Rit LbhÍ nr. 30

„Effects of plant density, interlighting, light intensity and light quality on growth, yield and quality of greenhouse sweet pepper“

FINAL REPORT

Christina Stadler

SAMBAND GARÐYRKJUBÆNDA

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Final report of the research project

„Effects of plant density, interlighting, light intensity and light quality on growth, yield and quality of greenhouse sweet pepper“

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Abbreviations

C	carbon
C/N	carbon/nitrogen ratio
$CaNO_3$	calcium nitrate
DM	dry matter yield
DS	dry substance
E.C.	electrical conductivity
H_2O	water
HPS	high-pressure vapor sodium lamps
HSD	honestly significant difference
IL	interlighting
KCl	potassium chloride
kWh	kilo Watt hour
LAI	leaf area index
M	mole
N	nitrogen
$p \leq 0,05$	5 % probability level
PAR	photosyntetically active radiation
pH	potential of hydrogen
PPF	photosynthetic photon flux
r^2	coefficient of determination
TL	top lighting
W	Watt
Wh	Watt hours

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 suitable placement, light intensity and colour of light are not yet available for sweet pepper production and need to be developed in conjunction with plant density.

An experiment with sweet pepper (*Capsicum annum* L. cv. Ferrari) was conducted in the experimental greenhouse of the Agricultural University of Iceland at Reykir. Plants (two stems per plant, double rows) were transplanted at two stem densities (6 and 9 stems/m^2) in four replicates. Sweet pepper was grown under high-pressure vapor sodium lamps either with only top lighting (TL) or additional interlighting (IL) at four different lighting regimes (TL 160 W/m^2, TL 120 W/m^2 + IL 120 W/m^2, TL 240 W/m^2, TL 160 W/m^2 + IL 120 W/m^2). Light was provided for 18 / 16 hours (low / high solar irradiation), but the lamps were automatically turned off when natural incoming illuminance was above the desired set-point. Temperature was kept at 22-23°C / 18-19°C (day / night) and carbon dioxide was provided (800 ppm CO_2). Sweet pepper received standard nutrition through drop irrigation.

Marketable yield of sweet pepper increased with light intensity. At the lowest light intensity the accumulated marketable yield was not influenced by stem density. However, with higher light intensity the positive effect of a higher stem density became obvious and with the highest light intensity marketable yield was significantly higher with 9 stems/m^2 than with 6 stems/m^2. This effect was developed during the low natural light level (environmental factors for growing were comparable within different treatments), whereas from the middle of April (with increasing solar irradiation) neither a higher stem density nor a higher light intensity was reflected in a significant yield increment. Placement of lamps (240 W/m^2 either as top lighting alone or subdivided into top lighting and interlighting) did not affect marketable yield. The yield increase was attributed to more fruits, whereas the average fruit weight was not influenced.

Marketable yield was 84-88 % of total yield during the whole harvest period. With top lighting not marketable yield was attributed to 7-8 % of fruits with too little weight (< 100 g), 1-2 % not well shaped fruits and 3 % blossom end rot. However, top lighting together with interlighting increased unmarketable yield (additional 2 % more

fruits with blossom end rot and 2 % fruits with damage from lighting). Especially, when interlights were lowered in between the rows, the amount of unmarketable fruits (damage from lighting) increased. It seems that sugar content and taste of fruits were not influenced by the lighting regime.

A higher light intensity resulted in same number of internodes at a lower average distance of internodes and consequently smaller plants. However, DM yield of stripped leaves, cumulative DM yield (yield of fruits, leaves, shoots) and N uptake by plants increased with light intensity.

Energy is converted less efficiently into yield at higher light intensity than at lower light intensity. Also, the profit margin was highest at a lower light intensity; especially with the combination “high light intensity and low stem density” profit margin decreased notably. This was attributed to high expenses (of about half of the expenses) for the investment into lamps and bulbs and the electricity itself. Future speculations regarding energy prices are highlighting the importance for growers to get subsidisation from the government and also the need to reduce production costs. Possible recommendations for saving costs other than lowering the electricity costs are discussed.

With respect to a light intensity adapted plant density, it is supposed that at higher light intensities, a higher stem density should be used to have a positive effect on yield. However, from the economic side of view a low light intensity would be recommended. Hence, with increasing solar irradiation vegetable growers could possibly decrease supplemental lighting without a reduction in yield and thus lowering energy costs.

2 INTRODUCTION

The intensity, colour and duration of the daily light that plants receive all affect photosynthesis and, hence, plant growth. 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., 1998), cucumbers (*Hao* & *Papadopoulos*, 1999) and sweet pepper (*Demers* & *Gosselin*, 1998) has been well studied. Photoperiod recommendations for different species have been proposed. Optimal growth and yields of sweet pepper for instance were obtained under photoperiods of 14 and 20 hours, respectively (*Demers* & *Gosselin*, 1998).

It is often assumed that an increment in light intensity results in the same yield increase. *Marcelis* et al. (2006) found that a 1 % light increment results in an increase in yield of 0,7-1 % for fruit vegetables. *Demers* et al. (1991) reported that biomass, early and total yield of sweet pepper, number of harvested fruits and the average weight were increased at 125 µmol/m^2/s (approx. 25 W/m^2) compared to 75 µmol/m^2/s (approx. 15 W/m^2).

Traditionally, lamps are mounted above the canopy (top lighting), which entails, that lower leaves are receiving limited light. Both old and more recent experiments (*Hovi-Pekkanen* & *Tahvonen*, 2008; *Grodzinski* et al., 1999; *Rodriguez* & *Lambeth*, 1975) imply that lower leaves are also able to assimilate quite actively, suggesting that a better utilization could be obtained by using interlighting (lamps in the row) in addition to top lighting. Indeed, the benefits from interlighting in contrast to top lighting alone have been confirmed with different vegetable crops. Interlighting increased first class yield of cucumbers along with increasing fruit quality and decreased unmarketable yield, both in weight and number (*Hovi-Pekkanen* & *Tahvonen*, 2008). However, only little is known about the impact of the proportion of interlighting to top lighting.

High-pressure vapor sodium lamps (HPS) are the most commonly used type of light source in greenhouse production due to their appropriate light spectrum for photosynthesis and their high efficiency. But HPS lamps are relatively poor in blue and far-red compared to the solar light (Photosyntetic Photon Flux) radiation. It is well known that spectral quality influences plant growth and development. High rates of red can stimulate fruit production, while blue light is responsible for keeping plant growth compact and shapely. *Ménard* et al. (2006) showed that adding blue light inside the canopy increased plant biomass and fruit yield of cucumbers and tomatoes. Thus, it appears to be more than appropriate to investigate the influence of blue light by increasing the light intensity and, consequently, the amount of blue light.

The influence of lighting is not considered as a separate growth factor in horticulture, but rather as an integral part. It is assumed that at different lighting regimes an adaption of the plant density may be useful. Modifying the plant or stem density is a possible means to maximize light interception and yield. Based on a review of articles of the influence of plant spacing on light interception in tomatoes, *Papadopoulos* & *Pararajasingham* (1997) concluded that a greater fruit yield is possible in narrow compared with wide plant spacing in greenhouse tomato, owning to increased PPF density interception, greater crop biomass and increased availability of total assimilates for distribution to the fruits. *Motsenbocker* (1996) reported that pepperoncini pepper resulted in lower biomass, lower yield/plant but more yield/m^2 and fuits/m^2 as plant density increased, considering that average fruit weight was unaffected. Also in experiments from *Rodriguez* & *Lambeth* (1975) lighting and wide spacing increased yield of tomatoes by increasing fruit size and number. They concluded that the higher yields were due to less overlapping and shading of leaves, better light penetration to the basal leaves, less competition for light, water and nutrients, and higher and more efficient CO_2 fixation.

Incorporating lighting into a production strategy is an economic decision involving added costs versus potential returns. Higher light intensity and interlighting in addition to top lighting increase energy costs. Therefore, the question arises whether the increase in the costs for the lighting system is reflected in better energy use efficiency. *Hovi-Pekkanen* & *Tahvonen* (2008) reported that interlighting (compared to top lighting) improved energy use efficiency in lighting. Therefore, in addition to different lighting systems also the plant density should be considered with respect to the profit margin of the horticultural crops.

Sugar content increases with total daily irradiance (*Davies* & *Hobson*, 1981) and is reduced by shading treatments (*Winsor*, 1966). Therefore, it can be concluded that the lighting regime as well as the plant density may influence sugar content of sweet pepper. Furthermore, it is known that the water content is higher in faster growing vegetables.

Spectral composition may indirectly affect plant nutrition (*Ehret* et al., 1989) and therefore it is necessary to evaluate also the N supply of plants by determining the N uptake and the input and runoff of the fertilization water. Higher leaf transpiration at higher light intensity can lead to higher nutrient content in leaves and possibly in fruits, too. *Treder* (2003), for instance, observed a significantly higher content of N, P, K, Ca and Mg in aerial plant parts of lily when supplemental lighting was used. Therefore, the light intensity may also influence the nutrient content in plant parts.

Preliminary experiments with sweet pepper have already been conducted at Reykir. Supplemental light increased yield of fruits, but average fruit size was not affected. Yield was higher with top lighting than with interlighting, whereas the effect of stem density (5,4 and 5,9 stems/m^2) was small. The proportion of unmarketable fruits was higher with lighting and highest with interlighting (*Árnason*, 2006). Yield increased when stem density increased from 4,8 to 5,9 stems/m^2 (*Árnason*, 2004), and from 5,5 to 6,0 stems/m^2 (*Björnsson*, 2008), but decreased again from 5,9 to 6,5 and 7,0 stems/m^2 (*Árnason*, 2004).

The objective of this study was to test if (1) light intensity is affecting growth, yield and quality of sweet pepper and the N uptake of the plant, (2) this parameters are subject to modification by different stem densities, (3) the placement of the lights is affecting results and (4) the profit margin can be improved by lighting regimes and stem densities. This study should enable to strengthen the knowledge on the ligthing regime and give vegetable growers advice how to improve their sweet pepper production by modifiing the efficiency of electricity consumption in lighting.

3 MATERIALS AND METHODS

3.1 Greenhouse experiment

An experiment with sweet pepper (*Capsicum annum* L. cv. Ferrari) was conducted at the Agricultural University of Iceland at Reykir. Seeds of sweet pepper were sown on 22.08.2008 in rock wool plugs. Seedlings were transplanted to rock wool cubes on 16.09.2008. On 20.10.2008 a pair of plants was transplanted in 11 l Bato-buckets (40 cm x 25 cm x 15 cm) filled with pumice stones and transferred to the cabinets with different lighting regimes.

Sweet pepper was trained to two stems per plant and was transplanted in double rows in four beds (A, B, C, D; Fig. 1) at two stem densities (6 stems/m^2 (B, D) and 9 stems/m^2 (A, C)). Four replicates, i.e. two replicates in each bed consisting of four buckets (8 plants) acted as subplots for measurements (see packet in beds, Fig. 1). Other buckets (white, Fig. 1) were not measured and acted as a shelter belt.

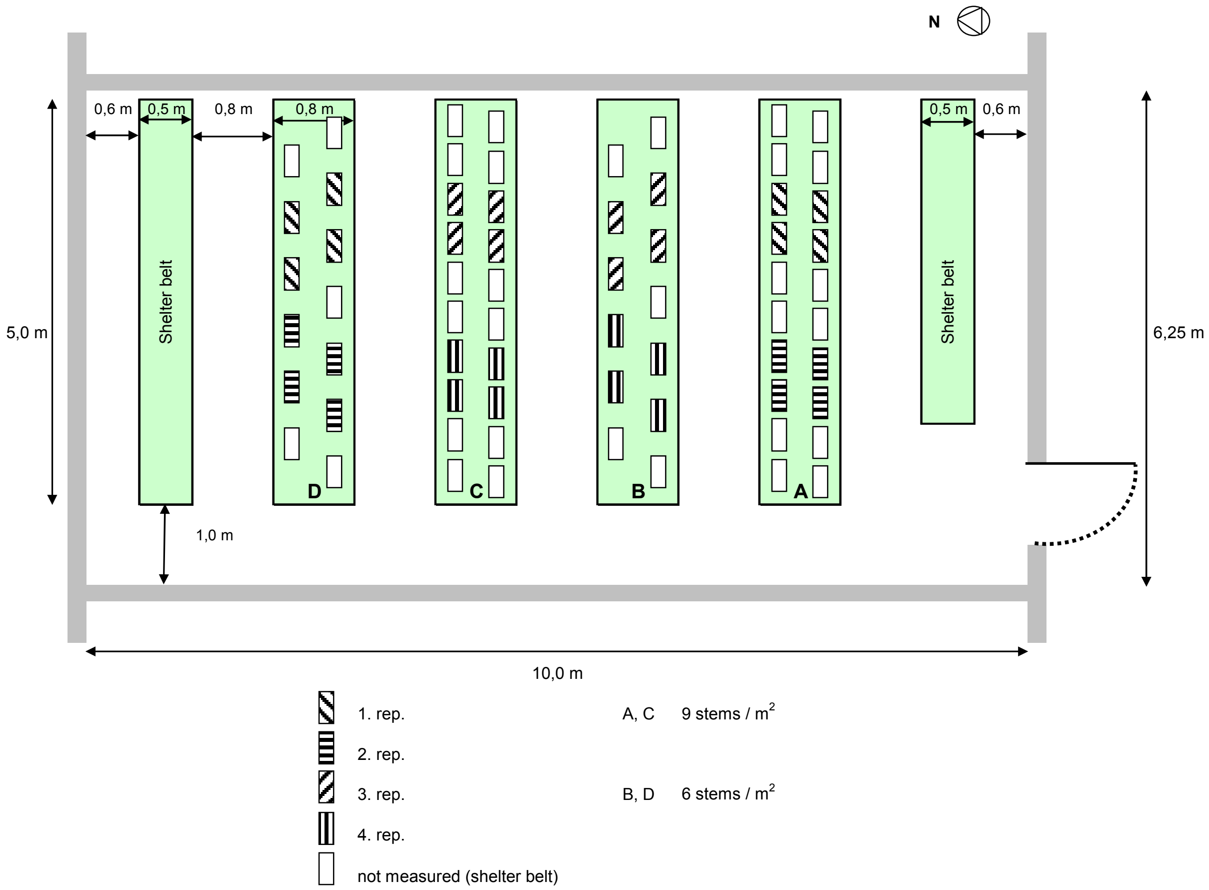

Fig. 1: Experimental design of cabinets.

Tab. 1: Irrigation of sweet pepper.

Group	Time of irrigation	Duration between irrigations	Duration of irrigation	Number of irrigations
		min	min	
Irrigation in all chambers				
20.10.08-26.10.08	07.00, 13.30, 18.00		3.00	3
27.10.08-01.11.08	07.00, 11.00, 14.30, 18.00		2.00	4
02.11.08-05.11.08	07.00, 11.00, 14.30, 18.00		2.30	4
06.11.08-13.12.08	07.00-19.05	180	2.30	5
14.12.08-21.12.08	06.00-21.05	150	2.00 2.15*	7
22.12.08-19.01.09	06.00-21.05	150	1.50 2.00*	7
20.01.09-25.01.09	05.00-21.05	120	1.50	9
26.01.09-03.02.09	05.00-21.05	105	1.30	10
04.02.09-11.02.09	05.00-21.05	90	1.30	11
12.02.09-09.03.09	04.30-21.35	60	1.00	18
10.03.09-09.04.09	04.30-21.35	45	1.00	23
Irrigation at light intensity over a special value				
28.01.09-10.02.09 (> 400 W/m^2)	05.45-11.05	90	1.00	4
11.02.09 (> 400 W/m^2)	10.30-13.35	60	1.00	7
12.02.09-09.03.09 (> 400 W/m^2)	11.00-14.05	60	1.00	0-10
10.03.09-12.03.09 (> 200 W/m^2)	10.00-17.00	60	1.00	6-9
13.03.09-27.07.09 (> 300 W/m^2)	10.00-17.00	60	1.00	0-16
Irrigation in nights in all chambers				
12.02.09-27.07.09	01.30		1.00	1
Irrigation in chambers with interlighting				
10.04.09-15.06.09	04.30-21.35	40	1.00	26
16.06.09-27.07.09	04.30-21.35	30	1.10 1.00*	35
Irrigation in chambers without interlighting				
10.04.09-15.06.09	04.30-21.35	45	1.00	23
16.06.09-27.07.09	04.30-21.35	35	1.00 0.55**	30

* TL 160 + IL 120

** TL 160

Temperature was kept at 22-23°C / 18-19°C (day / night) and ventilation started at 24°C. During a period of two weeks (middle to end of April) temperature was much lower (down to 14°C during nights and increased slower during day) because of local problems with the heating system. Carbon dioxide was provided (800 ppm CO_2 with no ventilation and 400 ppm CO_2 with ventilation). A misting system was installed.

Sweet pepper received standard nutrition (standard solution: 17,5 NH_4 mmol / l) consisting of calcium nitrate ($CaNO_3$, 15,5 % N) and Bröste red (9 % N): 9,8 kg $CaNO_3$ / 100 l H_2O and 8,5 kg Bröste red / 100 l H_2O) through drip irrigation (3 tubes per bucket). The watering was the following:

Plant cubes: 100 % $CaNO_3$: 70 % Bröste,
until 1. setting: 100 % $CaNO_3$: 76 % Bröste,
next 3 weeks 100 % $CaNO_3$: 100 % Bröste,
until 2. setting: 78 % $CaNO_3$: 100 % Bröste,
after 2. setting: 100 % $CaNO_3$: 100 % Bröste.

E.C. was adjusted to 1,8-2,5 depending on drainage E.C. and growth. Fertilizer application was kept the same in all cabinets until the beginning of April. After that the irrigation in cabinets with interlighting was increased, because plants differed in water uptake (Tab. 1).

Plant protection was managed by using beneficial organisms and if necessary with insecticides.

3.2 Lighting regimes

Sweet pepper was grown until 27.07.2009 under high-pressure sodium lamps (HPS) either with only top lighting (TL) or additional interlighting (IL) at four different lighting regimes, each in one cabinet:

1. TL 160 W/m^2
2. TL 120 W/m^2 + IL 120 W/m^2
3. TL 240 W/m^2
4. TL 160 W/m^2 + IL 120 W/m^2

HPS lamps for top lighting (600 W bulbs) were mounted horizontally over the canopy (4 m above ground) and lamps for interlighting (250 W bulbs) first 0,25-0,50 m over the canopy (depending on plant height) and on 17.03.2009 lamps were lowered and placed between plants in the rows (approximately 0,90 m above ground). Light was provided for 18 hours (20.10.2008-06.04.2009: 04.00-22.00) / 16 hours (07.04.2009-

27.07.2009: 04.00-20.00), but 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 illuminance (subdivided between vertical and horizontal illuminance) manually at the beginning of the growth period twice a month, but then monthly at different vertical heights above ground (0 m, 0,5 m, 1,0 m, 1,5 m, 2,0 m) and at different horizontal positions (near the plant, between two plants, at the end of the bed, Fig. 2) under diffuse light conditions.

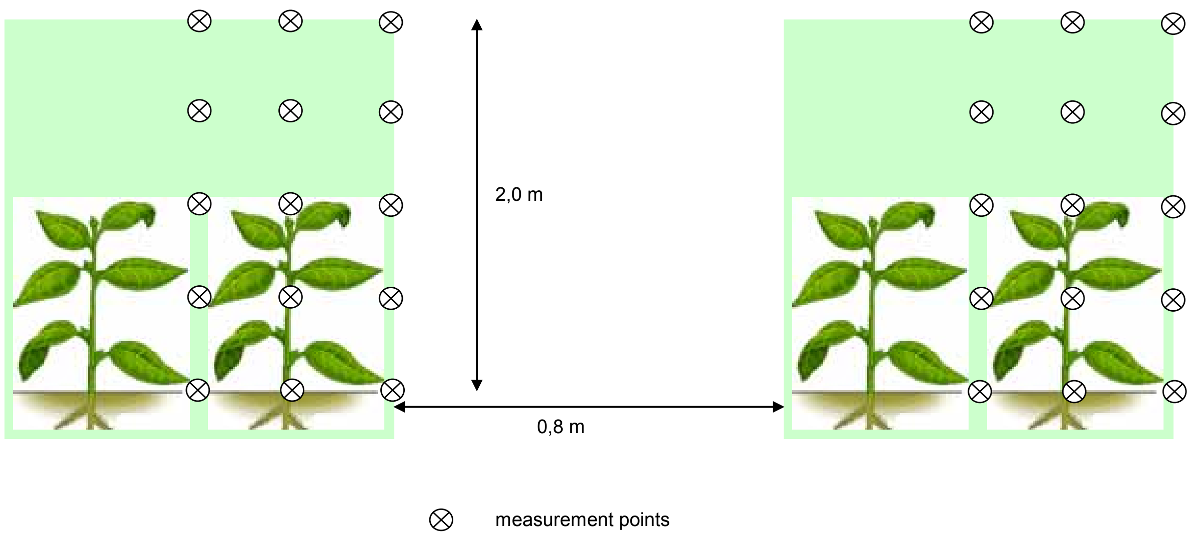

Fig. 2: Measurement points of illuminance and air temperature.

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 and the number of fruits was counted. Additional measurements included the time from the fruit setting up to the date of the harvest of the fruit. Leaf area index (LAI) was determined using a LI-COR Portable Area Meter (LI-3000, LICOR, Lincoln, Nebraska, USA) and the number and distance of nodes was measured at the end of the growth period.

Yield (fresh and dry biomass) of seedlings and their N content was analyzed. During the growth period, green and red fruits (> 50 % red) were regularly collected in the subplots each week. Total fresh yield, number of fruits, fruit category (1^{st} class) and not marketable fruits was determined, each subdivided into red and green fruits. Additional samplings included stripped leaves during the growth period. At the end of the growth period on two plants (plants from one bucket) from the subplots the weight and the number of harvested and immature fruits was measured. 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 (seven for stripped leaves, eight for green and red fruits) was 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 sweet pepper.

In addition to regularly deformation analyzes, 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 once per month. From the same harvest, the flavour of fresh fruits was examined three times (at the beginning, middle and end of the harvest period) in tasting experiments with untrained assessors.

Composite soil samples for analysis of nitrate-N and ammonium-N were taken before starting with different lighting regimes and from the subplots 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, also in interaction with stem density.

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 $p \leq 0,05$. Regression and correlation analyses were calculated using the SAS procedure “proc reg” and “proc corr”.

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. From the 20th of October 2008 (beginning of the experiment) to the end of February 2009 there was an extremely low natural light level with less than 5 kWh/m^2. However, with longer days solar irradiation increased naturally continuously to 15-20 kWh/m^2 at the middle of April 2009. Solar irradiation rose from the beginning of May until the end of the experiment to around 30 kWh/m^2 (Fig. 3).

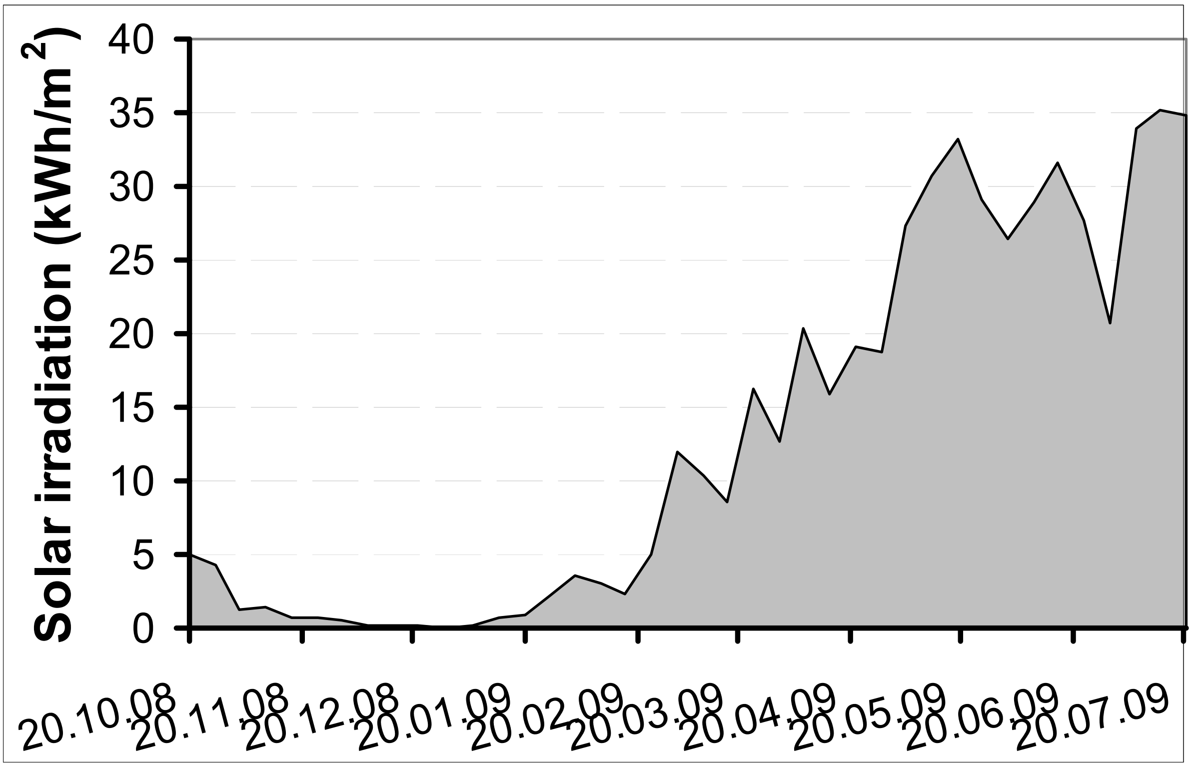

Fig. 3: Time course of solar irradiation. Solar irradiation was measured every day and values for one week were cumulated.

4.1.2 Illuminance

Illuminance is the total luminous flux incident on a surface, per unit area. In the case of the sweet pepper experiment solar irradiation was allowed to come into the greenhouse and therefore, illuminance is composed of solar irradiation and light

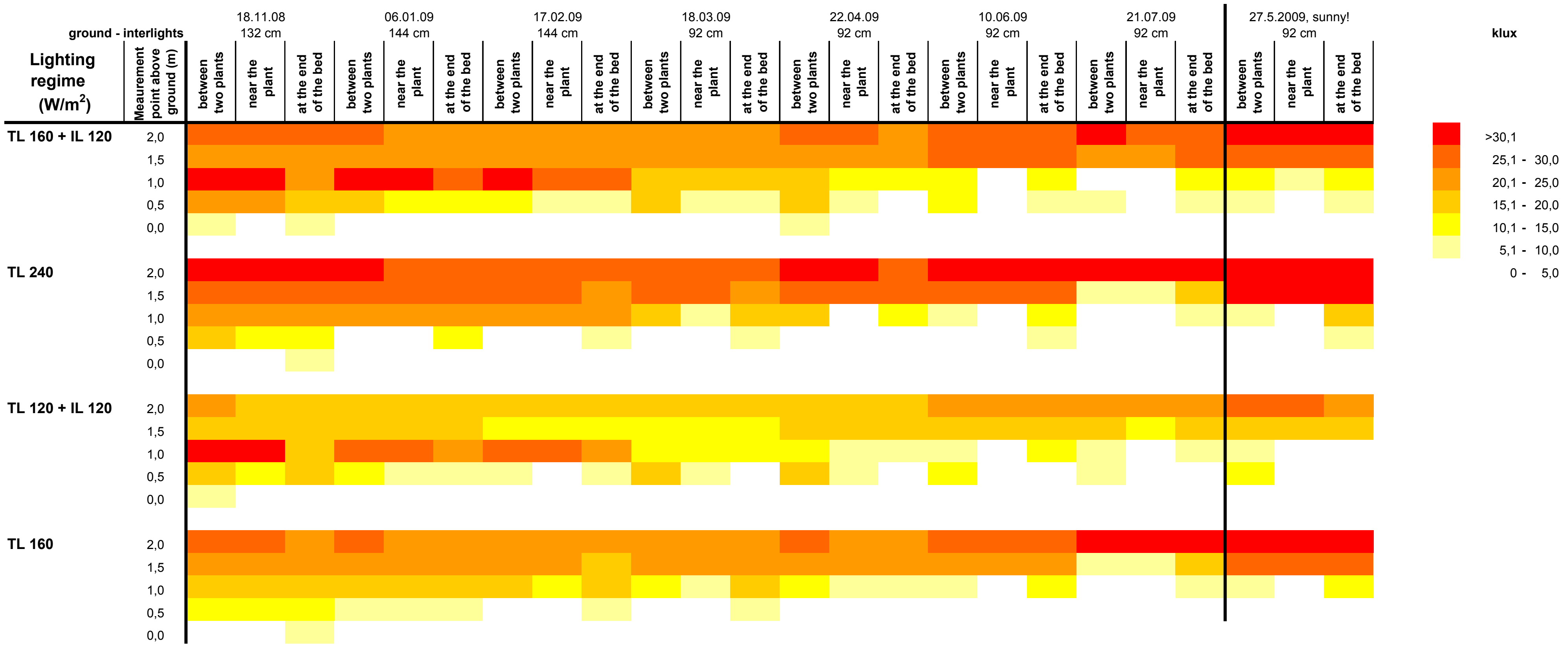

Fig. 4: **Illuminance (solar irradiation + light intensity of HPS lamps) at different lighting regimes. The illuminance was measured early in the morning at cloudy days. Interlights were placed in between the rows on 17.03.2009.**

intensity of HPS lamps. To eliminate the incoming solar irradiation the illuminance was measured early in the morning during cloudy days.

The measured values for the illuminance are converted into colours (red for high illuminance, yellow / white for low illuminance). The illuminance increased naturally with light intensity (compare TL 160 with TL 240 and TL 120 + IL 120 with TL 160 + IL 120, Fig. 4). With top lighting alone the illuminance was highest at the uppermost measurement points (2 m). With interlighting the illuminance was highest close to the placement of the interlight; but when interlights were lowered in between the rows (17.03.2009), the highest illuminance was also measured at the uppermost measurement points. The addition of the interlight to TL 160 did not change the illuminance at the upper levels, but close to the placement of the interlight the light intensity increased. With longer growing period the illuminance at lower heights decreased (Fig. 4) because of increased sweet pepper biomass and shading of leaves. Stem density did not influence illuminance (data not shown).

In contrast to cloudy days, at sunny days (27.05.2009, Fig. 4) the illuminance did not differ much between different lighting regimes.

4.1.3 Air temperature

HPS light bulbs produce light as well as heat. Therefore, air temperature is composed of adjusted air temperature in the cabinets and heat of HPS lamps. To eliminate the temperature from incoming solar irradiation the air temperature was measured early in the morning during cloudy days.

The measured values for the air temperature are converted into colours (red for high air temperature, yellow / white for low air temperature). With top lighting the air temperature increased with light intensity (compare TL 160 with TL 240, Fig. 5) and was quite similar at all measurement points. In contrast, the air temperature was similar with TL 120 + IL 120 and TL 160 + IL 120. With interlighting the air temperature was highest close to the placement of the interlight, but when interlights were lowered in between the rows (17.03.2009), the air temperature was high close to the interlight and also at the uppermost measurement points. The addition of the interlight to TL 160 changed the air temperature at all measurement points.

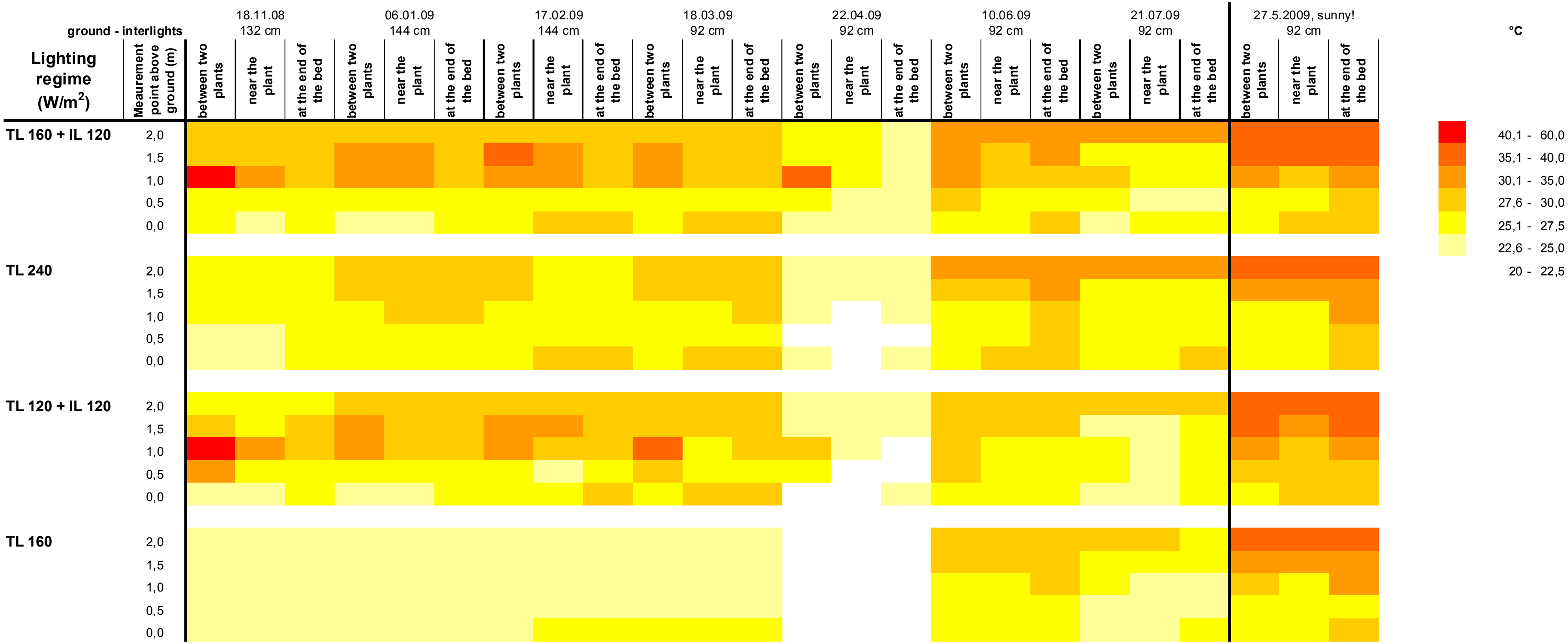

Fig. 5: **Air temperature (adjusted air temperature in the cabinet + heat of HPS lamps) at different lighting regimes. The air temperature was measured early in the morning at cloudy days. Interlights were placed in between the rows on 17.03.2009.**

There was a problem with the heating system from the middle to the end of April, which is the reason why the temperature dropped down. Therefore, on 22.04.2009 the air temperature was much lower compared to the other dates and the heating effect of the interlights was becoming obvious (Fig. 5). No differences in the air temperature between different stem densities could be observed (data not shown). But, air temperature was lowest (about 1-2°C lower compared to the other beds) at the bed close to the window (6 stems/m^2). This effect was less pronounced at TL 160.

In comparison to cloudy days, the air temperature did not differ much between different lighting regimes at sunny days (27.05.2009, Fig. 5).

4.1.4 Soil temperature

Soil temperature was mainly influenced by temperature of the heating pipe and was measured weekly at low solar irradiation early in the morning. Since the middle of February the heating pipe was at maximum temperature (50°C), but before at a lower value.

Until the end of April soil temperature was fluctuating much. However, from May to the end of the experiment (and included high solar irradiation), soil temperature stayed steady between 22-25°C (Fig. 6). When the temperature of the heating pipe was of a similar value in all cabinets, soil temperature was lowest at the lowest light intensity (TL 160) or mostly low compared to the other light intensities. When temperature of the heating pipe was highest at the lower light intensity, soil temperature did show much variation from low, average and very high in relation to the other light intensities. Soil temperature at TL 160 + IL 120 was almost always higher than at TL 120 + IL 120. From the middle to the end of April soil temperature was low because of problems with the heating system. Soil temperature was slightly higher at 6 stems/m^2 compared to 9 stems/m^2.

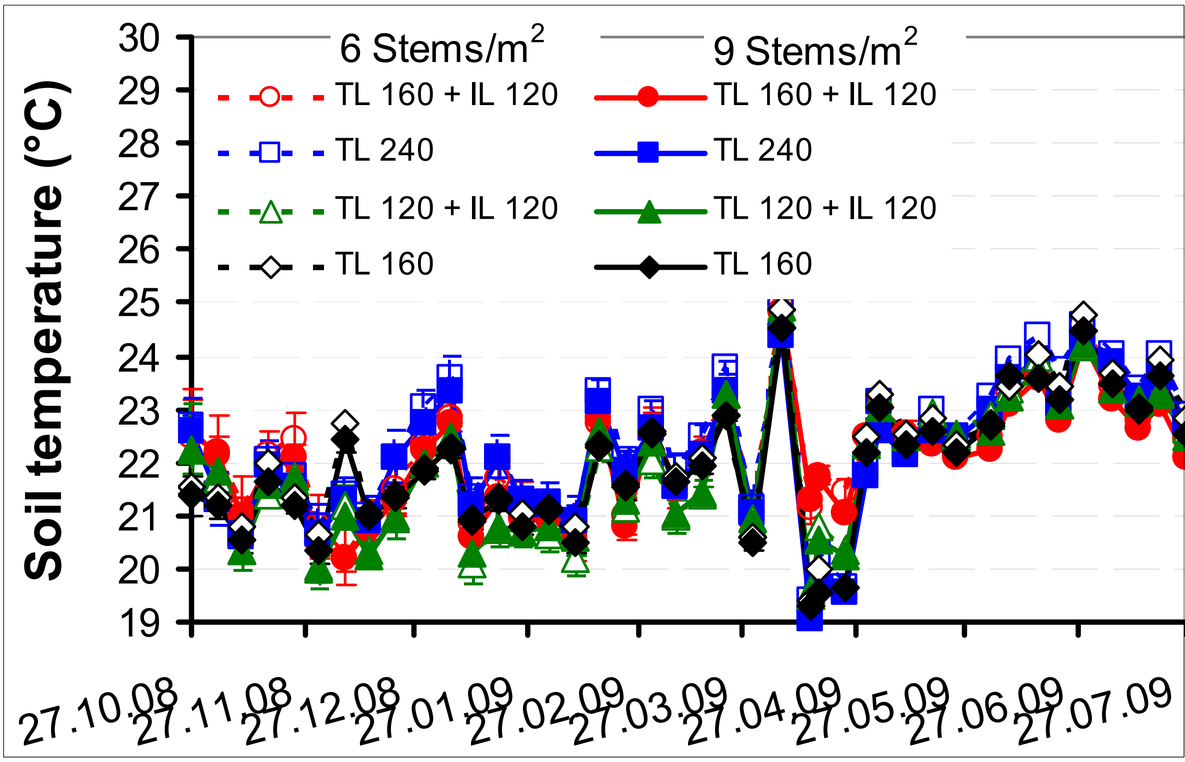

Fig. 6: **Soil temperature at different lighting regimes and different stem densities. The soil temperature was measured at little solar irradiation early in the morning.**

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

4.1.5 Irrigation of sweet pepper

E.C. and pH of irrigation water was fluctuating much (Fig. 7 a, b). E.C. ranged between 1,5 and 3,0 and pH between 5,0 and 6,5. E.C. of runoff increased during the growth period from 2,0 to about 3,0 (Fig. 7 c). PH of runoff decreased from 8,0 to 4,5 at the end of February and increased after that to about 6,5 in April and stayed at that value until the end of the experiment (Fig. 7 d). E.C. and pH of runoff increased with light intensity (Fig. 7 c, d).

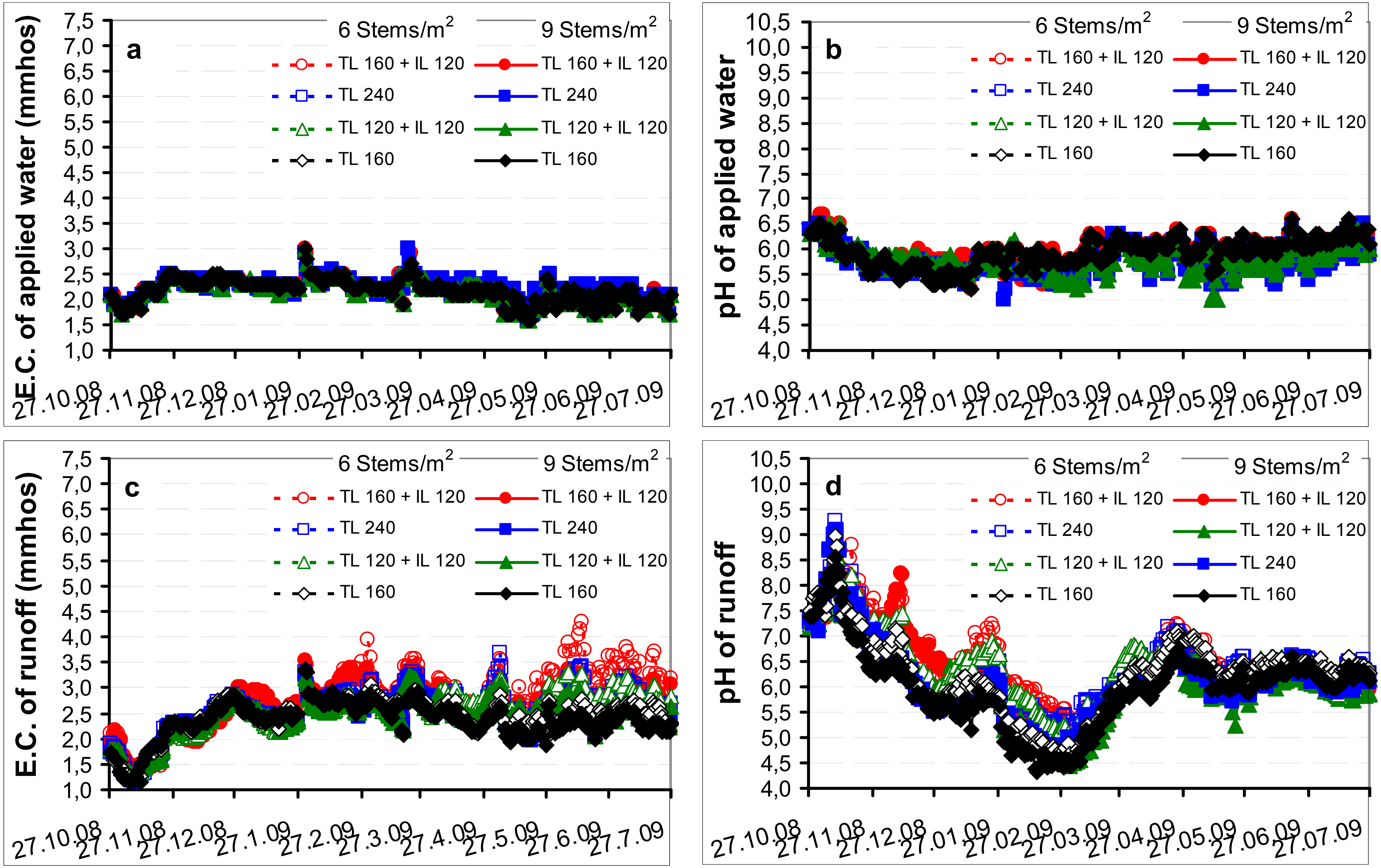

Fig. 7: E.C. (a, c) and pH (b, d) of irrigation water (a, b) and runoff of irrigation water (c, d).

The amount of runoff from applied irrigation water was about 20-60 % (Fig. 8). From the end of January to the end of the experiment, the amount of runoff from applied water decreased. The decrease was most obvious with the highest light intensity and with the lowest stem density.

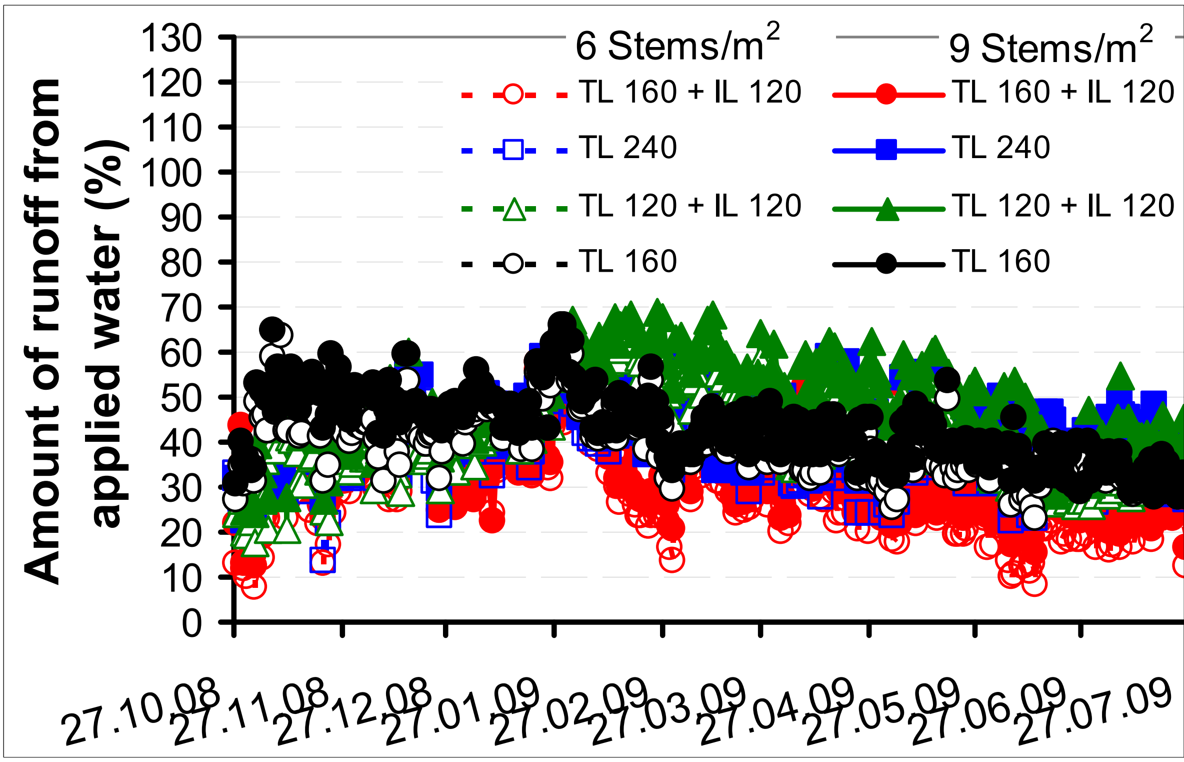

Fig. 8: **Proportion of amount of runoff from applied irrigation water at different lighting regimes and stem densities.**

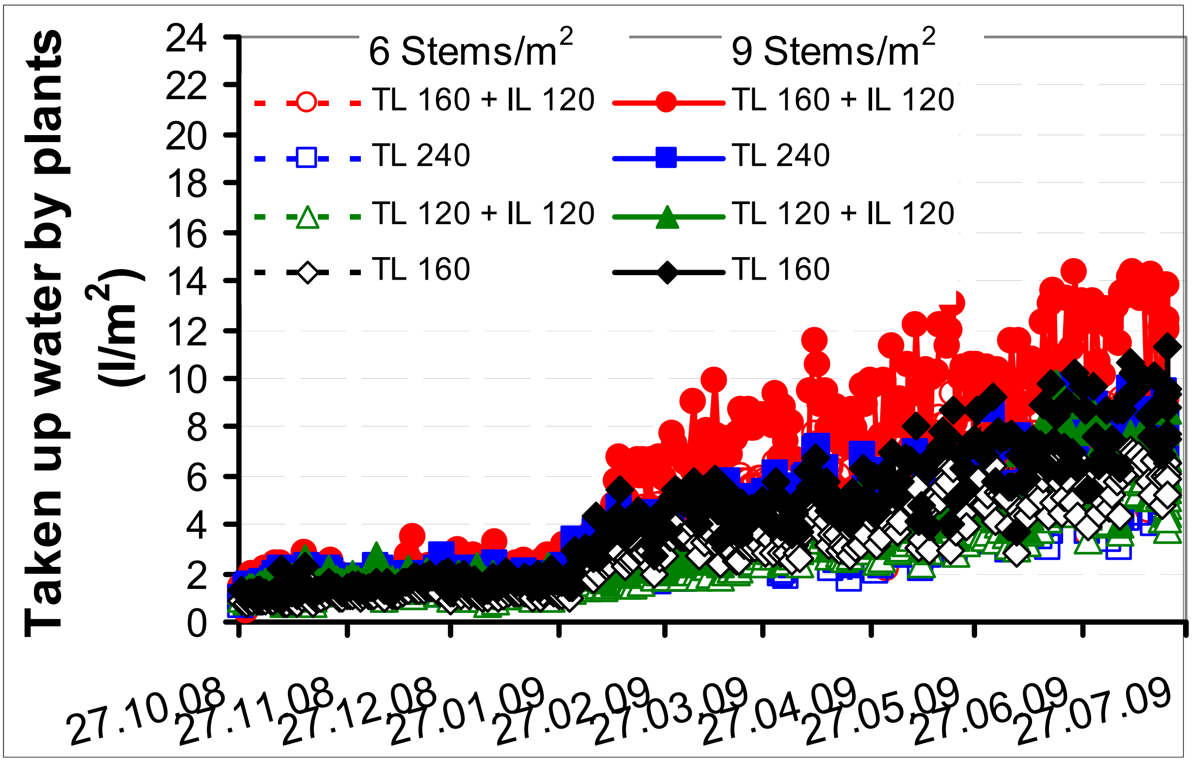

Fig. 9: **Water uptake at different lighting regimes and stem densities.**

With longer growing period taken up water by plants increased naturally (Fig. 9). Until the end of January plants took up approximately 2 l/m^2. Thereafter, water uptake highly increased to 4-14 l/m^2, and was higher with the highest light intensity.

4.2 Development of sweet pepper

4.2.1 Height

35 cm high sweet pepper was transplanted into the greenhouse. Sweet pepper was growing 1 cm/day at the beginning of the growth period, but decreased to 0,5 cm/day after 3 weeks. Since the middle of December sweet pepper was growing 0,3-0,4 cm/day and since the middle of May about 0,5-0,6 cm/day (Fig. 10). The height of plants decreased with light intensity. Plants with 6 stems/m^2 receiving the highest light intensity were significantly lower than all other light intensities with 9 stems/m^2. Plants with 9 stems/m^2 were tendentially higher than with 6 stems/m^2.

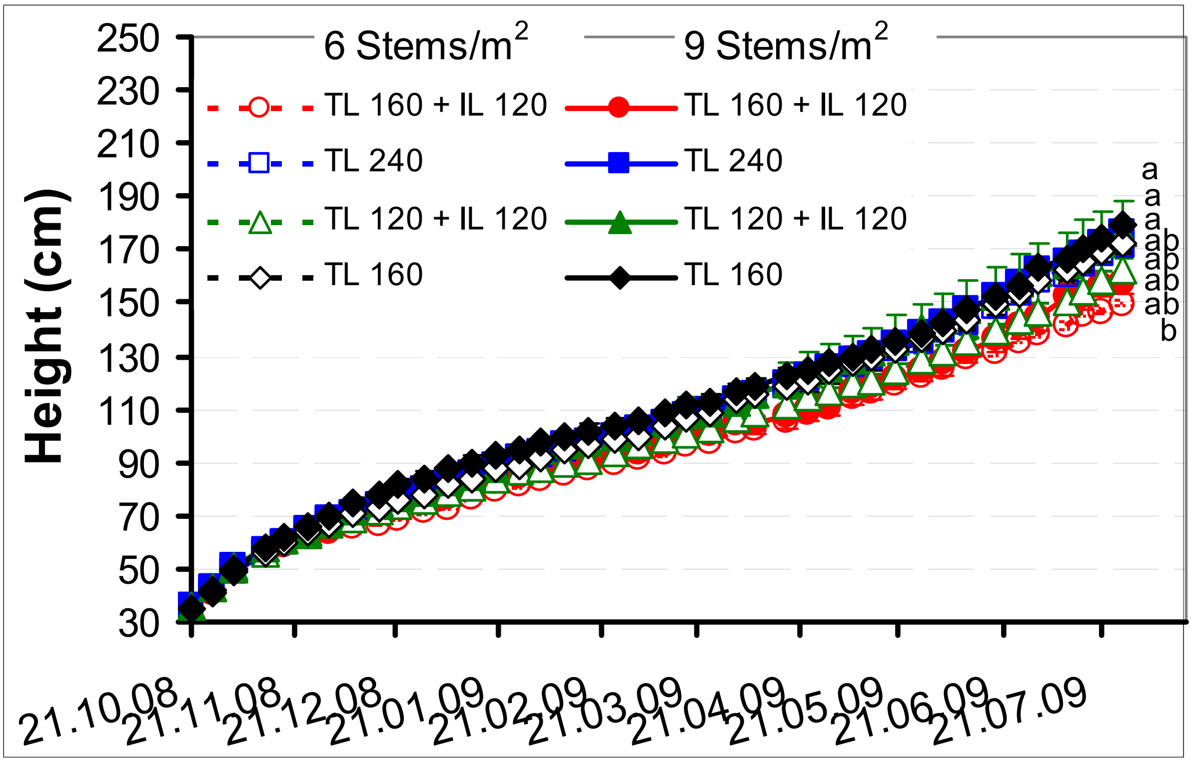

Fig. 10: Height of sweet pepper at different lighting regimes and stem densities.

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, $p \leq 0,05$).

With increasing height of sweet pepper water consumption rose (Fig. 11). With top lighting alone the increment of taken up water was comparable with both light intensities. However, with top lighting and interlighting the increase was more obvious with the higher light intensity.

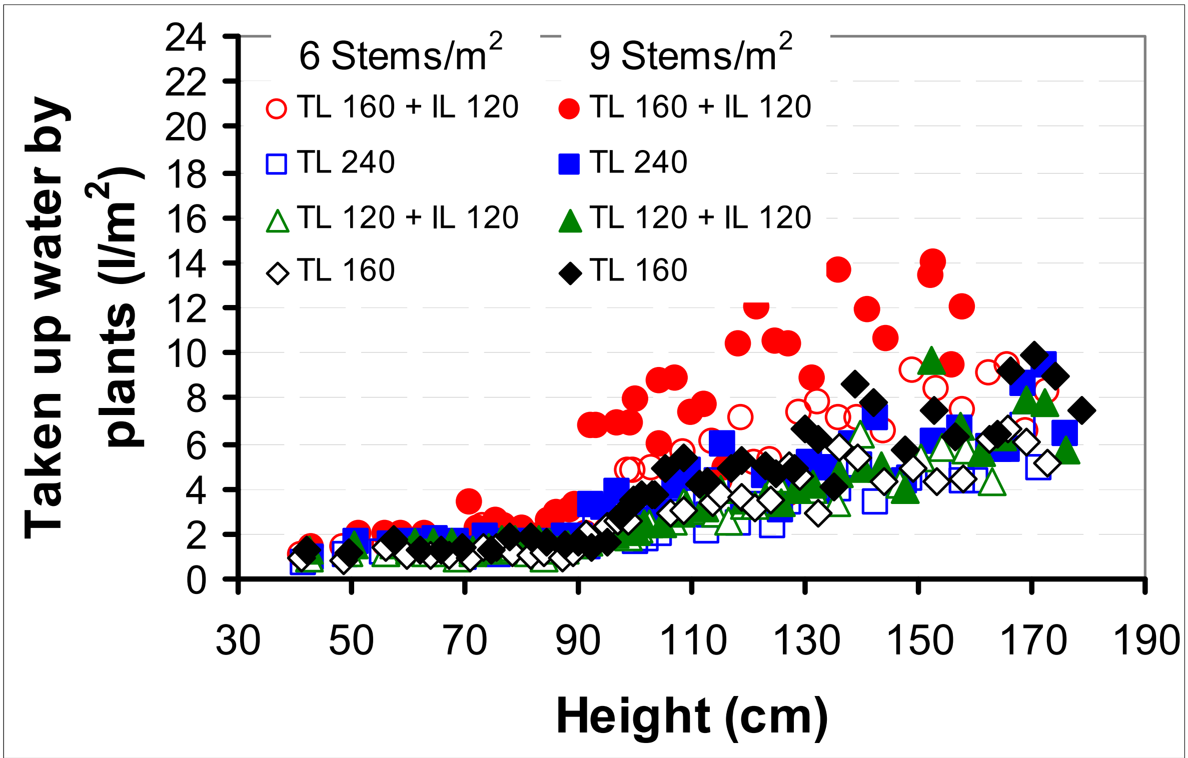

Fig. 11: Relationship between height of sweet pepper and taken up water by sweet pepper plants at different lighting regimes and stem densities.

4.2.2 Number of fruits on a plant

The number of fruits on the plant was fluctuating between 30-50 fruits/m^2 (Fig. 12). The number of fruits per square meter increased with a higher stem density. It seems that the number of fruits at 9 stems/m^2 was higher with a higher light intensity, whereas the number at 6 stems/m^2 was not influenced by light intensity. This influence was more obvious at the beginning of the growth period, but from middle of April with higher solar irradiation, number of fruits was more or less the same at different light intensities. The placement of the lamps (either 240 W/m^2 as top lights or subdivided into top lights and interlights) did not influence number of fruits.

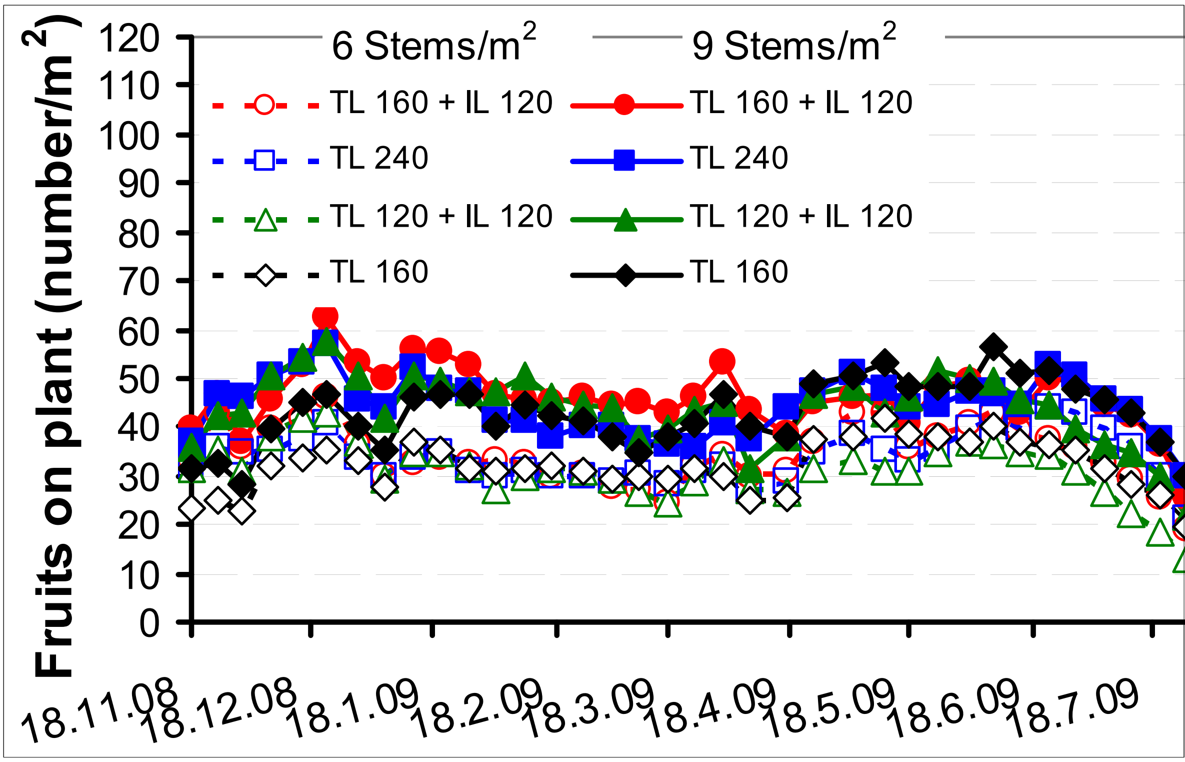

Fig. 12: Number of fruits (green and red) on the plant at different lighting regimes and stem densities.

4.3 Yield

4.3.1 Total yield of fruits

The yield of sweet pepper included all harvested red and green fruits and the green fruits at the end of the growth period. The fruits were classified in 1st class fruits (> 100 g/fruit), fruits with too little weight (< 100 g), fruits with blossom end rot, fruits with damage from lighting, not well shaped fruits, and fruits that were too mature and at the same time not mature. More than 50 % of the harvested marketable fruits were red.

Cumulative total yield of sweet pepper ranged between 28-43 kg/m^2 and increased with light intensity (Fig. 13). The yield level was significant / tendential higher at 9 stems/m^2 than at 6 stems/m^2 at the highest light intensity / at all other light intensities. An increase of the light intensity from TL 160 to TL 240 / TL 120 + IL 120 to TL 160 + IL 120 resulted in a cumulative total yield increase of 8 / 7 % (6 stems/m^2) and 17 / 18 % (9 stems/m^2). The total cumulative yield was the same, independently of the placement of the lights, however with a tendentially higher yield advantage when light intensity was subdivided into top lights and interlights (Fig. 13).

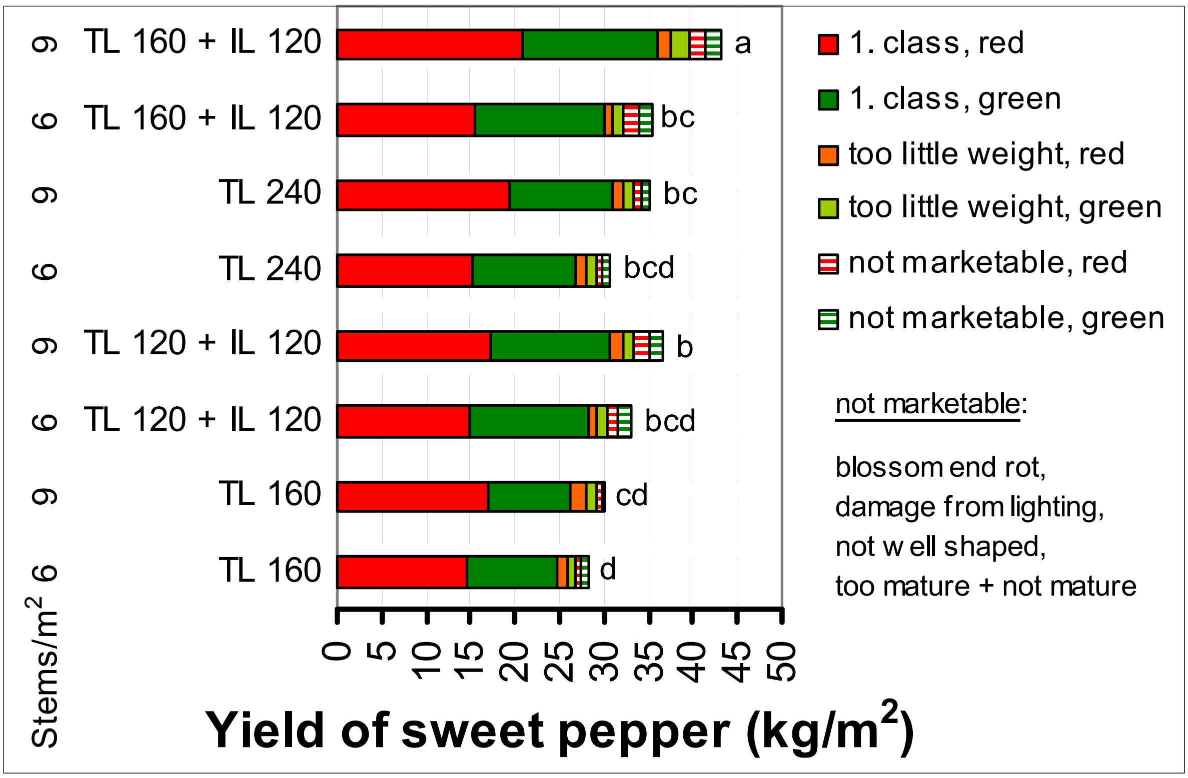

Fig. 13: Cumulative total yield at different lighting regimes and stem densities. (1st class: > 100 g, too little weight: < 100 g).
Yield of too little weight was also not marketable, but classified as an extra group because there was a relatively high amount of these fruits.

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

4.3.2 Marketable yield of fruits

Marketable yield of sweet pepper increased with light intensity (Fig. 14). At the lowest light intensity the accumulated marketable yield was not influenced by stem density. However, with higher light intensity the positive effect of a higher stem density was becoming obvious and with the highest light intensity, marketable yield was significantly higher with 9 stems/m^2 than with 6 stems/m^2. This effect was developed during the low natural light level (26.11.2008-06.04.2009, Tab. 2), whereas from the middle of April (and involving increasing solar irradiation, Fig. 3) neither a higher stem density nor a higher light intensity was reflected in a significant yield increment (Tab. 2). Marketable yield of weekly harvests differed between lighting regimes until the middle of April, but thereafter marketable yield between different treatments was more or less the same (Fig. 14). Placement of lamps (240 W/m^2 either as top lighting alone or subdivided into top lighting and interlighting) did not affect marketable yield (Fig. 14, Tab. 2).

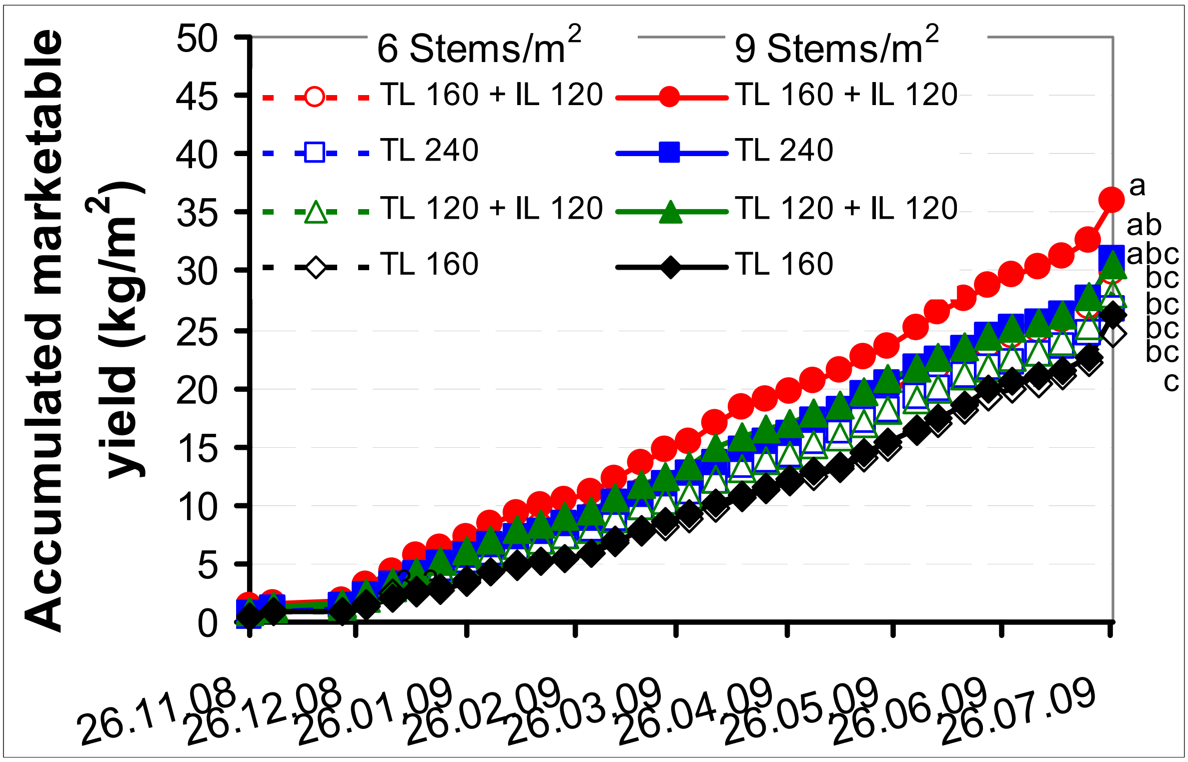

Fig. 14: Time course of accumulated marketable yield at different lighting regimes and stem densities.

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

Tab. 2: Cumulative marketable yield at different lighting regimes and stem densities.

Light intensity	**Stem density** Stems/m^2 6	 9	 6	 9
	Accumulated marketable yield kg/m^2			
	26.11.2008-06.04.2009		**14.04.2009-27.07.2009**	
TL 160 + IL 120	13,8 ab	17,0 a	16,2 ab	19,0 a
TL 240	12,0 bcd	13,7 abc	14,7 b	17,2 ab
TL 120 + IL 120	12,3 bcd	15,0 ab	15,9 ab	15,6 b
TL 160	9,7 d	10,1 cd	15,0 b	16,1 ab

Letters indicate significant differences (HSD, p ≤ 0,05).

During low solar irradiation an increase of the light intensity of 50 % (from TL 160 W/m^2 to TL 240 W/m^2) increased the yield by 24 % (6 stems/m^2) respectively 36 % (9 stems/m^2). However, at higher light intensities nearly the same yield increment (12 % at 6 stems/m^2 and 13 % at 9 stems/m^2) was reached with only a W/m^2 increase of 17 % (from TL 120 + IL 120 to TL 160 + IL 120). Out from this calculations, it can be concluded, that 0,5-0,8 % yield increase was achieved by an 1 % increase in light increment.

The relationship between the accumulated marketable yield and the light intensity showed clearly the yield advantage of a higher stem density at a higher light intensity (Fig. 15). However, if the trend line would be extrapolated, there would be at < 112,5 W/m^2 a higher accumulated marketable yield with 6 stems/m^2 than with 9 stems/m^2.

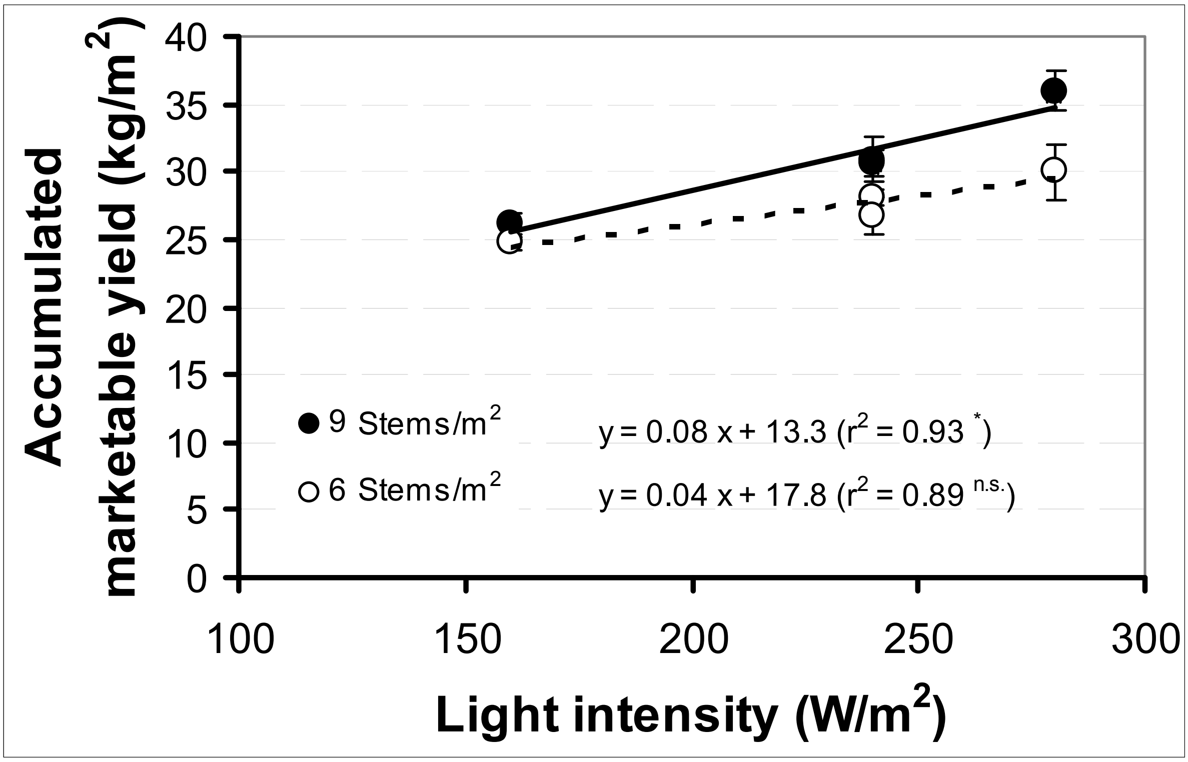

Fig. 15: Relationship between accumulated marketable yield and light intensity.

Coefficient of determination was significant at the 0,1 % probability level (n = 3).

The first harvest at the end of November included only green fruits. After that no fruits were harvested for two weeks in December (Fig. 16), as fruits needed time to ripe red. Problems with the heating system and therefore cold temperatures in the greenhouse caused low yields at the end of April. Despite high solar irradiation from middle of April to the end of the experiment (Fig. 16), weekly harvests did not increase. At the end of the growing period all fruits were harvested, hence marketable yield was very high compared to the other harvests.

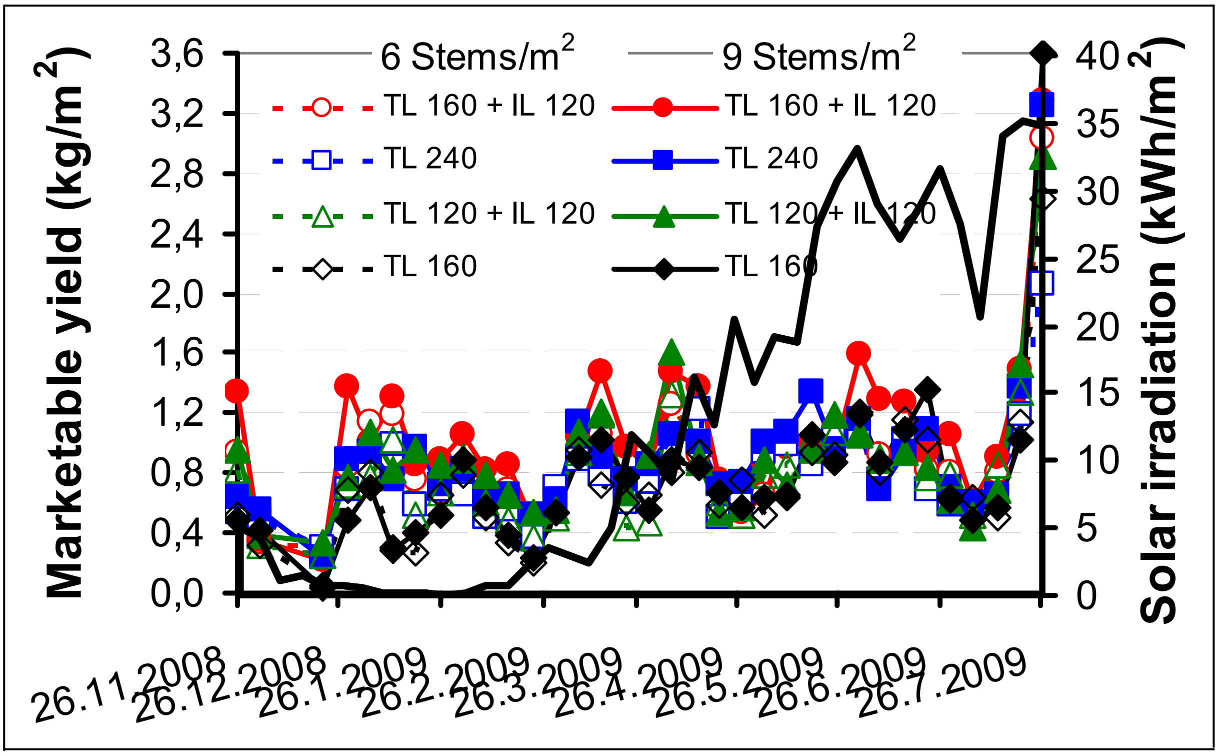

Fig. 16: Time course of marketable yield at different lighting regimes and stem densities and solar irradiation.

When the marketable yield of the highest light intensity (TL 160 + IL 120) corresponded to 100 % and regarding this the % marketable yield of the lowest light intensity (TL 160) was calculated, this value reached at the beginning of the harvest period 50-60 % (Fig. 17). However, the proportion of marketable yield of the lowest light intensity on the highest light intensity increased at the end of February. This increase was especially pronounced since middle of April and reached 80 % at the end of the harvest period.

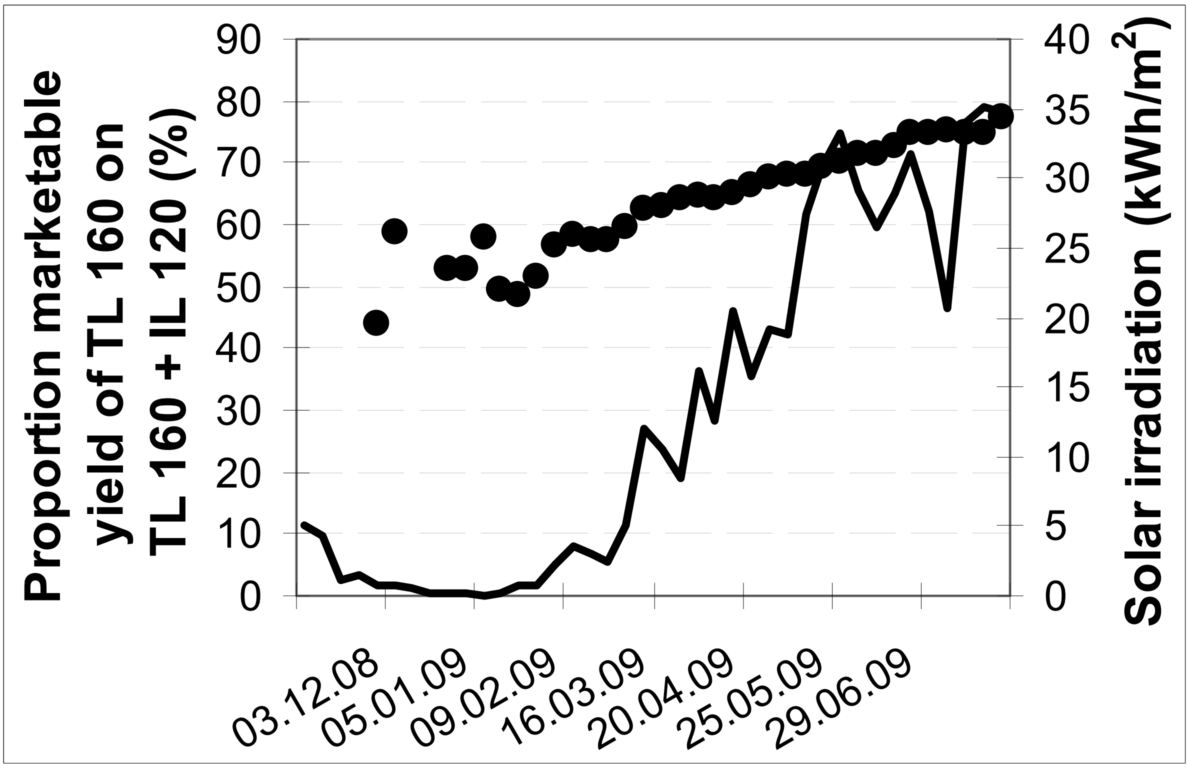

Fig. 17: Proportion of marketable yield of the lowest light intensity (TL 160) on marketable yield of the highest light intensity (TL 160 + IL 120).

Number of marketable fruits increased with light intensity as well as with stem density (Tab. 3). When light intensity was increased from the lowest light intensity to the highest light intensity the increment in marketable fruits was 22 % at 6 stems/m^2 and 35 % at 9 stems/m^2.

Tab. 3: Cumulative total number of marketable fruits (red and green) at different lighting regimes and stem densities.

	Stem density			
Light intensity	Stems/m^2			
	6	9	6	9
	Number of marketable fruits		**Proportion of red fruits on marketable fruits**	
			%	
TL 160 + IL 120	218 abc	252 a	54	48
TL 240	189 bc	219 ab	58	53
TL 120 + IL 120	196 bc	219 ab	53	48
TL 160	173 c	187 bc	62	55

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

The proportion of red fruits on marketable fruits was higher at 6 stems/m^2 (53-62 %) than at 9 stems/m^2 (48-55 %). Less red fruits were harvested at regimes with interlighting (Tab. 3).

Average fruit size was consistently unaffected by stem density and light intensity. Red fruits were harvested with about 150 g and green fruits with about 130 g (data not shown).

4.3.3 Ripening time of fruits

From fruit setting to harvest, green fruits were harvestable in 4-5 weeks and red fruits in 8-9 weeks (Tab. 4). The highest light intensity influenced time from fruit setting to harvest positively and fruits from TL 160 + IL 120 were mostly significantly earlier mature than fruits from TL 160. The placement of the lights, either as top lights alone or subdivided into top lights and interlights did not influence ripening. The comparison of the stem densities could indicate that maybe a higher stem density would extend the ripe (Tab. 4).

Tab. 4: Time from fruit setting to harvest of green and red fruits at different lighting regimes and stem densities at low solar irradiation.

Light intensity	Stem density Stems/m^2 6	 9	 6	 9
	Weeks from setting to harvest of green fruits		**Weeks from setting to harvest of red fruits**	
TL 160 + IL 120	4,2 c	4,4 bc	8,2 b	8,4 ab
TL 240	5,0 ab	4,9 ab	8,7 ab	8,6 ab
TL 120 + IL 120	4,4 bc	4,7 bc	8,5 ab	8,8 ab
TL 160	4,9 ab	5,6 a	9,1 a	8,9 ab

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

4.3.4 Total fruit set

Total fruit set was calculated (fruit set (%) = (number of fruits harvested x 100) / total number of internodes) at the end of the harvest period and ranged from about 60 to 90 %. Fruit set increased with lower stem density and higher light intensity (Fig. 18). Interlighting increased slightly the fruit set (compare TL 240 with TL 120 + IL 120).

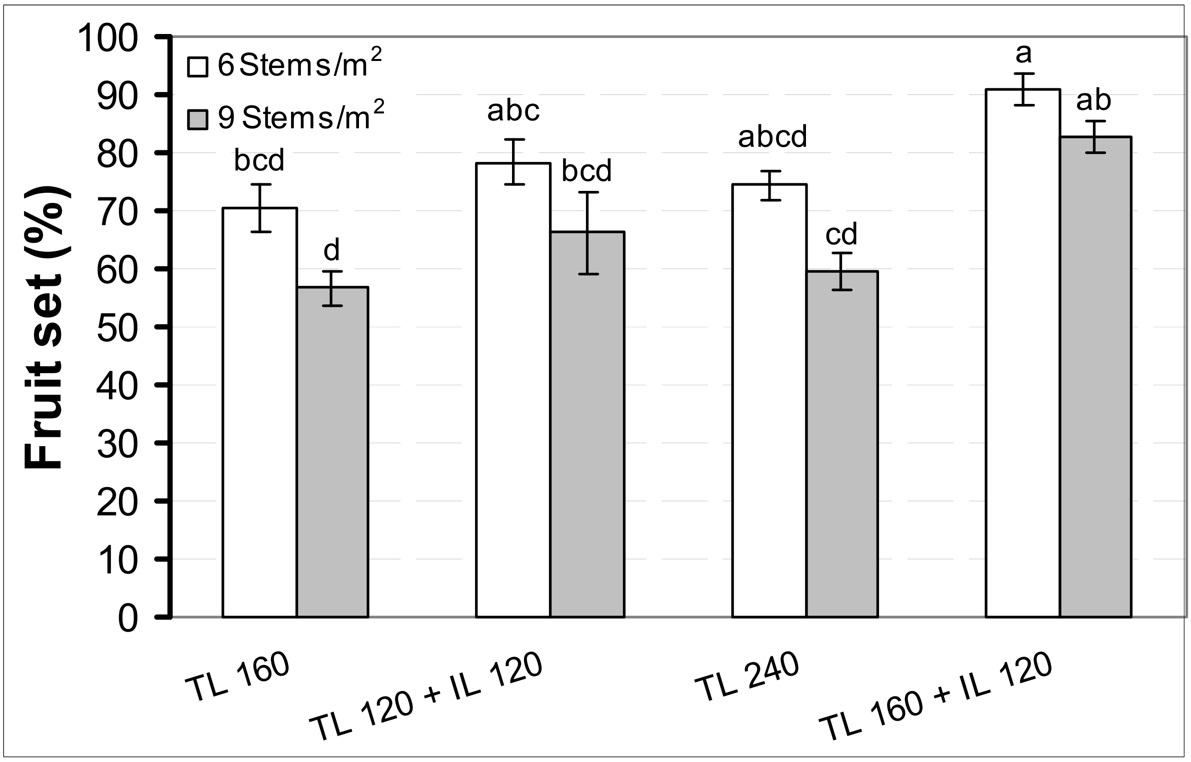

Fig. 18: **Fruit set** (fruit set (%) = (number of fruits harvested x 100) / total number of internodes) **at different lighting regimes and stem densities.**

Error bars indicate standard deviations.

Letters indicate significant differences (HSD, p ≤ 0,05).

4.3.5 Outer quality of yield

Marketable yield was 84-88 % of total yield during the whole harvest period. With top lighting not marketable yield was attributed to 7-8 % of fruits with too little weight (< 100 g), 1-2 % not well shaped fruits and 3 % blossom end rot (Fig. 19 a). However, top lighting together with interlighting increased unmarketable yield (additional 2 % more fruits with blossom end rot and 2 % fruits with damage from lighting) (Fig. 19 b). Especially, when interlights were lowered in between the rows the amount of unmarketable fruits (5 % fruits with damage of lighting from lowering the interlights to the end of the experiment) increased. The number of fruits with too little weight was highest with the lowest light intensity.

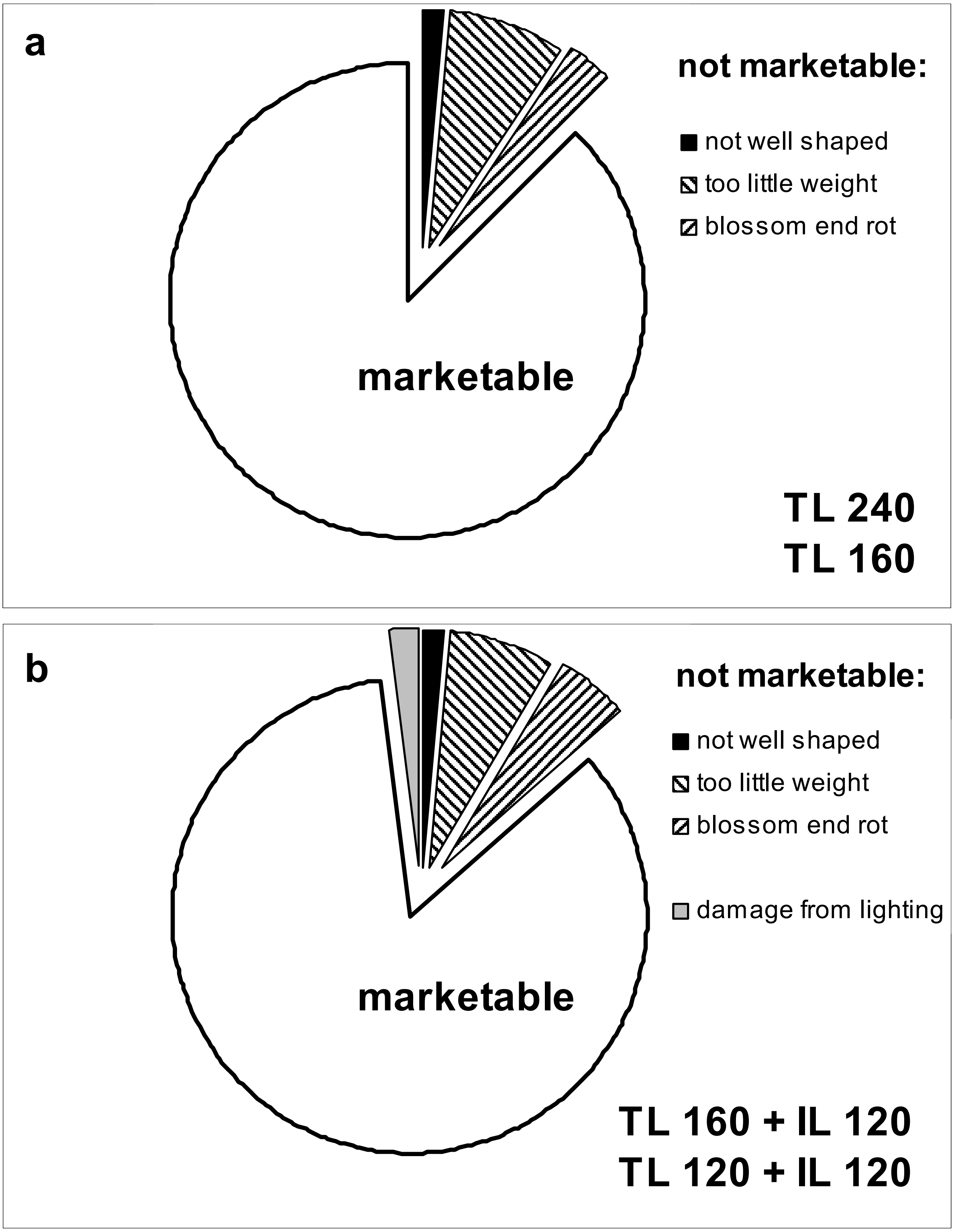

Fig. 19: Proportion of marketable and unmarketable yield at top lighting alone (a) and at top lighting together with interlighting (b).

4.3.6 Interior quality of yield

4.3.6.1 Sugar content

Sugar content of red and green fruits was measured monthly and increased with maturation of fruits from about 4 (green fruits) to about 7 °BRIX (red fruits) (Fig. 20).

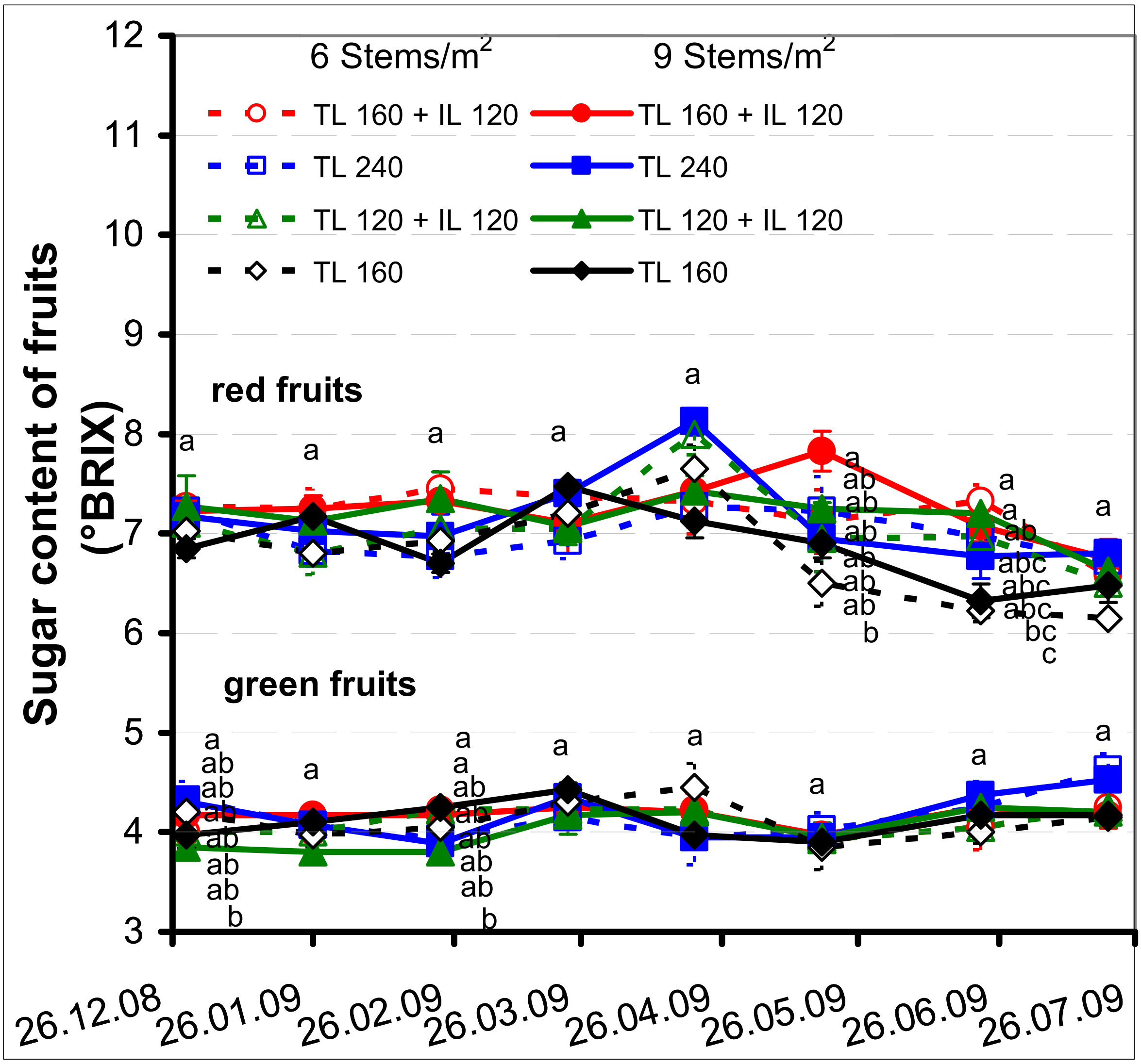

Fig. 20: Sugar content of green and red fruits at different lighting regimes and stem densities.

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 ≤ 0,05).

Most of the time there was no significant difference in sugar content between different lighting regimes and stem densities. It seems, that a higher light intensity may result in a higher sugar content (compare TL 160 with TL 240 and TL 120 + IL 120 with TL 160 + IL 120). Stem density was not affecting the sweetness of sweet pepper (Fig. 20).

4.3.6.2 Taste of red fruits

The taste of red fruits, subdivided into sweetness, flavour and juiciness was tested by untrained assessors at the beginning (27.02.2009), middle (24.03.2009) and at the end (23.06.2009) of the harvesting period. No differences in taste, sweetness, flavour and juiciness of red sweet pepper was found with regard to light intensities or between stem densities (data not shown). The rating within the same sample was varying very much and therefore, same treatments resulted in a high standard deviation. There was no relationship between measured sugar content and sweetness of fruits at the two former tastings (data not shown). However, at the last date there was a relationship ($r^2 = 0{,}66^{***}$) between the sugar content of red fruits and their sweetness in the tasting experiment (Fig. 21).

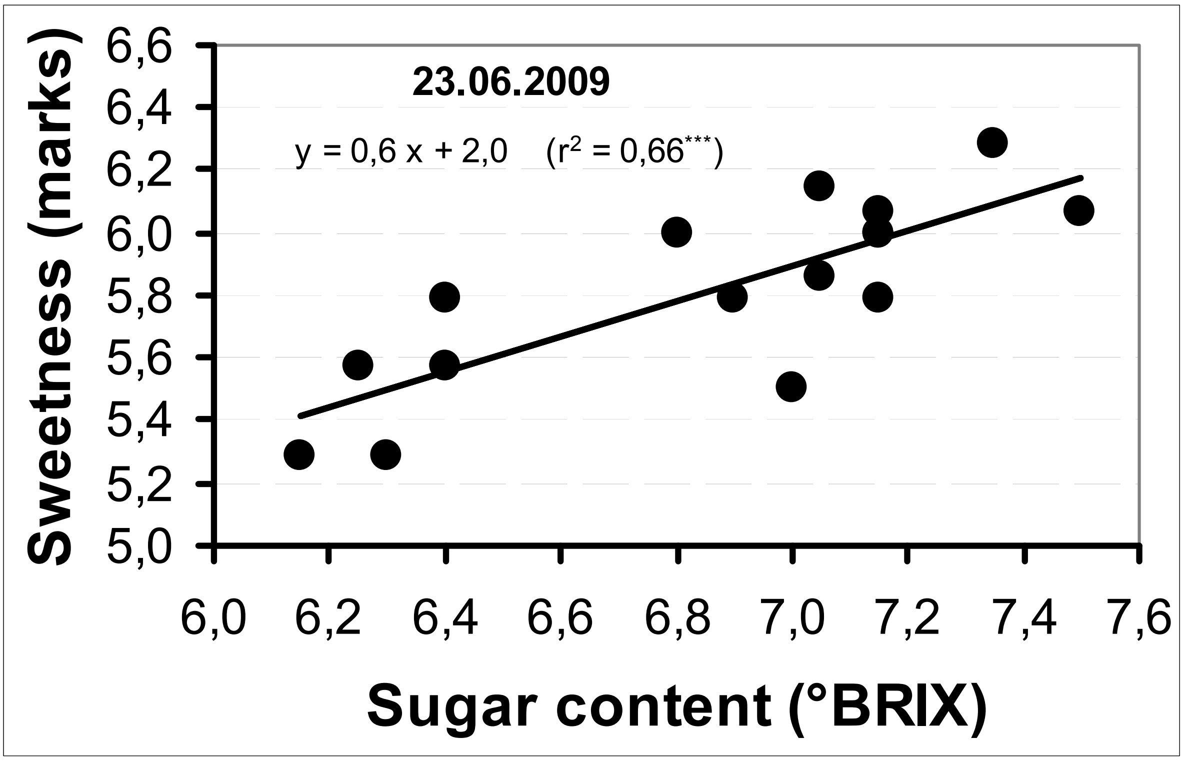

Fig. 21: Relationship between sweetness of red fruits in the tasting experiment and measured sugar content at the end of harvesting period.

Marks from 1 to 10 were possible to choose.

Coefficient of determination was significant at the 0,1 % probability level (n = 16).

4.3.6.3 Dry substance of fruits

Dry substance (DS) of fruits was measured monthly. DS increased with maturation of fruits from about 6 % for green fruits to about 8 % for red fruits (Fig. 22). DS was most of the time not significant between different lighting regimes and stem densities.

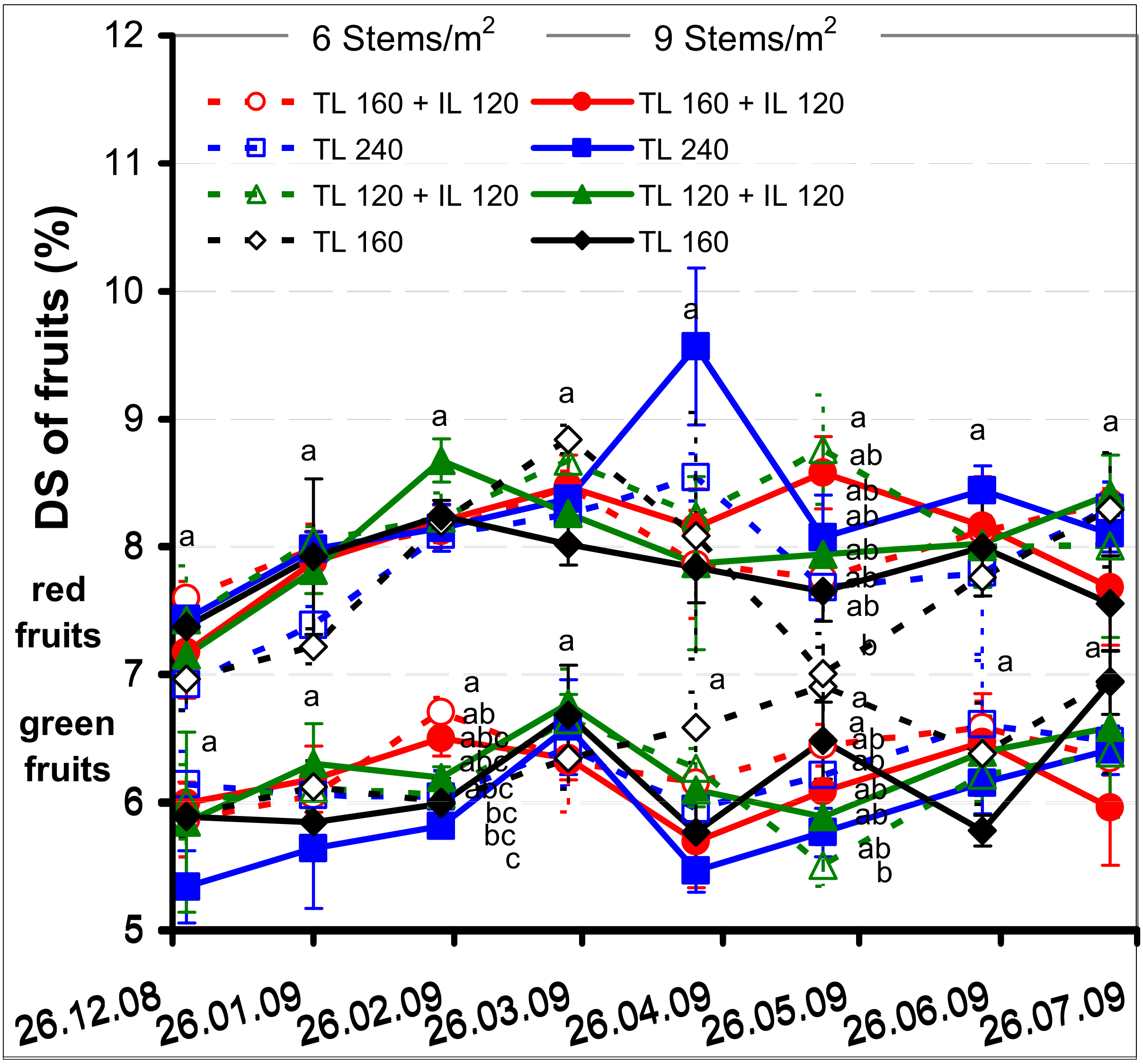

Fig. 22: Dry substance of green and red fruits at different lighting regimes and stem densities.

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 ≤ 0,05).

4.3.6.4 Nitrogen content of fruits

N content of fruits was measured monthly and varied between 1,8-2,6 %. N content was most of the time slightly higher with green fruits than with red fruits. N content

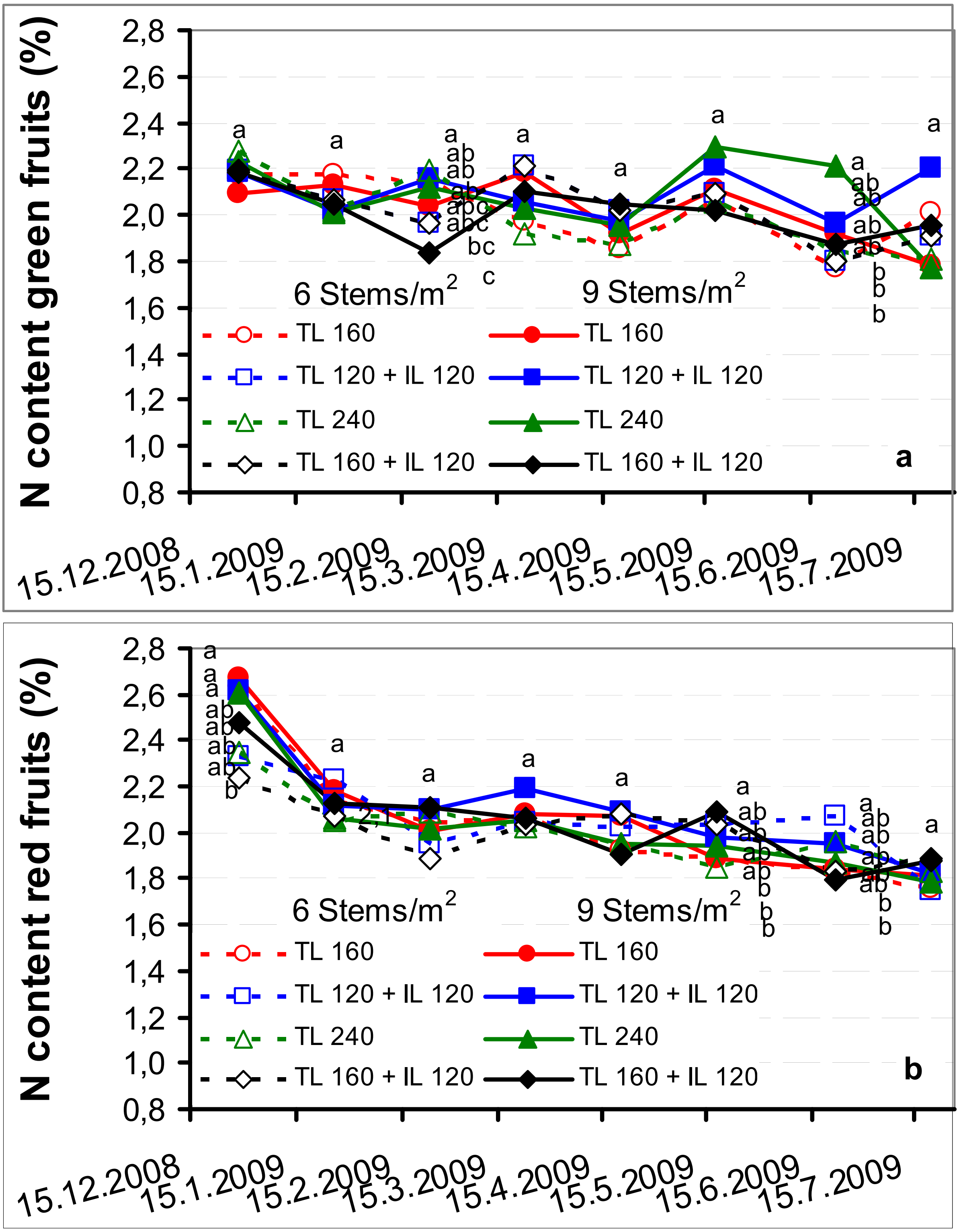

Fig. 23: N content of green (a) and red (b) fruits at different lighting regimes and stem densities.

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 ≤ 0,05).

decreased slowly with increasing sun / longer growing period, while N content was more or less stable with green fruits (Fig. 23). N content was most of the time not significant between different lighting regimes and stem densities.

4.3.7 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. DM yield increased with light intensity and number of stems/m^2 (Fig. 24) and the difference was significant between the lowest and highest light intensity (compare TL 160 and TL 160 + IL 120) at both stem densities. The placement of the light did not influence DM yield of stripped leaves.

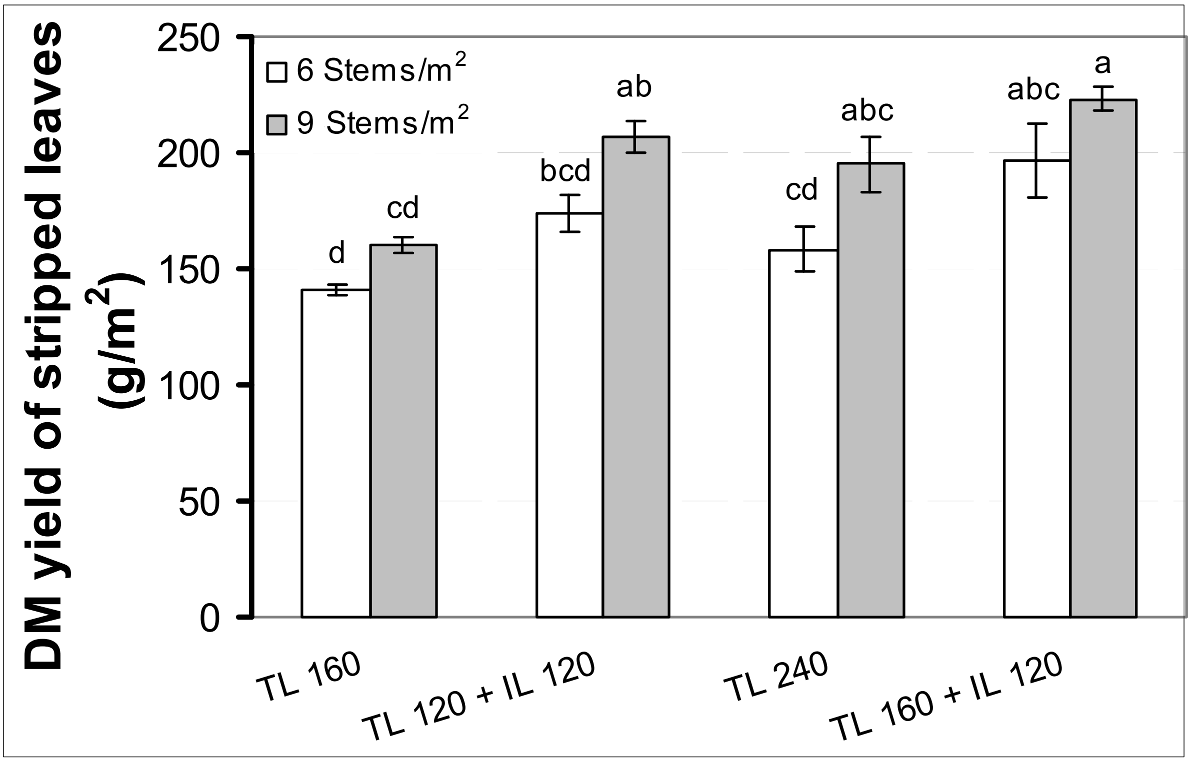

Fig. 24: Dry matter yield of stripped leaves at different lighting regimes and stem densities.

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 ≤ 0,05).

4.3.8 Cumulative dry matter yield

The cumulative DM yield included all harvested red and green fruits, the immature fruits at the end of the growth period, the stripped leaves during the growth period and the shoots. Cumulative DM yield increased with light intensity (Fig. 25). A higher stem density significantly increased DM yield at high light intensity. However, for the lowest light intensity the DM yield was only tendentially higher at 9 stems/m^2 compared to 6 stems/m^2. The placement of the lights did not influence cumulative DM yield. The ratio fruits : “shoots + leaves” was about 35:65.

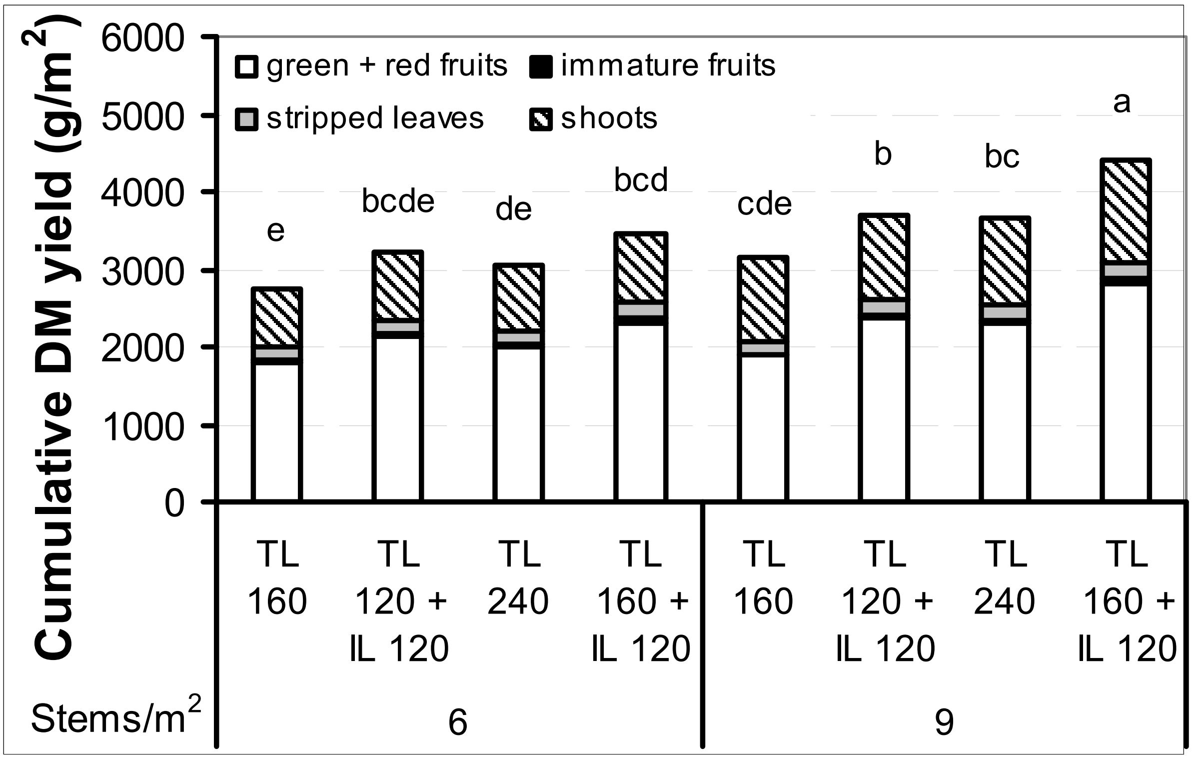

Fig. 25: Cumulative dry matter yield at different lighting regimes and stem densities.

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

4.4 Plant parameters

4.4.1 Leaf area index

The LAI was measured at the end of the growing season. LAI increased with higher number of stems and was with a higher light intensity (TL 160 + IL 120, TL 240) significantly higher at 9 stems/m^2 compared to 6 stems/m^2. Light intensity did not affect LAI at the lower stem density; however, it seems that at the higher stem density LAI increased with higher light intensity. No influence of the placement of the light on LAI was observed (Fig. 26).

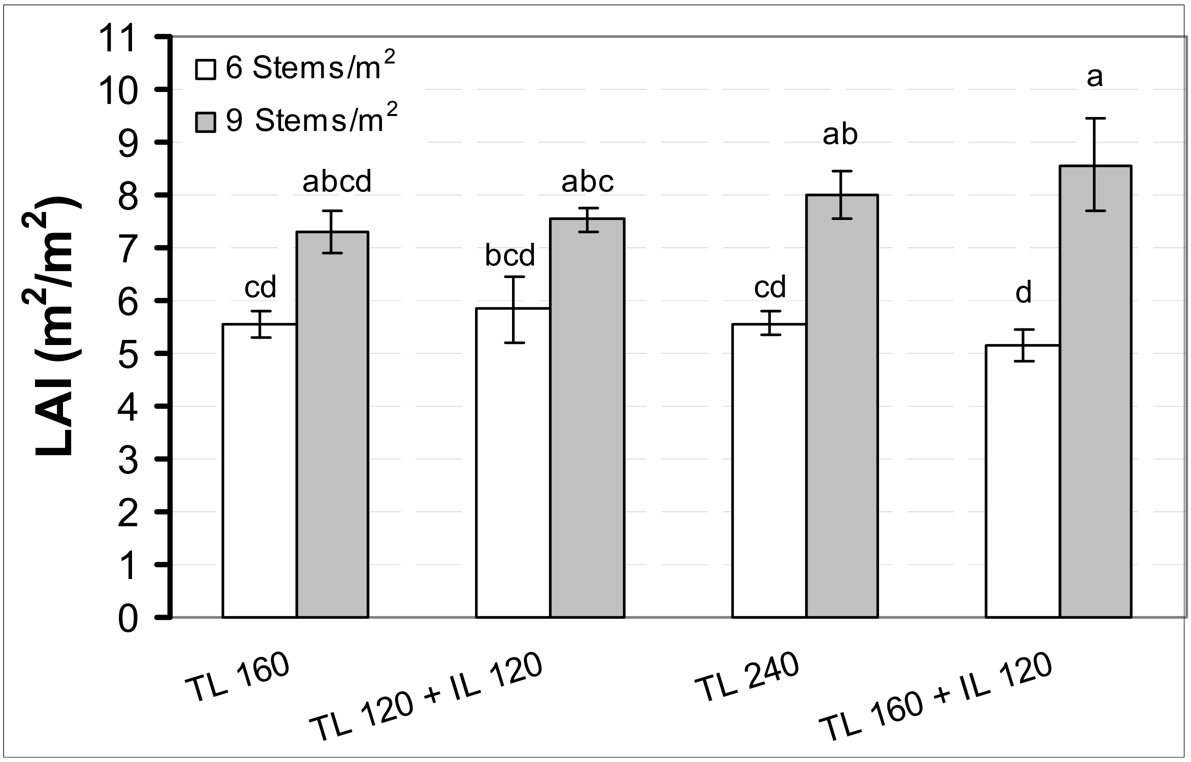

Fig. 26: LAI at different lighting regimes and stem densities.
Error bars indicate standard deviations.
Letters indicate significant differences at the end of the harvest period (HSD, $p \le 0{,}05$).

For all tested light intensities and stem densities, the LAI was significantly related to the weight of the leaves ($r^2 = 0{,}94^{***}$) (Fig. 27).

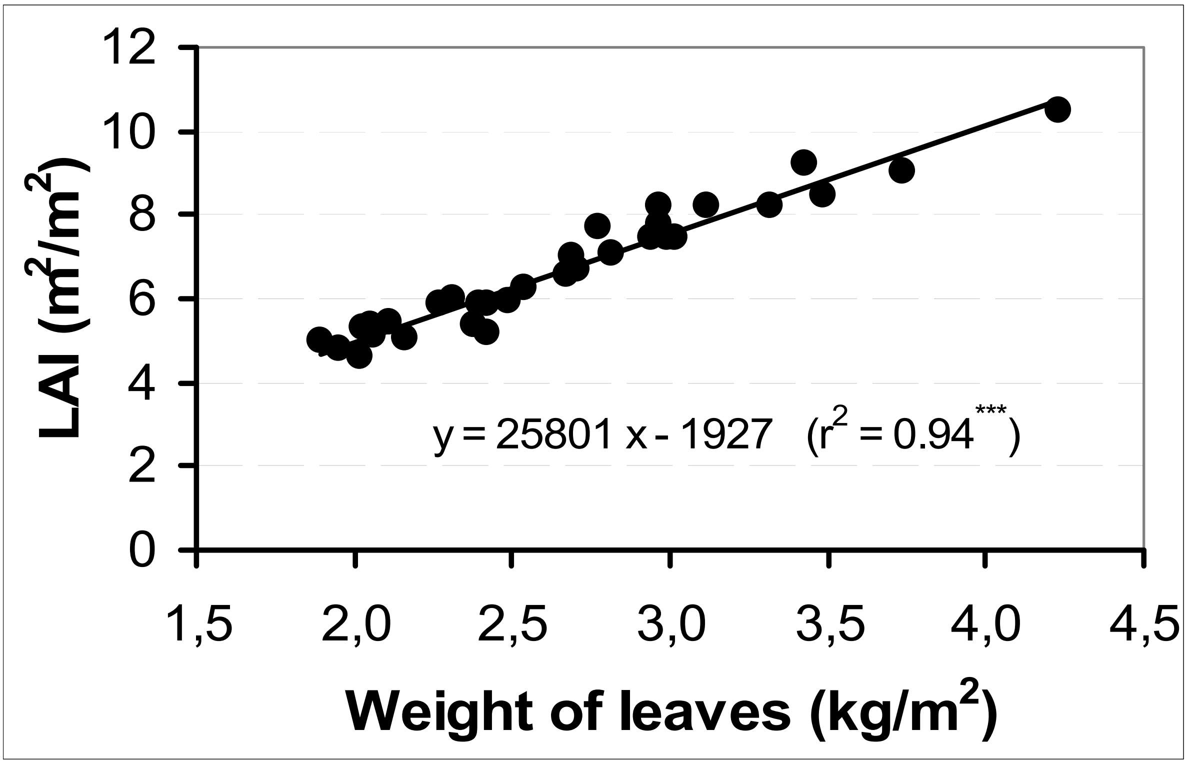

Fig. 27: Relationship between weight of leaves and their LAI.
Coefficient of determination was significant at the 0,1 % probability level (n = 32).

4.4.2 Distance between internodes

The distance between internodes was measured at the end of the growing season. The distance between internodes decreased with height (1st internode: counted from the division of the main stem into two stems), but from ca. 5th internode it stayed around 2-4 cm. Neither light intensity nor stem density seems to influence the distance between internodes (Fig. 28). However, if the average distance between internodes is examined, the distance decreased with higher light intensity (Tab. 5), with the difference in the average distance between internodes being significantly smaller for the highest light intensity than for the lowest light intensity. The average distance of internodes was predominantly influenced by the light intensity used, but also to a lesser degree by the stem density. The distance decreased tendentially with lower number of stems (Tab. 5). The placement of the light (compare TL 240 with TL 120 + IL 120) did not influence average distance between internodes. No difference in the number of internodes between treatments was observed (Tab. 5). Also, the height of the main stem until the division into two stems did not differ between treatments (data not shown) and amounted 17,5-19,5 cm.

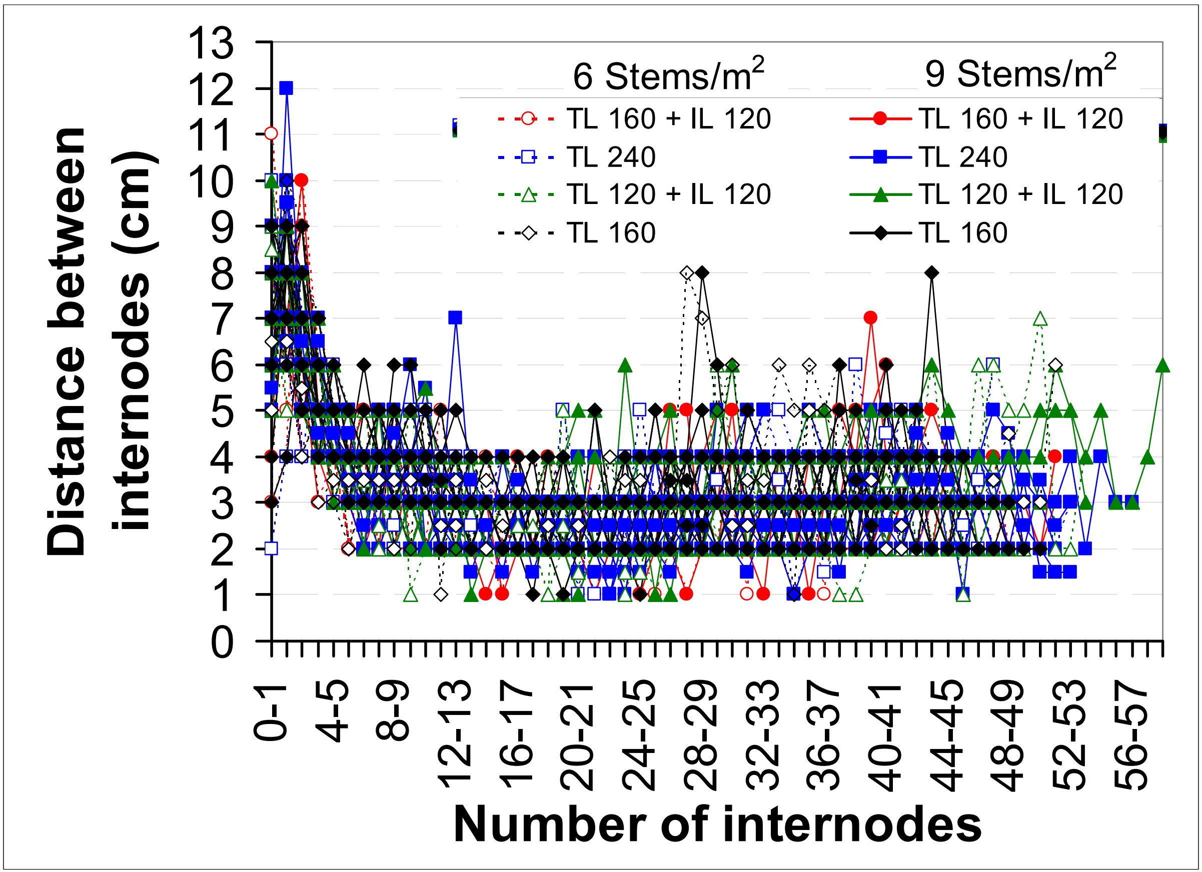

Fig. 28: Distance between internodes at different lighting regimes and stem densities. The distance was measured at the end of the growing period.

Tab. 5: Average distance between internodes and number of internodes at different lighting regimes and stem densities.

Light intensity	Stem density: Stems/m² 6	9	6	9
	Average distance between internodes in cm		Number of internodes	
TL 160 + IL 120	2,93 c	3,03 bc	46 a	44 a
TL 240	3,23 abc	3,23 abc	47 a	48 a
TL 120 + IL 120	3,20 abc	3,35 ab	46 a	45 a
TL 160	3,43 a	3,55 a	43 a	45 a

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

4.5 Nitrogen uptake und N accounting

4.5.1 Nitrogen uptake by plants

The cumulative N uptake included N uptake of all harvested red and green fruits, the immature fruits at the end of the growth period, the stripped leaves during the growth period and the shoots. The shoots and fruits contributed much more than the leaves to the cumulative N uptake (Fig. 29).

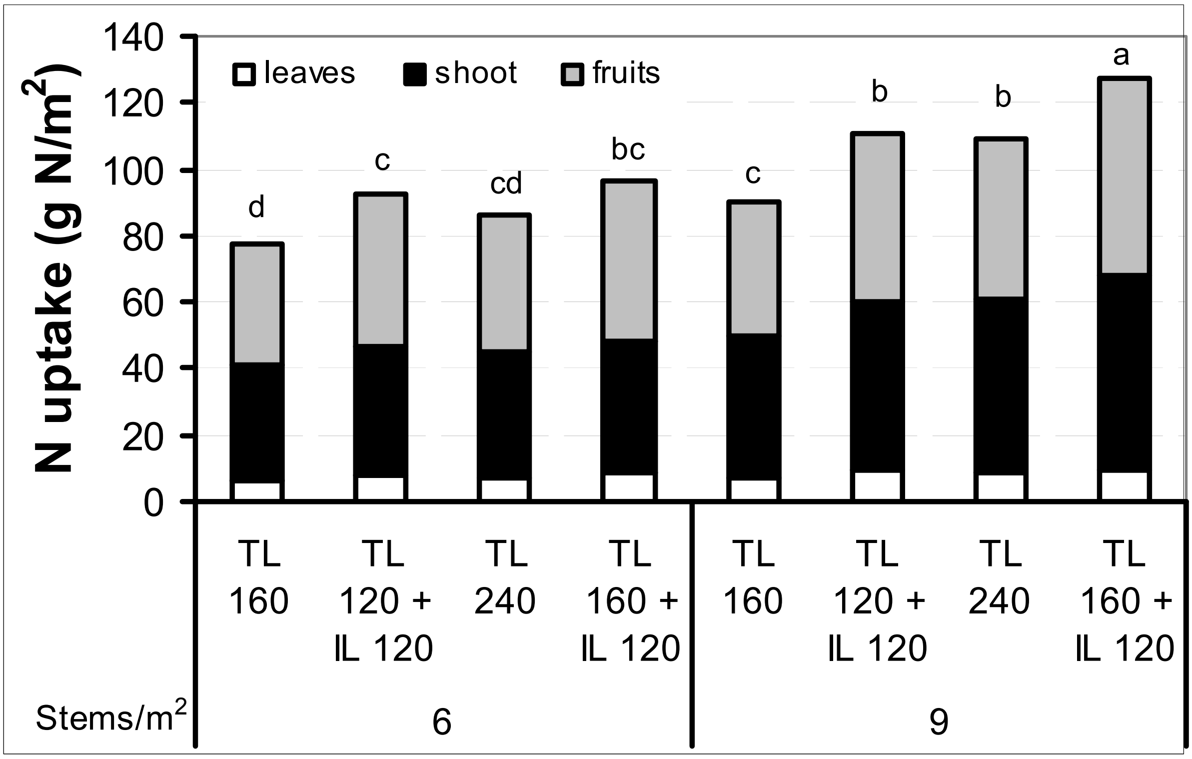

Fig. 29: Cumulative N uptake of sweet pepper (2 stems/plant).

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

Cumulative N uptake increased with light intensity (Fig. 29, Fig. 30). A higher stem density significantly increased N uptake at all light intensities. The placement of the lights did not influence cumulative N uptake (Fig. 29).

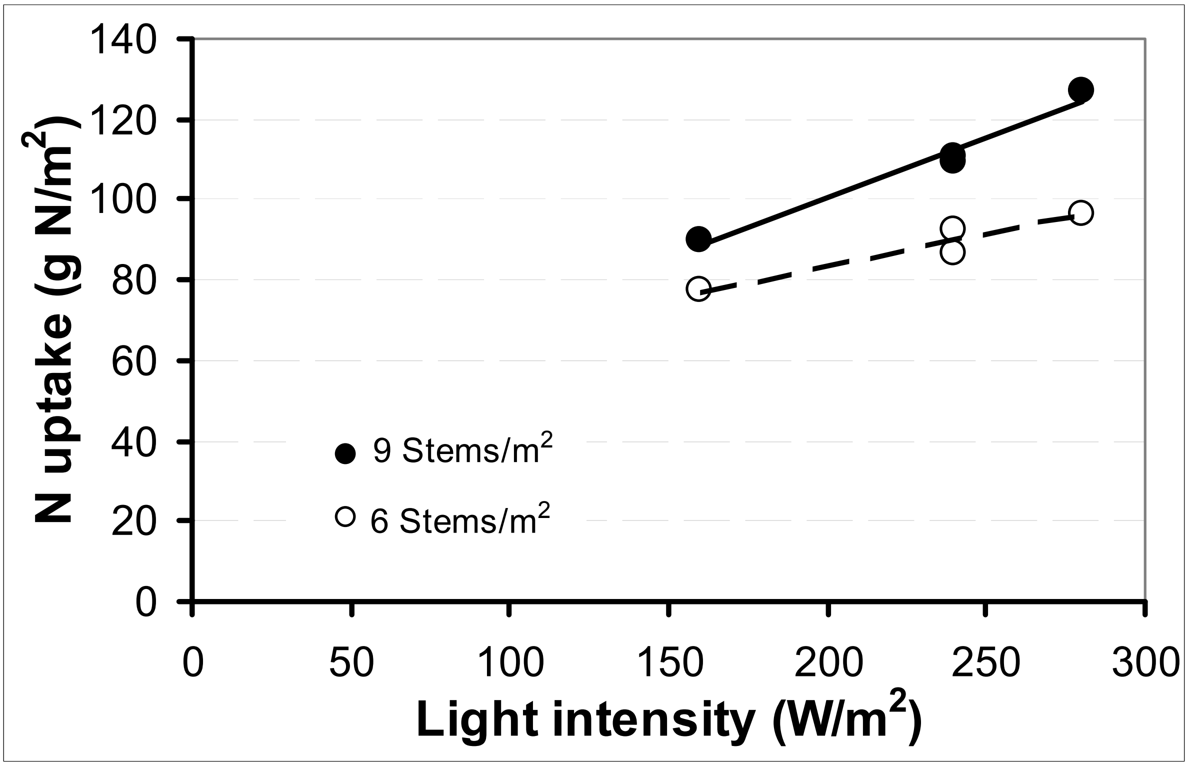

Fig. 30: Relationship between light intensity and cumulative N uptake of sweet pepper.

4.5.2 N accounting

N accounting was calculated to include beside N uptake by plants, nitrate-N and ammonium-N remaining in pumice at the end of the growth period, for loss evaluation through comparing of the amount of fertilized N through the irrigation water (sum of N uptake by plants, N in runoff, N in soil and N losses).

N applied through the irrigation water differed between stem densities (6 stems/m^2: around 300 g N/m^2, 9 stems/m^2: around 400 g N/m^2), but was comparable within lighting regimes except for the highest light intensity, where this value was about 100-150 g N/m^2 higher and can be explained by higher water uptake (Fig. 31).

N losses were lowest for medium light intensity (30-70 g N/m^2), but increased for the lowest light intensity (70-120 g N/m^2) as well as the highest light intensity (140-210 g N/m^2). In addition, nitrogen losses increased with a higher stem density (Fig. 31).

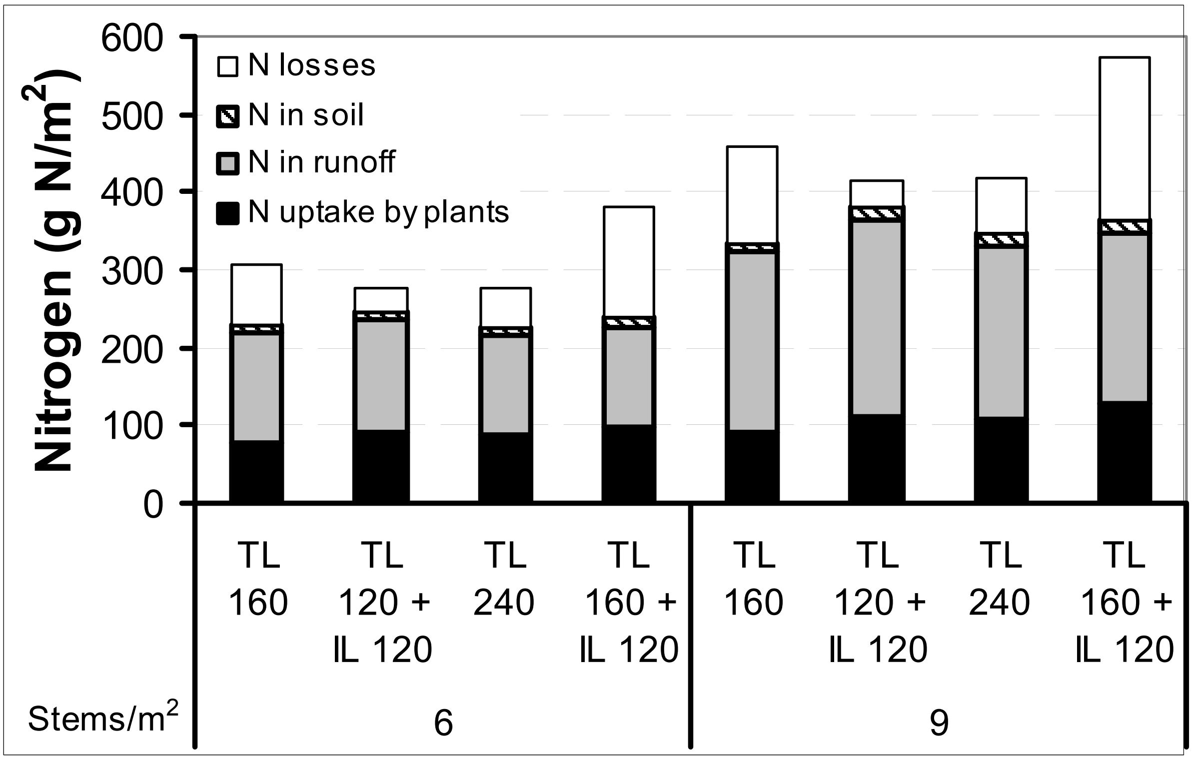

Fig. 31: N accounting of sweet pepper cultivation at different lighting regimes and stem densities. The fertilized N through the irrigation water is known (cumulative pillars) and making losses obvious through addition of N uptake by plants, N in runoff and N in soil.

4.6 Economics

4.6.1 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 sweet pepper from 20.10.2008-27.07.2009 was known. The amount for top lighting and interlighting was in all cabinets the same. For economic calculations average lighting hours per day were calculated based on solar radiation and on lighting hours set up in the computer and extrapolated to lighting hours for one year (Tab. 6). Lamps for interlighting were turned off during harvest and during tending strategies. Therefore, the number of lighting hours was lower for interlighting than for top lighting. Lighting hours per month increased with less solar irradiation in winter month (Tab. 6).

Tab. 6: Overview of lighting hours.

Month	Number of days	Top lighting		Interlighting	
		Average h/day	Total h/month	Average h/day	Total h/month
October	31	18,00	558,00	17,50	542,50
November	30	18,00	540,00	17,50	525,00
December	31	18,00	558,00	17,50	542,50
January	31	18,00	558,00	17,25	534,75
February	28	17,75	497,00	17,00	476,00
March	31	17,25	534,75	16,50	511,50
April	30	15,50	465,00	15,00	450,00
May	31	13,50	418,50	13,00	403,00
June	30	13,50	405,00	13,00	390,00
July	27	13,00	351,00	12,50	337,50
August	31	13,50	418,50	13,00	403,00
September	30	13,50	465,00	13,00	450,00
Total Winter			**3711**		**3582**
Total Summer			**2058**		**1984**

4.6.2 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 with high prices during the day but much lower during the night, which mostly suites customers with electrical heating, but seem to be restricting for growers, and
c) demand based tariffs, for larger users, who pay according to the maximum power demand (*Eggertsson*, 2009).

It is assumed that most growers will be using demand based tariffs, because the other 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. RARIK has also applied for special rural tariff area, where tariffs are higher than in the urban areas, even though they are subsidised by the state. Many growers are situated in the rural areas and must therefore pay higher prices (similar to the most expensive urban tariffs) than those in urban areas of RARIK (*Eggertsson*, 2009).

Costs for distribution are divided into an annual fee and costs for the consumption based on used energy (kWh) and maximum power demand (kW) (Tab. 8). Growers in an urban area in “RARIK areas” can choose between “VA110” and “VA210” and possibly “VA410” and growers in a rural area can choose between “VA130” and “VA230” and possibly “VA430” (*Eggertsson*, 2009).

Since 2005 the growers have been free to choose from which electricity sellers, they buy the electricity. And due to their size they are in good position to exploit the competition between various sellers. However, many of the sales companies do not advertise their large consumers’ tariffs. In this report, the cheapest advertised tariff, (“B4” from Orkuveita Reykjavíkur) is used. It can however be assumed that growers should be able to get some discount from that price. The general rule is that electricity is cheaper in the summer than in winter (*Eggertsson*, 2009).

The government subsidises the distribution cost of growers that comply to certain criterias. Currently 67,0 % and 75,9 % 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 each cabinet the energy costs per m^2 and year that growers have to pay were calculated (subsidy is already subtracted). Not surprisingly the costs of electricity increased with light intensity (Tab. 7). When 50 % of the lamps were top lights and 50 % interlights, costs were slightly lower compared to 100 % top lighting, because interlights were turned off more often than top lights (due to harvest and tending strategies).

Growers should decide the most efficient tariff for electricity according to their lightened greenhouse area (Tab. 8). E.g. for a greenhouse in an urban area and a light intensity of 160 W/m^2 in 300 m^2 tariff “VA110” should be chosen, but tariff

Tab. 7: Annual costs and costs for consumption of energy for distribution and sale of energy.

Light intensity	Annual costs ISK/y	Costs for consumption: Power ISK/kW/y	Energy ISK/kWh		Energy costs with subsidy per m^2 ISK/m^2/y: TL 160	TL 120 + IL 120	TL 240	TL 160 + IL 120
DISTRIBUTION								
RARIK Urban					67,0 % subsidy from the state			
VA110	145848	6608	1,88		922	1367	1382	1598
VA210	179714	6179	1,73		853	1266	1280	1479
VA410	1663935	5887	1,15		661	982	992	1148
RARIK Rural					75,9 % subsidy from the state			
VA130	174800	8190	2,76		930	1378	1395	1611
VA230	222785	7661	2,58		869	1289	1304	1506
VA430	1663935	5887	1,26		507	754	761	880
SALE								
			Winter	Summer				
Orkuveita Reykjavíkur								
B1		7256	2,24	1,33	2929	4347	4393	5079
B4		10057	1,55	0,91	2829	4211	4244	4919
Hitaveitu Suðurnesja hf								
BS		6029	2,66	1,58	3064	4541	4596	5307
Orkubú Vestfjarða								
B10S		6200	2,41	2,41	3216	4766	4825	5570

Source: Composition from *Eggertsson* (2009)

"VA210" if 500 m^2 are lightened. The minimum lightened area decreased with light intensity. Growers that are using a high light intensity should therefore change earlier than growers with a low light intensity to larger tariffs. Because of the subsidy, the overall cheapest tariff and the cheapest tariff for the grower, may not be the same, as high fixed prices will be paid by the grower alone while the state will participate in sharing the lower variable cost. Thus, tariffs like "VA410" and "VA430" would require much less area without the subsidy.

Tab. 8: Overview of minimum lighting area at different tariffs.

	Minimum lightened area m^2			
Light intensity	TL 160	TL 120 + IL 120	TL 240	TL 160 + IL 120
RARIK Urban				
VA110	0	0	0	0
VA210	496	334	330	286
VA410	7727	5236	5151	4478
RARIK Rural				
VA130	0	0	0	0
VA230	794	536	529	458
VA430	3981	2692	2654	2303

Source: Composition from *Eggertsson* (2009)

4.6.3 Costs of electricity in relation to yield

Costs of electricity in relation to yield were calculated. In contrast to the measured lighting hours that were extrapolated to lighting hours for one year (Tab. 6), yield was not extrapolated to one year. It is assumed, that the increase in yield would be the same in all treatments in the missing weeks with high solar irradiation and yield was therefore not extrapolated to decrease possible mistakes. However, it has to take into account, that yield per year would be higher and therefore, costs of electricity in relation to yield would decrease (Tab. 9).

While for the distribution several tariffs were possible, for the sale the tariff "B4" from Orkuveita Reykjavíkur was most attractive and was therefore only considered. The costs of electricity increased with higher light intensity and ranged between 127-152 ISK/kg for 160 W/m^2, 162-211 ISK/kg yield for 240 W/m^2 and 161-218 ISK/kg for 280 W/m^2. The placement of the light did nearly not influence the costs for the electricity per kg yield at the higher stem density, but was higher for only top lighting at 6 stems/m^2. The stem density was contributing to a minor effect than the light intensity: The costs for the electricity were slightly lower at a higher stem density. With a larger tariff, costs of electricity per kg yield decreased (Tab. 9). At both smaller tariffs there were minimal differences in the costs between urban and rural areas. However, with the largest tariff there was a surprising advantage for rural areas, due to the subsidy distortion.

Tab. 9: Variable costs of electricity in relation to yield.

	Variable costs of electricity per kg yield ISK/kg							
Light intensity	TL 160		TL 120 + IL 120		TL 240		TL 160 + IL 120	
Stem density	6	9	6	9	6	9	6	9
Yield/m^2	24,7	26,2	28,1	30,7	26,7	30,9	30,0	36,0
Urban area (Distribution + Sale)								
VA110 + BS	152	143	198	182	211	182	217	181
VA210 + BS	149	141	195	179	207	179	214	178
VA410+ BS	141	133	185	169	196	169	202	169
Rural area (Distribution + Sale)								
VA130 + BS	152	144	199	182	211	182	218	182
VA230 + BS	150	141	195	179	208	180	214	179
VA430 + BS	135	127	176	162	188	162	194	161

4.6.4 Energy use efficiency

Energy use efficiency is an indicator how efficient the kWhs are converted into yield, whereby a high value is showing better efficiency. The energy use efficiency decreased with light intensity and increased slightly with a higher stem density (Fig. 32). However, if the trend line would be imagined to be lengthened, with lower light intensity a lower stem density would result in a higher efficiency.

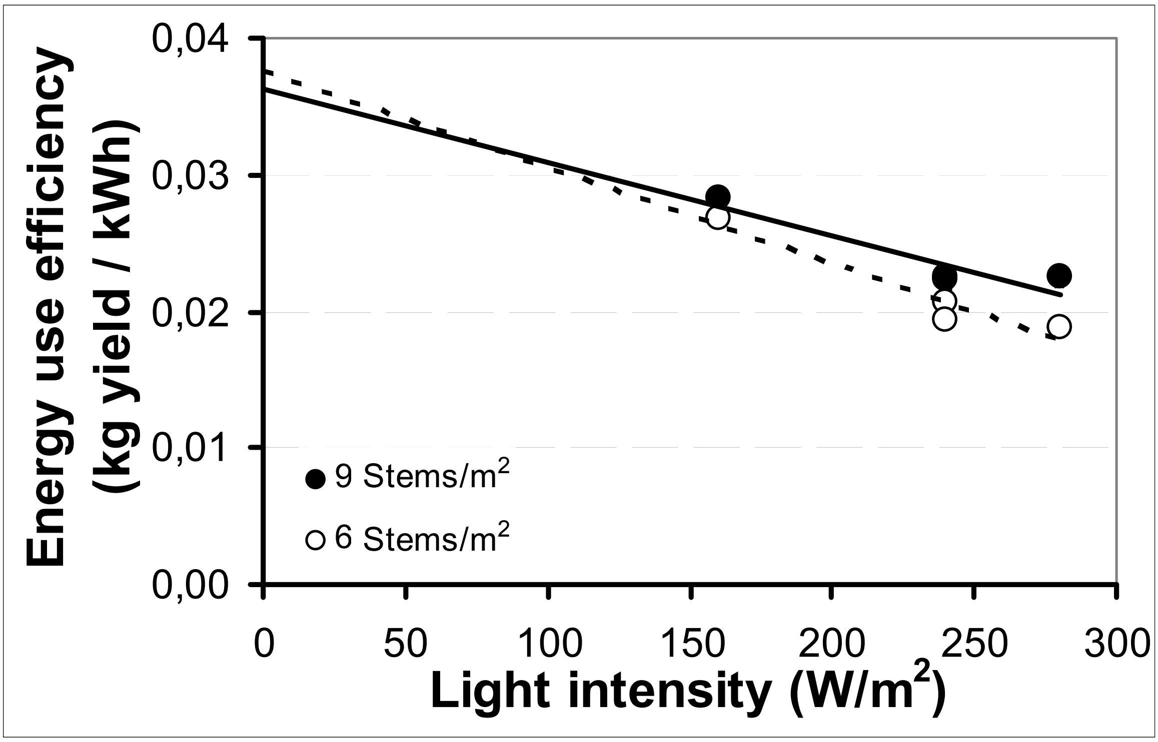

Fig. 32: Relationship between light intensity and energy use efficiency.

4.6.5 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 price of the sale of the fruits and kg yield. For each kg of sweet pepper, growers are getting about 386 ISK from Sölufélag garðyrkjumanna (SfG) and in addition nearly 200 ISK from the government. Naturally, the revenues are higher with more yield and therefore the revenues increased with light intensity (Fig. 33).

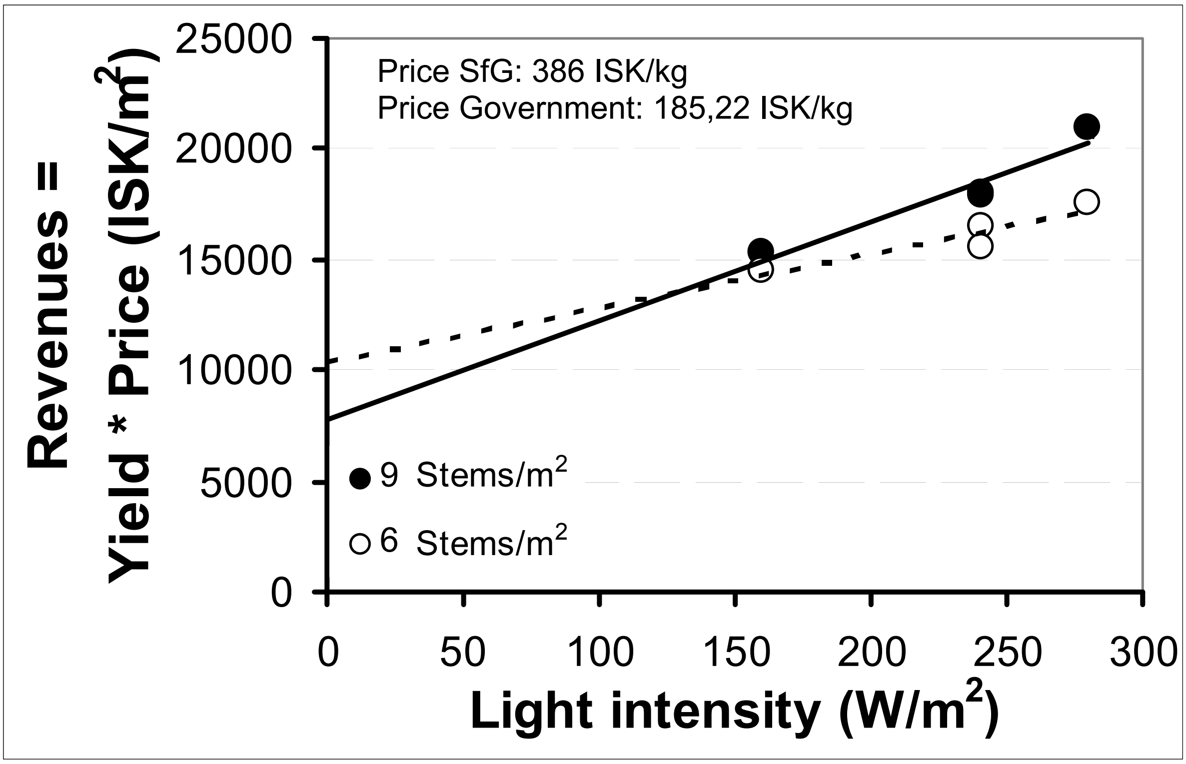

Fig. 33: Revenues at different light intensities and stem densities.

When considering the results of previous chapter, one must keep in mind that there are other cost drivers in growing sweet peppers than electricity alone (Tab. 10). Among others, a huge amount was the costs of seeds (≈ 400 ISK/m^2) and seedling production (600 ISK/m^2), costs for wasps for plant protection (≈ 500 ISK/m^2), NPK Bröste for plant nutrition (≈ 500 ISK/m^2), liquid CO_2 (≈ 1000 ISK/m^2) and rent of the tank (≈ 400 ISK/m^2) as well as the black platter (≈ 500 ISK/m^2) and the rent of the green box (≈ 400 ISK/m^2) for preparing sweet pepper for selling (Fig. 34).

However, in Fig. 34 three of the biggest cost drivers are not included and that is the investment into lamps and bulbs, the electricity and the labour costs. These variable costs are also included in Fig. 35 and it is obvious, that especially the electricity and the investment into lamps and bulbs are contributing much to the variable costs and to a lesser degree the labour costs. The highest amount of the last group is the costs of packing and marketing, and the CO_2 costs.

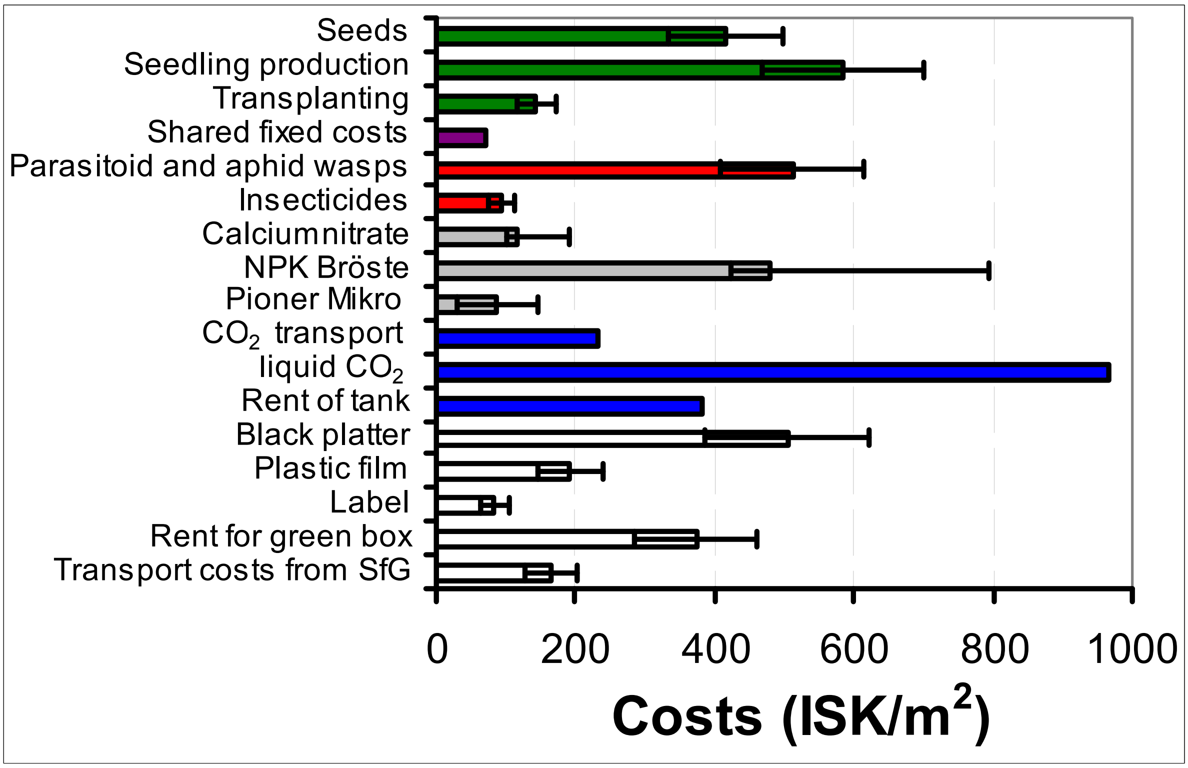

Fig. 34: Variable costs (without lighting and labour costs).
I: variation at different light intensities and stem densities (minimum and maximum)

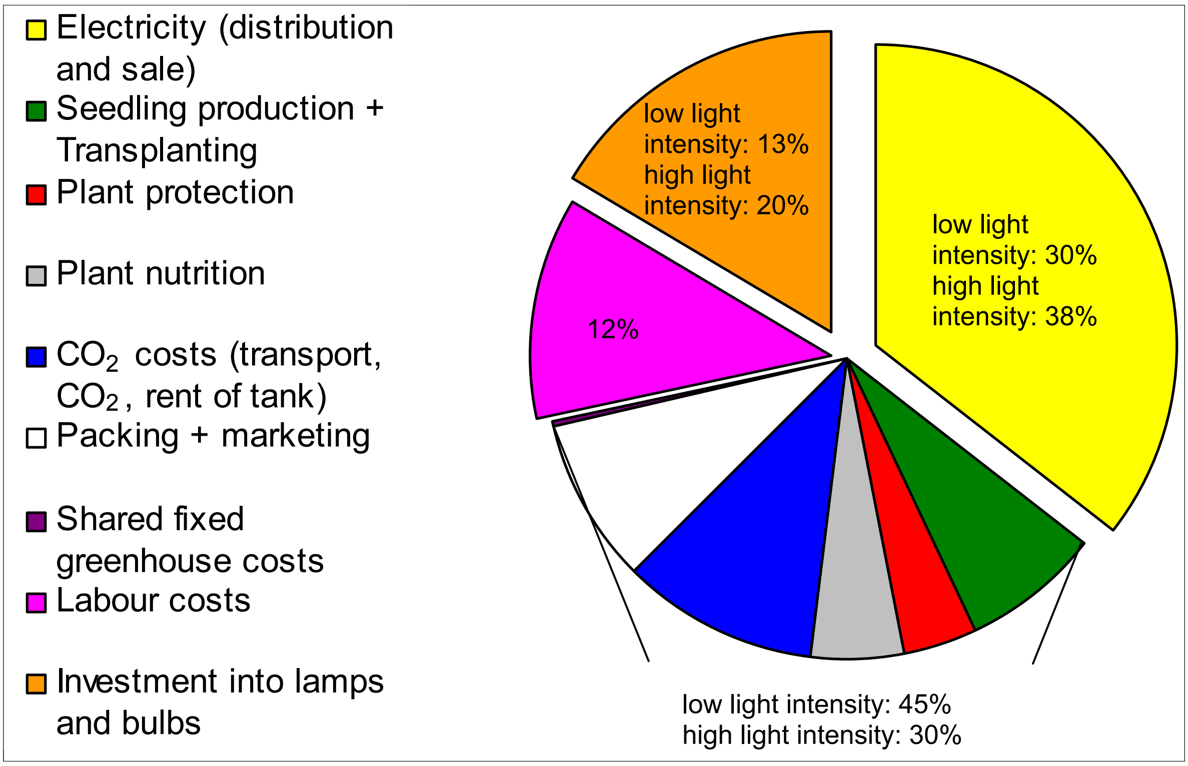

Fig. 35: Division of variable costs.

A detailed composition of the variable costs at each treatment is shown in Tab. 10.

Tab. 10: Profit margin of sweet pepper at different lighting regimes and stem densities.

Light intensity	TL 160		TL 120 + IL 120		TL 240		TL 160 + IL 120	
Stem density	6	9	6	9	6	9	6	9
Marketable yield/m^2	24,7	26,2	28,1	30,7	26,7	30,9	30,0	36,0
Sales								
SfG (ISK/kg)	386	386	386	386	386	386	386	386
Government (ISK/kg) [1]	185,22	185,22	185,22	185,22	185,22	185,22	185,22	185,22
Revenues (ISK/m^2)	**14114**	**14950**	**16074**	**17510**	**15245**	**17653**	**17116**	**20540**
Variable costs (ISK/m^2)								
Electricity distribution [2]	1033	1033	1446	1446	1460	1460	1659	1659
Electricity sale	2829	2829	4211	4211	4244	4244	49193	4919
Seeds [3]	332	498	332	498	332	498	332	498
Seedling production	285	427	285	427	285	427	285	427
Grodan small [4]	34	50	34	50	34	50	34	50
Grodan big [5]	149	224	149	224	149	224	149	224
Pumice [6]	98	146	98	146	98	146	98	146
Parasitoid wasps [7]	241	361	241	361	241	361	241	361
Aphid wasps [8]	168	252	168	252	168	252	168	252
Insecticides	76	114	76	114	76	114	76	114
Calciumnitrate [9]	102	153	92	139	93	139	127	191
NPK 9-5-30 Bröste [10]	423	635	383	575	385	578	528	793
Pioner Mikro [11]	78	116	70	105	71	106	97	145
CO_2 transport [12]	231	231	231	231	231	231	231	231
Liquid CO_2 [13]	966	966	966	966	966	966	966	966
Rent of CO_2 tank [14]	383	383	383	383	383	383	383	383
Strings	17	25	17	25	17	25	17	25
Black platter [15]	428	453	487	531	462	535	519	623
Plastic film [16]	163	173	186	203	177	204	198	238
Label [17]	71	76	81	89	77	89	87	104
Rent of box from SfG [18]	317	336	361	393	343	397	385	461
Transport from SfG	140	148	159	173	151	175	169	203
Shared fixed costs [19]	71	71	71	71	71	71	71	71
Lamps [20]	1071	1071	1646	1646	1429	1429	2003	2003
Bulbs [21]	571	571	1295	1295	762	762	1486	1486
∑ variable costs	**10278**	**11345**	**13469**	**14555**	**12702**	**13867**	**15227**	**16574**
Revenues - ∑ variable costs	**3836**	**3605**	**2605**	**2954**	**2543**	**3785**	**1889**	**3966**
Working hours (h/m^2)	1,05	1,23	1,26	1,46	1,17	1,41	1,36	1,63
Salary (ISK/h)	1352	1352	1352	1352	1352	1352	1352	1352
Labour costs (ISK/m^2)	1417	1660	1705	1978	1588	1910	1833	2207
Profit margin (ISK/m^2)	**2419**	**1945**	**900**	**976**	**955**	**1876**	**56**	**1759**

[1] Final price for 2008: 198,92 ISK/kg
Final price for 2009: 185,22 ISK/kg
In the report the final price for 2009 was chosen. However, changes of the price should be considered in the economic calculation for the future.

[2] Assumption: urban area, tariff “VA210”, annual fee in relation to 1000 m^2 lightened area

[3] 8735 ISK / 100 seeds

[4] 36x36x40mm, 25584 ISK / 2900 Grodan small

[5] 6,75 42/40, 9679 ISK / 216 Grodan big

[6] 4650 ISK/m^3

[7] 3760 ISK / 3000 parasitoid wasps

[8] 2625 ISK / 500 aphid wasps

[9] 1950 ISK / 25 kg Calciumnitrate

[10] 9300 ISK / 25 kg NPK Makro 9-5-30 rauður Bröste

[11] 5790 ISK / 10 l Pioner Mikro plús járn

[12] CO_2 transport from Rvk to Hveragerði / Flúðir: 5,06 ISK/kg CO_2

[13] liquid CO_2: 21,14 ISK/kg CO_2

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

[15] 4,85 ISK / black platter

[16] 350 mm x 1000 m, 8100 ISK/roll

[17] 0,81 ISK/label

[18] 77 ISK / 6 kg box

[19] 94 ISK/m^2/year for common electricity, real property and maintenance

[20] top lights: 30000 ISK/lamp, interlights: 16300 ISK/lamp, life time: 8 years

[21] bulbs for top lights and interlights: 4000 ISK/bulb, life time: 2 years

The profit margin varies between 50 to about 2400 ISK/m^2 and was at the low light intensity slightly higher at 6 stems/m^2 than at 9 stems/m^2, but at the highest light intensity much higher at the higher stem density (1760 ISK/m^2) compared to the lower stem density (60 ISK/m^2). The trend line through profit margin at 9 stems/m^2 shows at each light intensity the same profit margin. However, focussing on the 6 stems/m^2 trend line makes it obvious, that it would be advantageous to have a lower light intensity and get a much higher profit margin (Fig. 36).

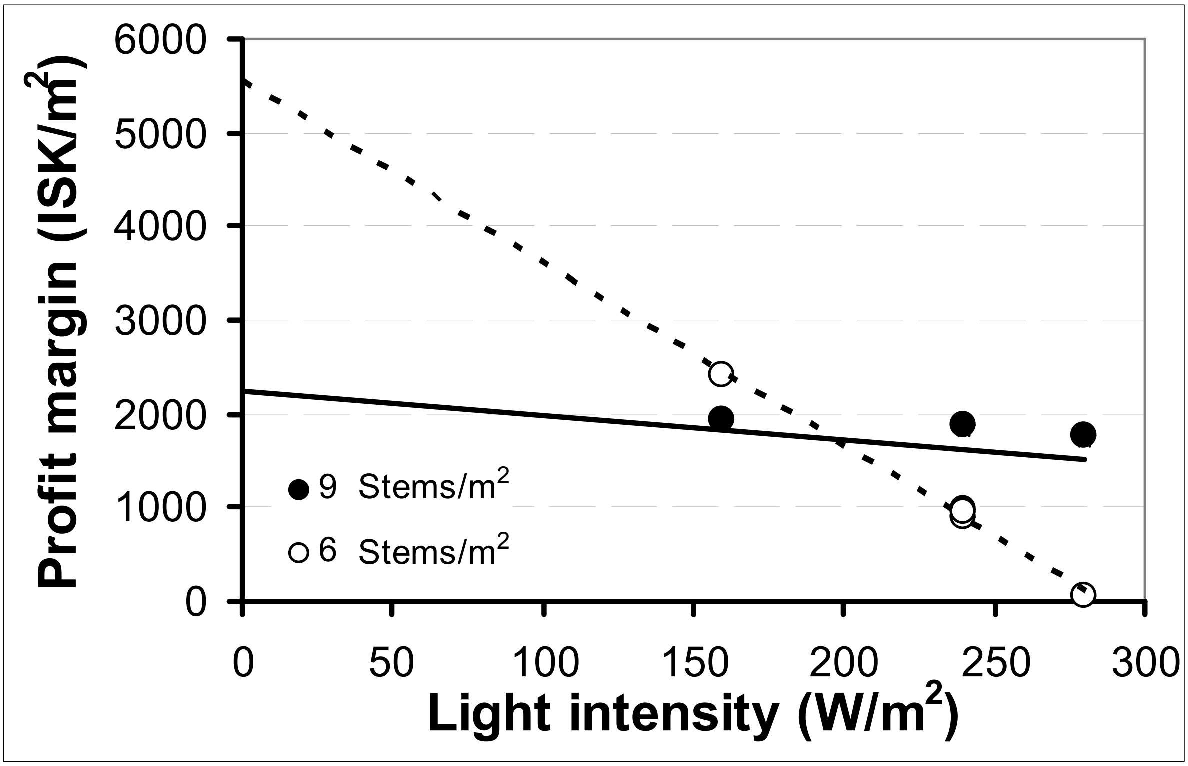

Fig. 36: Profit margin in relation to light intensity and stem density.

5 DISCUSSION

5.1 Yield in dependence of light intensity and stem density

The yield of sweet pepper was compared at different lighting regimes and stem densities. The results clearly show that it is possible to enhance sweet pepper productivity by distributing a higher amount of light intensity. At low natural light level the yield was higher at higher light intensities (yield at TL 240 was higher than at TL 160, yield at TL 160 + IL 120 was higher than TL 120 + IL 120), whereas at low light intensities, stem density did not influence yield. However, with a higher light intensity it was advantageous to have a higher stem density. This is indicating, that higher light intensities allow for the increase of stem density, which was also obtained by *Dorais* et al. (1991).

Generally, it can be said, that 1 % increase of light intensity is resulting in a yield increase of 0,7-1,0 % for fruit vegetables (*Marcelis* et al., 2006). These values are fitting well to the present findings. However, this value may not apply to all varieties of sweet pepper, because of a possible significant interaction between varieties and supplemental lighting (*Blain* et al., 1987).

The reason for the higher yield at higher light intensity was an increased number of harvested fruits, whereas the average fruit weight of sweet pepper was equal between lighting regimes. These results concur with the findings of *Dorais* et al. (1991), who attributed the increased yield with a higher light intensity to more, rather than heavier fruits. However, in the literature there are also other explanations for a higher yield. For example, pulled *Lorenzo* & *Castilla* (1995) in their conclusion a higher LAI together with a higher yield; i.e. higher values of LAI in the high density treatment lead to an improved radiation interception and, subsequently, to higher biomass and yield of sweet pepper than in the low density treatment. Also, in the present study a higher stem density was going along with a higher LAI, which was in accordance with *Motsenbocker* (1996), and resulting in a higher yield especially at higher light intensities. Beside that, plant density was affecting the PAR value: *Papadopoulos* & *Ormrod* (1988) observed that the proportion of available PAR intercepted increased with closer planting, but PAR penetration increased and distribution improved with increasing plant spacing. Plant density also had a large effect on the quality of canopy transmitted light.

Whereas the use of a high light intensity significantly increased marketable yield of sweet pepper during periods of low natural light level, the gain decreased with increasing natural light level and the yield was at high natural light level neither different within light intensities nor within stem densities. These results consist with the ones from *Hao* & *Papadopoulos* (1999) who reported that the response of leaf photosynthesis to supplemental lighting was much more obvious under low than under strong solar irradiance. Also, illuminance and air temperature measurements have shown that environmental conditions for growing were comparable at high solar irradiation. Therefore, it can be expected that with increasing solar irradiation vegetable growers could possibly decrease supplemental lighting without a reduction in yield and thus reduce energy costs.

However, beside the positive effect of higher yield due to increased fruit set, increasing the light intensity had also disadvantages to a more difficult harvest due to a decreased average distance of internodes, whereas number of internodes was unaffected. Also, *Heuvelink* et al. (2006) reported that plants were less elongated and had more internodes, when supplemental light was applied 13 h with 188 μmol/m^2/s compared to 17 h and 125 μmol/m^2/s. A higher light intensity improved yield by better fruit set while average fruit weight was hardly affected. In contrast, *Jolliffe* & *Gaye* (1995) indentified number of nodes as the most important contributor to the density effects and therefore as a direct source of yield variation.

Yield differences within different experiments may be induced by the kind of fertilizer. Measuring the N uptake is a way to see, how much of the applied N was apparently taken up by the plant. With a similar growth period (242 days and equal season) in Israel without artificial light, but grown in a climate-controlled greenhouse, N uptake of sweet pepper was with 32 g/m^2 (for the treatment with the highest yield) less than half of the present study (*Bar-Tal* et al., 2001b). However, both these values are fitting well together, if the trendline in Fig. 30 would be extrapolated. Regarding N accounting, the high losses especially with the highest light intensity (Fig. 31) may be explained by the fact that a higher amount of the irrigation water was not measured as runoff, because it disappeared due to evaporation and transpiration.

5.2 Placement of lights

Light response curves of leaf photosynthesis showed that photosynthesis and transpiration decreased from the top to the bottom of a sweet pepper canopy. *Dueck* et al. (2006) reported that these reductions in gas exchange lower in the canopy, likely result from adaption to lower ambient light conditions as well as leaf aging. Hence, side lighting / interlighting has the potential of improving photosynthetic activity of dense plant canopies by developing efficient forms of inner canopy illumination due to increased photosynthetic activity when used jointly with top lighting (*Grodzinski* et al., 1999). The mean artificial photosynthetic photon flux at different heights of the canopy was 14 % higher in the interlighting system (50 % top lamps and 50 % of lamps mounted vertically between the single plant rows) than with top lighting (*Hovi-Pekkanen* et al., 2006). Due to a better vertical light distribution (*Hovi* et al., 2004) and by increasing the amount of PPF in the lower parts of the canopy and thereby decreasing the abortion of flowers or small fruits, *Hovi-Pekkanen* et al. (2006) assumed that interlighting probably increased the source strength. The improved yield with interlighting was probably mainly due to higher illuminance, as there was no consistent difference observed in the temperature inside the canopy between the lighting regimes.

So far, several authors have conducted experiments with fluorescent tubes and HPS lights as interlights and reported an increase in yield compared to top lighting. For example, *Grimstad* (1987) reported that fluorescent tubes (44 W/m^2 installed) maintained within the canopy (permanently 1,30 m above the rock wool slabs) were more effective than lamps over the top of a tomato crop (2,70 m above the rock wool slabs), resulting in a significantly higher marketable yield primarily (83 %) due to the increase in fruit number as opposed to fruit weight (17 %). Also, in cucumbers top lighting + interlighting (163 W/m^2, either 24 or 48 % of the lamps were mounted between the rows at 1,30 m height) increased both the early yield and the annual yield compared to top lighting (170 W/m^2), mainly due to higher fruit weight, as there was no significant effect on the total yield in number (*Hovi-Pekkanen*, 2007). In sweet pepper top lighting + interlighting (50 % of top lamps and 50 % of lamps mounted vertically between the single plant rows) was shown to enhance productivity, increasing both the total and first class cumulative fruit yield in weight (19 % with 24 % interlights, 23 % with 48 % interlights) and number (*Hovi-Pekkanen* et al., 2006).

In contrast to this, in the present sweet pepper experiment an effect of the placement of the light on total and marketable yield as well as on number of fruits was not observed. This may possibly be because of a variety dependent yield advantage effect of interlighting. So have *Gunnlaugsson* & *Adalsteinsson* (2006) indicated, that some varieties of tomato grow equally well whether they are lit (238 W/m^2) by only top lights (600 W lamps) or in addition to that by interlights: The amount of interlight (22 or 45 % interlights, 250 W lamps) did not affect the tomato yield of the variety "Geysir" whereas "Espero" gave the highest yield when illuminated with 45 % interlight and the lowest yield when only top lights were used. Also *Heuvelink* et al. (2006) reported, that an application of 50 % of the light within the crop by fluorescent tubes instead of only HPS lamps above the crop, did not improve production but improved fruit quality in cucumber.

Beside a variety dependent effect, *Näkkilä* et al. (2007) observed a seasonal variation in yield increase (400 W HPS lamps, 171 W/m^2 installed lighting capacity, top lighting + interlighting: 50 % of the lamps mounted 3,50 m above ground and 50 % vertically 1,00-1,60 m above ground between plant rows). The interlighting regime gave a 23 % higher sweet pepper yield, increased the total number of fruits by 18 %, yielded 15 % more of first class fruits and a 30 / 8 % higher tomato yield in spring / summer was obtained with top lighting + interlighting than with top lighting alone. However, after midsummer both lighting regimes were equally productive. Also with cucumbers, the effects of the interlighting regime were more prominent in lower natural light conditions in winter and spring (*Hovi-Pekkanen & Tahvonen*, 2008; *Hovi-Pekkanen* et al., 2006). This can be explained by the fact that in winter, the environmental conditions (carbon dioxide concentration, air temperature) in the greenhouse were more easily controlled due to low outdoor temperature. Additionally, the difference between the lighting regimes became smaller as the proportion of artificial light of total light energy received by plants, decreased by increasing natural light and lower use of artificial lighting (*Hovi-Pekkanen* et al., 2006). Summing up, it is concluded that interlighting is efficient in low natural light conditions (*Näkkilä* et al., 2007).

The stem density was also interacting with the placement of the light. Increased plant density from 2,5 tops/m^2 to 3,3 tops/m^2 gave 9 % more yield when lit by top light but 12 % more when lit with 45 % interlight, indicating that interlight is more effective in increasing the yield at higher plant density (*Gunnlaugsson* & *Adalsteinsson*, 2006). This result was not in accordance with the present study.

In the present sweet pepper experiment also other yield parameters like DM yield of stripped leaves, cumulative DM yield, inner quality (sugar content, taste) were not affected by the placement of the light. In addition, no effect of the interlights on the morphology (height, LAI, average distance between internodes) of sweet pepper was observed. Also, *Hovi-Pekkanen* et al. (2006) found no significant difference between treatments in the number and length of the internodes, in the plant height at the end of the experiment or in the growth rate of the stem during the cultivation period.

However, with interlighting the amount of fruits with damage from lighting and also with blossom end rot increased. According to *Bar-Tal* et al. (2001a), an increase in the NH_4 concentration in the irrigation water is the main reason of the suppression of Ca concentration in the leaves and fruits and the increased incidence of blossom end rot. However, this was not investigated in the present study.

Also, *Hovi-Pekkanen* et al. (2006) reported, that blossom end rot was slightly increased in top lighting + interlighting (50 % interlights) and increased in each treatment (171 W/m^2) with increasing natural light and temperature during the summertime and was highest with top lighting + interlighting and two stems per sweet pepper plant. But in cucumbers, top lighting + interlighting decreased unmarketable yield in weight and number, increased chlorophyll concentration of fruit skin in each stand, made visually greener fruits and slightly extended the post-harvest shelf life of fruits, with the best results achieved by mounting one quarter of the installed lighting capacity in the lower part of the canopy (*Hovi-Pekkanen*, 2007). Also, supplemental lighting (135 W/m^2) with a combination of 50 % fixed HPS lamps at the top and 50 % interlighting with fluorescent tubes (total 194 $\mu mol/m^2/s$) showed a darker green colour of cucumbers than 100 % fixed HPS lamps on top of the canopy of 210 $\mu mol/m^2/s$ (*Heuvelink* et al., 2006).

In contrast to *Gunnlaugsson* & *Adalsteinsson* (2006), where top lighting + interlighting seems to enhance fruit maturation of tomatoes, possibly because of higher fruit temperature as a result of heat irradiation from the interlights, the present study shows no effect of placement of light on ripening.

5.3 Economy of lighting

The present experiment has shown, that it is recommended to lighten at low solar radiation, but reduce lighting at high solar irradiation due to no yield advantage. To a similar suggestion came *Hovi* et al. (2004), who considered the electricity consumption at different seasons when cucumbers were lit (170 W/m^2) either with top lighting or top lighting + interlighting (25 % interlights). The authors came to the conclusion, that both lighting systems were most efficient in springtime. In winter and spring, top lighting + interlighting was considerably more efficient than top lighting, but top lighting alone was more efficient in summer, possibly because plants suffered from high temperatures and were neither able to yield nor to exploit the interlighting efficiently. This is indicating that electricity consumption should be reduced during the summer.

Also with sweet pepper, a similar effect was observed. Top lighting + interlighting (50 % top lamps and 50 % of lamps mounted vertically between the single plant rows) increased both the total and first class cumulative fruit yield of sweet pepper (19/23 %) and number. There was a steady increase in yield with top lighting + interlighting from February until June, but thereafter the weekly yield was almost similar with top lighting. The efficiency of electricity consumption in lighting was 23 (top lighting), 40 (top lighting + interlighting, 1 stem) and 42 (top lighting+interlighting, 2 stems) g total yield/kWh (*Hovi-Pekkanen* et al., 2006). In the present study energy use efficiency was in the same range, however, with 19-28 g yield/kWh at the lower value and also with no differences regarding the placement of light, but increased with a lower light intensity.

Hovi-Pekkanen & Tahvonen (2008) investigated the amount of interlights and concluded that 24 % interlights is a better alternative than 48 % interlights, because the yield is similar, and with a smaller number of interlighting lamps, the installation costs are lower. However, if the grower’s main goal is to produce fruits with good quality, then a higher proportion of interlight is worth considering. It is suggested, that interlighting accelerated the growth rate of fruits. However, according to the present study top lighting + interlighting is not resulting in a gain of yield compared to top lighting alone.

Same as for the energy use efficiency, highest values for the profit margin were reached with a lower light intensity (with 6 stems/m^2), whereas with a higher stem density the light intensity was not affecting profit margin. Growers that decide to use a high light intensity have to use a high stem density to grow sweet pepper more economically. In order to make the economics of lighting in sweet pepper in Iceland more favourable, the results clarify that growers should reduce lighting at high solar radiation. Supplemental lighting in sweet pepper should only be used in low natural light conditions, which may possibly also apply for other vegetables. Furthermore, from the economic side of view, it is recommended to reduce the light intensity to be able to make sweet pepper production in Iceland more feasible.

Not only in Iceland, but also in other countries, sweet pepper production with supplemental lighting was evaluated. For instance for the Netherlands, *Heuvelink* et al. (2006) concluded, that supplementary assimilation light was not economically feasible.

5.4 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 black columns are representing the profit margin according to Fig. 36. 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 nearly all treatments (red columns, Fig. 37). In this case it would not be economic to grow sweet pepper in Iceland for the grower. So, without the subsidy of the state, probably no Icelandic grower would produce sweet pepper 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 again, in many cases the profit margin would be negative or range between 100-1500 ISK/m^2 (grey columns). Probably the sweet pepper 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 1700 to 3400 ISK/m^2. From these scenarios it can be concluded that from the grower's side it would be necessary to pay not more for the electricity than they do at the moment when all the other costs would stay stable. The current subsidy should therefore not be decreased.

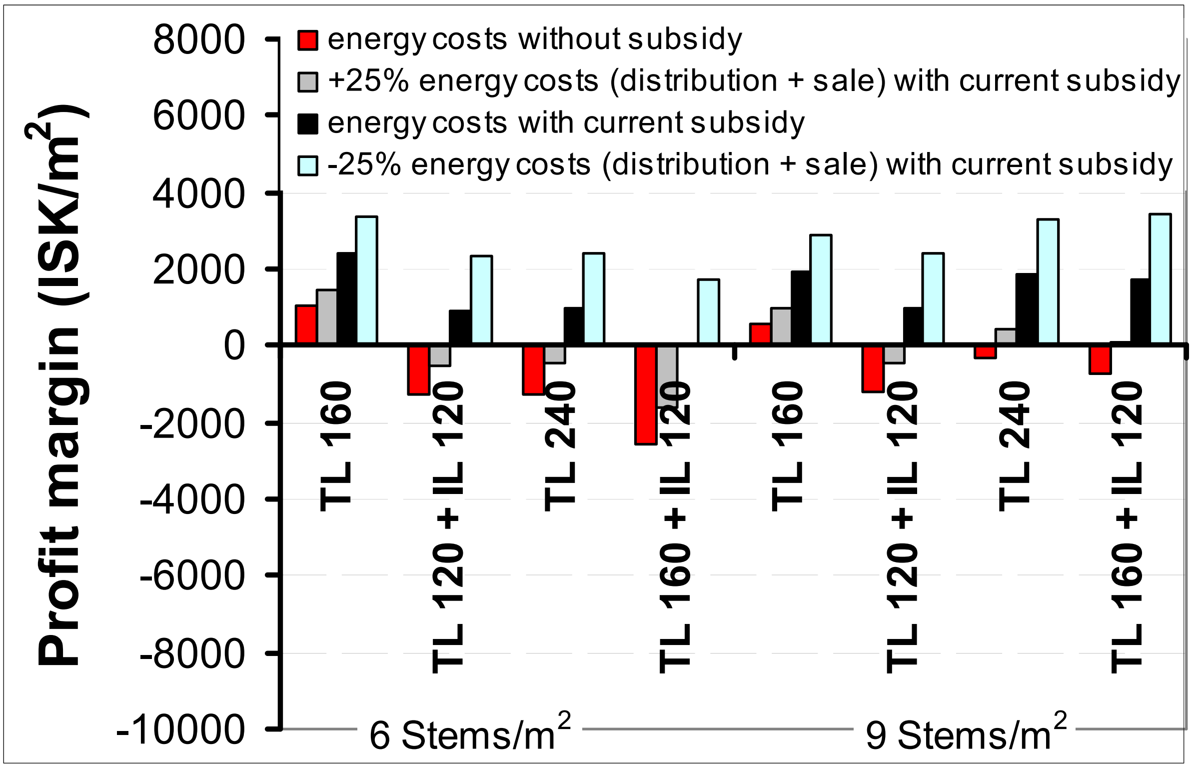

Fig. 37: Profit margin in relation to light intensity and stem density – calculation scenarios.

5.5 Recommendations for saving costs

The current economic situation for growing sweet pepper and the calculation scenarios for future speculations regarding energy prices, necessitate for reducing production costs to be able to heighten profit margin for sweet pepper production.

It can be suggested, that growers can improve their profit margin of sweet pepper 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) and also when 2nd class fruits would be sold or processed.

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 about 50 % of their fertilizer costs.

3. Lower CO_2 costs
   The costs for 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, especially the costs for the black platter or the rent of the box are high. Maybe there is a possibility to decrease these costs by finding other channels of distribution, where less or cheaper packing material is used.
5. Efficient employees
   The efficiency of each employee has to be checked regularly and growers will have an advantage to employ faster workers.
6. Decrease energy costs
   - Lower prices for distribution and sale of energy (which is less realistic)
   - Growers should decrease artificial light intensity at increased solar irradiation, because this would result in no lower yield.
   - 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 its 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.

- 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.
- Growers should try to utilize the energy better by lighting at cheaper times.
- It also needs to be tested, if LED lights are recommended due to their energy efficiency and if they can keep an appropriate yield.
- 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

1. The yield of sweet pepper can be increased by a higher light intensity. With respect to a light intensity adapted plant density, it is supposed that at higher light intensities, a higher stem density should be used to have a positive effect on yield. However, this higher yield at higher light intensities was not implicated in a higher profit margin. Therefore, it is recommended to use only a high light intensity if energy costs can be reduced and / or the revenues of the fruits can be increased, so that higher expenses for the electricity are feasible. From the current economic situation and calculation scenarios for future developments, growers are better off in using a low light intensity.
2. Supplemental lighting should only be used at low solar irradiation. It can be expected that with increasing solar irradiation vegetable growers could possibly decrease supplemental lighting without a reduction in yield and thus reduce energy costs.
3. Top lighting together with interlighting don´t appears to be a more suitable and recommendable lighting method for sweet pepper production (with the variety Ferrari) as compared to top lighting alone. Therefore growers do not need to change the lighting method of their greenhouse production. However, it may possible that other varieties would react with a significant gain when interlighting systems are used. Further investigation would be needed.
4. Growers should pay attention to possible reduction in their production costs for sweet pepper other than energy costs.

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