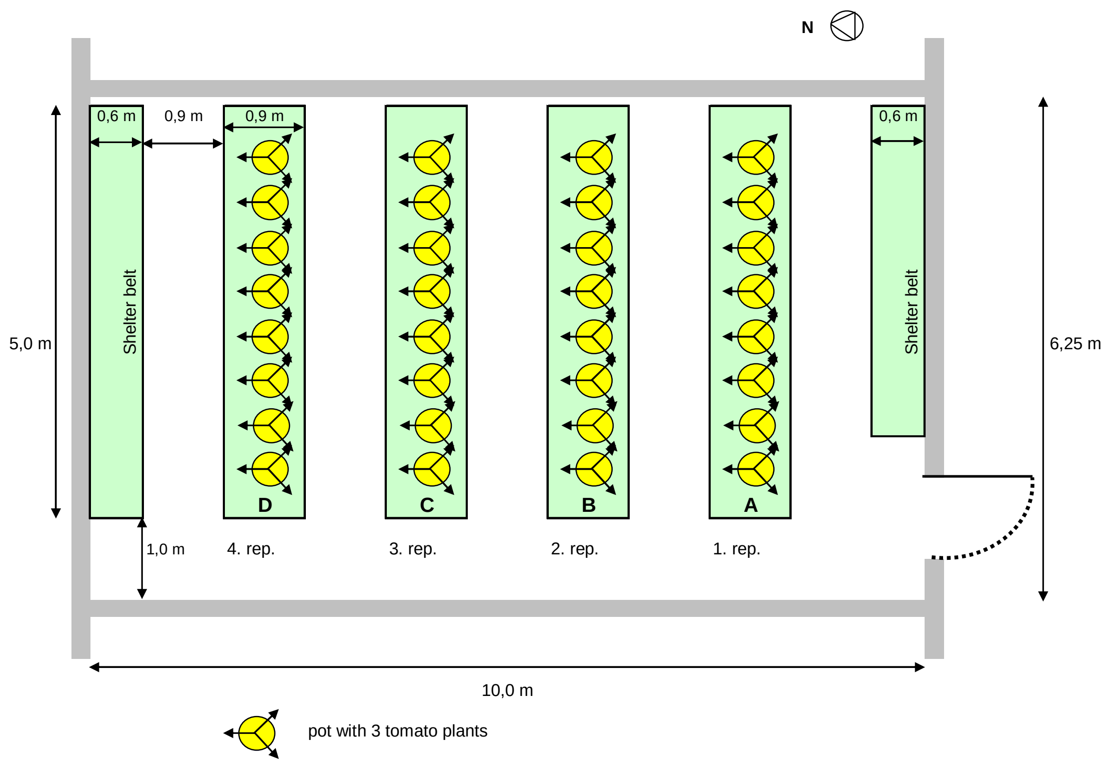


Fig. 1: Experimental design of cabinets.

Temperature was kept at 22-23 ° C / 18-19 ° C (day/night) and ventilation started at 24 ° C. In the cabinet with the highest light intensity, also a higher temperature was chosen (24-25 ° C / 20 ° C (day/night), ventilation with 27 ° C). Carbon dioxide was provided (800 ppm CO_2 with no ventilation and 400 ppm CO_2 with ventilation). A misting system was installed. Plant protection was managed by beneficial organisms and if necessary with insecticides.

Tomatoes received standard nutrition consisting of “Strong vegetable Superex L 540” (Kekkilä) according to the following fertilizer plan (Tab. 1):

Tab. 1: Fertilizer mixture according to advice from Kekkilä.

	Stem solution A (1000 l)						Stem solution B (1000 l)				Irrigation water		Runoff water	
Fertilizer (amount in kg)	Strong vegetable Superex L 540	Potassium nitrate	Potassium sulphate	Magnesium sulphate	Magnesium nitrate	Restart	Calcium nitrate	Nitric acid (57 %)	Potassium nitrate	Potassium chloride	E.C. (mS/cm)	pH	E.C. (mS/cm)	pH
1.-4. week **(after planting)**	50	0	0	50	0	20	128	0	35	7	3,0-4,5	5,4-5,8	4,5-6,0	5,2-6,3
next 2 months	50	25	0	50	0	21	103	0	25	7	2,9-2,6	5,5-6,0	4,5-6,0	5,2-6,3
until 12.01.2011	50	0	0	36	0	20	93	0	38	5	2,4-3,0	5,4-5,8	4,5-6,0	5,2-6,3

On the 12.01.2011 a new fertilizer mixture was applied (Tab. 2):

Tab. 2: New fertilizer mixture according to advice from Magnús Ágústsson.

	Stem solution A (1000 l)				Stem solution B (1000 l)						Irrigation water		Runoff water	
Fertilizer (amount in kg)	Calcium nitrate	Potassium nitrate	Potassium chloride	Iron chelate 6 %	Potassium nitrate	Magnesium sulphate	Strong vegetable Superex L 540	Natrium molybdate	Zinc sulphate	Borax	E.C. (mS/cm)	pH	E.C. (mS/cm)	pH
New mixture	93	25	7	1,2 (l)	25	42	40	4 gr	50 gr	100 gr	2,8		3,8	

Plants were irrigated through drip irrigation (3 tubes per bucket). Irrigation differed in cabinets (Tab. 3).

Tab. 3: Irrigation of tomatoes.

Group	Time of irrigation	Duration between irrigations	Duration of irrigation	Number of irrigations
		min	min	
WATERING IN ALL CABINETS				
13.09.10-23.09.10	Irrigation by hand			
29.09.10-18.10.10	01.00		2.00	1
19.10.10-31.10.10	23.00, 02.30		2.00	2
01.11.10-04.01.11	23.00, 02.30		1.30	2
Watering in cabinet “300 HPS, 04-22”				
24.09.10-28.09.10	05.00-21.05	90	3.00	11
29.09.10-03.09.10	05.00-21.05	60	3.00	17
04.10.10-07.10.10	05.00-21.05	40	2.15	25
08.10.10-31.10.10	05.00-21.05	30	2.00	33
04.02.11-13.02.11	04.00-19.00		1.35	37
14.02.11-16.03.11	10.00-16.30		1.30	14
14.02.11-16.03.11				30-42
Watering during the night				
04.02.11-13.02.11	22.00, 01.00		1.35	2
14.02.11-16.03.11	18.30-07.00		1.35	6
Watering in cabinet “240 HPS, 04-22”				
24.09.10-28.09.10	05.00-21.05	120	3.00	9
29.09.10-03.10.10	05.00-21.05	60	3.00	17
04.10.10-19.10.10	05.00-21.05	45	2.15	22
20.10.10-31.12.10	05.00-21.05	30	1.30-2.15	33
01.01.11-16.03.11				30-42
Watering in cabinet “240 HPS, weekend”				
24.09.10-28.09.10	05.00-21.05	120	3.00	9
29.09.10-03.10.10	05.00-21.05	60	3.00	17
04.10.10-19.10.10	05.00-21.05	45	2.15	22
20.10.10-31.12.10	05.00-21.05	30	1.30-2.15	33
02.11.10-05.02.11	20.30-09.00	40	1.30	23-27
06.02.11-16.03.11	20.30-09.30	30	1.25	27-32
Watering during the day while lighting during night				
01.11.10-03.12.10	10.30-19.30	60	1.30	7-14
04.12.10-01.02.11	10.05-20.00	35	1.20	10-20
02.02.11-01.03.11	10.05-20.00	35	1.25	10-20
Weekends in Nov.	10.00-20.00	60	1.30	5-11

continued from Tab. 3

Group	Time of irrigation	Duration between irrigations	Duration of irrigation	Number of irrigations
		min	min	
Additional watering during the day				
08.02.10-15.02.10	05.00-21.05		1.45	37
16.2.10-16.03.10	05.00-21.05		1.00	14
Watering in “240 HPS, 100 J”				
24.09.10-28.09.10	05.00-09.00	120	3.00	3
29.09.10-03.10.10	05.00-10.00	60	3.00	6
04.10.10-07.10.10	05.00-12.00	60	2.15	8
08.10.10-12.10.10	05.00-12.00	45	2.15	10
13.10.10-18.10.10	05.00-14.30	40	2.15	13
19.10.10-25.10.10	05.00-19.35	40	2.00	22
26.10.10-01.11.10	05.00-19.35	30	2.00	30
02.11.10-16.03.06				30-42
Additional watering during the day				
24.09.10-28.09.10	10.00-19.00	180	3.00	4
29.09.10-03.10.10	11.30-19.00	120	3.00	4
04.10.10-12.10.10	13.00-19.00	90	2.15	4
13.10.10-25.10.10	16.30-19.00	60	2.00	3
26.10.10-01.11.10	21.30		1.45	1

3.2 Lighting regimes

Tomatoes were grown until 16.03.2011 (10.02.2011 for the cabinet with the highest light intensity) under high-pressure sodium lamps (HPS) for top lighting at four different lighting regimes with different timings of light, each in one cabinet:

1. HPS top lighting 240 W/m^2
   - Light from 04.00-22.00

   240 HPS, 04-22

2. HPS top lighting 240 W/m^2
   - September, October, March: light from 04.00-22.00
   - November, December, January, February: light from 20.00-10.00, weekends

   240 HPS, weekend

3. HPS top lighting 240 W/m^2
   - natural light + top lighting 240 W/m^2 (daily-integral 100 J/cm^2/plant + 100 J/cm^2/cluster)

   240 HPS, 100 J

4. HPS top lighting 300 W/m^2
   - Light from 04.00-22.00

   300 HPS, 04-22

HPS lamps for top lighting (600 W bulbs) were mounted horizontally over the canopy. Light (240 W/m^2) was provided from 04.00-22.00 for 18 hours (1), but from 01.11-01.03 one cabinet was lightened at nights and weekends for 16,86 hours in average (2.). One cabinet received a daily integral of 100 J/cm^2/plant and in addition per cluster 100 J/cm^2 with 240 W/m^2 supplemental light and natural light (3). For the highest light intensity (300 W/m^2) a higher temperature was chosen (4), because the optimal temperature is increasing with light intensity (*Dorais*, 2003). The lamps were automatically turned off when incoming illuminance was above the desired set-point.

3.3 Measurements, sampling and analyses

Soil temperature was measured once a week and air temperature and irradiation (subdivided between vertical and horizontal irradiation) manually monthly at different vertical heights above ground (0 m, 0,5 m, 1,0 m, 1,5 m, 2,0 m) close to the plant under diffuse light conditions.

The amount of fertilization water (input and runoff) was measured every day and once a month the nitrate-N and ammonium-N of the applied water was analyzed with a Perkin Elmer FIAS 400 combined with a Perkin Elmer Lambda 25 UV/VIS Spectrometer.

To be able to determine plant development, the height of plants was measured each week and the number of clusters was counted.

Yield (fresh and dry biomass) of seedlings and their N content was analyzed. During the growth period, fruits were regularly collected (2-3 times per week) in the subplots. Total fresh yield, number of fruits, fruit category (A-class (> 55 mm), B-class (45-55 mm) and not marketable fruits (too little fruits (< 45 mm), fruits with blossom end rot) was determined. Additional samplings included samples from pruning during the growth period. From the 10.02.2011 onwards one or more fruits per cluster were frozen and number of seeds (divided into big and small seeds) were counted. At the end of the growth period (middle of March, but middle of February for the highest light intensity) on each plant from the subplots the number of immature fruits was counted. The aboveground biomass of these plants was harvested and divided into immature green fruits and shoots. For all plant parts, fresh biomass weight was determined and subsamples (three times for stripped leaves, fruits) were dried at 105 ° C for 24 h for total dry matter yield (DM). Dry samples were milled and N content was analyzed according to the DUMAS method (varioMax CN, Macro Elementar Analyser, ELEMENTAR ANALYSENSYSTEME GmbH, Hanau, Germany) to be able to determine N uptake from tomatoes.

The interior quality of fruits was determined. A brix meter (Pocket Refractometer PAL-1, ATAGO, Tokyo, Japan) was used to measure sugar content in fruits at the beginning, in the middle and at the end of the growth period. From the same harvest, the flavour of fresh fruits was examined in tasting experiments with untrained assessors.

Composite soil samples for analysis of nitrate-N and ammonium-N were taken from buckets at the end of the growth period. After sampling, soil samples were kept frozen. The soil was measured for nitrate (1,6 M KCl) and ammonium (2 M KCl) with a Perkin Elmer FIAS 400 combined with a Perkin Elmer Lambda 25 UV/VIS Spectrometer.

Energy use efficiency (total cumulative yield in weight per kWh) and costs for lighting per kg yield were calculated for economic evaluation of the lighting regimes.

3.4 Statistical analyses

SAS Version 9.1 was used for statistical evaluations. The results were subjected to one-way analyses of variance with the significance of the means tested with a Tukey/Kramer HSD-test at $p \leq 0,05$. Due to the earlier harvest of the cabinet with the highest light intensity, only results from the other cabinets are used for statistical analyses.

4 RESULTS

4.1 Environmental conditions for growing

4.1.1 Solar irradiation

Solar irradiation was allowed to come into the greenhouse. Therefore, incoming solar irradiation is affecting plant development and was regularly measured. The natural light level decreased after transplanting into the cabinets continuously to < 5 kWh/m^2 and was staying at this value to the middle of February 2011. However, with longer days solar irradiation increased naturally continuously to > 10 kWh/m^2 at the middle of March 2011 (Fig. 2).

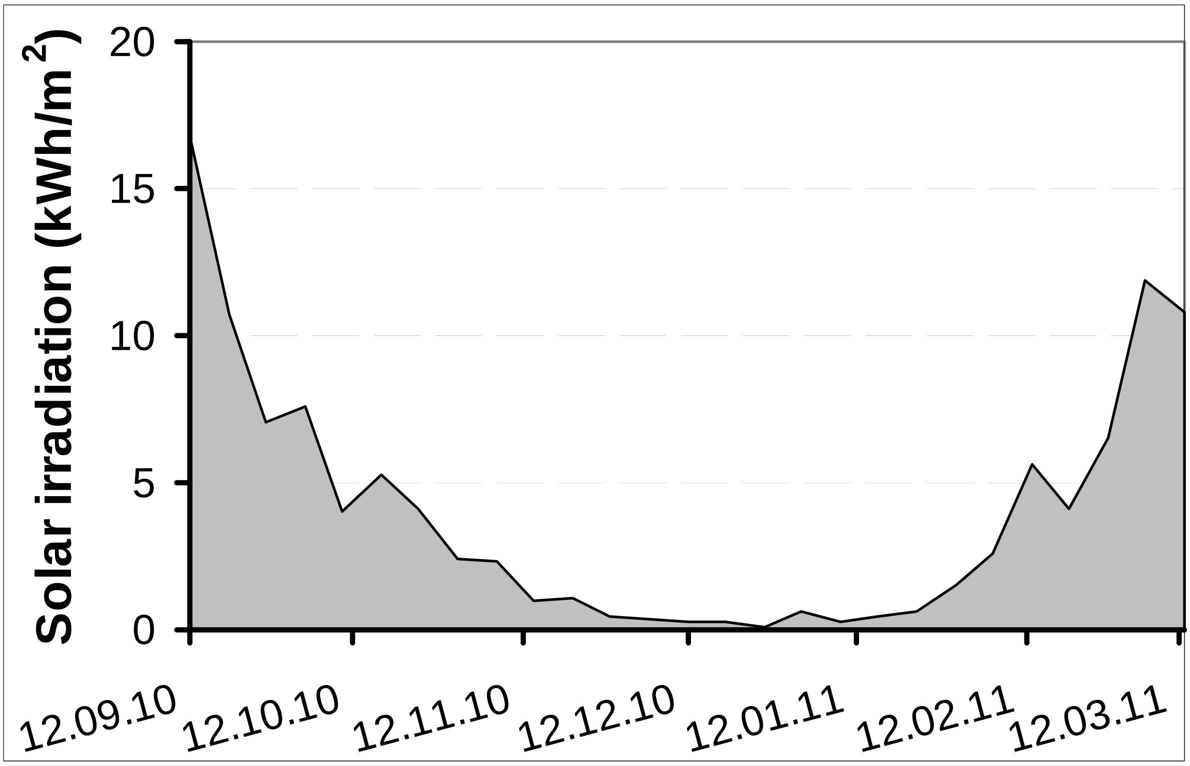


Fig. 2: Time course of solar irradiation. Solar irradiation was measured every day and values for one week were cumulated.

4.1.2 Illuminance and air temperature

Illuminance is the total luminous flux incident on a surface, per unit area. In the case of the tomato experiment solar irradiation was allowed to come into the greenhouse and therefore, illuminance and air temperature is composed of solar irradiation and irradiation of HPS lamps and adjusted air temperature in the cabinets and heat of HPS lamps. To eliminate the incoming solar radiation and the outside temperature, illuminance and air temperature were measured early in the morning during cloudy days.

The measured values for illuminance and air temperature are converted into colours (red for high illuminance / air temperature, yellow and white for low illuminance / air temperature). Naturally, with higher light intensity, illuminance and air temperature rose. Highest values were measured close to the lamps (Fig. 3).

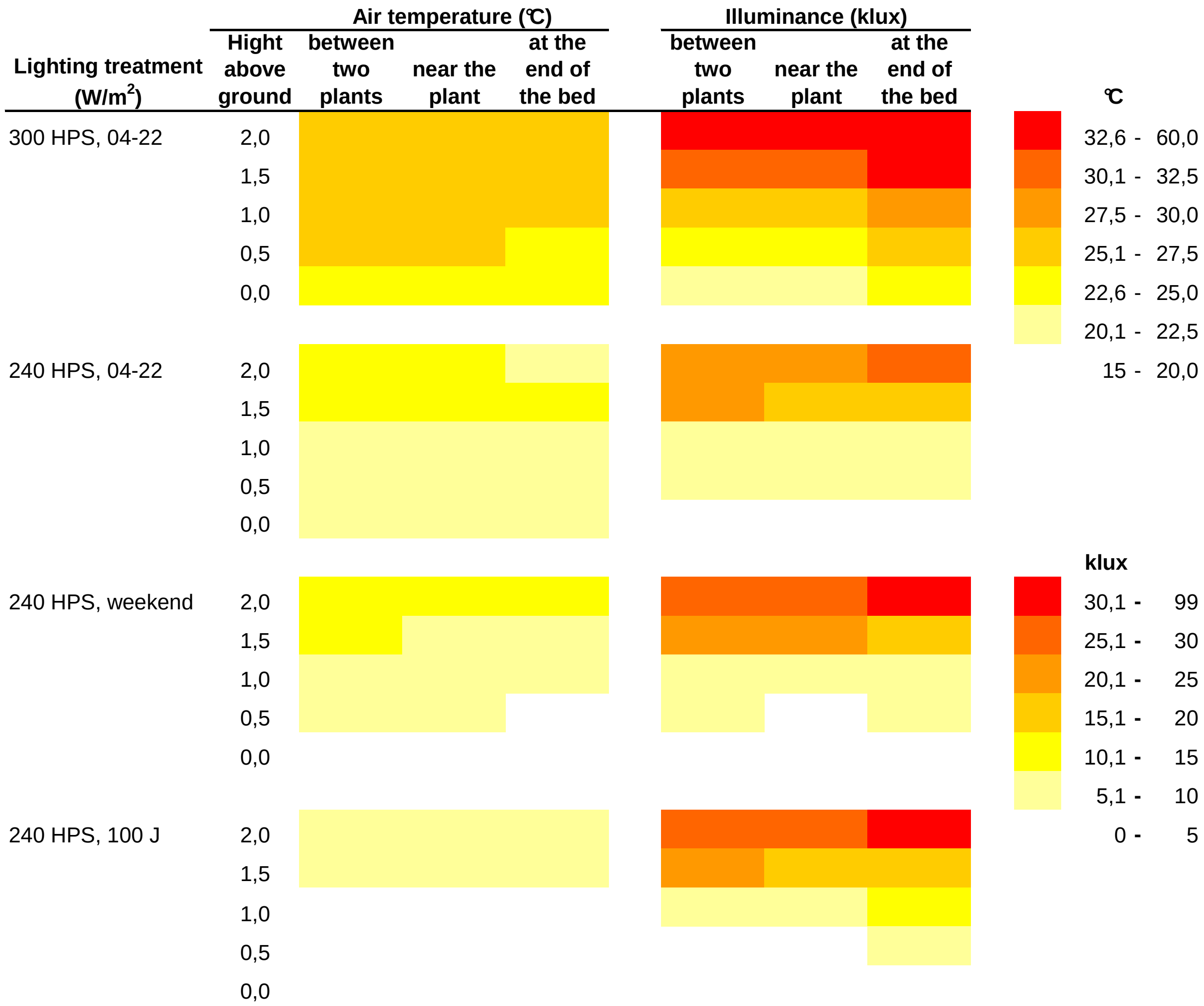


Fig. 3: Illuminance (solar + HPS lamps) and air temperature at different lighting regimes. Illuminance and air temperature was measured early in the morning at a cloudy day.

4.1.3 Soil temperature

Soil temperature was measured weekly at low solar radiation early in the morning (at about 8.30) and was mainly influenced by the lighting regime. Soil temperature stayed most of the time between 21-26 °C (Fig. 4). Naturally, the soil temperature of the highest light intensity “300 HPS, 04-22” was most of the time highest. “240 HPS, 04-22” and “240 HPS, 100 J” were comparable. Compared to that, the temperature of “240 HPS, weekend” was higher during the time plants were lightened during nights and weekends.

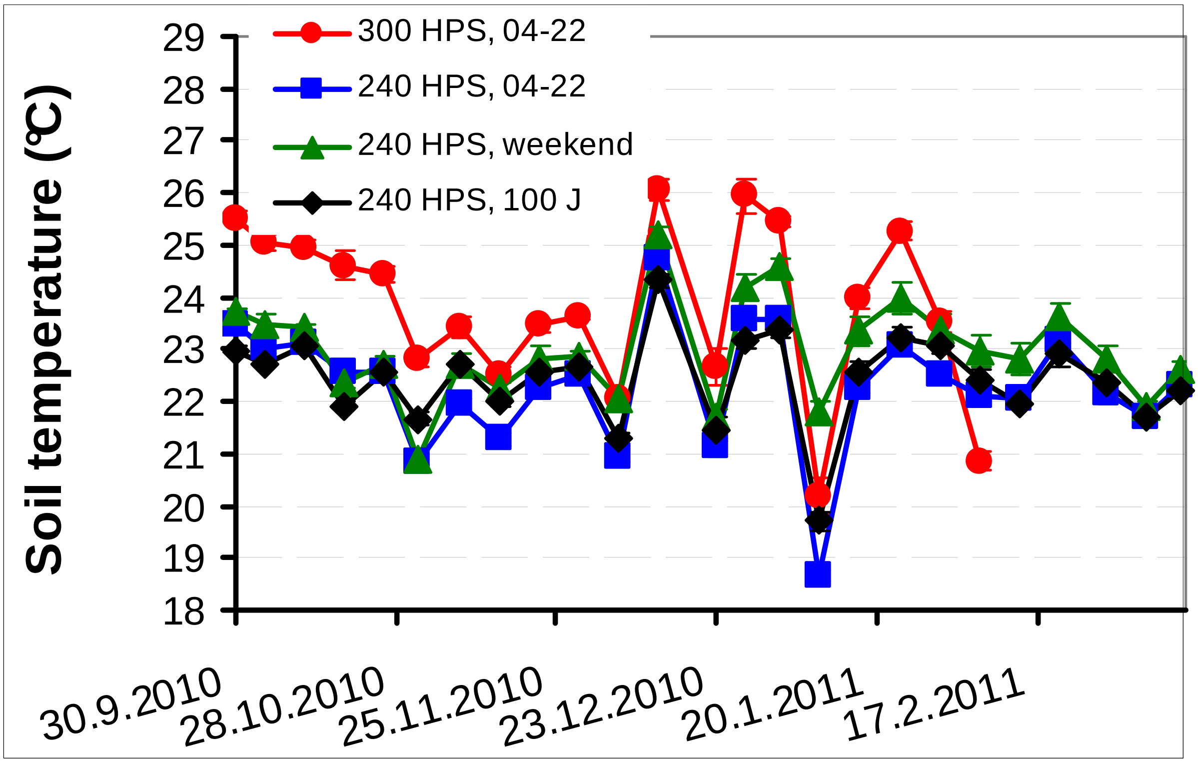


Fig. 4: Soil temperature at different lighting regimes. The soil temperature was measured at little solar irradiation early in the morning.

Error bars indicate standard deviations and are contained within the symbol if not indicated.

4.1.4 Irrigation of tomatoes

At the end of 2010 tomato plants showed zinc (Zn) deficiency, which was confirmed through leaf analyses. Zinc deficiency occurred because of high pH (more than 6 in runoff water, see Fig. 5). If pH is too high, zinc, iron and cooper are less available. Also, a high phosphor content can decrease uptake of Zn. Therefore, it was decided to chance the fertilizer mixture (Tab. 4) and shorten the growth period of the cabinet with the highest light intensity.

E.C. and pH of irrigation water was fluctuating much (Fig. 5 a, b). E.C. of applied water ranged between 2,2 and 3,4 and pH between 5,6 and 6,6. E.C. of runoff increased during the growth period from 2,5 to 6 and pH between 5,5-7 (Fig. 5 c, d).

The amount of runoff from applied irrigation water was about 10-50 % (Fig. 6).

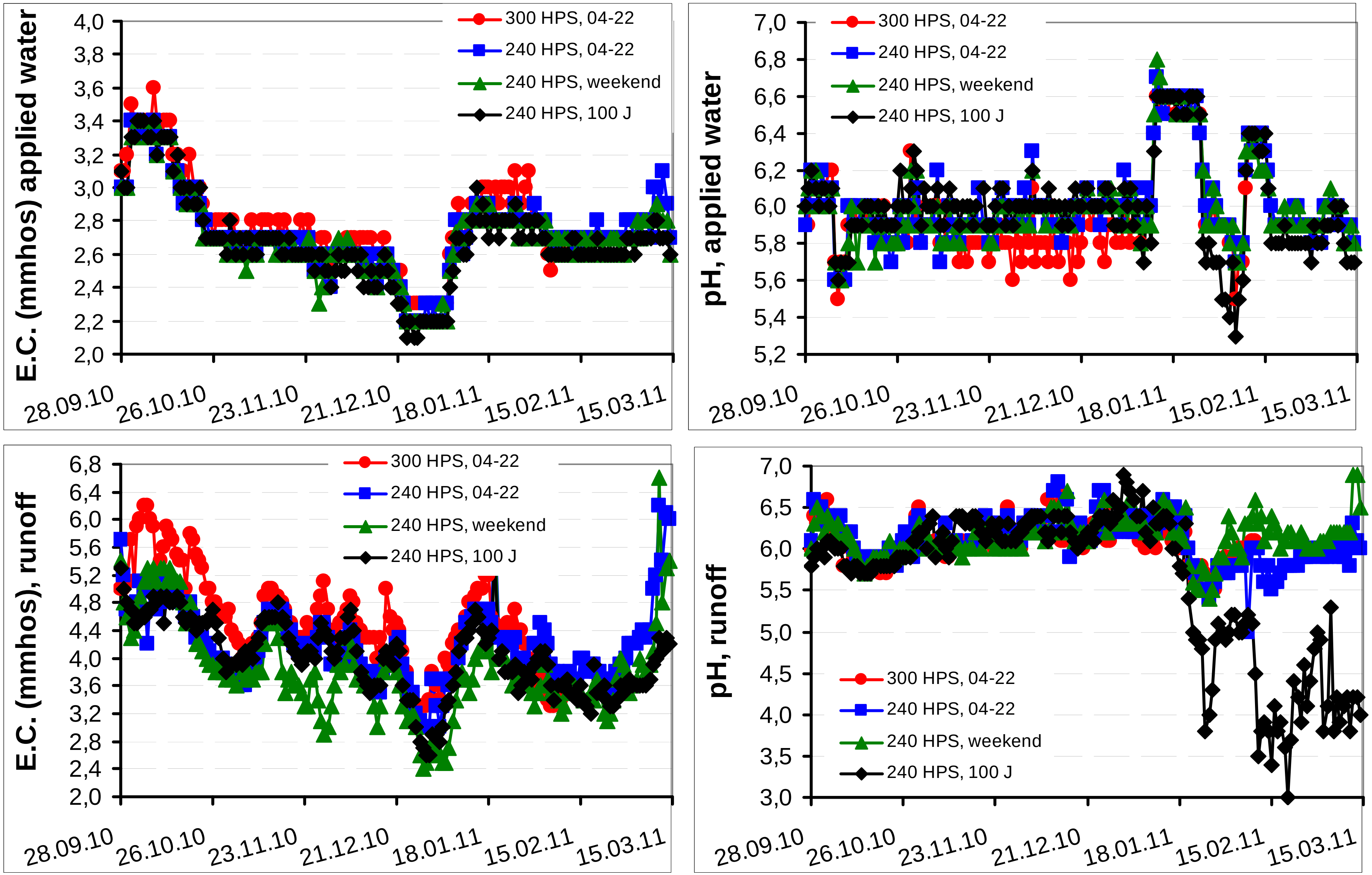


Fig. 5: **E.C. (a, c) and pH (b, d) of irrigation water (a, b) and runoff of irrigation water (c, d).**

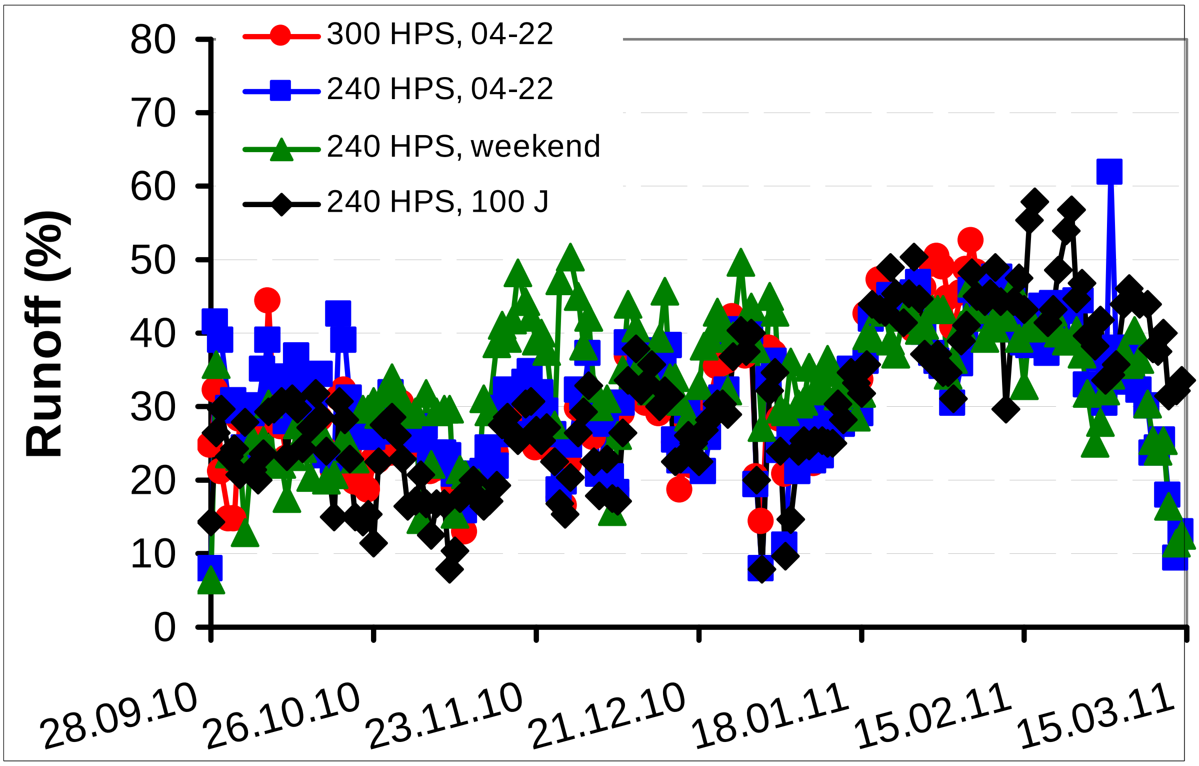


Fig. 6: **Proportion of amount of runoff from applied irrigation water at different lighting regimes.**

Plants took up between 2 and 4,5 l/m^2 with less differences between lighting regimes (Fig. 7).

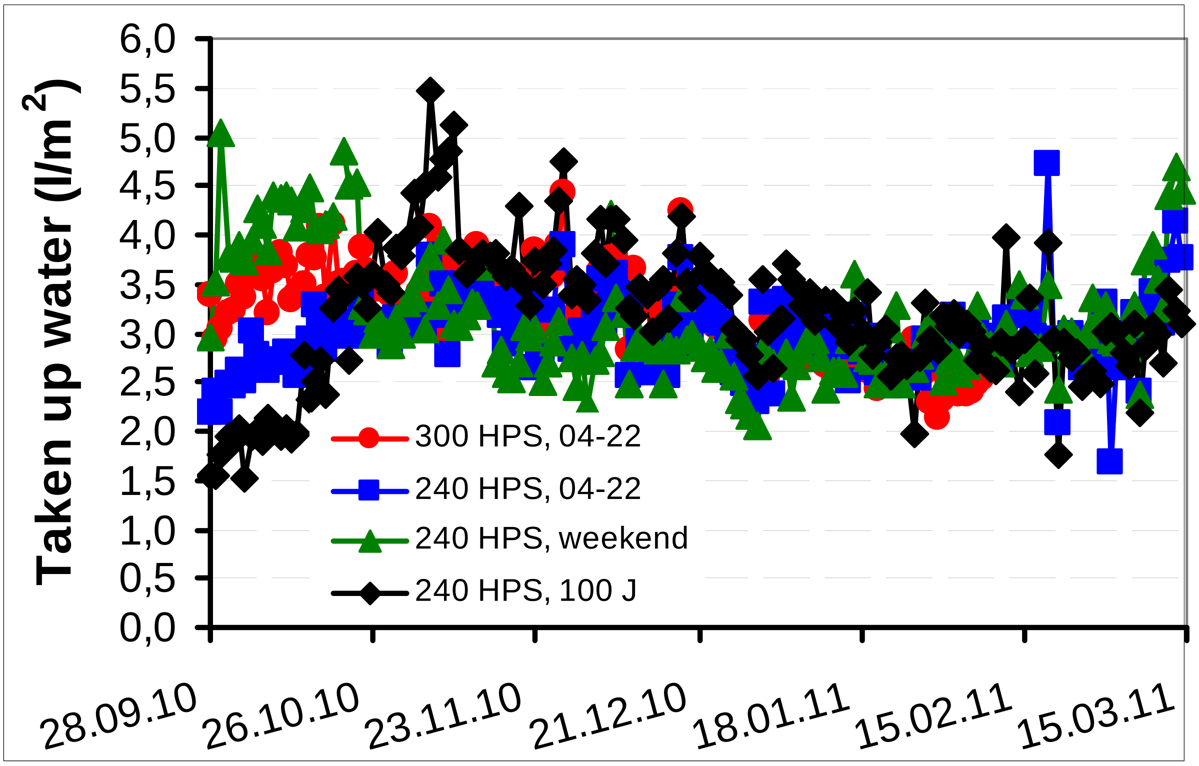


Fig. 7: **Water uptake at different lighting regimes.**

4.2 Development of tomatoes

4.2.1 Height

Tomato plants were growing about 3 to 4 cm per day and reached at the end of the experiment heights from about 7 m (Fig. 8).

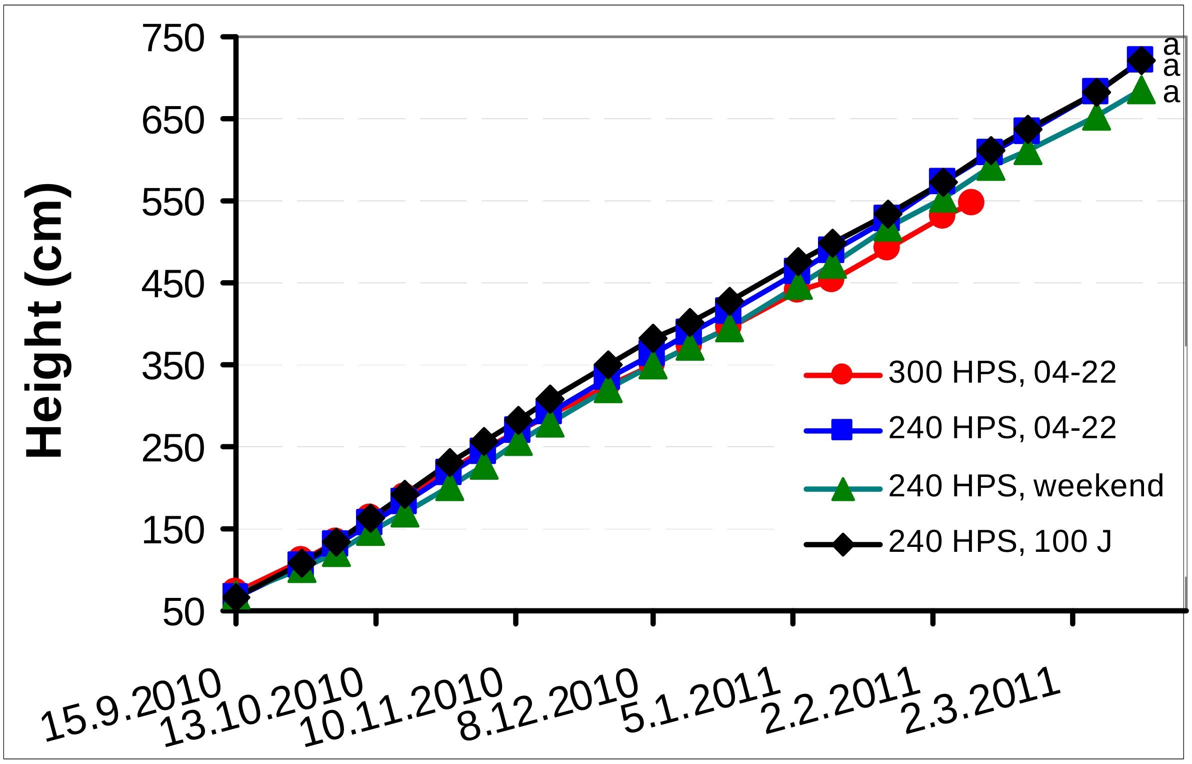


Fig. 8: Height of tomatoes at different lighting regimes.
Error bars indicate standard deviations and are contained within the symbol if not indicated.
Letters indicate significant differences at the end of the experiment (HSD, $p \leq 0,05$).

4.2.2 Number of clusters

The number of clusters increased with approximately one additional cluster per week. No differences between lighting regimes were found (Fig. 9).

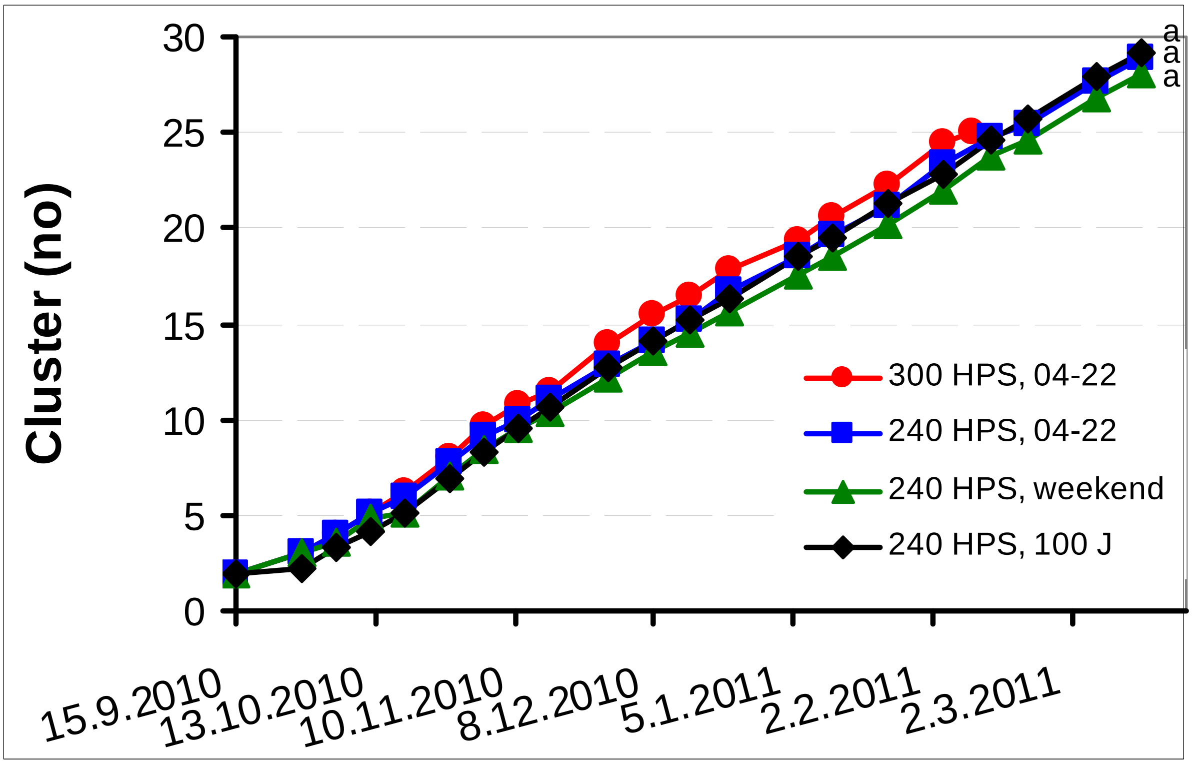


Fig. 9: Number of clusters at different lighting regimes.
Letters indicate significant differences at the end of the experiment (HSD, $p \leq 0,05$).

4.2.3 Distance between internodes

The distance between internodes was regularly measured and was fluctuating much. The distance increased from about 20 cm (October to December) to about 35 cm (January, February) and decreased then again to about 20 cm (March). It seems that the distance between internodes was decreased with a higher light intensity (Fig. 10). In average, the distance between internodes of "300 HPS, 04-22" amounted 3-4 cm less compared to the lower light intensity.

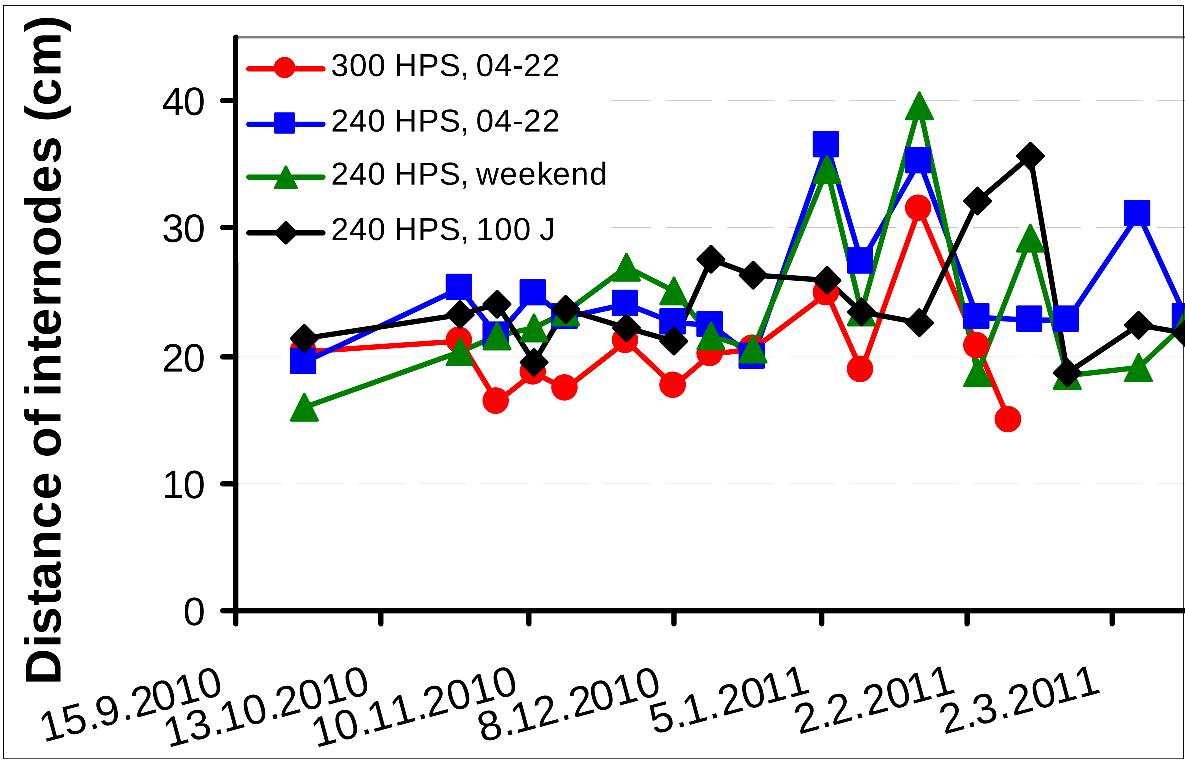


Fig. 10: Average distance between internodes at different lighting regimes.

4.3 Yield

4.3.1 Total yield of fruits

The yield of tomatoes included all harvested red fruits at the end of the growth period. The fruits were classified in 1. class (> 55 mm), 2. class (45-55 mm) and not marketable fruits (too little fruits (< 45 mm), fruits with blossom end rot, flawed, cracked and not well shaped fruits).

Cumulative total yield of tomatoes ranged between 28-35 kg/m^2 (Fig. 11). Abnormal lighting times (nights, whole weekends) during November until end of February reduced total yield significantly, whereas lighting depending on the number of clusters and natural irradiation did not affect total yield (Fig. 11).

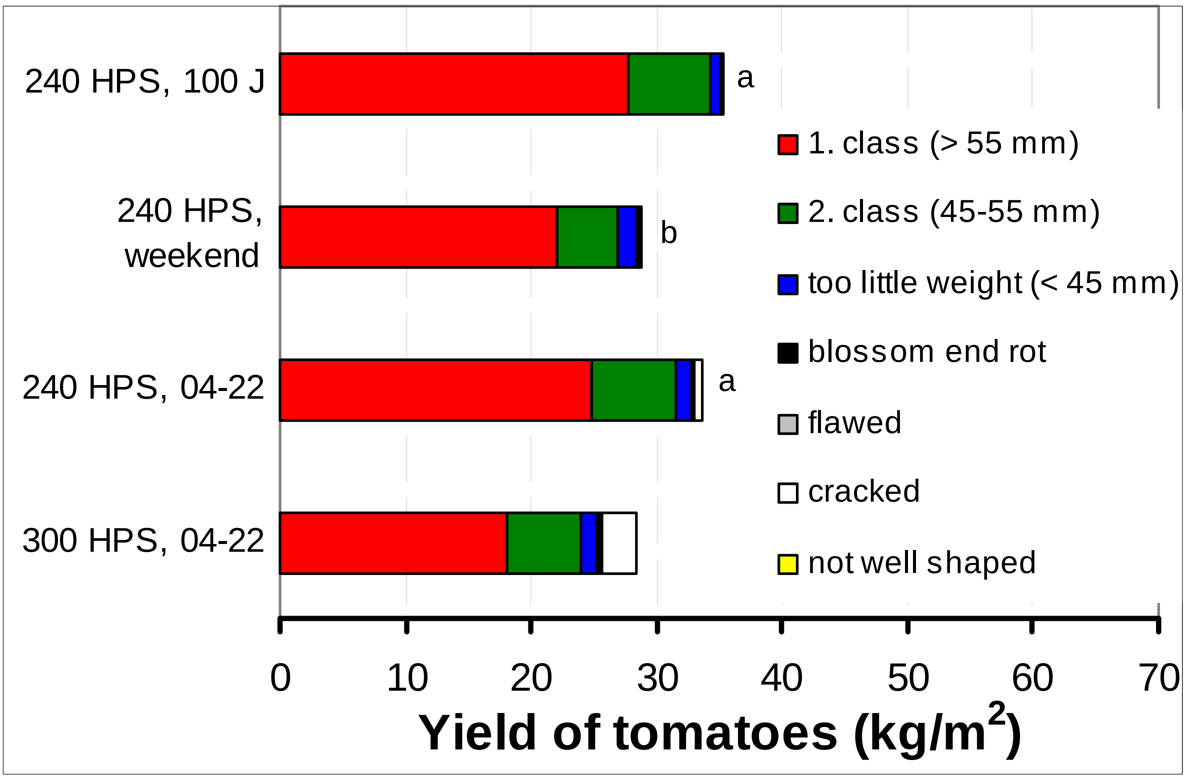


Fig. 11: Cumulative total yield at different lighting regimes.
Letters indicate significant differences at the end of the harvest period (HSD, $p \leq 0{,}05$).

4.3.2 Marketable yield of fruits

Marketable yield of tomatoes differed depending on the lighting regime (Fig. 12). The significantly highest yield was obtained with the lowest amount of light (240 HPS, 100 J). Light was provided in all cabinets from 04.00-22.00, but lighting time differed between cabinets from the beginning of November to the end of February. The lighting time influenced marketable yield. Light during nights and weekends decreased yield significantly compared to the normal lighting time. While yield of “240 HPS, 04-22” and “240 HPS, weekend” was comparable until the third week of November, the yield advantage of light at normal lighting times was after that becoming obvious and at the middle of March yield was up to 14 % decreased when light was provided from November until end of February during nights and weekends. A higher light intensity (300 HPS, 04-22) resulted in an earlier yield, while plants at “240 HPS, 100 J” were one week later harvestable.

Weekly harvest of first class fruits increased until the end of November to 2-3 kg/m^2, but decreased thereafter continuously and reached about 1 kg/m^2 at the middle of January and stayed until middle of March at about this value (Fig. 13).

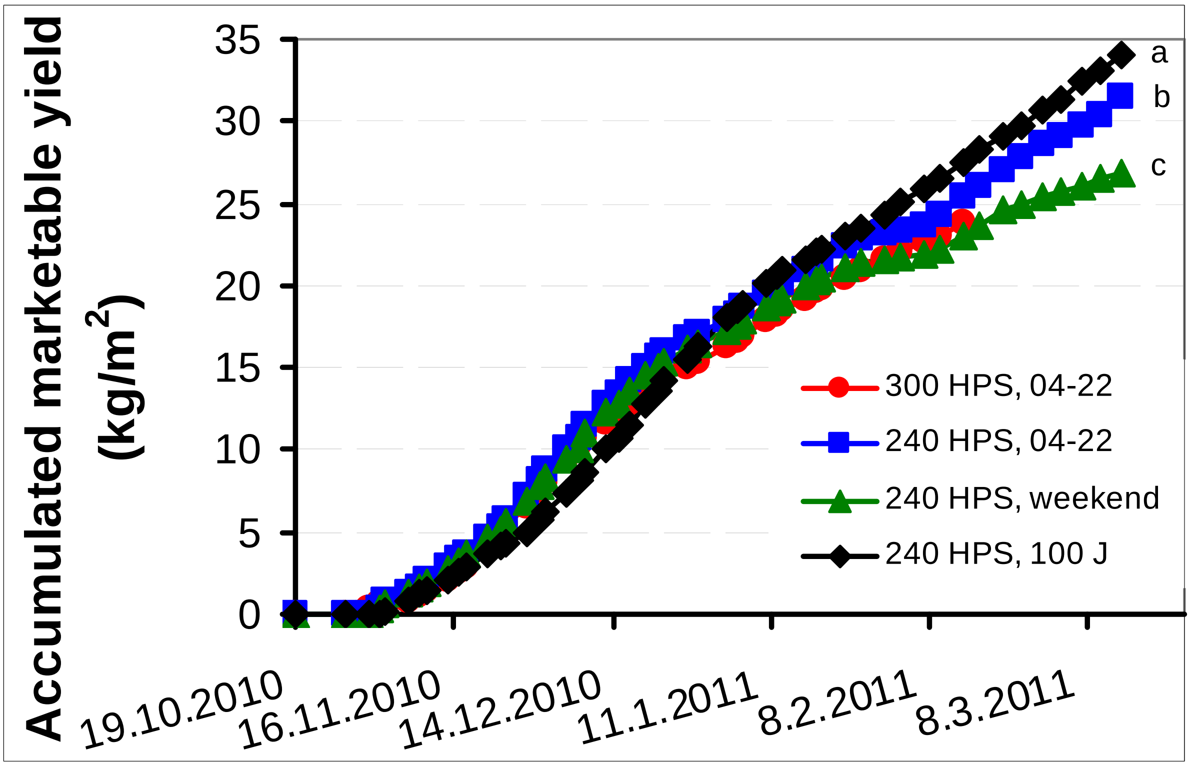


Fig. 12: **Time course of accumulated marketable yield (1. and 2. class fruits) at different lighting regimes.**

Letters indicate significant differences at the end of the harvest period (HSD, $p \leq 0,05$).

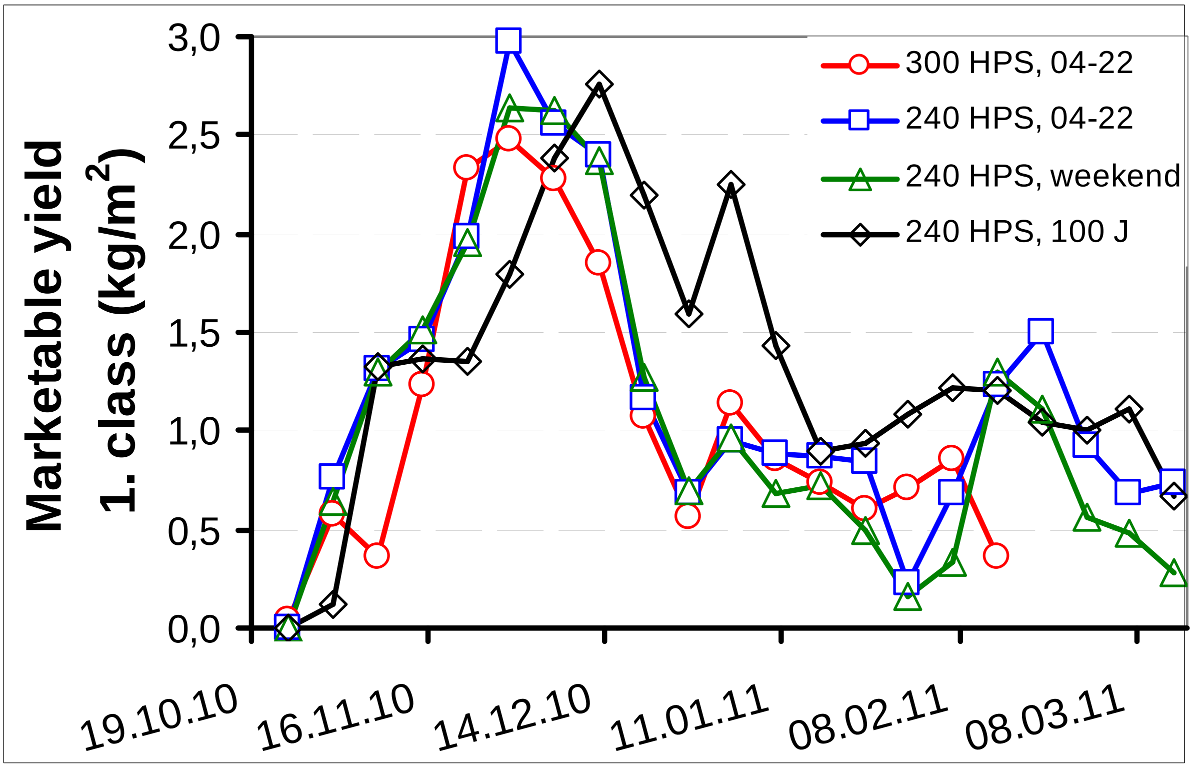


Fig. 13: **Time course of marketable yield at different lighting regimes.**

Number of marketable fruits was highest at “240 HPS, 100 J” (Tab. 4). Not common lighting times (during nights, weekends) decreased significantly number of marketable yield compared to the normal lighting time.

Tab. 4: Cumulative total number of marketable fruits at different lighting regimes.

Lighting regime	**Number of marketable fruits**	
	1. class	2. class
300 HPS, 04-22	197	89
240 HPS, 04-22	262 b	103 a
240 HPS, weekend	224 c	74 b
240 HPS, 100 J	295 a	98 a

Letters indicate significant differences at the end of the harvest period (HSD, p ≤ 0,05).

Average fruit size of first class tomatoes was varying between 80-115 g / fruit (Fig. 14). A high light intensity (300 HPS, 04-22) seems to decrease the average weight of first class tomatoes. It seems that “240 HPS, weekend” had bigger fruits.

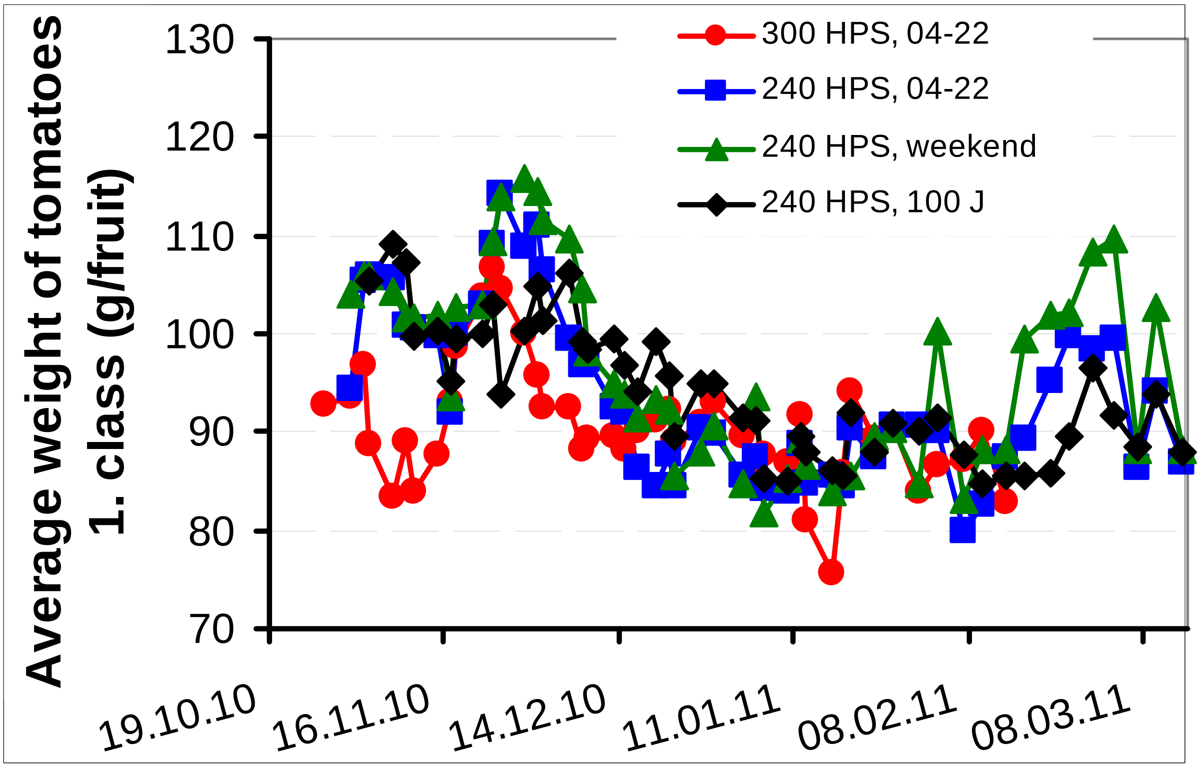


Fig. 14: Average weight of tomatoes (1. class fruits) at different lighting regimes.

4.3.3 Seeds

Heavier fruits had a higher number of seeds (Fig. 15 a, b). It seems that “240 HPS, 100 J” had a higher number of big as well as big and small seeds together.

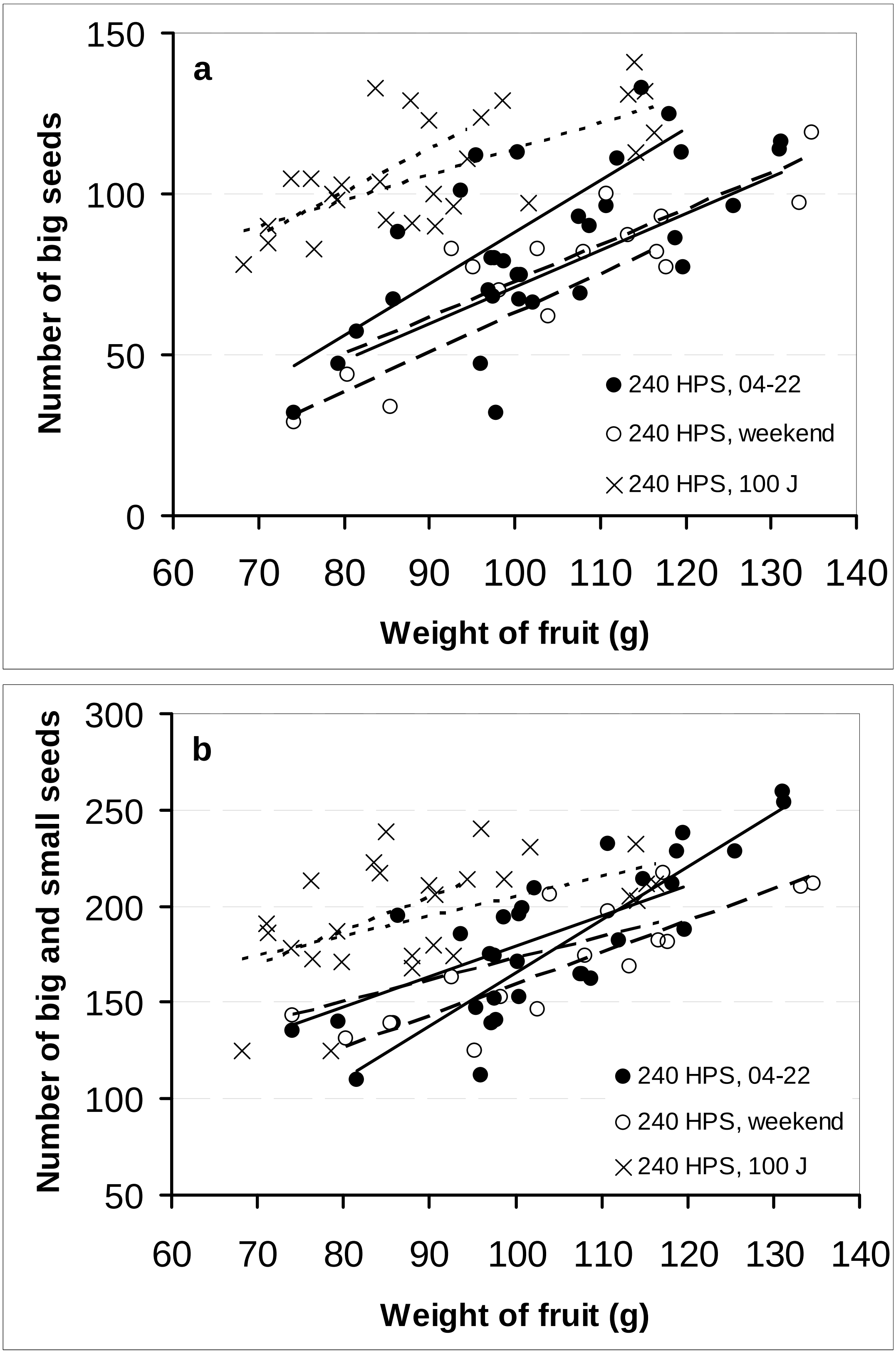
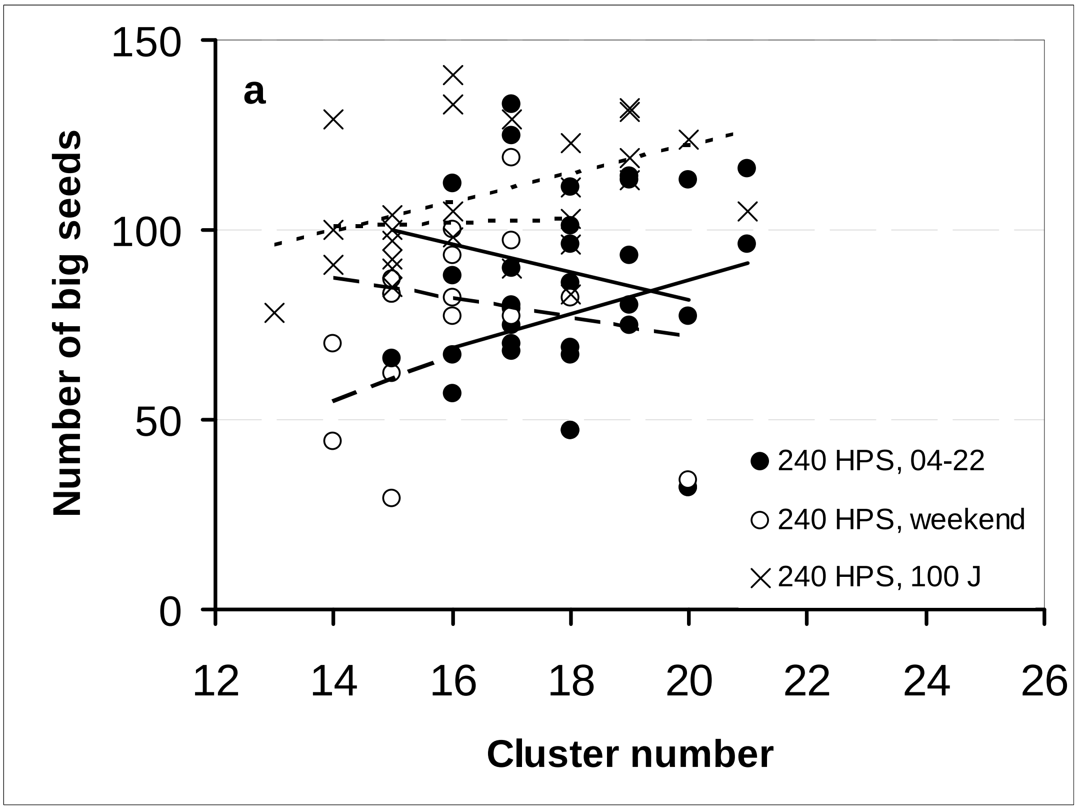


Fig. 15: Relationship between number of big seeds and big and small seeds together and weight of fruits at different lighting regimes.

It seems that a higher cluster number showed a slightly higher number of seeds in "240 HPS, 100 J", but this was not obvious in the other treatments (Fig. 16 a, b).



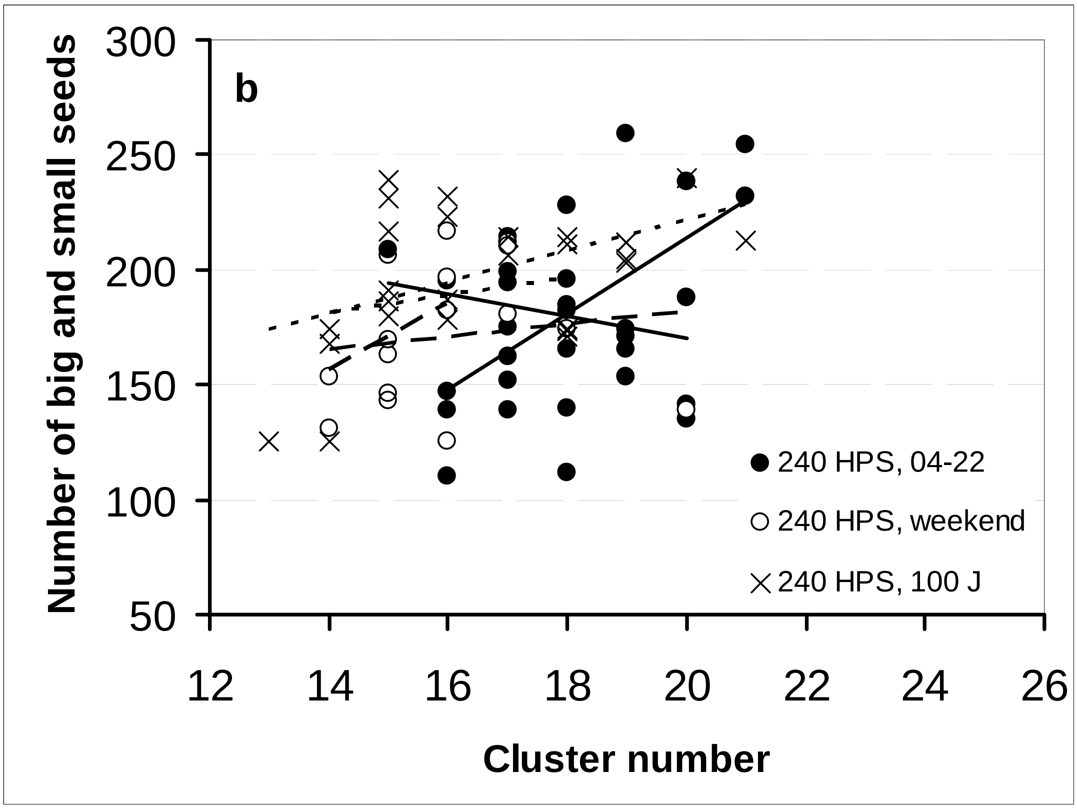
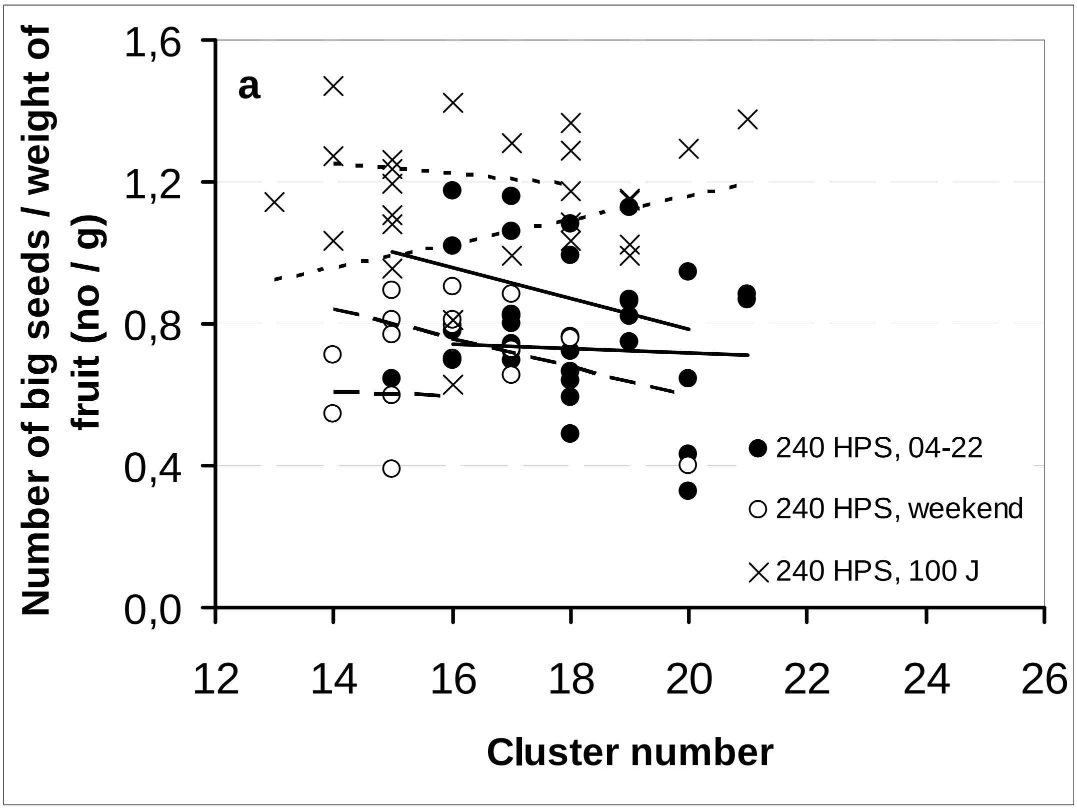


Fig. 16: Relationship between number of big seeds and big and small seeds together and cluster number at different lighting regimes.

No relationship could be found between the cluster number and the number of seeds divided through the weight of the fruit (Fig. 17 a, b).



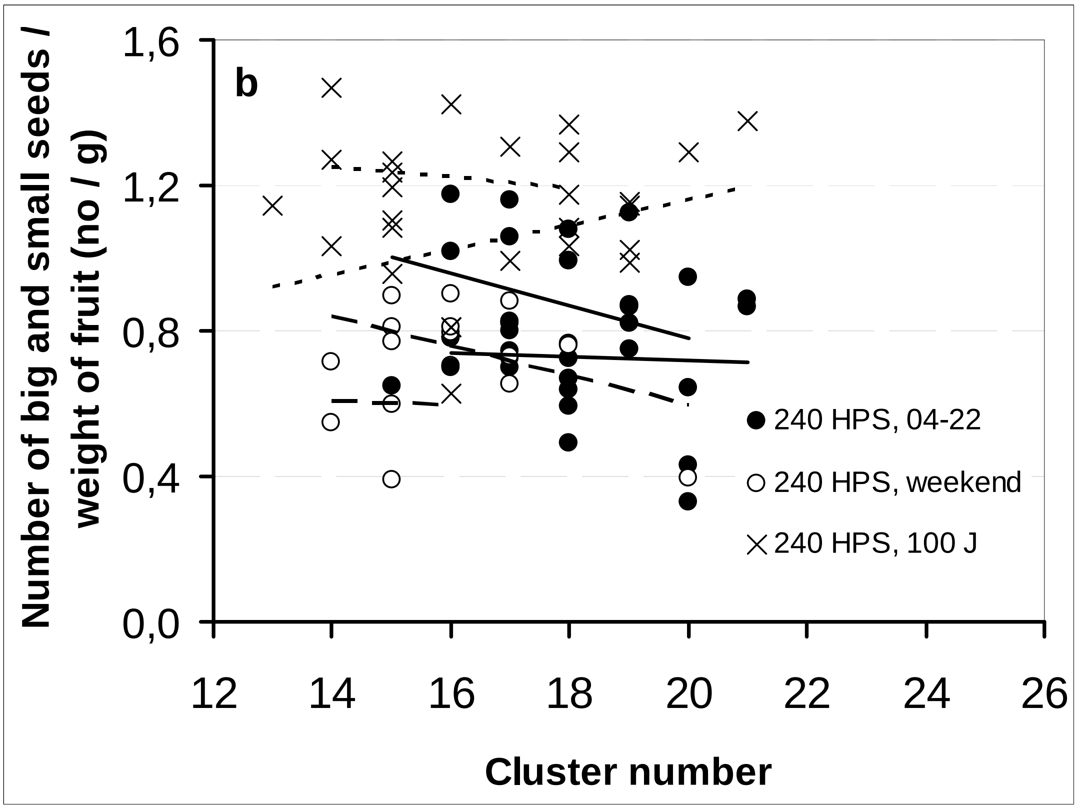


Fig. 17: Relationship between cluster number and number of big seeds and big and small seeds together divided through the weight of the fruit at different lighting regimes.

4.3.4 Outer quality of yield

Marketable yield was about 94-97 %. However, with “300 HPS, 04-22” marketable yield amounted 85 % of total yield, because a high amount of cracked fruits was detected. Also, the number of fruits with blossom end rot seems to be increased. This seems to be also the case for the treatment with light during nights and weekends (Tab. 5).

Tab. 5: Proportion of marketable and unmarketable yield at different lighting regimes.

Lighting regime	Marketable yield		Unmarketable yield				
	1. class	2. class	too little weight	blossom end rot	flawed	cracked	not well shaped
300 HPS, 04-22	64	21	4	1	1	9	0
240 HPS, 04-22	74	20	4	0	1	1	0
240 HPS, weekend	77	17	4	1	0	1	0
240 HPS, 100 J	79	18	3	0	0	0	0

4.3.5 Interior quality of yield

4.3.5.1 Sugar content

Sugar content of tomatoes was measured three times during the harvest period and varied between 3,7 and 4,5. It seems that sugar content decreased with longer growing period when the last sampling date from “240 HPS, weekend” is excluded (Fig. 18). No significant differences between lighting regimes were observed, except for the last sampling date.

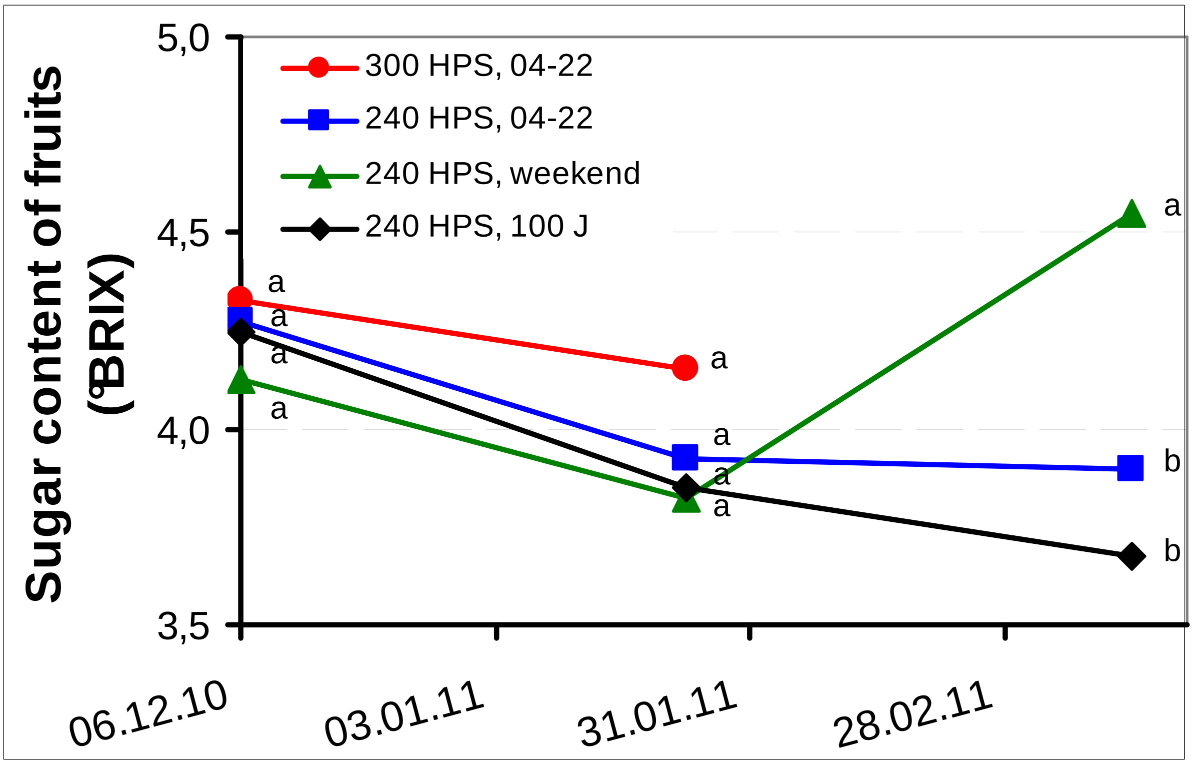


Fig. 18: Sugar content of fruits at different lighting regimes.

Letters indicate significant differences (HSD, $p \leq 0{,}05$).

4.3.5.2 Taste of fruits

The taste of tomatoes, subdivided into sweetness, flavour and juiciness was tested by untrained assessors at the beginning (07.12.2010), middle (25.01.2011) and at the end (15.03.2011) of the harvest period. Mainly, no differences in taste, sweetness, flavour and juiciness of tomatoes were found between different lighting regimes (data not shown). The rating within the same sample was varying very much and therefore, same treatments resulted in a high standard deviation. However, it seems that in the January testing was less juice in “240 HPS, weekend”. There was no relationship between measured sugar content and sweetness of fruits at all tasting dates (data not shown).

4.3.5.3 Dry substance of fruits

Dry substance (DS) of fruits was measured three times during the harvest period. DS stayed stable during the harvest period and varied between 4,5 and 5 %. It seems that a higher light intensity caused a tendentially higher dry substance, while a lower amount of light resulted in a tendentially lower value (Fig. 19).

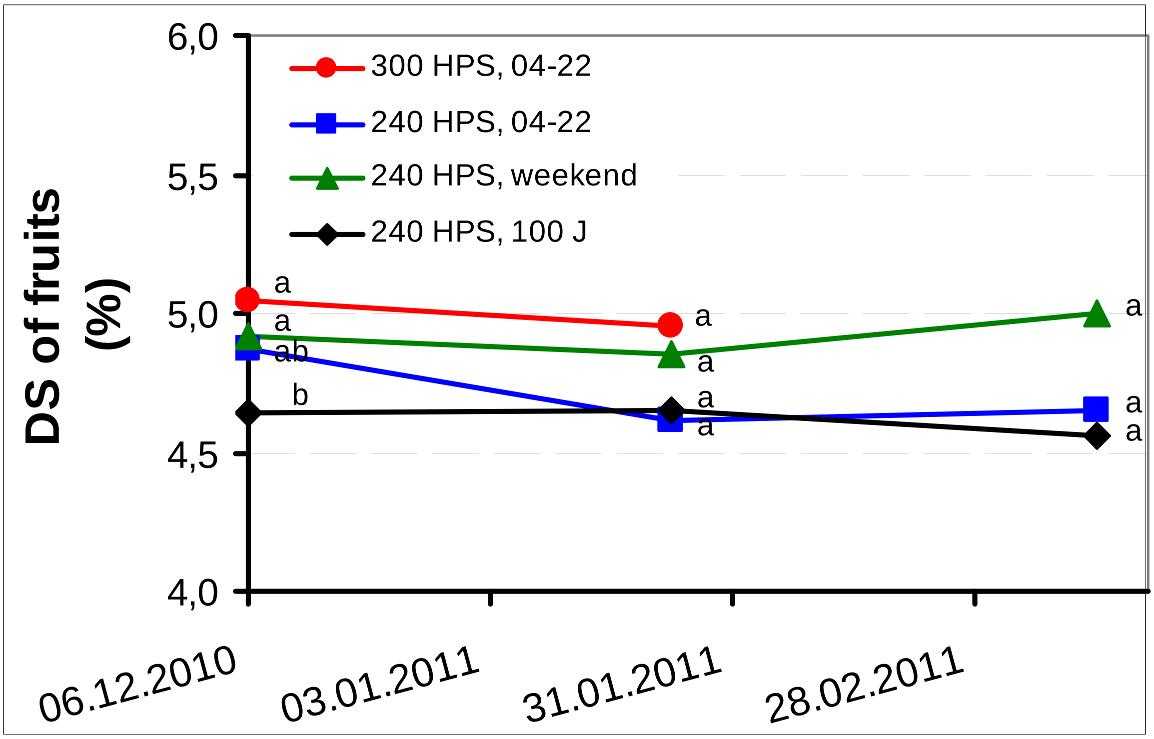


Fig. 19: Dry substance of fruits at different lighting regimes.
Letters indicate significant differences (HSD, p ≤ 0,05).

4.3.5.4 Nitrogen content of fruits

N content of fruits was measured three times during the harvest period and varied between 1,8-2,3 % with nearly no differences between treatments (Fig. 20).

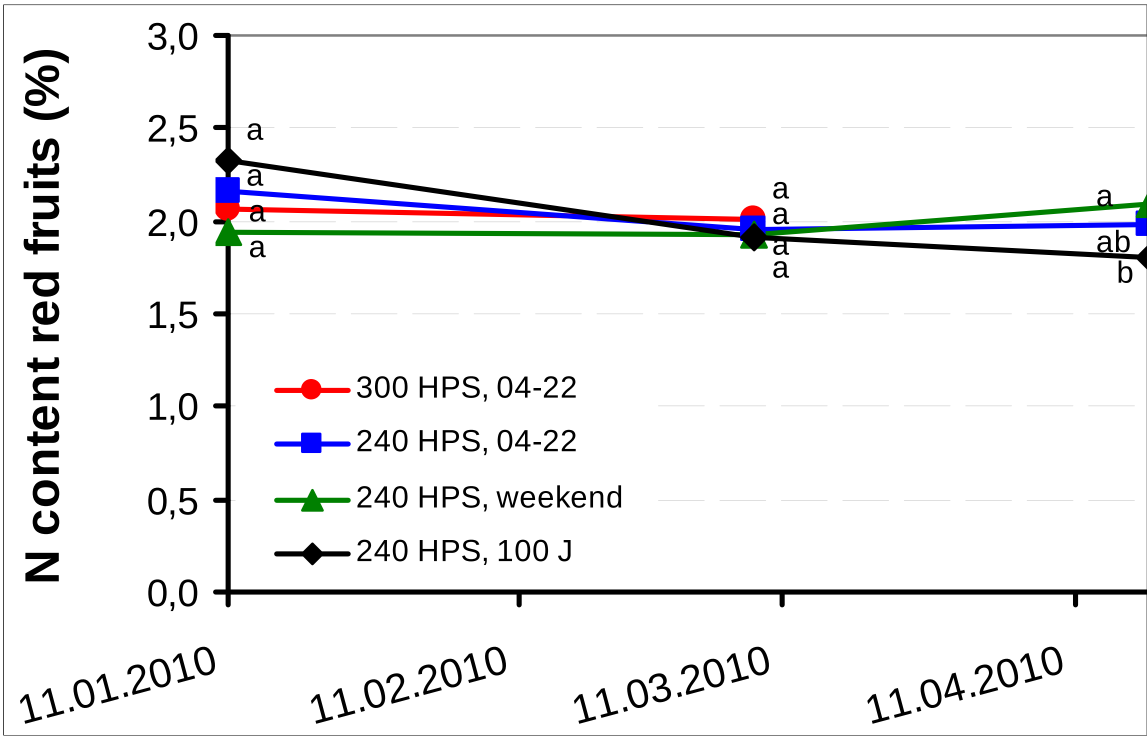


Fig. 20: N content of fruits at different lighting regimes.
Letters indicate significant differences (HSD, p ≤ 0,05).

4.3.6 Dry matter yield of stripped leaves

During the growth period, leaves were regularly taken off the plant and the cumulative DM yield of these leaves was determined. No significant differences between lighting regimes were detected (Fig. 21).

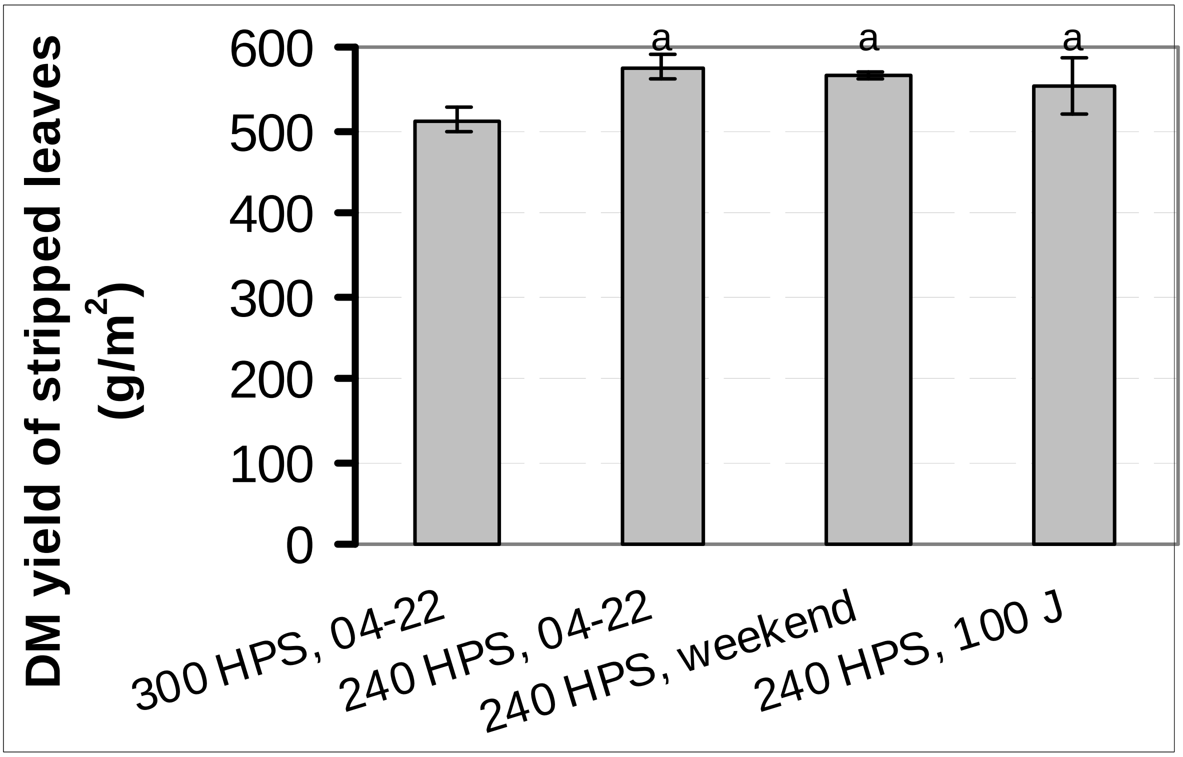


Fig. 21: Dry matter yield of stripped leaves at different lighting regimes.

Error bars indicate standard deviations and are contained within the symbol if not indicated.
Letters indicate significant differences at the end of the harvest period (HSD, $p \leq 0{,}05$).

4.3.7 Cumulative dry matter yield

The cumulative DM yield included all harvested red fruits, the immature fruits at the end of the growth period, the stripped leaves during the growth period and the shoots. The cumulative DM yield was independent of the lighting regime (Fig. 22). The ratio fruits on “shoots + leaves” was about 50 %, but slightly higher at “240 HPS, 100 J”.

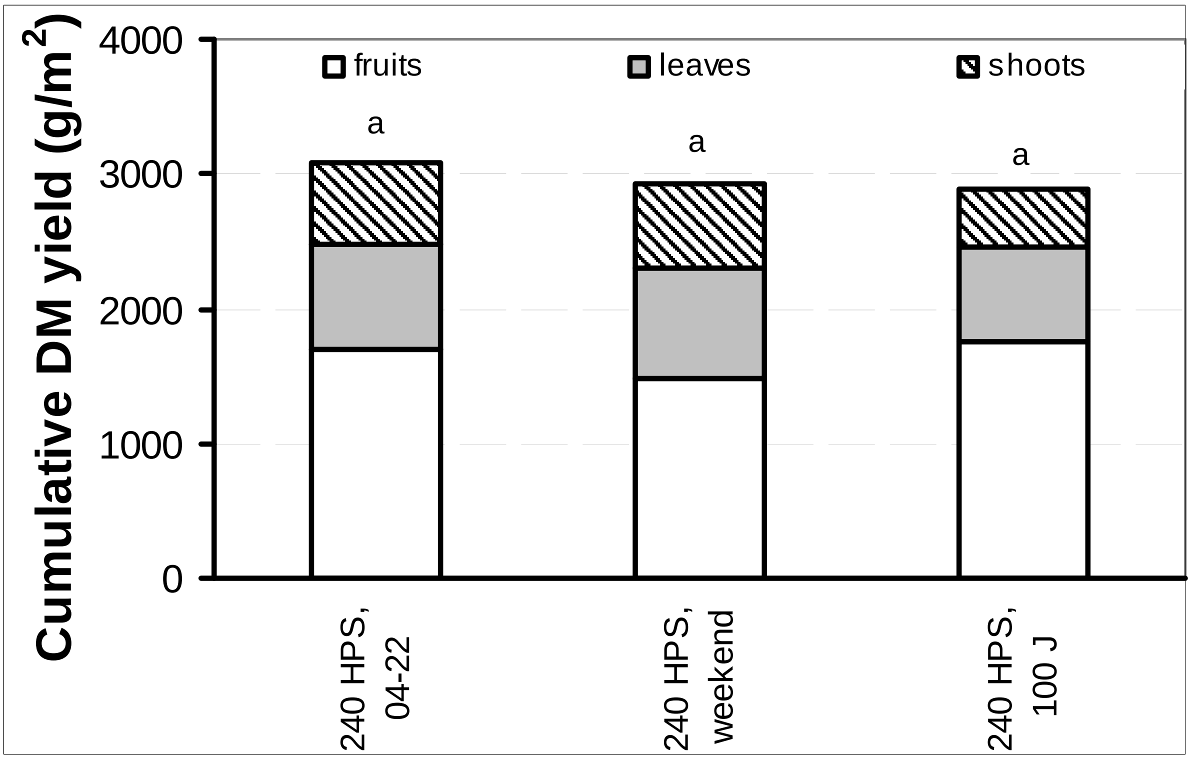


Fig. 22: Cumulative dry matter yield at different lighting regimes.

Letters indicate significant differences at the end of the harvest period (HSD, $p \leq 0,05$).

4.4 Nitrogen uptake, nitrogen in water and nitrogen left in pumice

4.4.1 Nitrogen uptake by plants

The cumulative N uptake included N uptake of all harvested fruits, the immature fruits at the end of the growth period, the stripped leaves during the growth period and the shoots. The fruits and leaves contributed much more than the shoots to the cumulative N uptake (Fig. 23). The N uptake was independent of the lighting regime.

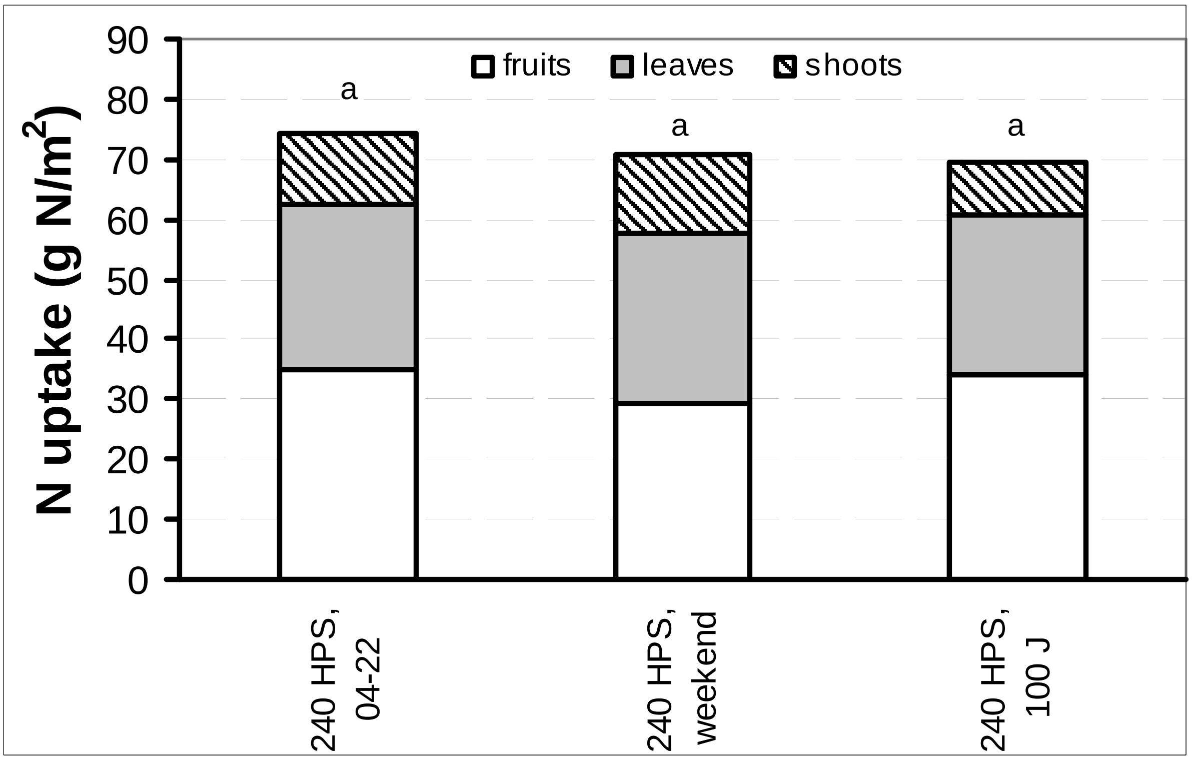


Fig. 23: Cumulative N uptake of tomatoes.

Letters indicate significant differences (HSD, $p \leq 0,05$).

4.4.2 Nitrogen in input and runoff water and nitrogen left in pumice

The amount of NO_3-N in input and runoff water was higher than the amount of NH_4-N (Fig. 24). NH_4-N amounted to be less than 10 mg/kg and NO_3-N 150-350 mg/kg. The amount of NO_3-N was higher in the runoff than in input water.

NH_4-N and NO_3-N in pumice were measured at the end of the experiment. NO_3-N + NH_4-N did not differ between treatments (Fig. 25).

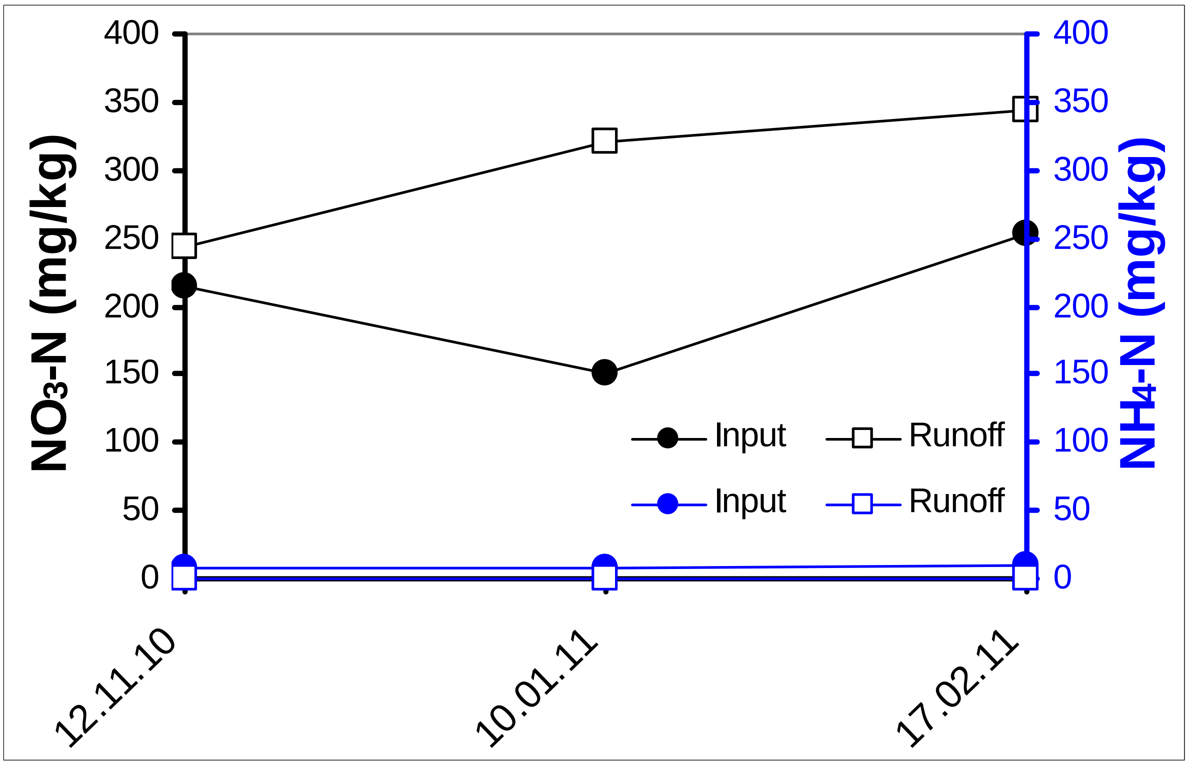


Fig. 24: NO_3-N and NH_4-N in input and runoff water.

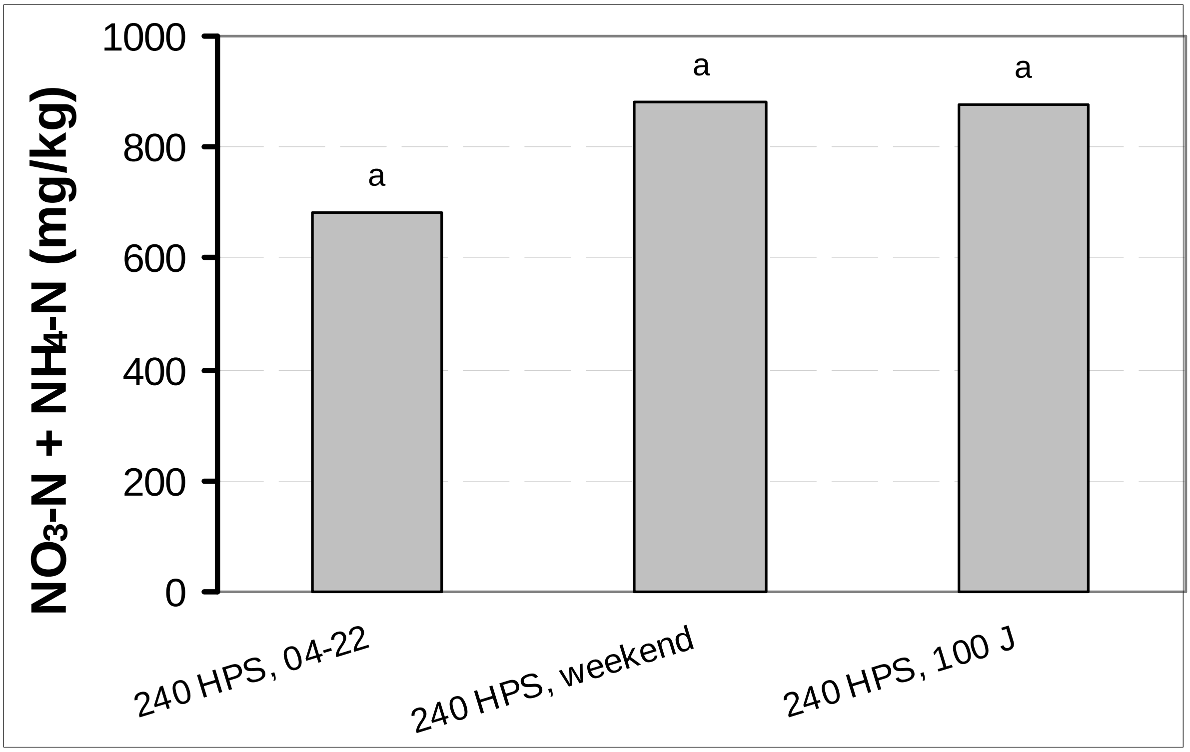


Fig. 25: NO_3-N and NH_4-N in pumice at the end of the experiment.

Letters indicate significant differences (HSD, $p \leq 0{,}05$).

4.5 Economics

4.5.1 Lighting hours

The number of lighting hours is contributing to high annual costs and needs therefore special consideration in order to find the most efficient lighting treatment to be able to decrease lighting costs per kg marketable yield.

The total hours of lighting during the growth period of tomatoes were both simulated and measured with dataloggers. The cabinet "300 HPS, 04-20" with the shorter growing period is excluded for economic evaluation.

The simulated value was higher than the measured one, because in there it was not considered that lamps were automatically turned off, when incoming solar radiation was above the set-point (Tab. 6). The calculation of the power was higher for the measured values than for the simulated ones, because lights at the outer beds were also partly contributing to lighten the shelter belt. For calculation of the power different electric consumptions were made, because the power consumption is higher than the Watt of the bulb: one was based on the power of the lamps (nominal Watts, 0 % more power consumption), one with 6 % more power consumption for HPS bulbs and one for 10 % more power consumption.

Tab. 6: Lighting hours, power and energy in the cabinets.

	Hours h	**Power** W	**Energy** kWh	**Energy/m^2** kWh/m^2
240 HPS, 04-22				
Measured values	3001	268	40 215	804
Simulated values				
0 % more power consumption (nominal)	3294	240	39 528	791
6 % more power consumption	3294	254	41 900	838
10 % more power consumption	3294	264	43 481	870
240 HPS, weekend				
Measured values	3026	268	40 550	811
Simulated values				
0 % more power consumption (nominal)	3157	240	37 882	758
6 % more power consumption	3157	254	40 155	803
10 % more power consumption	3157	264	41 671	833
240 HPS, 100 J				
Measured values	2694	268	36 104	722
Simulated values				
0 % more power consumption (nominal)	2949	240	35 388	708
6 % more power consumption	2949	254	37 511	750
10 % more power consumption	2949	264	38 927	779

4.5.2 Energy prices

Since the application of the electricity law 65/2003 in 2005, the cost for electricity has been split between the monopolist access to utilities, transmission and distribution and the competitive part, the electricity itself. Most growers are, due to their location, mandatory customers of RARIK, the distribution system operator (DSO) for most of Iceland except in the Southwest and Westfjords (*Eggertsson*, 2009).

RARIK offers basically three types of tariffs:

a) energy tariffs, for smaller customers, that only pay fixed price per kWh,
b) “time dependent” tariffs (Þrígjaldstaxti) with high prices during the day and winter but much lower during the night and summer, which mostly suites customers with electrical heating, but seem to be restricting for growers, and
c) demand based tariffs (Afltaxti), for larger users, who pay according to the maximum power demand (*Eggertsson*, 2009).

In the report, only Afltaxti is used. The first two types of tariffs are not economic. Since 2009, RARIK has offered special high voltage tariffs (“VA410” and “VA430”) for large users, that must either be located close to substation of the transmission system operator (TSO) or able to pay considerable upfront fee for the connection. The tariff “Þrígjaldstaxti TT” is for growers.

Costs for distribution are divided into an annual fee and costs for the consumption based on used energy (kWh) and maximum power demand (kW) respectively the costs at special times of usage. The annual fee is pretty low for “VA210” and “VA230” when subdivided to the growing area and is therefore not included into the calculation. However, the annual fee for “VA410” and “VA430” is much higher. Growers in an urban area in “RARIK areas” can choose between different tariffs. In the report only the possibly most used tariffs “VA210” and “VA410” in urban areas and “VA230” and “VA430” in rural areas are considered.

The government subsidises the distribution cost of growers that comply to certain criterias. Currently 76,4 % and 84,0 % of variable cost of distribution for urban and rural areas respectively. This amount can be expected to change in the future.

Based on this percentage of subsidy and the lighting hours (Tab. 6), for the cabinets the energy costs with subsidy per m^2 during the time of the experiment that growers have to pay were calculated (Tab. 7).

Tab. 7: Costs for consumption of energy for distribution and sale of energy.

	Costs for consumption											
	Energy ISK/kWh						Energy costs with subsidy per m^2 ISK/m^2					
Lighting regime	240 HPS, 04-22		240 HPS, weekend		240 HPS, 100 J		240 HPS, 04-22		240 HPS, weekend		240 HPS, 100 J	
	real	calculated	real	calculated	real	calculated	real	calculated	real	calculated	real	calculated
DISTRIBUTION												
RARIK Urban							76,4 % subsidy from the state					
VA210		0,76		0,77		0,79		602		586		561
	0,79	0,76	0,78	0,77	0,82	0,79	632	638	636	621	592	595
		0,76		0,77		0,79		662		644		617
VA410		0,59		0,61		0,62		464		460		436
	0,63	0,59	0,63	0,61	0,66	0,62	507	492	509	487	479	462
		0,59		0,61		0,62		510		506		479
RARIK Rural							84,0 % subsidy from the state					
VA230		0,68		0,69		0,70		535		520		499
	0,70	0,68	0,70	0,69	0,73	0,70	562	567	565	552	525	528
		0,68		0,69		0,70		588		573		548
VA430		0,44		0,45		0,46		347		339		326
	0,46	0,44	0,45	0,45	0,48	0,46	367	368	369	359	346	346
		0,44		0,45		0,46		382		373		359
SALE												
Afltaxti	4,25	4,17	4,24	4,20	4,45	4,32						
Þrígjalds-taxti TT	6,09	5,77	4,07	3,86	6,37	6,04						
Þrígjalds-taxti TV	6,02	5,90	4,13	4,12	6,22	6,11						
								3295		2921		3055
							3420	3493	3303	3097	3214	3239
								3624		3214		3361

Source: Composition from *Eggertsson* (2012)

Comments: The first number for the calculated value is with 0 % more power consumption, the second value with 6 % more power consumption and the last value with 10 % more power consumption.

The calculations are based on prices in January 2012.

The energy costs per kWh for distribution after subsides are around 0,7-0,8 ISK/kWh for „VA210“ and „VA230“, around 0,6 ISK/kWh for „VA410“ and around 0,5 ISK/kWh for „VA430“. The energy costs for sale are for „Afltaxti“ around 4 ISK/kWh with less difference between cabinets and for „Þrígjaldstaxti TT“ and „Þrígjaldstaxti TV“ around 6 ISK/kWh for “240 HPS, 04-22” and “240 HPS, 100 J”, but around 4 ISK/kWh for „240 HPS, weekend“.

Cost of electricity was at calculated values only slightly lower with “240 HPS, weekend” compared to “240 HPS, 04-22”. In contrast, costs could be decreased by about 6 % when “240 HPS, 100 J” was used (Tab. 7). In general, with higher tariffs costs decreased.

4.5.3 Costs of electricity in relation to yield

Costs of electricity in relation to yield for wintergrown tomatoes were calculated (Tab. 8).

Tab. 8: Variable costs of electricity in relation to yield.

	Variable costs of electricity per kg yield ISK/kg					
Lighting regime	240 HPS, 04-22		240 HPS, weekend		240 HPS, 100 J	
Yield/m²	33,5		28,8		35,3	
	real	calculated	real	calculated	real	calculated
Urban area (Distribution + Sale)						
VA210		116		122		102
	121	123	137	129	108	109
		128		134		113
VA410		112		117		99
	117	119	132	124	105	105
		123		129		109
Rural area (Distribution + Sale)						
VA230		114		119		101
	119	121	134	126	106	107
		126		131		111
VA430		109		113		96
	113	115	127	120	101	102
		119		124		105

While for the distribution several tariffs were possible, for the sale only the cheapest tariff was considered. The costs of electricity decreased – also due to the higher yield – by more than 10 % for “240 HPS, 100 J” compared to “240 HPS, 04-22”. Due to the lower yield of “240 HPS, weekend” compared to “HPS, 04-22”, costs of electricity per kg yield increased by nearly 15 %. In general, with a larger tariff, costs of electricity per kg yield decreased (Tab. 8).

4.5.4 Profit margin

The profit margin is a parameter for the economy of growing a crop. It is calculated by subtracting the variable costs from the revenues. The revenues itself, is the product of the price of the sale of the fruits and kg yield. For each kg of tomatoes, growers are getting about 400 ISK from Sölufélag garðyrkjumanna (SfG) and in addition about 64 ISK from the government. Therefore, the revenues were higher with more yield (Fig. 26).

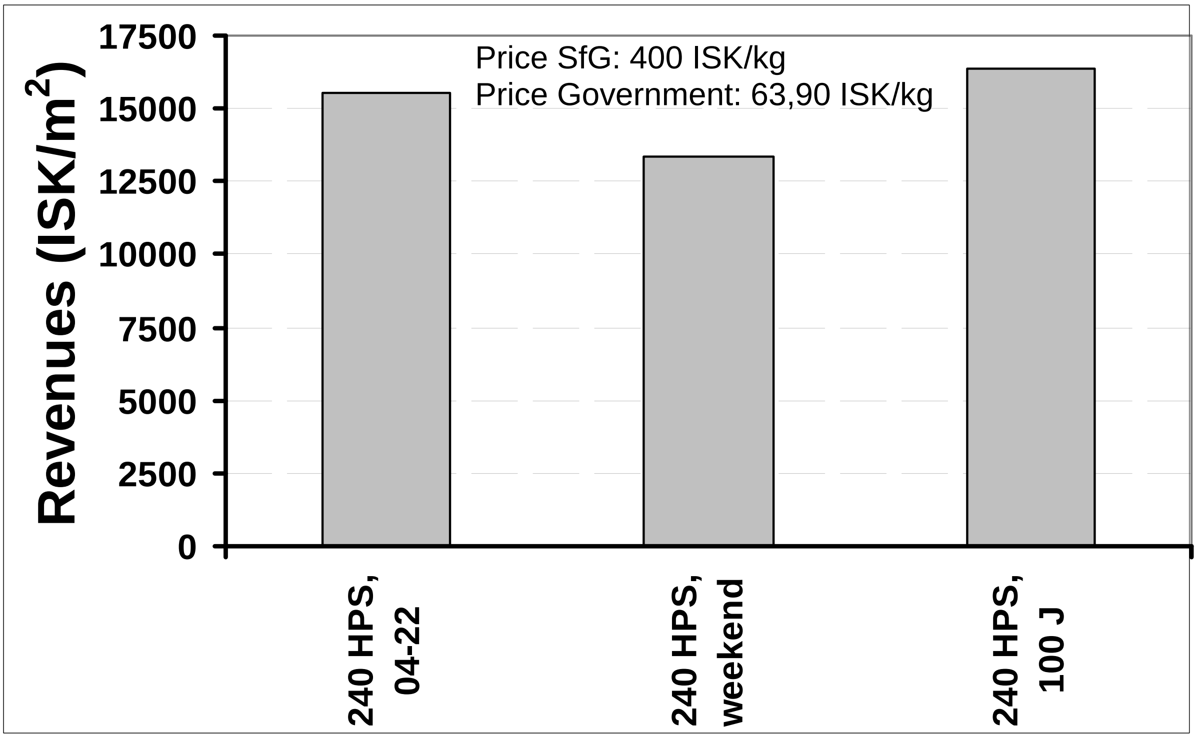


Fig. 26: Revenues at different lighting regimes.

When considering the results of previous chapter, one must keep in mind that there are other cost drivers in growing tomatoes than electricity alone (Tab. 8). Among others, this are e.g. the costs of seedling production (≈ 200 ISK/m^2) and transplanting (≈ 250 ISK/m^2), costs for plant protection (≈ 200 ISK/m^2), plant nutrition

(≈ 300 ISK/m^2), liquid CO_2 (≈ 700 ISK/m^2), the rent of the tank (≈ 300 ISK/m^2), the rent of the green box (≈ 200 ISK/m^2), material for packing (≈ 1500 ISK/m^2) and packing costs with the machine from SfG (≈ 400 ISK/m^2) and transport costs from SfG (≈ 200 ISK/m^2) (Fig. 27).

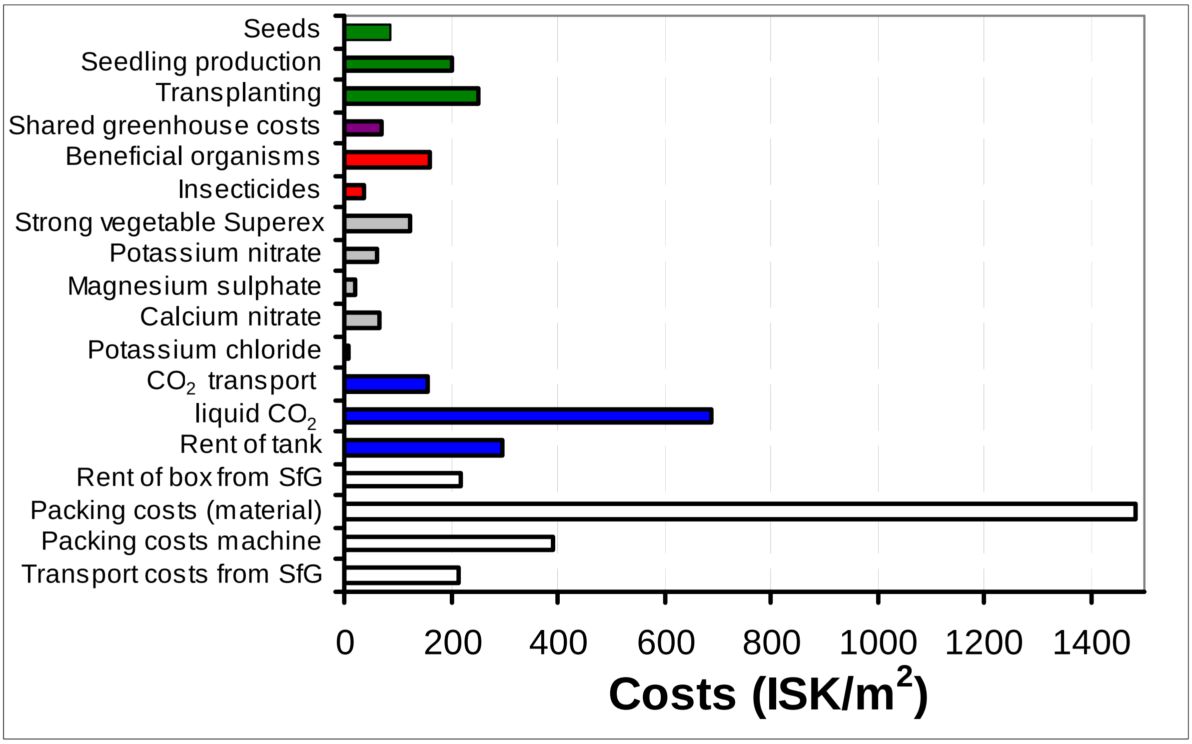


Fig. 27: Variable costs (without lighting and labour costs).

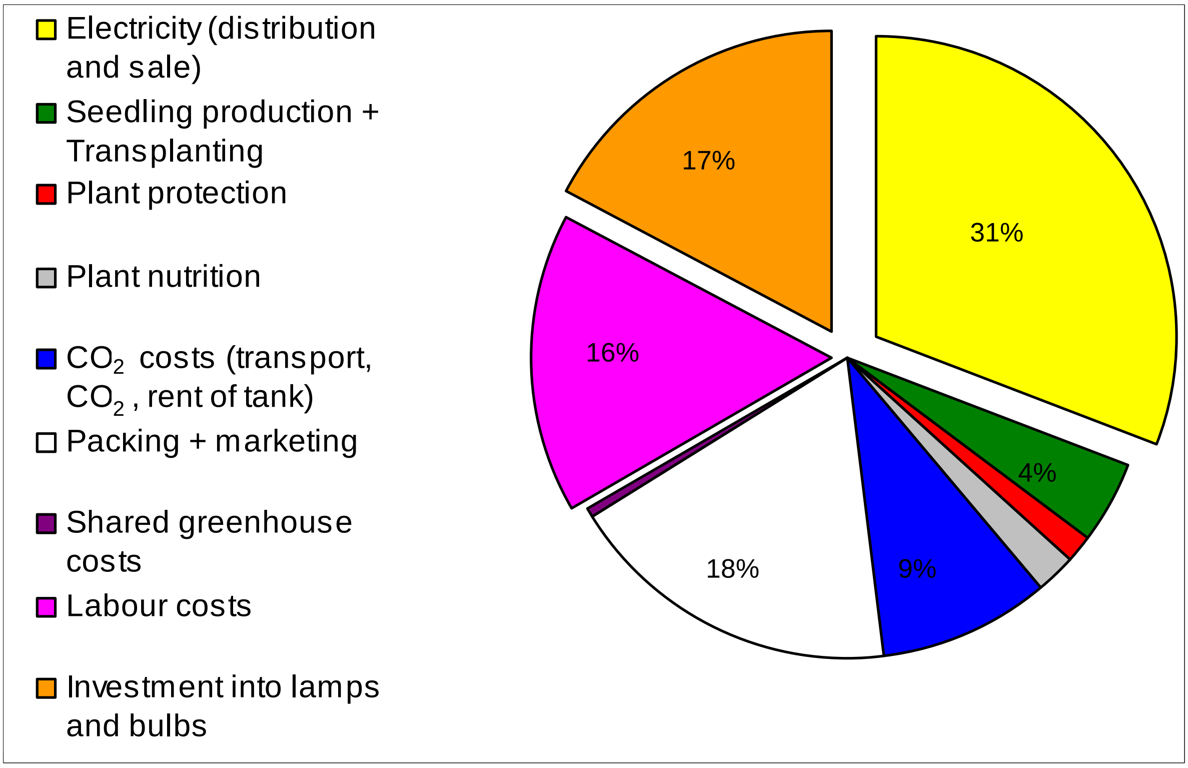


Fig. 28: Division of variable costs.

However, in Fig. 27 three of the biggest cost drivers are not included and these are the investment into lamps and bulbs, the electricity and the labour costs. These variable costs are also included in Fig. 28 and it is obvious, that especially the electricity and the investment into lamps and bulbs as well as the labour costs are contributing much to the variable costs beside the costs for packing and marketing.

A detailed composition of the variable costs at each treatment is shown in Tab. 9.

The profit margin was dependent on the lighting regime, whereas the tariff was only influencing profit margin slightly (Fig. 29). Profit margin was with nearly 4000 ISK/m^2 highest with “240 HPS, 100 J”. Light at uncommon times was influencing the profit margin negative (around 1000 ISK/m^2 at “240 HPS, weekend”) (Fig. 29). Compared to the normal lighting time, the uncommon lighting time decreased profit margin by about 1500 ISK/m^2. A higher tariff slightly increased profit margin. At a higher tariff there was a surprisingly small advantage of rural areas due to the state subsidies (Fig. 29).

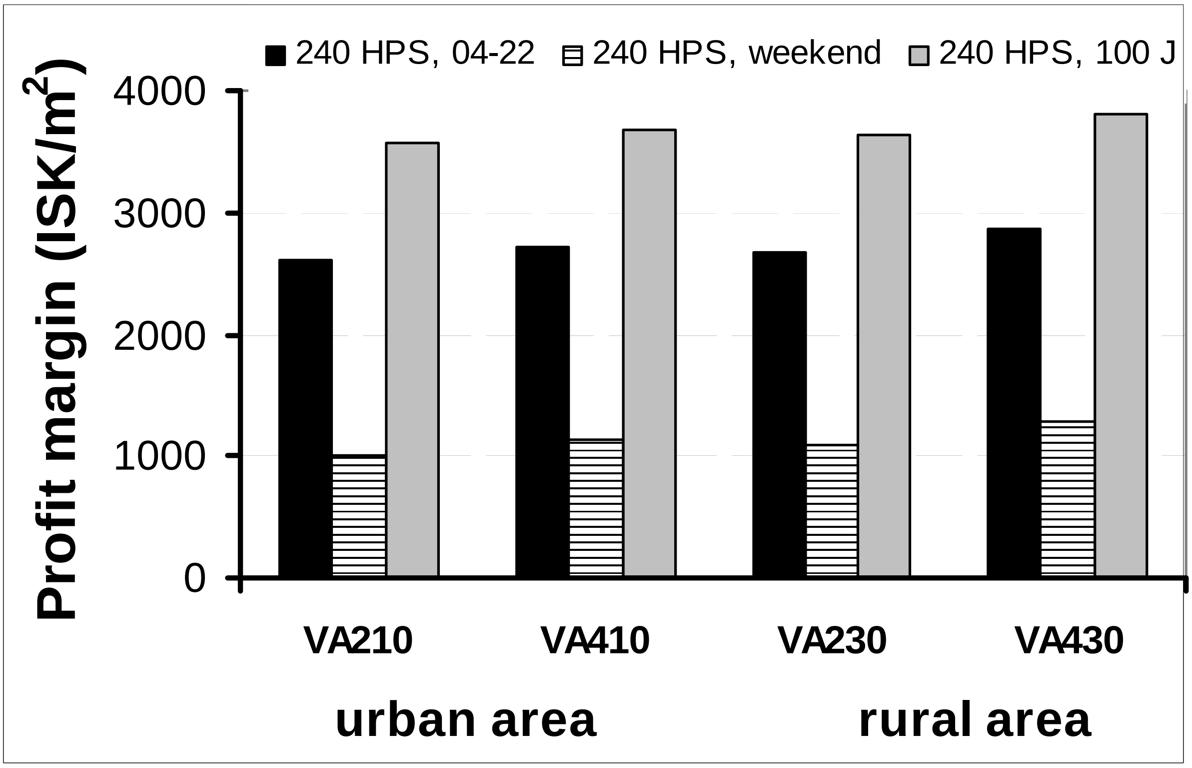


Fig. 29: Profit margin in relation to tariff and lighting regime.

Tab. 9: Profit margin of tomatoes at different lighting regimes (urban area, VA210).

Lighting regime	240 HPS, 04-22	240 HPS, weekend	240 HPS, 100 J
Marketable yield/m²	33,5	28,8	35,3
Sales			
SfG (ISK/kg) [1]	400	400	400
Government (ISK/kg) [2]	63,90	63,90	63,90
Revenues (ISK/m²)	**15 556**	**13 382**	**16 369**
Variable costs (ISK/m²)			
Electricity distribution [3]	632	636	592
Electricity sale	3420	3303	3214
Seeds [4]	86	86	86
Seedling production	200	200	200
Grodan small [5]	22	22	22
Grodan big [6]	130	130	130
Pumice [7]	94	94	94
Predatory bug [8]	41	41	41
Parasitic wasps [9]	75	75	75
Aphids [10]	44	44	44
Insecticides	37	37	37
Strong vegetable Superex L 539 [11]	117	127	123
Potassium nitrate [12]	60	65	64
Magnesium sulphate [13]	18	20	19
Calcium nitrate [14]	65	71	68
Potassium chloride [15]	7	8	8
CO_2 transport [16]	157	157	157
Liquid CO_2 [17]	689	689	689
Rent of CO_2 tank [18]	298	298	298
Strings	7	7	7
Rent of box from SfG [19]	223	192	235
Packing material [20]	1527	1314	1607
Packing (labour + machine) [21]	402	346	423
Transport from SfG	220	189	231
Shared fixed costs [22]	71	71	71
Lamps [23]	1429	1429	1429
Bulbs [24]	762	762	762
∑ variable costs	**10 834**	**10 412**	**10 725**
Revenues -∑ variable costs	**4722**	**2970**	**5644**
Working hours (h/m²)	1,57	1,45	1,54
Salary (ISK/h)	1352	1352	1352
Labour costs (ISK/m²)	2120	1957	2079
Profit margin (ISK/m²)	**2602**	**1014**	**3565**

[1] price winter 2010/2011: 400 ISK/kg

[2] price in October for 2011: 63,90 ISK/kg

[3] assumption: urban area, tariff "VA210", no annual fee (according to datalogger values)

[4] 34 340 ISK / 1000 Encore seeds

[5] 36x36x40mm, 25 584 ISK / 2900 Grodan small

[6] 6,56 42/40, 8635 ISK / 216 Grodan big

[7] 5653 ISK/m^3 (2,6 m^3 big pumice, 0,65 m^3 small pumice)

[8] 8947 ISK / unit predatory bug (*Macrolophus caliginosus*)

[9] 8118 ISK / unit parasitic wasps (*Encarsia formosa*)

[10] 3151 ISK / unit aphids (*Aphidius colemani*, *Aphidoletes aphidimyza*)

[11] 8664 ISK / 25 kg Strong vegetable Superex L 539

[12] 4380 ISK / 25 kg Potassium nitrate

[13] 1360 ISK / 25 kg Magnesium sulphate

[14] 2200 ISK / 25 kg Calcium nitrate

[15] 3767 ISK / 25 kg Potassium chloride

[16] CO_2 transport from Rvk to Hveragerði / Flúðir: 5,51 ISK/kg CO_2

[17] liquid CO_2: 24,10 ISK/kg CO_2

[18] rent for 6 t tank: 42597 ISK/month, assumption: rent in relation to 1000 m^2 lightened area

[19] 77 ISK / 12 kg box

[20] packing costs (material):

costs for packing of 6 tomatoes (0,50 kg): platter: 9 ISK / 0,5 kg,
plastic film: 10 ISK / 0,5 kg,
label: 1 ISK / 0,5 kg;

costs for packing of big tomatoes (0,75 kg): platter: 10,9 ISK / 0,75 kg,
plastic film: 10 ISK / 0,75 kg,
label: 1,25 ISK / 0,75 kg

[21] packing costs (labour + machine): 12 ISK / kg

[21] packing costs (labour + machine): 12 ISK / kg

[22] 94 ISK/m^2/year for common electricity, real property and maintenance

[23] HPS lights: 30 000 ISK/lamp, life time: 8 years

[24] HPS bulbs: 4000 ISK/bulb, life time: 2 years

5 DISCUSSION

5.1 Yield in dependence of light intensity

The growth period in the cabinet with the highest light intensity was shorter and therefore no statements can be done regarding yield in dependence of the light intensity. Therefore, also literature results that are dealing with light intensity are not mentioned.

5.2 Yield in dependence of lighting time

Accumulated marketable yield of tomatoes that received light during nights and weekends was lower compared to the normal lighting time. Also, when normal lighting time had been restored, the yield did not approach the yield obtained at normal lighting time with final yields amounting to about 15 % less yield. However, marketable yield of sweet pepper that received light during nights and weekends, was 5-10 % lower compared to the normal lighting time and when normal lighting time had been restored, the yield continuously approached the yield of the traditional lighting time (*Stadler* et al., 2011).

Did plants receive not only during weekends but continuously (24 h) light, tomatoes started developing leaf chlorosis after seven weeks, while during the first five to seven weeks tomato plants grown under continuous light had better growth and higher yields than plants receiving 14 h supplemental light (*Demers* et al, 1998a). The authors suggest that is may be possible to use long photoperiods for a few weeks to grow tomato plants during periods of low natural light level and to decrease the photoperiod back to a shorter one.

Growing eggplant under continuous light resulted in leaf chlorosis after four days and a sharp decline in the chlorophyll content (*Murage* & *Masuda*, 1997). For eggplant nine hours of darkness were necessary in order to prevent leaf injury characterized by leaf chlorosis and necrosis (*Murage* et al., 1996). However, the incidence of leaf chlorosis under continuous illumination was strongly dependent on the light quality and quantity, and the temperature regime, which interact to exert their effects through changes in the leaf photosynthetic activity and the overall carbon metabolism (*Murage* et al., 1997).

Continuously (24 h) light in sweet pepper resulted also in lower yields and leaf deformation (*Demers* et al., 1998b). The authors discussed that it may be an opportunity to provide continuous light for a few weeks to improve growth and yields. If the continuous lighting during weekends is considered as such a system, then this could not be confirmed in the present experiment with tomatoes, where light during nights and weekends reduced yield. However, *Masuda* & *Murage* (1998) reported that pepper with a 12 h photoperiod for three weeks and then 24 h continuous light for three weeks gained more shot dry weight, produced more leaves with heavier specific leaf weight and had greater fruit set than those grown under a 12 h photoperiod.

However, not only continuous light, but also a 20 h photoperiod had negative effects on growth of cucumber and especially tomatoes compared to 12 h photoperiod (*Ménard* et al., 2006). *Dorais* (2003) reported chlorosis on tomato after only several days with more than 17 h or continuous supplemental light. In contrast, tomato plants showed nearly no negative symptoms under almost 24 hours of natural sunlight in Finland. Therefore, on the one hand the quality of light (natural / artificial light) and on the other hand the duration of the supplemental light seems to be the crucial factor for positive / negative effects. Thus, the duration of the continuous light during weekends may be decisive for the lower yields of tomatoes in the present experiment.

In tomato, extended photoperiod (18 h instead of 12 h) favoured shoot development and dry weight of tomato plants increased by 30 %, although no significant differences were observed in fruit yields. In contrast, extended photoperiod did not increase shoot dry weight of pepper plants but significantly increased fruit yields (*Dorais* et al, 1996). However, if in the present experiment the weekend lighting is considered as extended photoperiod, tomato yields and cumulative dry matter yield were tendentially decreased compared to the common lighting system. Same was observed in sweet pepper (*Stadler* et al., 2011).

When supplemental light was provided from 04-22 h compared to 23-17 h *Gunnlaugsson* & *Adalsteinsson* (2003) observed 12 % higher yields of tomatoes, this compensated for higher electricity costs of 11 % at normal lighting times. Hence, the authors concluded that therefore it is not necessary to adjust the lighting time for tomatoes to the tariffs of electricity. This was confirmed in the present experiment with tomatoes and also in the previous experiment with sweet pepper (*Stadler* et al., 2011). A reason for the lower yield might also be that plants did not really get a night – respectively a night that was long enough – when light was provided during nights or during nights and weekends.

Beside that, species are differing in their tolerance to continuous light; e.g. eggplant and tomato is known to be a continuous light – sensitive species (*Velez-Ramirez* et al., 2011; *Sysoeva* et al., 2010). This might explain why in the present experiment the yield of tomatoes was more decreased than the yield of sweet pepper (*Stadler* et al., 2011).

5.3 Future speculations concerning energy prices

In terms of the economy of lighting – which is not looking very promising from the growers' side – it is also worth to make some future speculations about possible developments. In the past and present there have been and there are still a lot of discussions concerning the energy prices. Therefore, it is necessary to highlight possible changes in the energy prices. The white columns are representing the profit margin according to Fig. 29. Where to be assumed, that growers would get no subsidy from the state for the distribution of the energy, that would result in a negative profit margin for the weekend lighting and about 500-1500 for the other treatments (black columns, Fig. 30). In this case it would not be economic to grow tomatoes in Iceland during the winter. Without the subsidy of the state, probably less Icelandic grower would produce tomatoes over the winter months. When it is assumed that the energy costs, both in distribution and sale, would increase by 25 %, but growers would still get the subsidy, then the profit margin would range between 0-2500 ISK/m^2 (dotted columns). Probably the tomato production would decrease, if the growers would have to pay 25 % more for the electricity. When it is assumed, that growers have to pay 25 % less for the energy, the profit margin would increase to 2000-4000 ISK/m^2. From these scenarios it can be concluded that from the grower's side it would be necessary to get subsidy to be able to grow tomatoes over the winter. The current subsidy should therefore not be decreased.

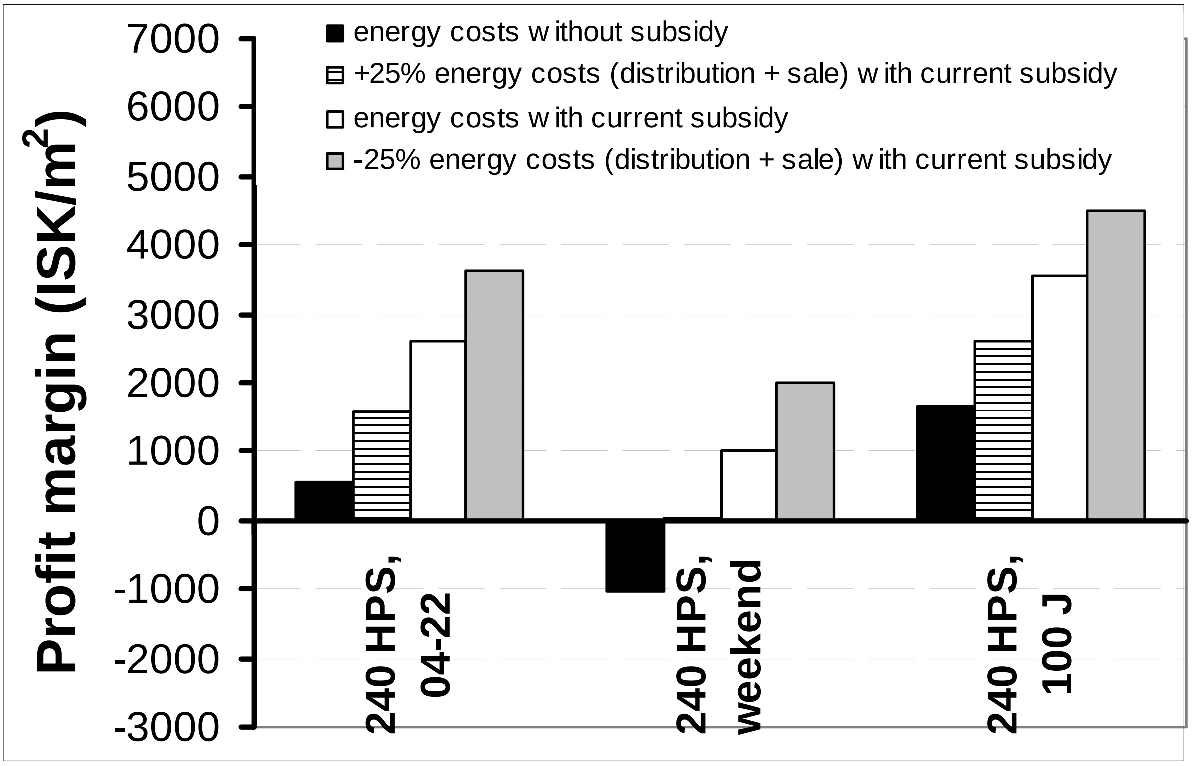


Fig. 30: Profit margin in relation to lighting regime – calculation scenarios (urban area, VA210).

5.3 Recommendations for increasing profit margin

The current economic situation for growing tomatoes necessitate for reducing production costs to be able to heighten profit margin for tomato production. On the other hand side, growers have to think, if tomatoes should be grown during low solar irradiation.

It can be suggested, that growers can improve their profit margin of tomatoes by:

1. Getting higher price for the fruits
   It may be expected to get a higher price, when consumers would be willing to pay more for Icelandic fruits than imported ones. Growers could also get a higher price for the fruits with direct marketing to consumers (which is of course difficult for large growers).

2. Decrease plant nutrition costs
   Growers can decrease their plant nutrition costs by mixing their own fertilizer. When growers would buy different nutrients separately for a lower price and mix out of this their own composition, they would save fertilizer costs.

3. Lower CO_2 costs

   The costs of CO_2 are pretty high. Therefore, the question arises, if it is worth to use that much CO_2 or if it would be better to use less and get a lower yield but all together have a possible higher profit margin. The CO_2 selling company has currently a monopoly and a competition might be good.

4. Decrease packing costs

   The costs for packing (machine and material) from SfG and the costs for the rent of the box are high. Costs could be decreased by using less or cheaper packing materials. Also, packing costs could be decreased, when growers would due the packing at the grower's side. They could also try to find other channels of distribution (e.g. selling directly to the shops and not over SfG).

5. Efficient employees

   The efficiency of each employee has to be checked regularly and growers will have an advantage to employ faster workers. Growers should also check the user-friendliness of the working place to perform only minimal manual operations. Very often operations can be reduced by not letting each employee doing each task, but to distribute tasks over employees. In total, employees will work more efficiently due to the specialisation.

6. Decrease energy costs

   - Lower prices for distribution and sale of energy (which is not realistic)
   - Growers should decrease artificial light intensity at increased solar irradiation, because this would result in no lower yield.
   - Also, growers could decrease the energy costs by about 6 % when they would lighten according to the treatment 100 J/cm^2/cluster and 100 J/cm^2 for plant maintenance. This would mean that especially at the early stage after transplanting, plants would get less hours light. Also at high natural light, lamps would be turned off. In doing so, compared to the traditional lighting system, profit margin could be increased by about 10 % (assuming similar yield).
   - Light during nights and weekends from the beginning of November to the end of February is not recommended due to the lower yield and lower profit margin.

- Growers should check if they are using the right RARIK tariff and the cheapest energy sales company tariff. Unfortunately, it is not so easy, to say, which is the right tariff, because it is grower dependent.

- Growers should check if they are using the power tariff in the right way to be able to get a lowered peak during winter nights and summer (max. power -30 %). It is important to use not so much energy when it is expensive, but have a high use during cheap times.

- Growers can save up to 8 % of total energy costs when they would divide the winter lighting over all the day. That means growers should not let all lamps be turned on at the same time. This would be practicable, when they would grow in different independent greenhouses. Of course, this is not so easy realisable, when greenhouses are connected together, but can also be solved there by having different switches for the lamps to be able to turn one part of the lamps off at a given time. Then, plants in one compartment of the greenhouse would be lightened only during the night. When yield would be not more than 2 % lower with lighting at nights compared to the usual lighting time, dividing the winter lighting over all the day would pay off.

  The present experiment showed that the yield was decreased by about 15 % when tomatoes got from the beginning of November to the end of February light during nights and weekends. This resulted in a profit margin that was about 18 % lower compared to the traditional lighting system.

- For large growers, that are using a minimum of 2 GWh it could be recommended to change to “stórnotendataxti” in RARIK and save up to 35 % of distribution costs.

- It is expected, that growers are cleaning their lamps to make it possible, that all the light is used effectively and that they are replacing their bulbs before the expensive season is starting.

- *Aikman* (1989) suggests to use partially reflecting material to redistribute the incident light by intercepting material to redistribute the incident light by intercepting direct light before it reaches those leaves facing the sun, and to reflect some light back to shaded foliage to give more uniform leaf irradiance.

6 CONCLUSIONS

The very low reduction in energy costs by lighting during nights and weekends was accompanied by a higher loss in yield. From the economic side it seems to be recommended to provide light at normal times with HPS lamps.

However, by providing light at normal times, growers could decrease the energy costs by about 6 % in using light with 100 J/cm^2/cluster and 100 J/cm^2 for plant maintenance. After consideration of the revenues this resulted in a clearly profit benefit from about 10 % compared to the traditional lighting system. Therefore, growers are better off to decrease the lighting time during the early stage after transplanting and also turning lights of at high natural light levels.

Growers should pay attention to possible reduction in their production costs for tomatoes other than energy costs.

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