Rit LbhÍ nr. 43

„Áhrif ljósstyrks, rótarbeðsefnis, vökvunar og umhirðu á vöxt, uppskeru og gæði gróðurhúsatómata“

FINAL REPORT

Christina Stadler

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FINAL REPORT

Christina Stadler

Landbúnaðarháskóli Íslands

Febrúar 2013

Final report of the research project
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Abbreviations

B	boron
Ca	calcium
Cu	cooper
DM	dry matter yield
DS	dry substance
E.C.	electrical conductivity
Fe	iron
HPS	high-pressure vapour sodium lamps
K	potassium
KCl	potassium chloride
kWh	kilo Watt hour
LAI	leaf area index
M	mole
Mg	magnesium
Mn	manganese
N	nitrogen
P	phosphor
pH	potential of hydrogen
ppm	parts per million
S	sulphur
W	Watt
Wh	Watt hours
Zn	zinc

Other abbreviations are explained in the text.

1 SUMMARY

In Iceland, winter production of greenhouse crops is totally dependent on supplementary lighting and has the potential to extend seasonal limits and replace imports during the winter months. Adequate guidelines for increasing yield and decreasing production costs are not yet in place for tomato production and need to be developed.

An experiment with tomato (*Lycopersicon esculentum* Mill. cv. Encore) was conducted from 01.09.2011-26.04.2012 in the experimental greenhouse of the Agricultural University of Iceland at Reykir. Tomatoes were grown in four replicates with 2.5 tops/m^2 in pumice or peat-boards (Kekkilä GroBoard®, 60 cm, Kekkilä Oy, Vantaa, Finland) under high-pressure vapour sodium lamps (HPS, 240 W/m^2) for a maximum of 18 hours light. The comparison „grafted - ungrafted“ was conducted with 3.33 tops/m^2 (grafted: 2 tops/plant, ungrafted: 1 top/plant) at 300 W/m^2. Irrigation was conducted in one cabinet with a scale by regularly controlling the weight of the pot and irrigating at a special target value.
Temperature was kept at 21 °C / 18 °C (day / night) for cabinets with 240 W/m^2, but 23 °C / 14-16 °C (day / night) for the cabinet with 300 W/m^2. Carbon dioxide was provided (800 ppm at 240 W/m^2 and 1,400 ppm CO_2 at 300 W/m^2). Tomatoes received standard nutrition through drip irrigation.

The influence of the light intensity, growing media, grafting and watering strategy on growth, yield and quality of tomato was tested and the profit margin calculated.

By choosing a higher light intensity yield could be slightly increased. This was attributed to more, rather than heavier fruits. The choice of the growing media did not influence the accumulated marketable yield. At the highest light intensity increased grafting the unmarketable yield. Watering with the scale saved up to 20 % of water at low solar irradiation with the same yield, whereas nearly no savings were observed at higher solar irradiation.

Marketable yield was 77-91 % of total yield and was lower with the highest light intensity due to a high amount of flawed and cracked fruits.

There was no influence of the treatment on height, number of clusters and distance between internodes. However, grafted plants were lower and also the distance between clusters was at the beginning of the growth period lower. There were less

fruits per cluster at high light intensity and pollination was decreased. Cumulative DM yield (yield of fruits, leaves, shoots) was highest for the high light intensity, whereas N uptake was only increased for the grafted plants.

The very high increase in energy costs by lighting 60 W/m^2 more was accompanied by only a small yield increase and therefore this light increase can only be recommended when an almost 10 kg higher yield would be reached.

Due to the later planting of grafted plants, a plant nutrition that was not adjusted to the needs of grafted plants and the stripping of leaves that was not done properly at the beginning of the growth period, further experiments need to verify if grafting is advisable.

Possible recommendations for saving costs other than lowering the electricity costs are discussed. From an economic viewpoint it is recommended to irrigate with a scale at low solar irradiation.

2 YFIRLIT

Vetrarræktun í gróðurhúsum á Íslandi er algjörlega háð aukalýsingu. Viðbótarlýsing getur því lengt uppskerutímann og komið í stað innflutnings að vetri til. Fullnægjandi leiðbeiningar fyrir hagkvæmasta ljósstyrk, rótarbeðsefni, ágræðsluna og vökvunar aðferðin vegna ræktunar á tómötum eru ekki til staðar og þarfnast frekari þróunar.

Framkvæmd var tilraun með tómata (*Lycopersicon esculentum* Mill. cv. Encore) þann 01.09.2011-26.04.2012 í tilraunagróðurhúsi Landbúnaðarháskóla Íslands að Reykjum. Tómatarnir voru ræktaðir í fjórum klefum með 2.5 toppa/m^2 í vikri eða torfmottu (Kekkilä GroBoard®, 60 cm, Kekkilä Oy, Vantaa, Finland) undir topplýsingu frá háþrýstum natríumlömpum (HPS, 240 W/m^2) að hámarki 18 klst ljós. Samanburðurinn á ágræddu og óágræddu fór fram með 3.3 toppa/m^2 (ágræddar: 2 toppar/plöntu, óaágræddar 1 toppur/plöntu) við 300 W/m^2. Í einum klefana var notast við vökvunarvog til þess að stjórna vökvun, þyngd eins pottsins og vökvað eftir ákveðinni þyngd.

Hitastig var haldið 21 ℃ / 18℃ (dag/nótt) í klefu m með 240 W/m^2, en 23 ℃ / 14-16 ℃ (dag/nótt) fyrir klefa með 300 W/m ^{2}. Koltvísýringur var gefin (800 ppm CO_2 við 240 W/m^2 og 1400 ppm CO_2 við 300 W/m^2). Tómatarnir fengu tilætlaða næringu með dropavökvun.

Áhrif ljósstyrks, rótarbeðsefnis, ágræðslunar og vökvunar aðferðin á vöxt, uppskeru og gæði tómatanna var prófaður og framlegð reiknuð út.

Með því að velja meiri lýsingu er hægt að auka uppskeru magnið lítilega en það skilaði sér frekar í magni heldur en aukinni þyngd aldina. Val rótarbeðsefnis hafði ekki áhrif á söluhæft magn uppskeru. Þar sem lýsingin var mest jóku ágræddu plönturnar uppskeru ósölulegra aldina. Vökvun með vökvunarvog sparaði allt að 20% af vatni við lága inngeislun með sömu uppskeru, en lítill sem engin sparnaður við meiri inngeislun.

Hlutfall uppskerunar sem hægt var að markaðssetja var 77-91% af heildar uppskerunni en lægst var hlutfallið þar sem mesta lýsingin var þar sem það orsakaði korkrákaða og sprungna tómata.

Aðferðin hafði engin áhrif á hæð, fjölda klasa eða lengd milli stöngulliða. Hinsvegar voru ágræddu plönturnar lægri og einnig lengdin milli klasa við byrjun ræktunartímans. Það voru færri aldin á klasa þar sem lýsingin var mikil og frjövgun slök. Samantekið DM uppskeru (aldina, laufa, sprota) var mest þar sem mesta lýsingin var gefin, upptaka N jókst aðeins hjá ágræddu plöntunum.

Mikil hækkun í orkukostnaði með því að lýsa með auka 60 W/m^2 fylgdi ekki í nema lítil aukning í uppskeru og þarf því að ná allt að 10 kg hærri uppskeru ef mæla á með því.

Sökum þess að ágræddu plöntunum var plantað seinna, áburður ekki stilltur rétt að þörfum þeirra og afblöðun framkvæmd sem ekki var vandað til í byrjun ræktunartímans þá er þörf á frekari rannsóknum til að staðfesta hvort ágræðsla sé ráðleg.

Möguleikar til þess að minnka kostnað, aðrir en að lækka rafmagnskostnað eru ræddir. Frá efnahagslegu sjónarmiði er mælt með því að nota vog við vökvun við lága inngeislun.

2 INTRODUCTION

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

The positive influence of artificial lighting on plant growth, yield and quality of tomatoes (*Demers* et al., 1998a), cucumbers (*Hao* & *Papadopoulos*, 1999) and sweet pepper (*Demers* et al., 1998b) has been well studied. It is often assumed that an increment in light intensity results in the same yield increase. Indeed, yield of sweet pepper in the experimental greenhouse of the Agricultural University of Iceland at Reykir increased with light intensity (*Stadler* et al., 2010). However, with tomatoes, a higher light intensity resulted not in a higher yield (*Stadler*, 2012). In contrast to sweet pepper, with increased light intensity in tomatoes the temperature was changed whereas the amount of applied CO_2 stayed at the same value. Also, a higher stem density was transfered better into yield of sweet pepper at high light intensity (*Stadler* et al., 2010). Additional research is needed to verify the influence of light intensity in connection with temperature and CO_2.

Since decades is pumice the most common substrate component used in Iceland. Peat is rarely used. However, different growing media are expected to have an influence on the growth of vegetables. *Owen* et al. (w.y.) measured an increased shoot and root dry weight of *Weigela florida* and *Azalea* when 30-45 % screened pumice compared to 30-45 % sphagnum peat was added to Douglas fir bark.

Also, the watering strategy might influence growth. One Icelandic grower is using a scale to measure the runoff each three hours. The scale is connected to the computer and watering is done according to the measurements of the runoff. It can be assumed that this watering strategy is influencing growth positively, as the applied amount of water is regulated according to environmental factors and to the plant needs.

Environmental conditions and the tending strategy are expected to have also an impact on the plants growth. Plants can be too vegetative or too generative often due to environmental conditions. Plants can be kept in balance or steered back in the required direction by changing light, temperature, humidity, CO_2, irrigation, nutrition and plant management. Plants become vegetative in favourable, mild growing conditions and generative in harsh growing conditions. Determining the plant balance requires accurate observation of the plants, which is reached by weekly crop registration (*Houter* et al., 2007a; *Houter* et al., 2007b).

Also the question if plants should be grafted or ungrafted is getting important.

Incorporating light intensity, growing media, watering and tending strategy into a production strategy is an economic decision involving added costs versus potential returns. Therefore, the question arises whether these factors are leading to an appropriate yield of fruits. Also, the profit margin of the horticultural crop was considered.

The objective of this study was to test if (1) different light intensities, growing media, watering and tending strategy are affecting growth, yield and quality of tomatoes and the N uptake of the plant, (2) a higher light intensity is converted efficiently into yield, and (3) the profit margin can be improved by light intensities, growing media, watering and tending strategy. This study should enable to strengthen the knowledge on the lighting regime and give vegetable growers advice how to improve their tomato production by modifying the efficiency of electricity consumption in lighting.

3 MATERIALS AND METHODS

3.1 Greenhouse experiment

An experiment with tomatoes (*Lycopersicon esculentum* Mill. cv. Encore) and grafted and ungrafted tomatoes, two light intensities, two growing media, watering and tending strategy was conducted in four cabinets at the Agricultural University of Iceland at Reykir. Seeds of tomatoes were sown on 14.07.2011 (Maxifort) and 21.07.2011 (Encore) in rock wool plugs. On 01.09.2011 (respectively 13.09.2011 for grafted tomatoes) four plants were transplanted in 18 l pots filled with pumice stones respectively six plants in a mat of peat and transferred to the cabinets with different lighting regimes. Tomatoes were transplanted in rows in four 70 cm high beds (A, B, C, D; Fig. 1) with 2.5 tops/m^2. Beds were equipped with 6 pots / 4 mats of peat, respectively 24 plants. However, in the cabinet with the high light intensity, 3.33 tops/m^2 were transplanted with grafted tomatoes (2 tops/plant) in two beds and ungrafted tomatoes (1 top/plant) in two beds. Beds were equipped with 8 pots, respectively 32 tops. Four replicates, one replicate in each bed consisting of two pots (8 plants) acted as subplots for measurements. However, in the two cabinets, where two different treatments were in one cabinet, two replicates in each bed consisting of two pots (8 plants) / 1.33 mat (8 plants) acted as subplots for measurements. Other pots / mats were not measured. Do to the weekly hanging down, all plants were at least once at the end of the bed.

Wires were placed in about 3.56 m height from the floor with each 90 cm distance between floors and beds. Bumblebees were used for pollination and hives were open from 11.00-14.00. Hives were replaced every two to three weeks.

Temperature was kept at 21° C / 18° C (day / night) and ventilation started at 24° C but in the cabinet with the high light intensity temperature was 23℃ / 14-16℃ (day/night) and ventilation with 26℃. Carbon dioxi de was provided (800 ppm CO_2 with no ventilation and 400 ppm CO_2 with ventilation, respectively 1,400 ppm CO_2 with no ventilation and 700 ppm CO_2 with ventilation). A misting system was installed. Plant protection was managed by beneficial organisms and if necessary with insecticides.

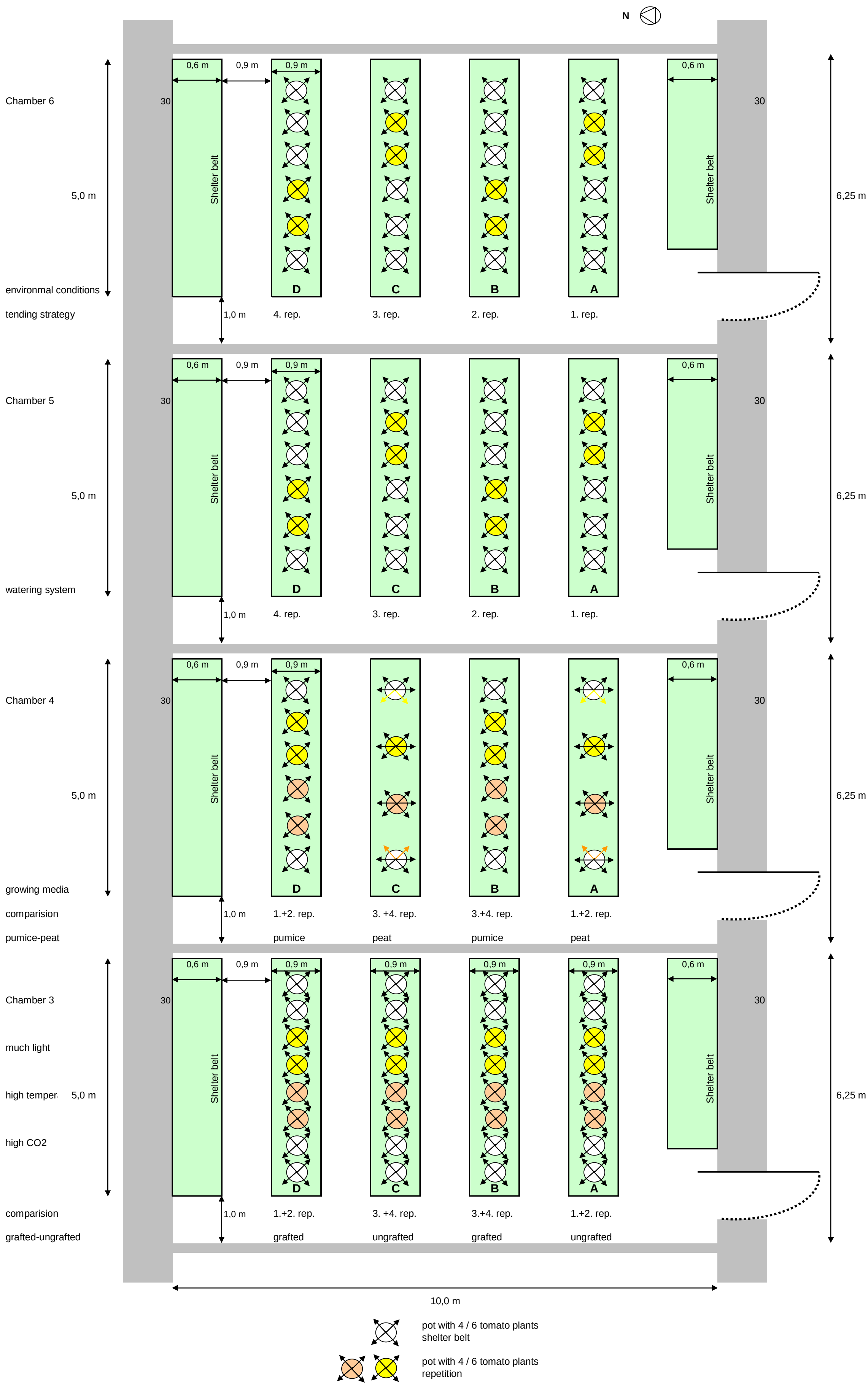

Fig. 1: Experimental design of cabinets.

Tomatoes received standard nutrition consisting of “Sérblandað Superex L 549” or “Tómato Superex L 553” (Kekkilä) according to the following fertilizer plan (Tab. 1):

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

	Stem solution A (1000 l)	**Stem solution B** (1000 l)					**Irrigation water**		**Runoff water**	
Fertilizer (amount in kg)	Strong vegetable Superex L 540	Calcium nitrate	Calcium chloride	Potassium nitrate	Urea	Nitric acid (38 %)	E.C. (mS/cm)	pH	E.C. (mS/cm)	pH
1.-4. week (after planting)	125	100					3,5		4,5-6,0	5,7-6,2
next 2 months	125	75	5	25	10	10	2,7		3,5-4,5	5,7-6,2

	Stem solution A (1000 l)				**Stem solution B** (1000 l)				**Irrigation water**		**Runoff water**	
Fertilizer (amount in kg)	Tomato Superex L 553	Potassium nitrate	Potassium suplhate	Restart (l)	Magnesium sulphate	Calcium nitrate	Potassium chloride	Magnesium nitrate	E.C. (mS/cm)	pH	E.C. (mS/cm)	pH
until topping	50	25		10	25	102	8	15	2,6-2,8	5,3-5,6	2,5-3,0	5,7-6,2
From topping to end	75		16	16	47	142	16		2,2-2,6	5,3-5,6	2,5-3,0	5,7-6,2

Plants were irrigated through drip irrigation (4 tubes per bucket). Irrigation differed in cabinets (Tab. 2).

Tab. 2: Irrigation of tomatoes.

Group	Time of irrigation	Duration between irrigations	Duration of irrigation	Number of irrigations
	05.30-21.30	min	min	
Watering in “300 HPS, grafted”				
09.09.11-16.09.11		120	1.40	9-34
17.09.11-23.09.11		120	1.40	27
24.09.11-30.09.11		120	1.40	31
01.10.11-05.10.11		90	1.40	35
06.10.11-28.10.11		90	1.40	41
29.10.11-09.11.11		50	1.35	31
10.11.11-24.11.11		50	1.35	29
25.11.11-08.12.11		50	1.35	25
09.12.11-12.12.11		50	1.35	10
13.12.11-20.12.11		50	1.35	35
21.12.11-31.01.12		50	1.35	8-36
01.02.12-26.04.12		30	1.30	36
Watering in “300 HPS, ungrafted”				
09.09.11-16.09.11		120	1.40	9-34
17.09.11-23.09.11		120	1.40	27
24.11.11-30.09.11		120	1.40	31
01.10.11-05.10.11		90	1.40	35
06.10.11-29.11.11		50	1.35	41
30.10.11-08.11.11		50	1.35	35
09.11.11-24.11.11		50	1.35	41
25.11.11-13.12.11		50	1.35	30
14.12.11-29.12.11		50	1.35	23
30.12.11-14.02.12		50	1.35	30
15.02.12-26.04.12		30	1.35	35
Watering in “240 HPS, pumice”, “240 HPS, tending”				
09.09.11-23.09.11		120	1.40	15-27
24.09.11-30.09.11		120	1.40	31
01.10.11-24.11.11		90	1.40	35
25.11.11-13.12.11		50	1.35	30
14.12.11-29.12.11		50	1.35	23
30.12.11-26.02.12		50	1.35	30
27.02.12-26.04.12		30	1.25	35
Watering in “240 HPS, peat”				
09.09.11-11.09.11				4
12.09.11-16.09.11				5

17.09.11-23.09.11				6
24.09.11-14.10.11				7
15.10.11-09.03.11				9
10.03.11-26.04.12			7	8
Watering in cabinet 5 “240 HPS, scale”				
09.09.11-26.04.12		30	1.35	15-42
Watering in all cabinets during the night				
06.09.11-26.04.12	2.00			1

Numbers for “time of irrigation”, “duration between irrigations” and “duration of irrigation” are only very rough available, because it was not written down well enough from the personal that was daily taking care of the tomatoes.

3.2 Treatments

Ungrafted tomatoes (*Lycopersicon esculentum* Mill. cv. Encore) were grown until 26.04.2011 under high-pressure sodium lamps (HPS) for top lighting at different light intensities, different growing media (pumice, peat-boards (Kekkilä GroBoard®, 60 cm x 20 cm x 30 cm, Kekkilä Oy, Vantaa, Finland)), different watering technique (watering with scale) and tending strategies in four cabinets at the Agricultural University of Iceland in Reykir. However, in one cabinet (1) in addition to ungrafted tomatoes, also grafted tomatoes were grown:

1. HPS top lighting 300 W/m^2 + high plant density + high temperature + high CO_2
   300 HPS, ungrafted
   300 HPS, grafted
2. HPS top lighting 240 W/m^2 + different growing media (pumice, peat)
   240 HPS, pumice
   240 HPS, peat
3. HPS top lighting 240 W/m^2 + watering strategy (normal / with scale)
   240 HPS, scale
4. HPS top lighting 240 W/m^2 + environmental conditions / tending strategy
   240 HPS, tending

HPS lamps for top lighting (600 W bulbs) were mounted horizontally over the canopy. Light (240 W/m^2) was provided for 0-18 hours, depending on solar irradiation and age of plants (1-4). For the highest light intensity (300 W/m^2) a higher temperature

(23℃ / 14-16℃) and higher CO_2 (1,400 ppm) was chosen (1), because the optimal temperature is increasing with light intensity (*Dorais*, 2003). The other chambers (2-4) received 240 W/m^2 and 21℃ / 18℃ (day / night) and 800 ppm CO_2. The lamps were automatically turned off when incoming illuminance was above the desired set-point.

In the cabinet with the scale (3) the runoff was measured each three hours. The scale was connected to the computer and it was watered according to the measurements of the runoff.

In one cabinet ten plants were measured weekly and regarding the growth (vegetative/generative) it was acted on environmental factors and tending strategies (4).

3.3 Measurements, sampling and analyses

Soil temperature was measured once a week and air temperature and irradiation (subdivided between vertical and horizontal irradiation) manually monthly at different vertical heights above ground (0 m, 0.5 m, 1.0 m, 1.5 m, 2.0 m) close to the plant under diffuse light conditions.

The amount of fertilization water (input and runoff) was measured every day and regularly analyzed for nutrients.

To be able to determine plant development, the height of plants was measured each week and the number of clusters was counted and distance of clusters measured. Further weekly plant measurements include diameter of head, length growth, leaf length, flowering cluster, set cluster, total fruit on plant per stem, highest cluster, totally set and harvested cluster.

Yield (fresh and dry biomass) of seedlings and their N content was analyzed. During the growth period, fruits were regularly collected (2-3 times per week) in the subplots. Total fresh yield, number of fruits, fruit category (A-class (> 55 mm), B-class (45-55 mm) and not marketable fruits (too little fruits (< 45 mm), fruits with blossom end rot) was determined. Additional samplings included samples from pruning during the growth period. Plants were topped at 09.03.2012. At the end of the growth period on each plant from the subplots the number of immature fruits was counted. The aboveground biomass of these plants was harvested and divided into immature green fruits and shoots. For all plant parts, fresh biomass weight was determined and subsamples (three times for stripped leaves, fruits) were dried at 105° C for 24 h for total dry matter yield (DM). Dry samples were milled and N content was analyzed according to the DUMAS method (varioMax CN, Macro Elementar Analyser, ELEMENTAR ANALYSENSYSTEME GmbH, Hanau, Germany) to be able to determine N uptake from tomatoes.

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

Composite soil samples for analysis of nitrate-N and ammonium-N were taken from buckets at the end of the growth period. After sampling, soil samples were kept frozen. The soil was measured for nitrate (1.6 M KCl) and ammonium (2 M KCl) with a Perkin Elmer FIAS 400 combined with a Perkin Elmer Lambda 25 UV/VIS Spectrometer.

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

3.4 Statistical analyses

Statistical analyses were not conducted, because grafted plants were transplanted two weeks later and results are therefore not directly comparable.

4 RESULTS

4.1 Environmental conditions for growing

4.1.1 Solar irradiation

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

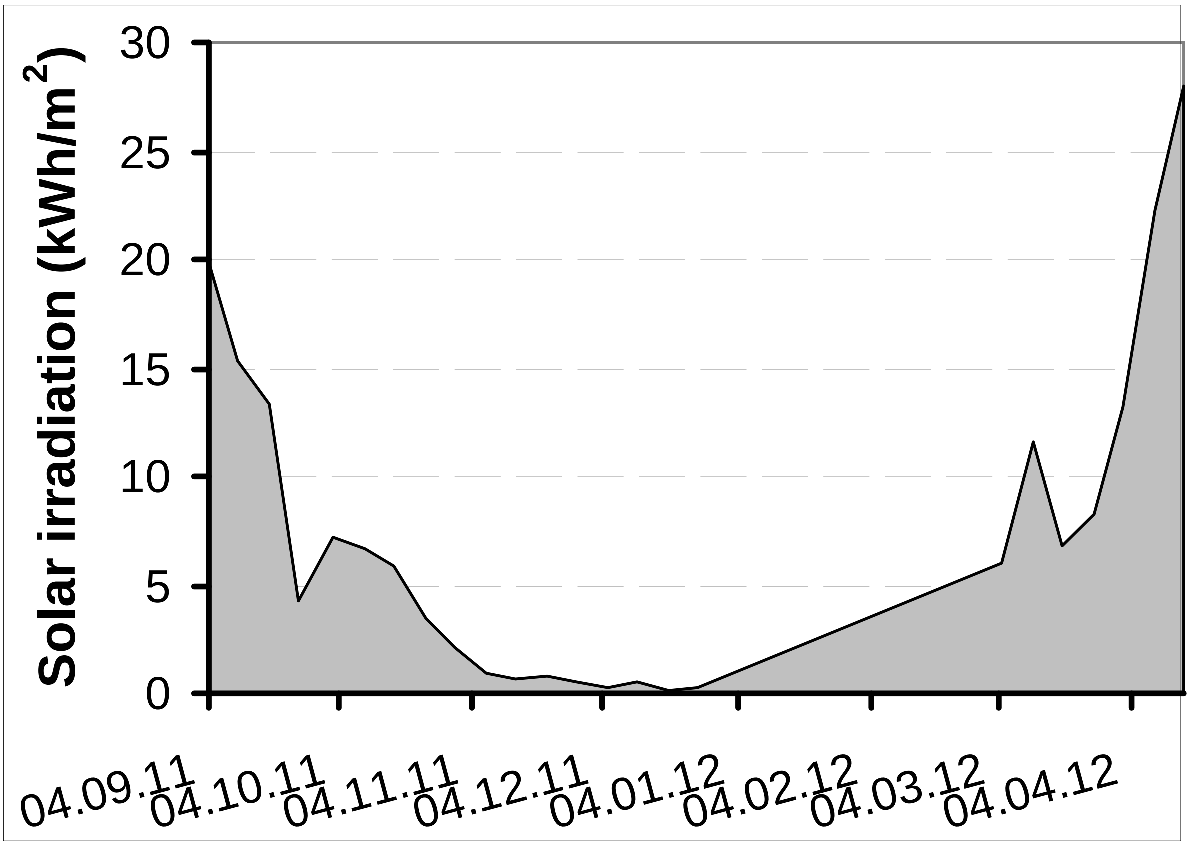

Fig. 2: Time course of solar irradiation. Solar irradiation was measured every day and values for one week were cumulated.

4.1.2 Illuminance and air temperature

Illuminance is the total luminous flux incident on a surface, per unit area. In the case of the tomato experiment solar irradiation was allowed to come into the greenhouse and therefore, illuminance and air temperature is composed of solar irradiation and irradiation of HPS lamps and adjusted air temperature in the cabinets and heat of

HPS lamps. To eliminate the incoming solar radiation and the outside temperature, illuminance and air temperature were measured early in the morning during cloudy days.

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

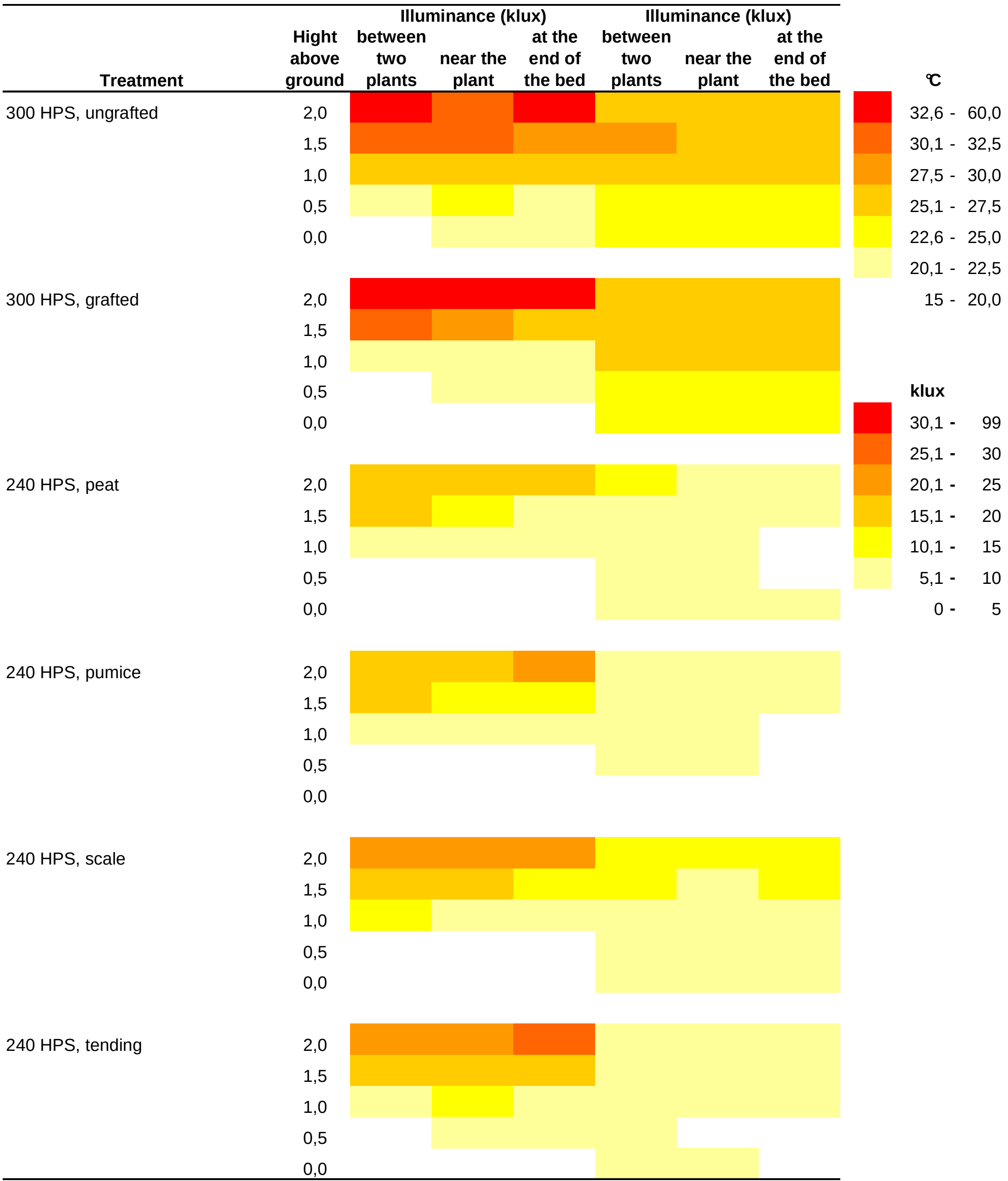

Fig. 3: **Illuminance (solar + HPS lamps) and air temperature at different treatments. Illuminance and air temperature was measured early in the morning at a cloudy day.**

4.1.3 Soil temperature

Soil temperature was measured weekly at low solar radiation early in the morning (at about 8.30) and was mainly influenced by the light intensity. Soil temperature stayed most of the time between 21-24° C (Fig. 4). Naturally, the soil temperature of the highest light intensity "300 HPS, ungrafted" and "300 HPS, grafted" was most of the time highest. "240 HPS, peat" was warmer than "240 HPS, pumice". "240 HPS, scale" showed most of the time the lowest temperature.

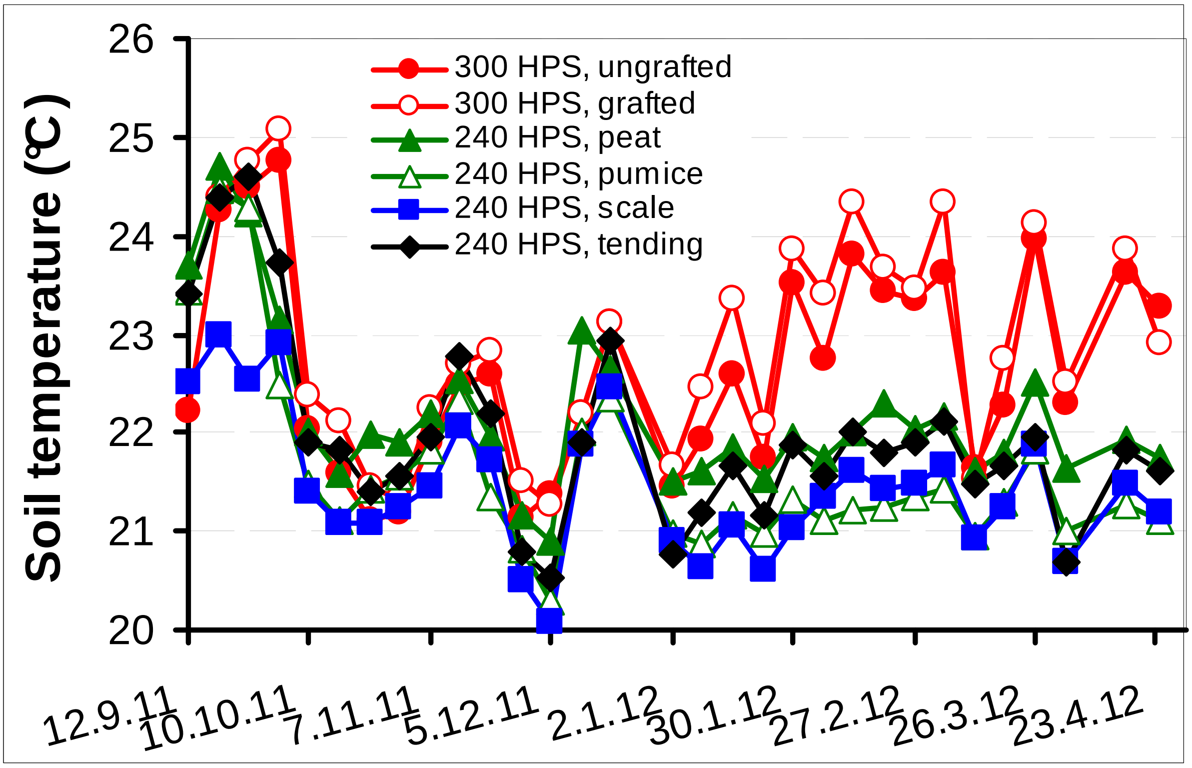

Fig. 4: Soil temperature at different treatments. The soil temperature was measured at little solar irradiation early in the morning.

4.1.4 Irrigation of tomatoes

The amount of applied water differed depending on the light intensity. A higher light intensity (and top density) was going ahead with a higher amount of applied water (114 % (ungrafted) / 129 % (grafted)) compared to 100 % for the treatment "240 HPS, pumice". Also, it seems that with watering with the scale about 20 % of irrigation water can be saved (Fig. 5).

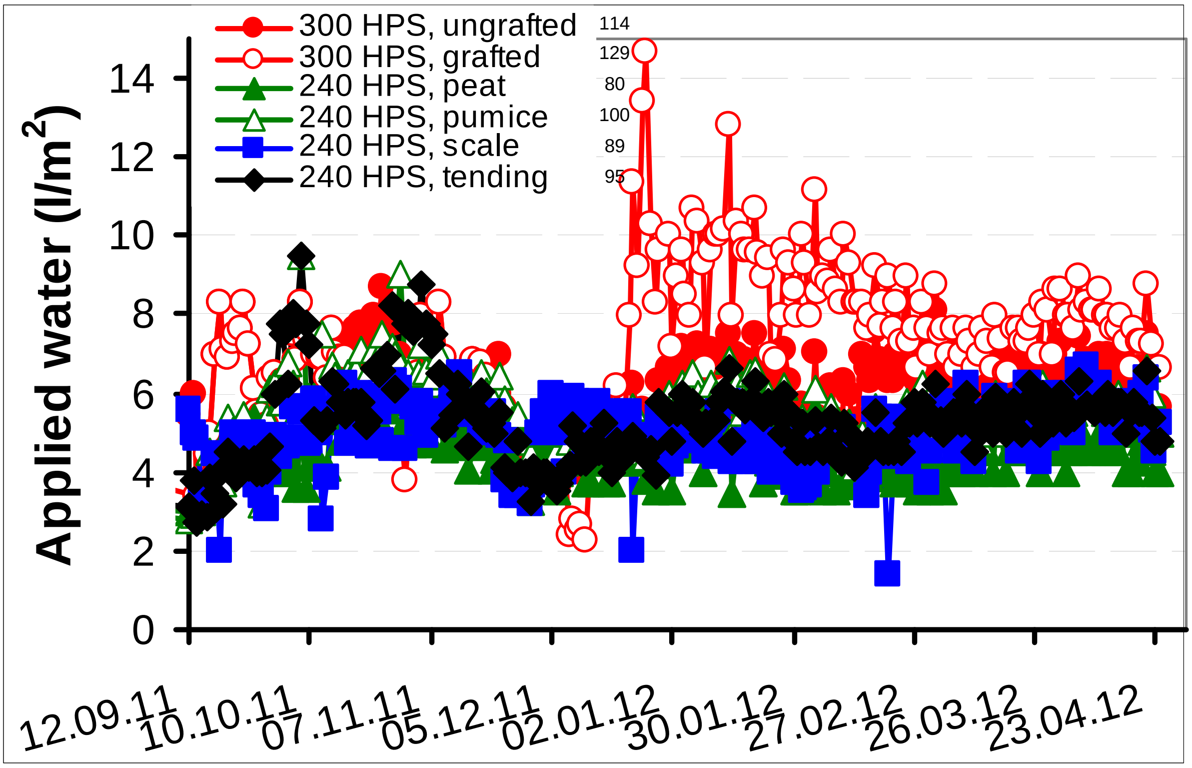

Fig. 5: **Daily applied water at different treatments.**

By calculating the daily applied water rate per months it is getting clearer when these savings by watering with the scale occur: Especially during low solar irradiation (October – February) around 20 % of irrigation water can be saved. In contrast, during higher solar irrigation, savings by watering with the scale are small (Fig. 6).

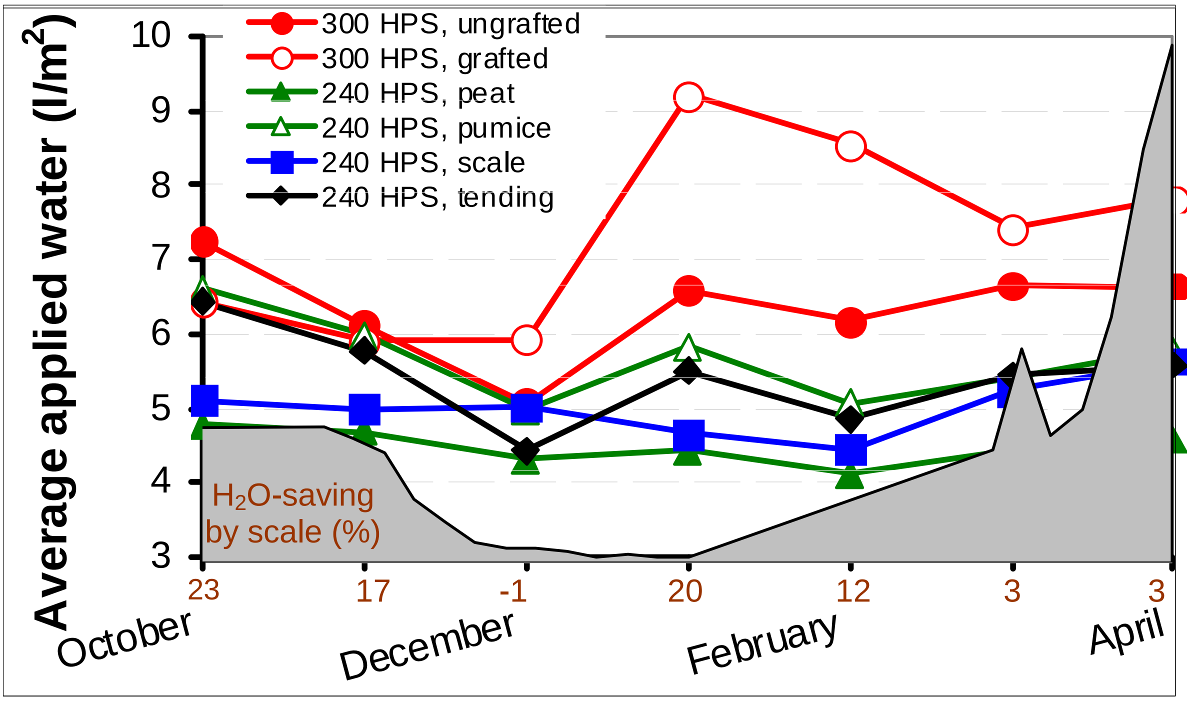

Fig. 6: **Average daily applied water at different treatments and solar irradiation and water savings by watering by scale.**

E.C. and pH of irrigation water was fluctuating much (Fig. 7 a, b). E.C. of applied water ranged most of the time between 2.0 and 3.0 and pH between 5.0 and 6.0. E.C. of runoff stayed mostly between 3.0 and 5.0 and was lowest for the grafted tomatoes and highest for peat. The pH of runoff decreased during the growth period from 5.5-7.0 to 4.0-6.0. At the end of the growth period the lowest pH of runoff was measured for the cabinet with the highest light intensity and here especially for the ungrafted tomatoes (Fig. 7 c, d). The pH of runoff was lower for peat than for pumice.

The amount of runoff from applied irrigation water was about 20-50 % (Fig. 8).

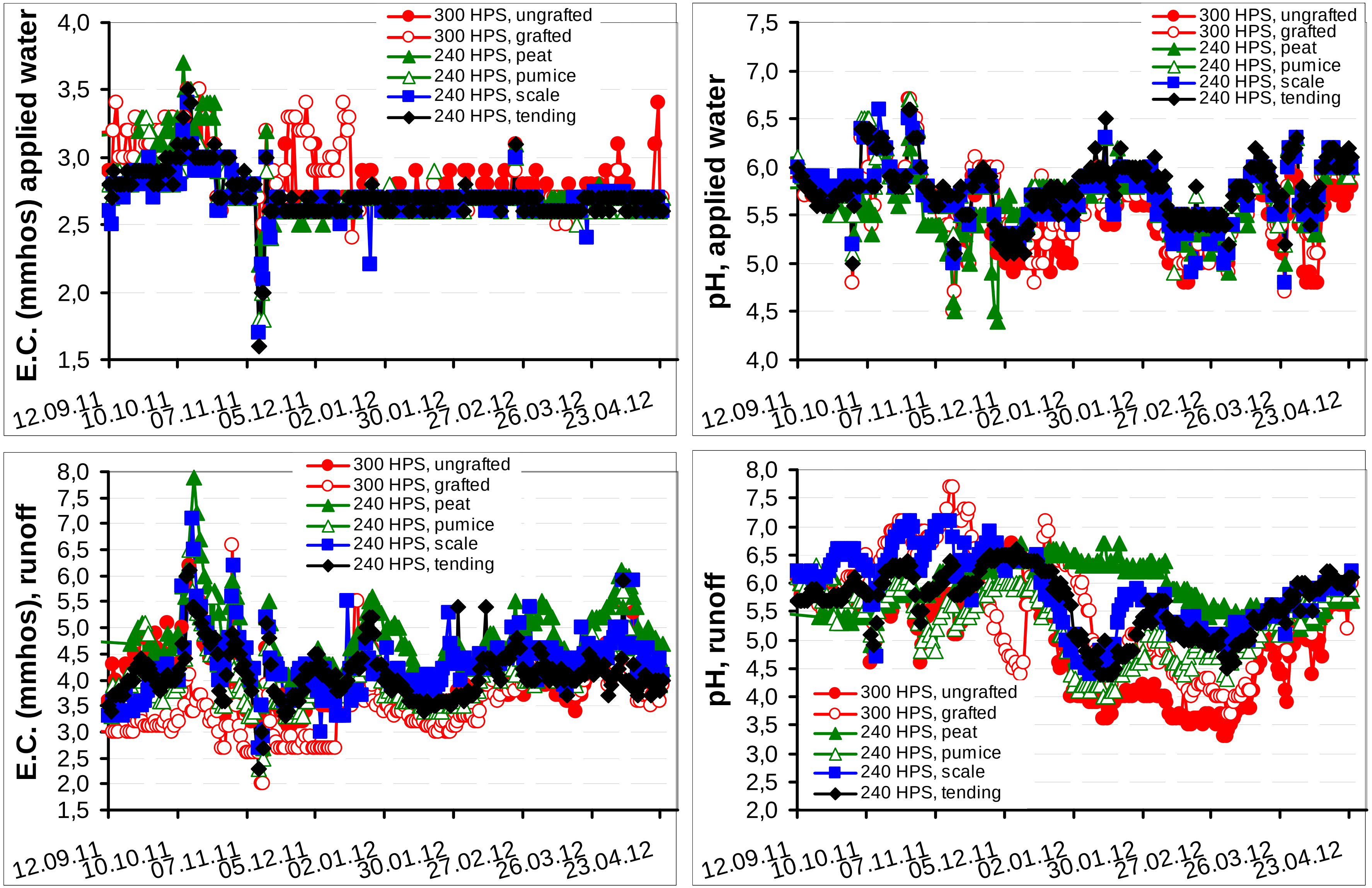

Fig. 7: **E.C. (a, c) and pH (b, d) of irrigation water (a, b) and runoff of irrigation water (c, d).**

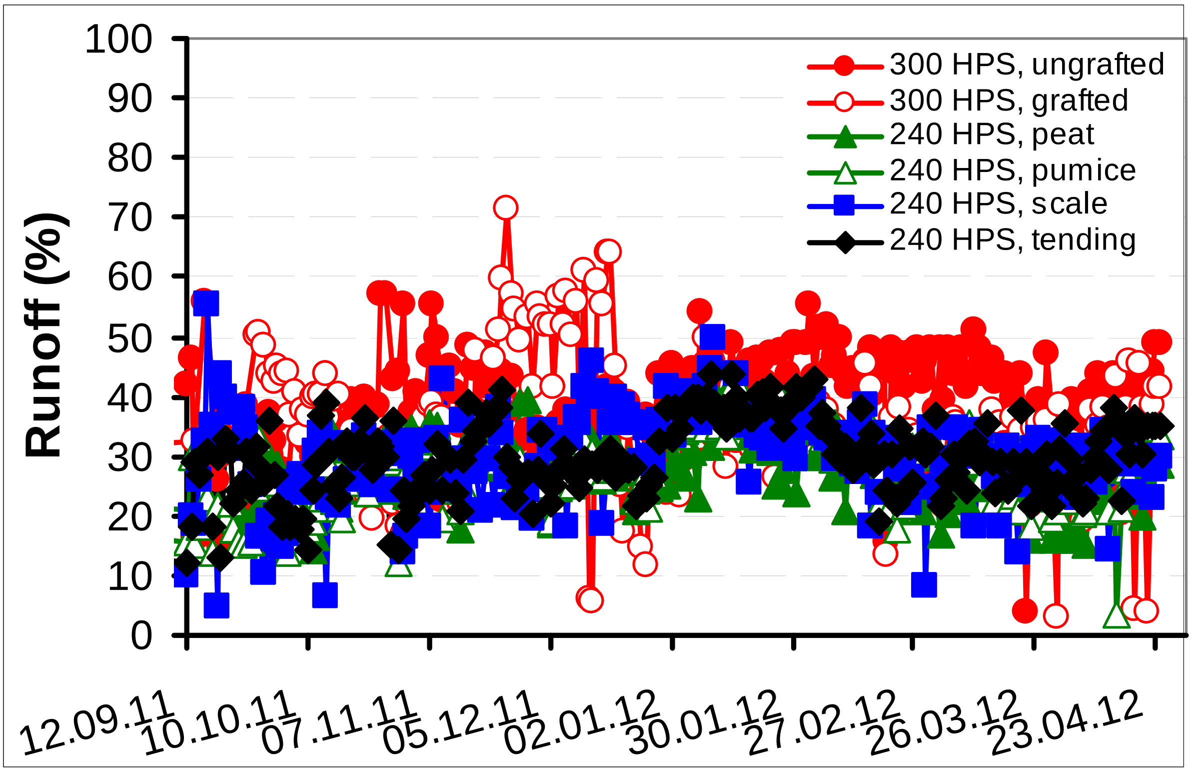

Fig. 8: **Proportion of amount of runoff from applied irrigation water at different treatments.**

Plants took up between 2 and 5 l/m^2 with 240 W/m^2 and up to 8 l/m^2 with 300 W/m^2 for grafted tomatoes (Fig. 9).

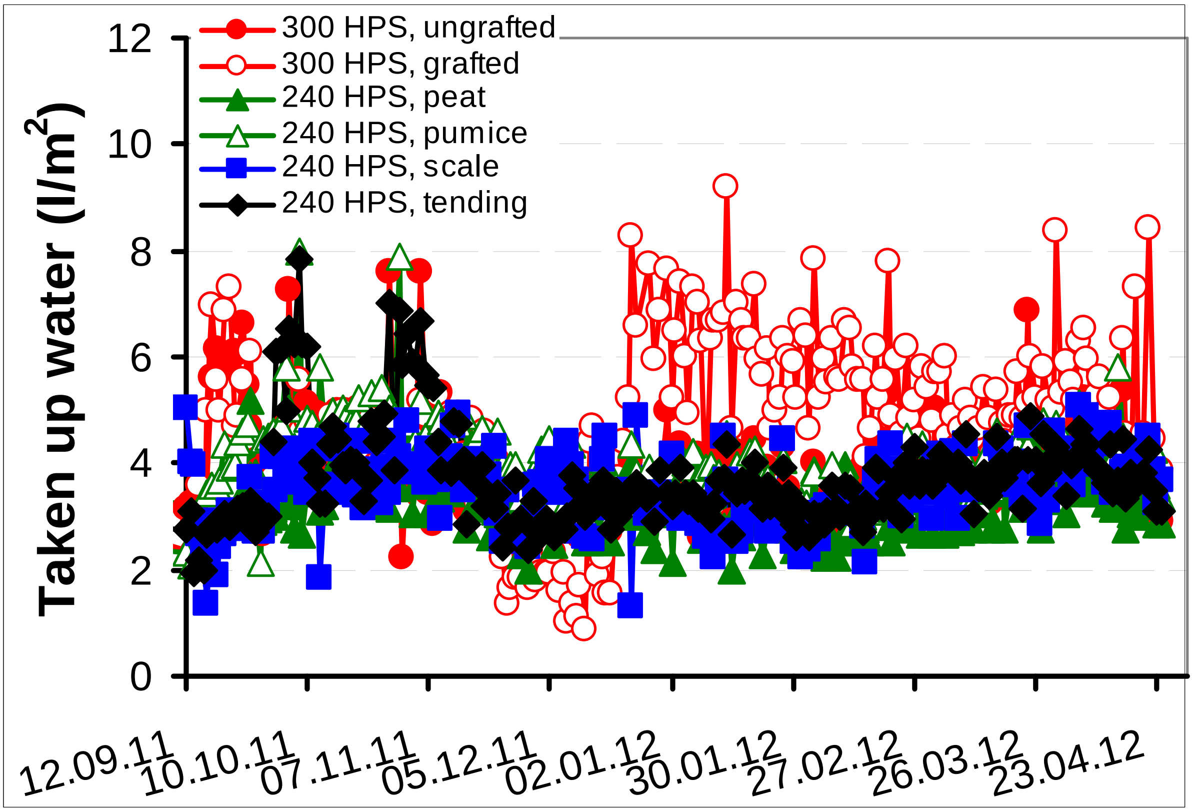

Fig. 9: **Water uptake at different treatments.**

Monthly taken water samples from the drip and the runoff water provide an information basis on which nutrients are close to the target of the drain water. At the beginning of November, all chambers showed a high Cu content. In addition, “240 HPS, pumice” had a high P and Fe content and low Mo content. At the beginning of December all chambers except “240 HPS, peat” showed a high Cu content (“300 HPS, grafted” and “240 HPS, pumice” got lost). “240 HPS, peat” showed a high Mn content and Mo was low for “240 HPS, scale”. All chambers showed at the beginning of January a low Mo content (“300 HPS, ungrafted” was not measured). Cu was high for all chambers except for “240 HPS, peat” and P high for all chambers except for “240 HPS, scale”. At the beginning of February, P was high in all chambers and Cu high in all chambers except for “240 HPS, peat”. Mo was low for “240 HPS, peat” and Fe high for “240 HPS, scale”.

Leaves were taken on the 14.02.2012 and a plant tissue analysis was done to measure nutrient concentrations within the growing plant. Testing of tomato leaves provides information on whether or not nutrients are sufficient for optimum crop development. Not only does it identify and verify observed nutrient deficiencies and/or toxicities, but it can also identify nutrient shortages before symptoms appear. The plant tissue analysis showed that nitrogen was rather low in all treatments,

Tab. 3: Plant tissue analysis.

Nutrient	**Nutrient Sufficiency**	**300 HPS, ungrafted**	**300 HPS, grafted**	**240 HPS, peat**	**240 HPS, pumice**	**240 HPS, scale**	**240 HPS, tending**
N (g/kg)	35–50	32.4	41.8	41.0	34.7	34.1	34.1
P (g/kg)	3–6.5	5.12	6.65	5.72	6.73	5.65	6.07
K (g/kg)	28–40	34.0	41.5	44.4	36.6	36.6	37.1
Ca (g/kg)	10–30	13.5	22.5	18.7	16.5	16.0	18.5
Mg (g/kg)	3.5–10	2.71	4.71	2.95	2.72	2.95	2.89
S (g/kg)	2–10	5.79	6.63	9.19	7.96	7.69	9.40
Fe (mg/kg)	50–300	54	78	75	69	52	61
B (mg/kg)	30–75	34	30	39	37	38	42
Cu (mg/kg)	5–35	7	8	10	8	6	7
Mn (mg/kg)	25–200	180	200	260	230	180	250
Zn (mg/kg)	18–80	17	18	17	12	12	12

except in the grafted ones and in the peat treatment (Tab. 3). Also, magnesium and zinc were rather low, but not with grafted tomatoes. In contrast, manganese was high in “240 HPS, peat”, “240 HPS, pumice” and “240 HPS, tending” and phosphor was high for “300 HPS, grafted” and “240 HPS, pumice”, while potassium was high for “300 HPS, grafted” and “240 HPS, peat”.

4.2 Development of tomatoes

4.2.1 Height

Tomato plants were growing about 3-4 cm per day and reached at the end of the experiment about 7 m (Fig. 10). Until the beginning of December the grafted plants grow slightly slower (0.5-1.5 cm per day less) than the ungrafted ones. However, when stripping of leaves was done more strictly, the weekly growth increased middle of January and was about 0.5 cm/day higher compared to ungrafted tomatoes.

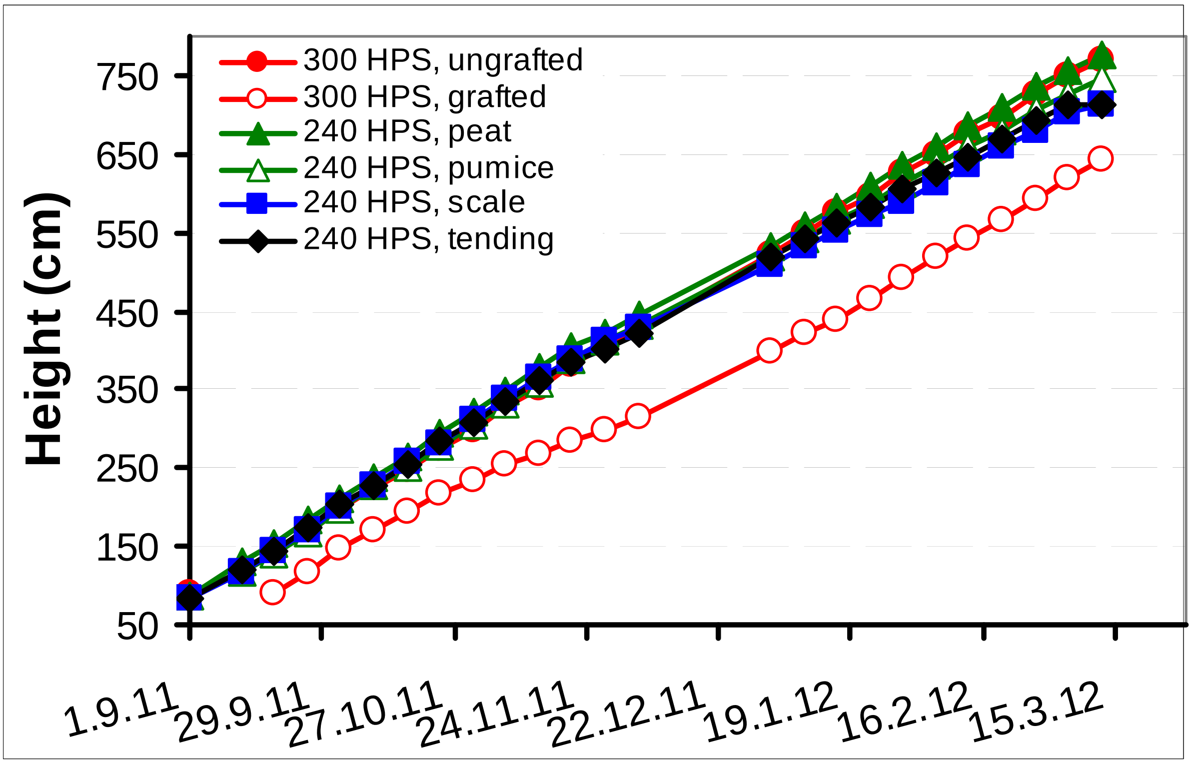

Fig. 10: Height of tomatoes at different treatments.

4.2.2 Number of clusters

The number of clusters increased with approximately one additional cluster per week. No differences between treatments were found (Fig. 11). However, grafted plants produced faster an additional cluster at the latter part of the growth period.

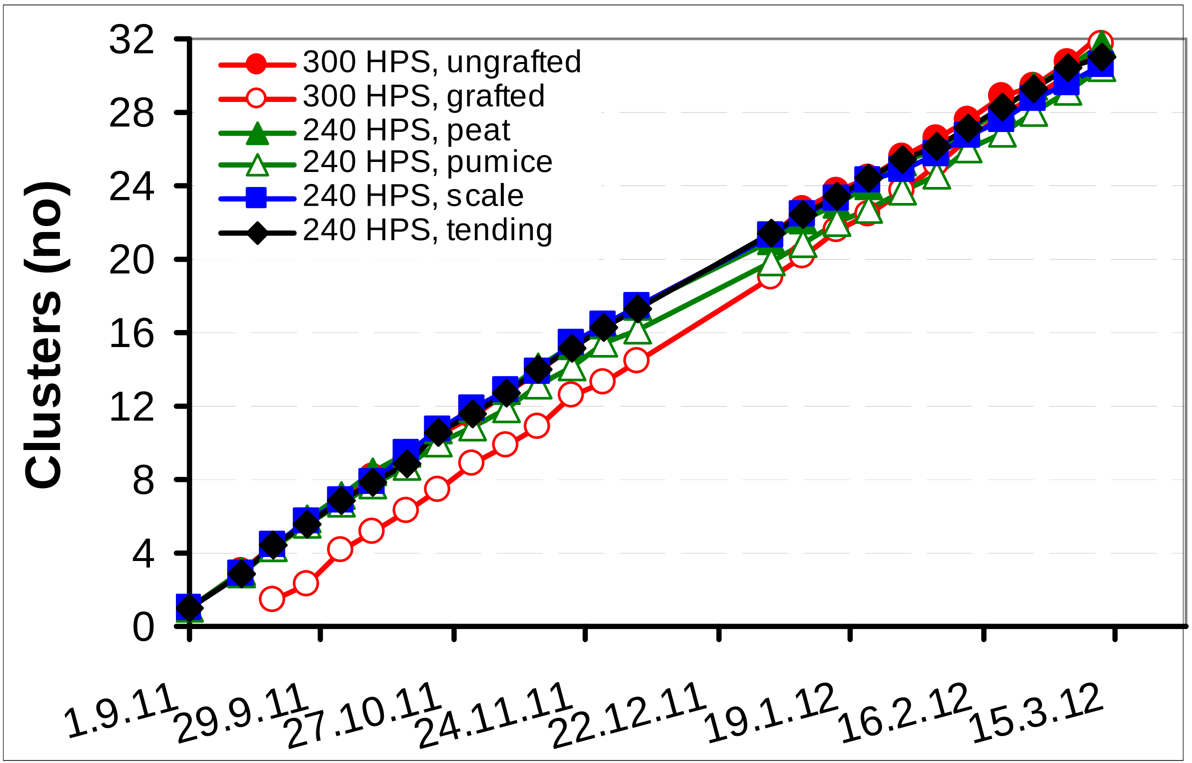

Fig. 11: Number of clusters at different treatments.

4.2.3 Distance between clusters

The distance between clusters was regularly measured and stayed most of the time between 20 and 25 cm (chamber average: 22-23 cm). However, the average for the

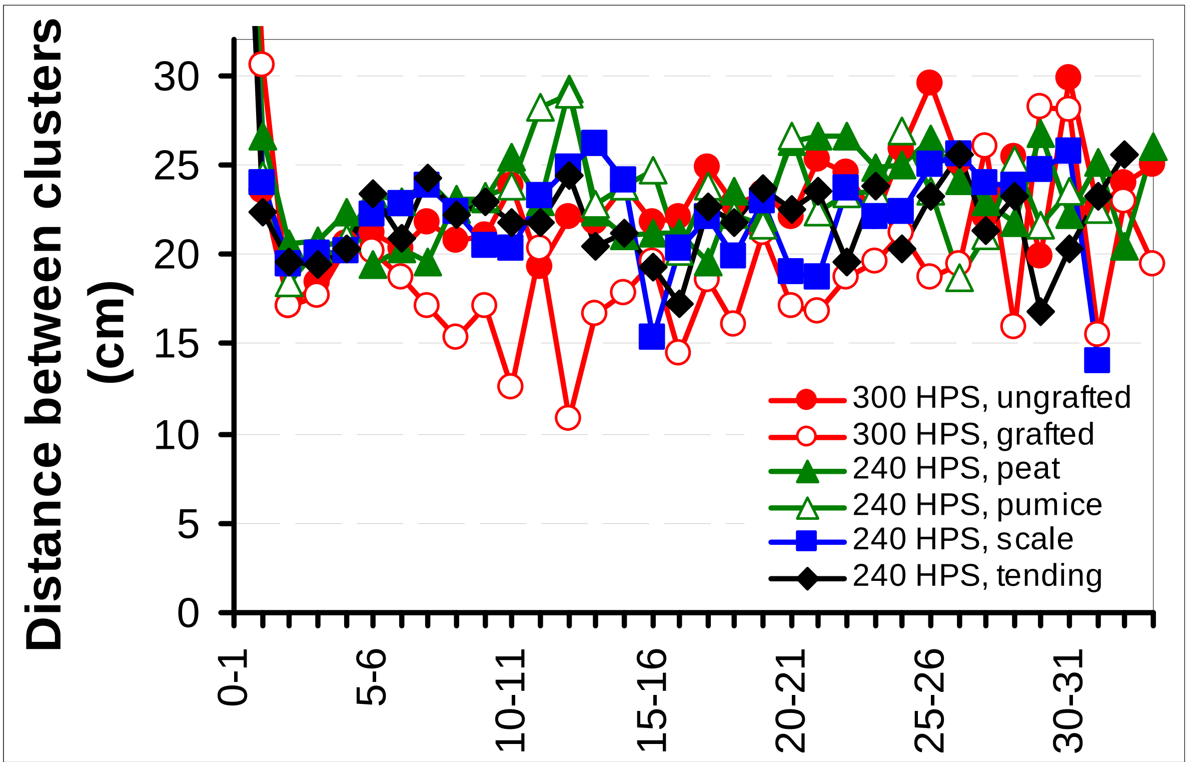

Fig. 12: Average distance between clusters at different treatments.

grafted plants was only 19 cm. In this chamber, especially at the beginning of the growth period the distance was low, but increased later (Fig. 12), because during the latter part stripping of leaves was done more strict.

Fruits and not pollinated fruits per cluster fluctuated much (Fig. 13, Fig. 14).

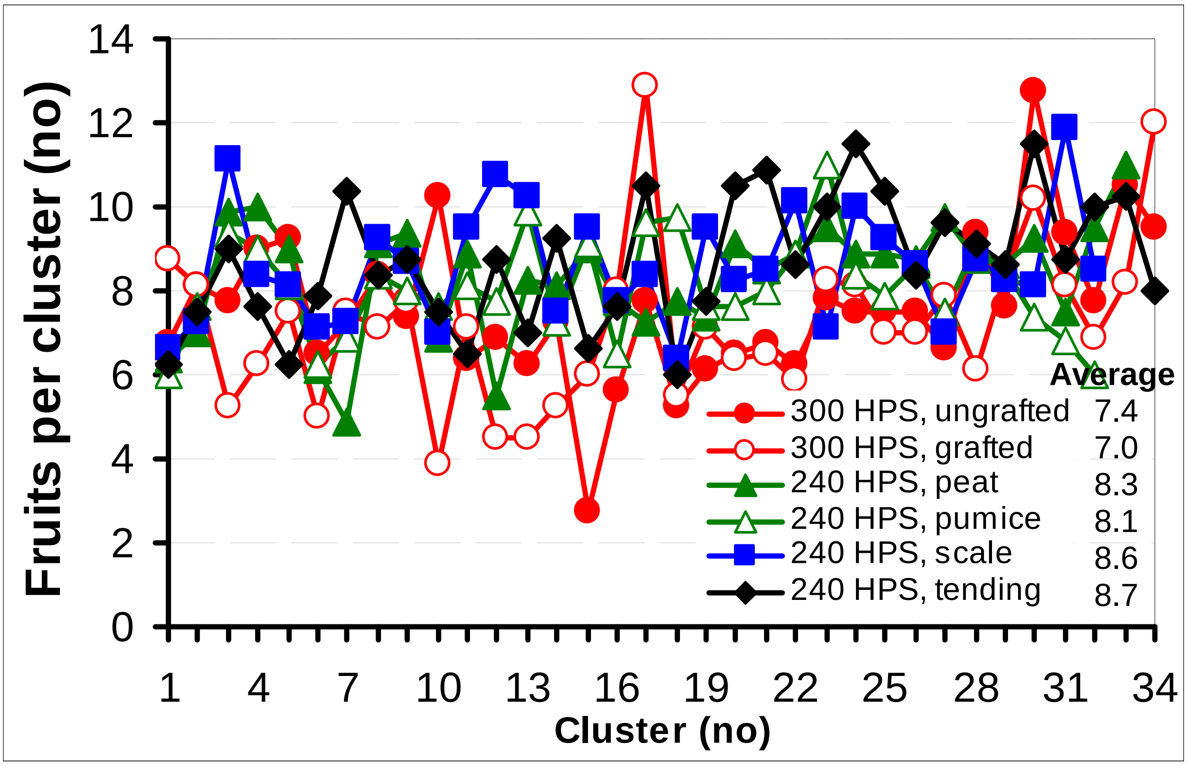

Fig. 13: Fruits per cluster at different treatments.

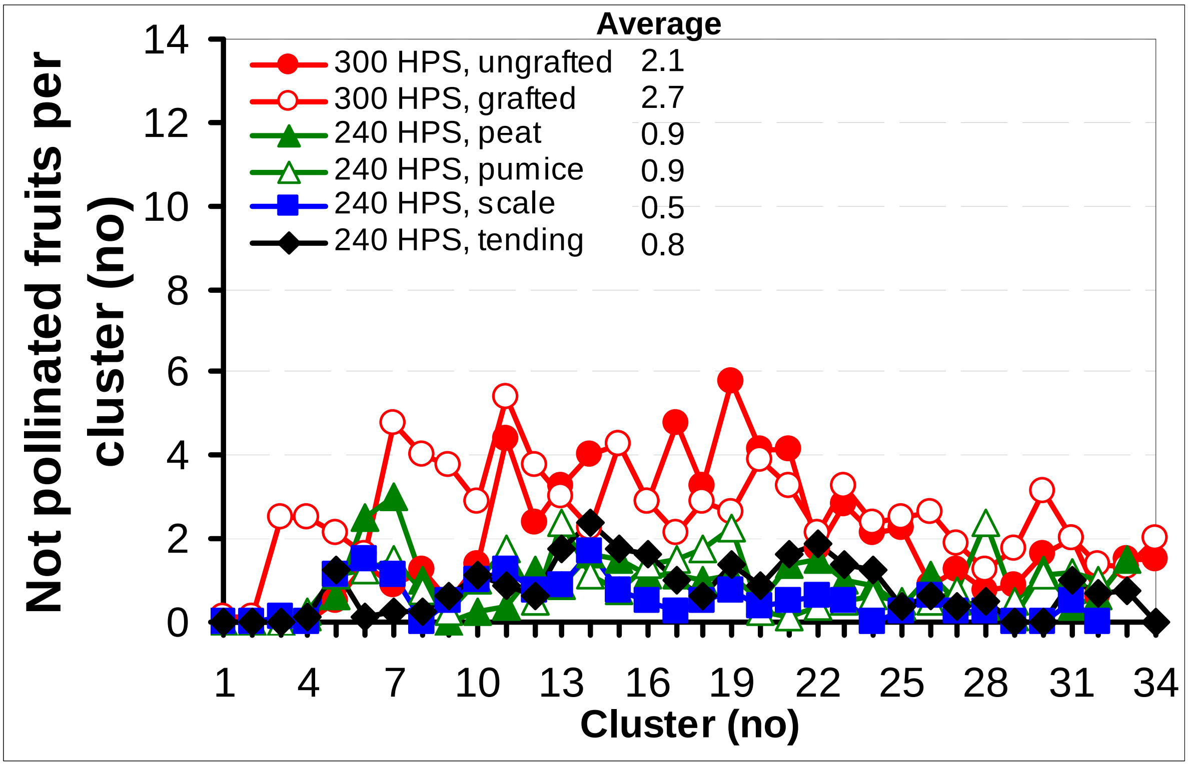

Fig. 14: Not pollinated fruits per cluster at different treatments.

Fruits per cluster amounted mostly between 6 and 11. In average, plants with the highest light intensity had less fruits per cluster (average 7.4 and 7.0) whereas the other treatments had in average 8.1-8.7 fruits (Fig. 13). Most not pollinated fruits were detected in the cabinet with the high light intensity and here especially the grafted plants showed a high number of not pollinated fruits (average 2.7). In contrast, not pollinated fruits were with less than one fruit rather low in the other treatments (Fig. 14).

Lengths of leaves decreased until the end of November from about 37-40 cm to 26-34 cm. A higher light intensity decreased lengths of leaves. Grafted plants had bigger leaves. With the beginning of December only the chamber "240 HPS, tending" was measured and length of leaves increased slightly again at the end of January to 33 cm (Fig. 15).

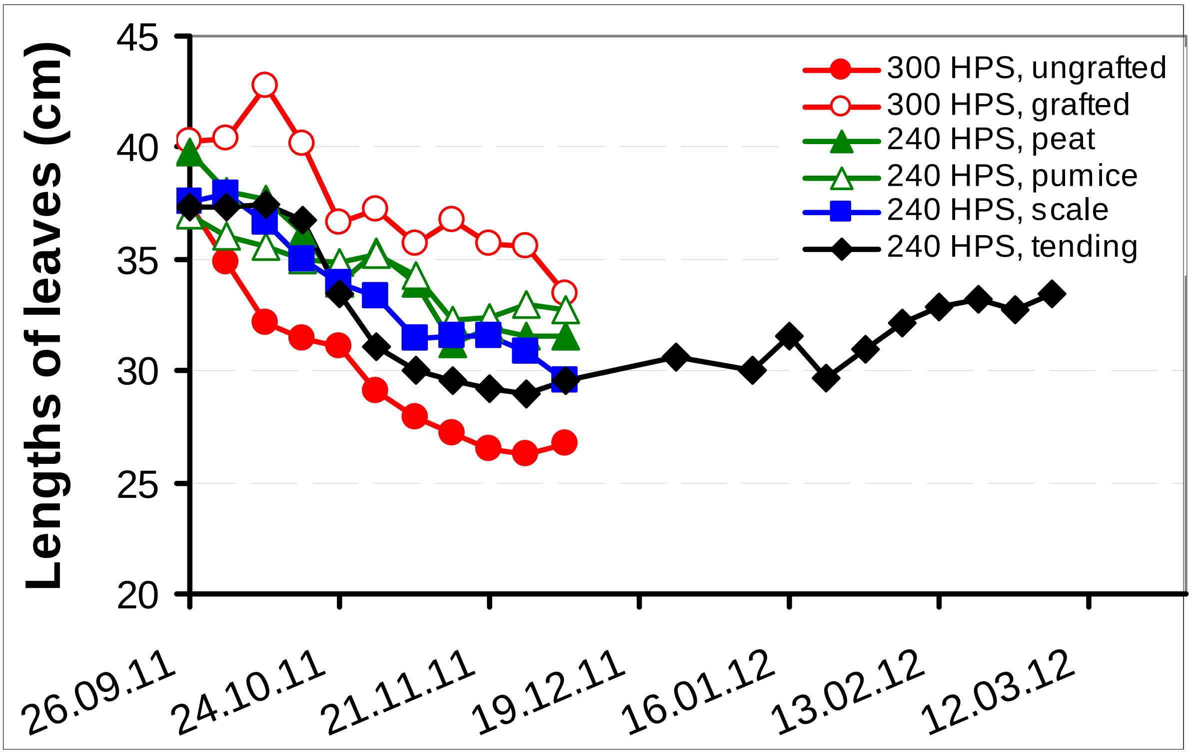

Fig. 15: Length of leaves at different treatments.

Stem diameter was varying very much from 0.6 to 1.5 cm and was highest for grafted plants (average 1.4 cm), whereas in the other chambers stem diameter amounted in average 0.9-1.0 cm (Fig. 16). Ungrafted tomatoes had most of the time a quotient of "lengths to top to stem diameter" of more than 15 and grouped into „little vegetative". Grafted plants had with the average of 14.4 a lower quotient (Fig. 17). However, the grouping “very generative” needs to be considered as groupings of ungrafted plants can not offhand be transferred to grafted plants.

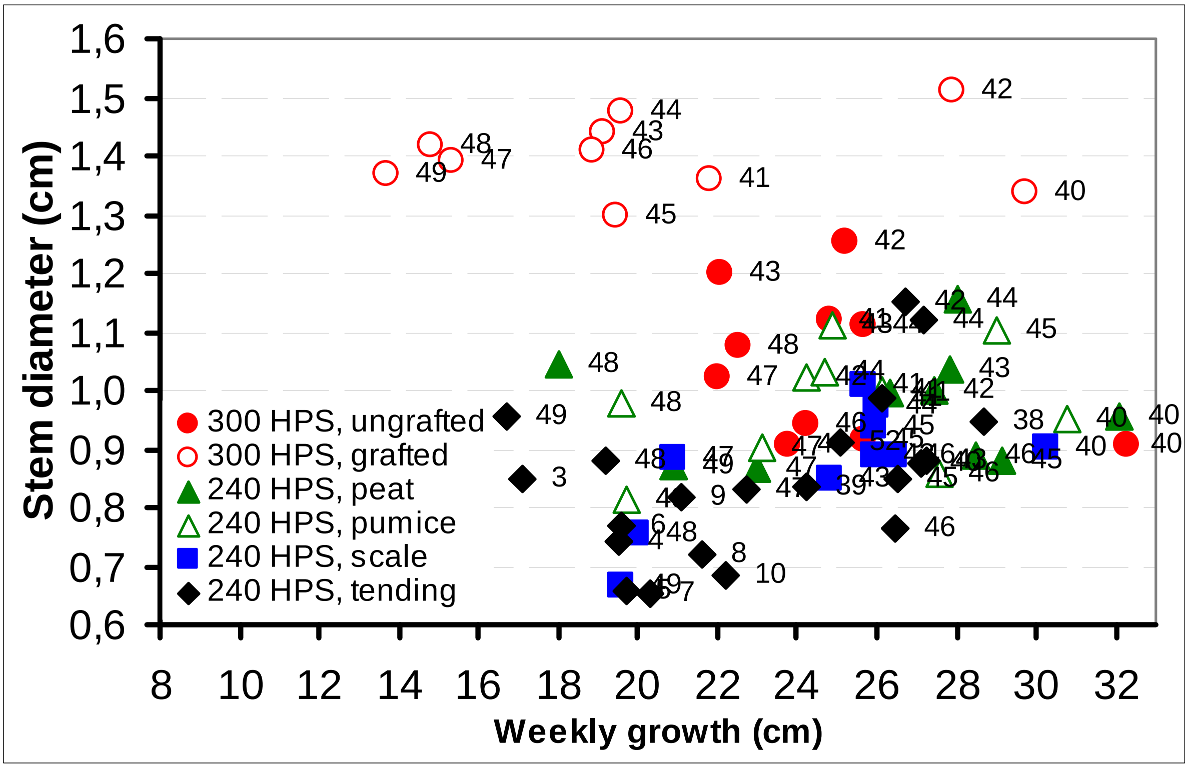

Fig. 16: Stem diameter and weekly growth at different treatments.
Numbers are representing the week number.

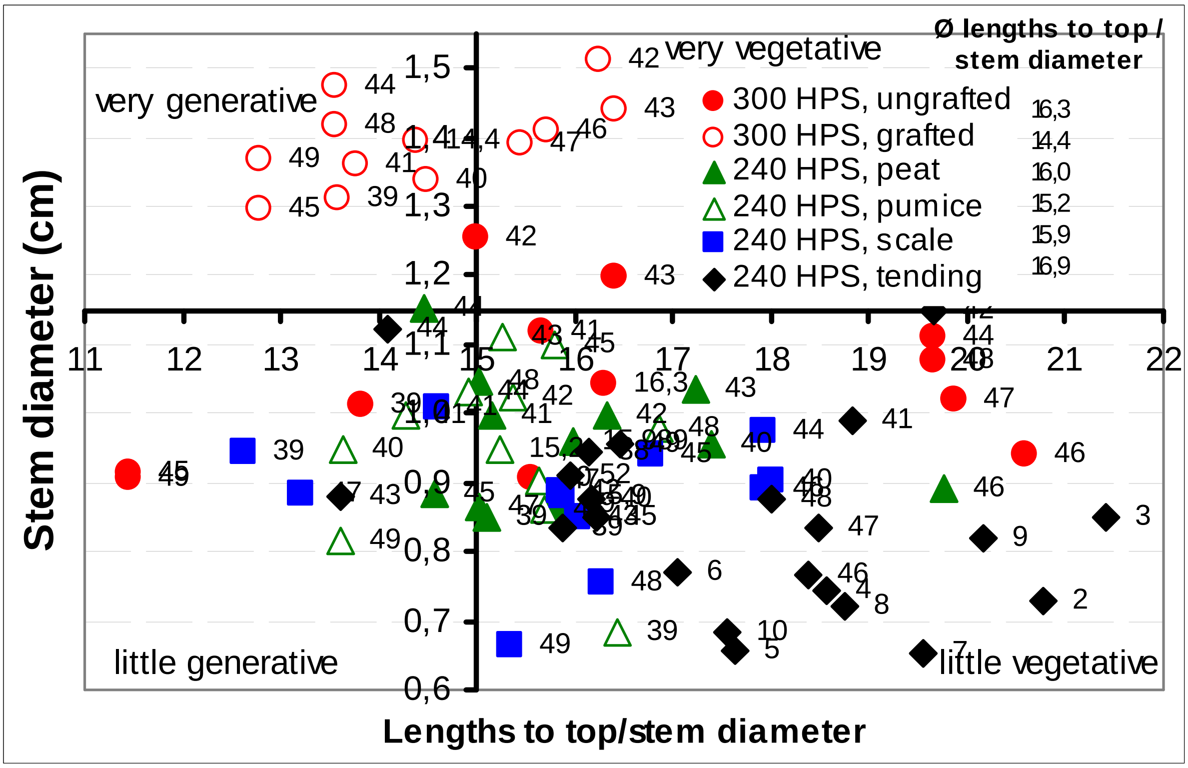

Fig. 17: Stem diameter and quotient lengths to top and stem diameter at different treatments.
Numbers are representing the week number.

4.3 Yield

4.3.1 Total yield of fruits

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

Cumulative total yield of tomatoes ranged between 47-58 kg/m^2 (Fig. 18). A higher light intensity and top density increased total yield slightly, whereas other treatments were comparable (Fig. 18).

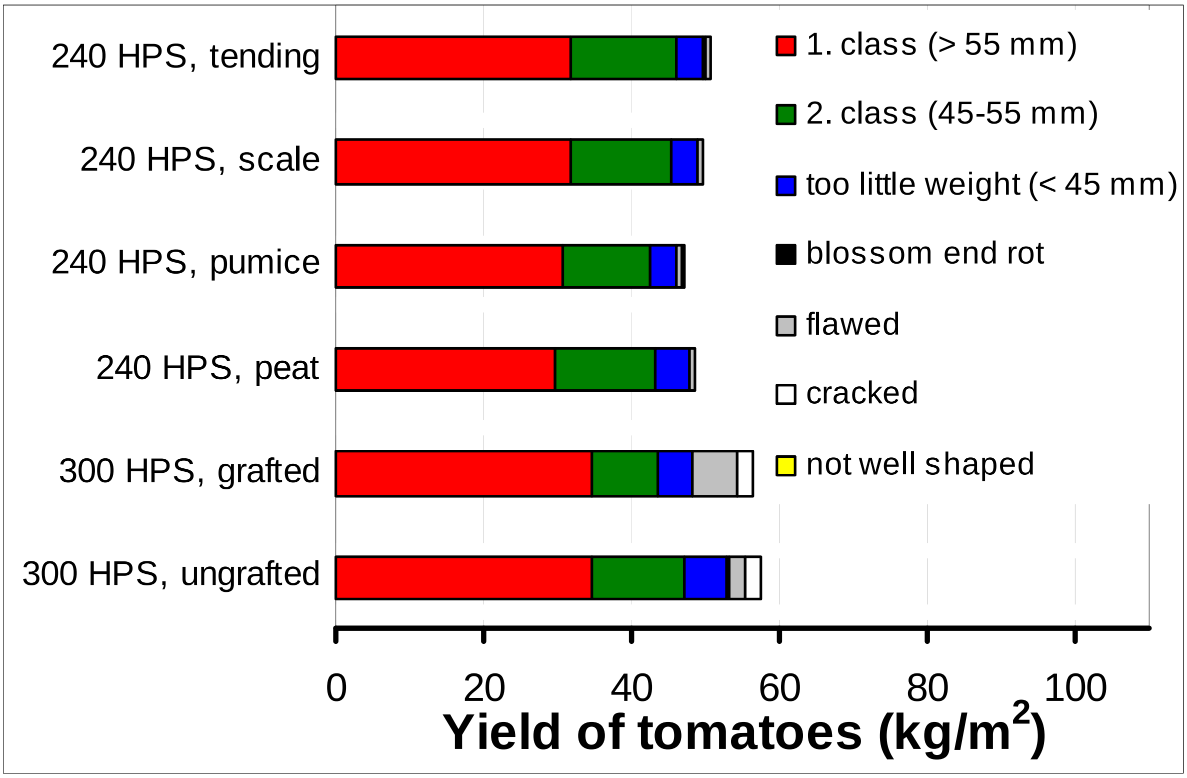

Fig. 18: Cumulative total yield at different treatments.

4.3.2 Marketable yield of fruits

Marketable yield of tomatoes was at the highest light intensity at the end of the growth period nearly comparable between grafted und ungrafted tomatoes (Fig. 19). However, it has to be taken into account that grafted tomatoes were transplanted two weeks later and therefore, probably also the harvest started later. This makes it difficult to compare both treatments. However, at the middle of December the increase of accumulated marketable yield of ungrafted tomatoes decreased, whereas this decrease was lower for grafted tomatoes.

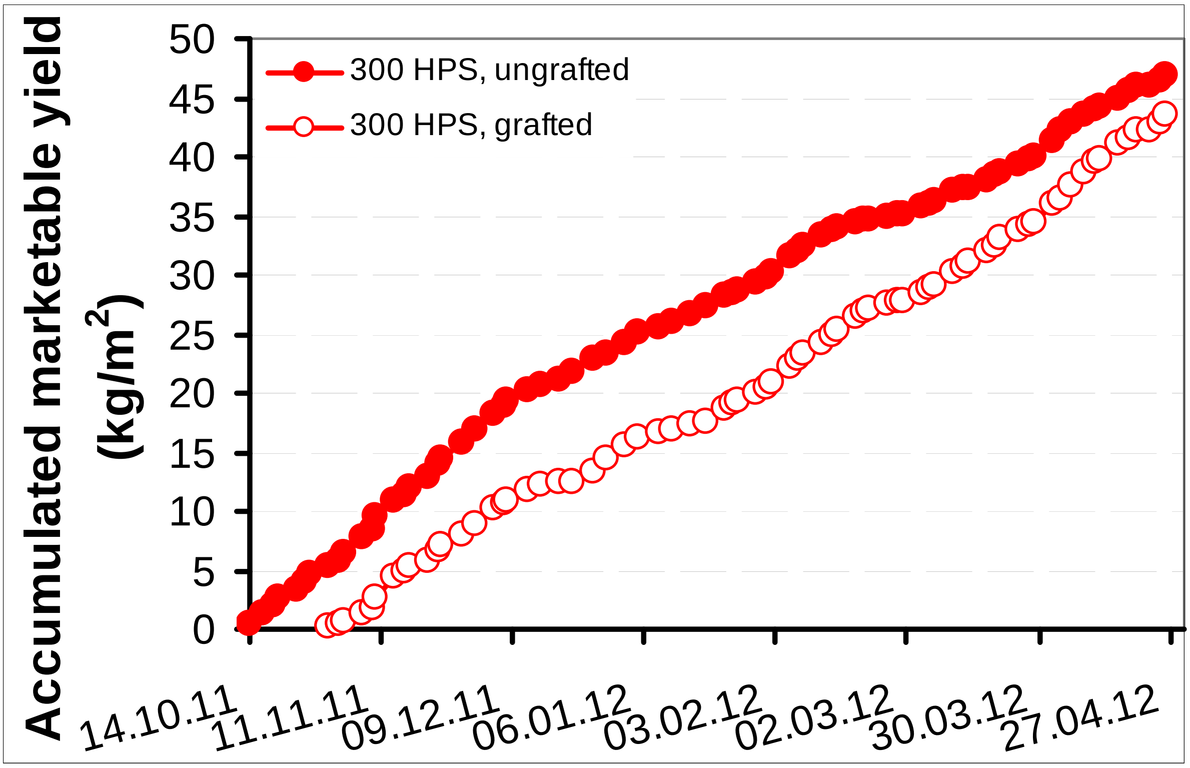

Fig. 19: **Time course of accumulated marketable yield (1. and 2. class fruits) with grafted and ungrafted tomatoes.**

In the cabinet, where tomatoes were both grown in pumice and peat, there was a 7 % yield advantage of peat (Fig. 20). However, when the other cabinets were taken

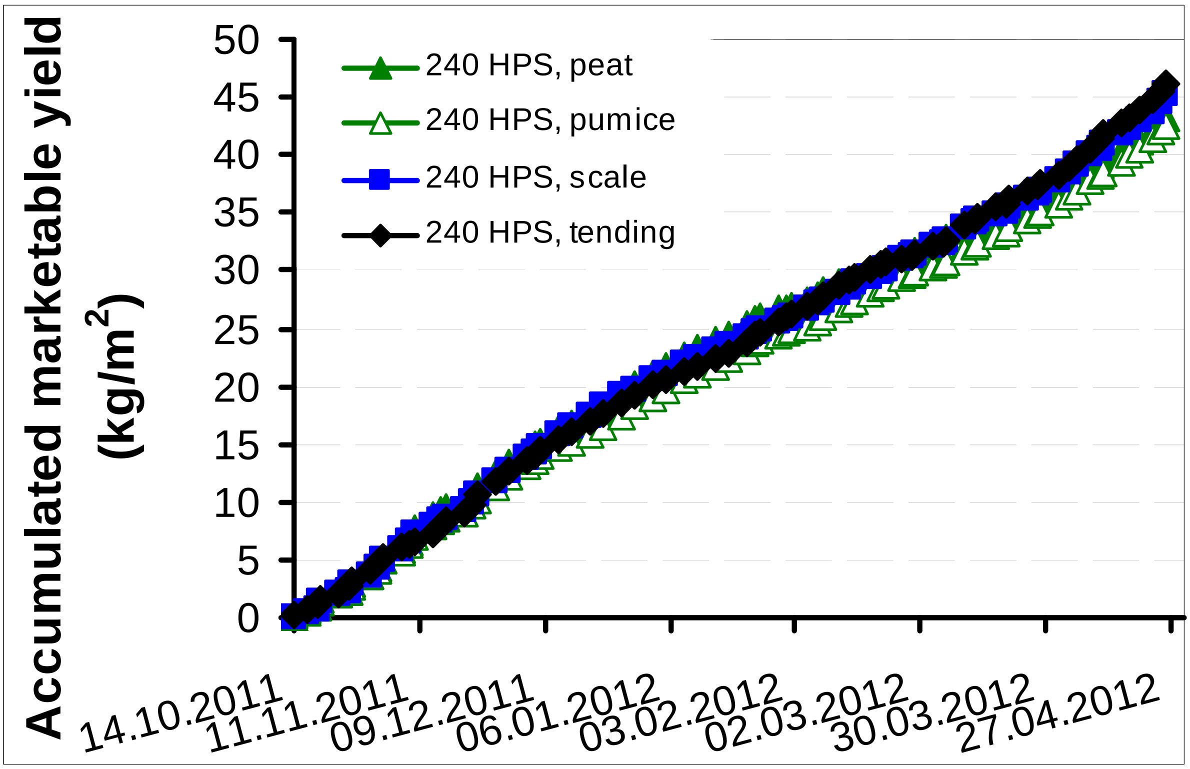

Fig. 20: **Time course of accumulated marketable yield (1. and 2. class fruits) with different growing media.**

into account, where also pumice was used, it was obvious, that in these cabinets yield was 5-6 % higher than with the pumice treatment in the pumice-peat cabinet. Therefore, it can be said that the growing media had no influence on yield.

A higher light intensity (and top density) increased yield slightly (Fig. 21).

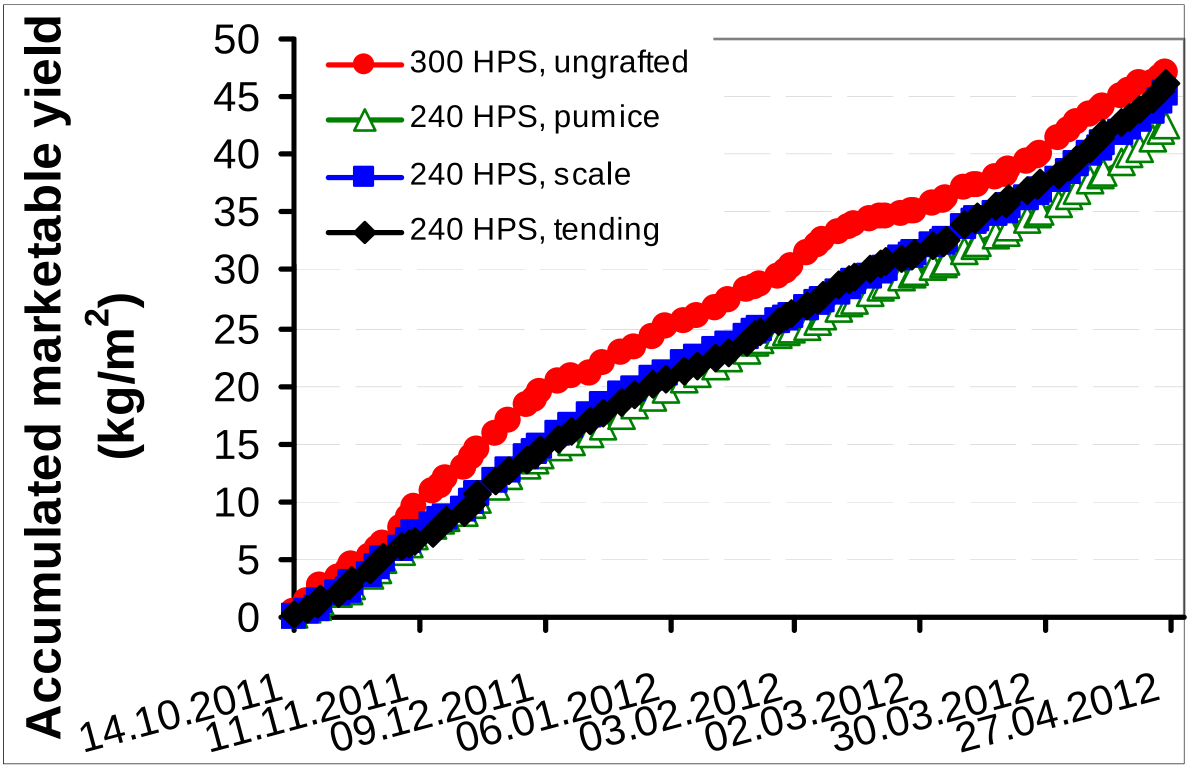

Fig. 21: Time course of accumulated marketable yield (1. and 2. class fruits) at different light intensities.

At the beginning of the harvest period, all treatments had a high 1. class yield. However, at the middle of December, 1. class yield decreased (Fig. 22) and 2. class yield increased (Fig. 23) and thus, decreasing the proportion of 1. class yield on total yield.

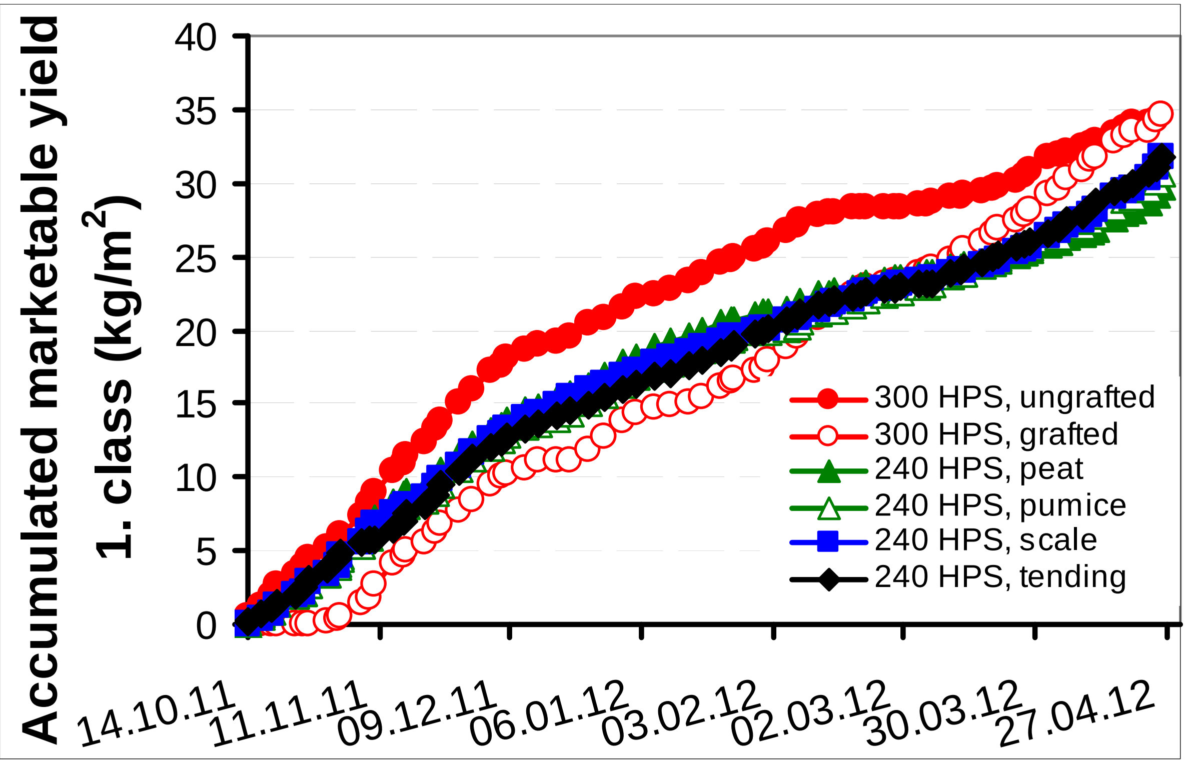

Fig. 22: Time course of accumulated marketable 1. class yield at different treatments.

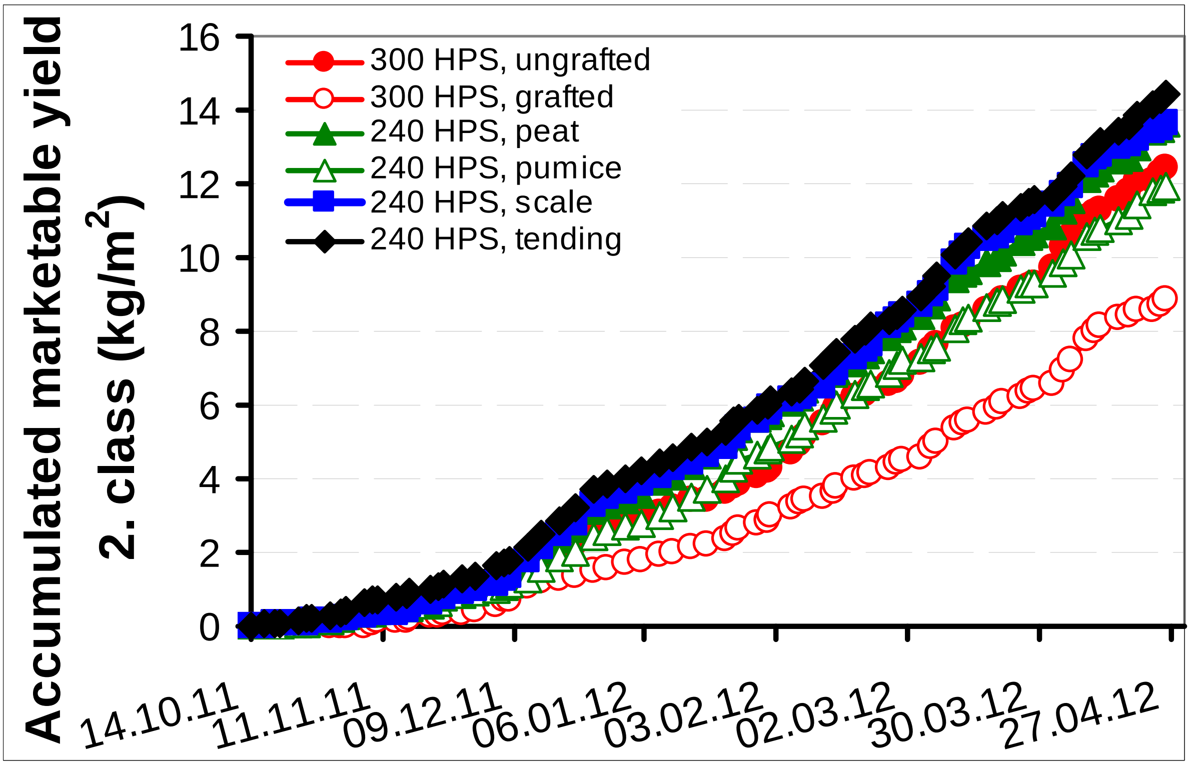

Fig. 23: Time course of accumulated marketable 2. class yield at different treatments.

Weekly harvest of first class fruits increased until the beginning of November to 2-3 kg/m^2, but decreased thereafter and reached about 0.5-1.5 kg/m^2 at the middle of

December and stayed until the end of March at this value and increased then again (Fig. 24).

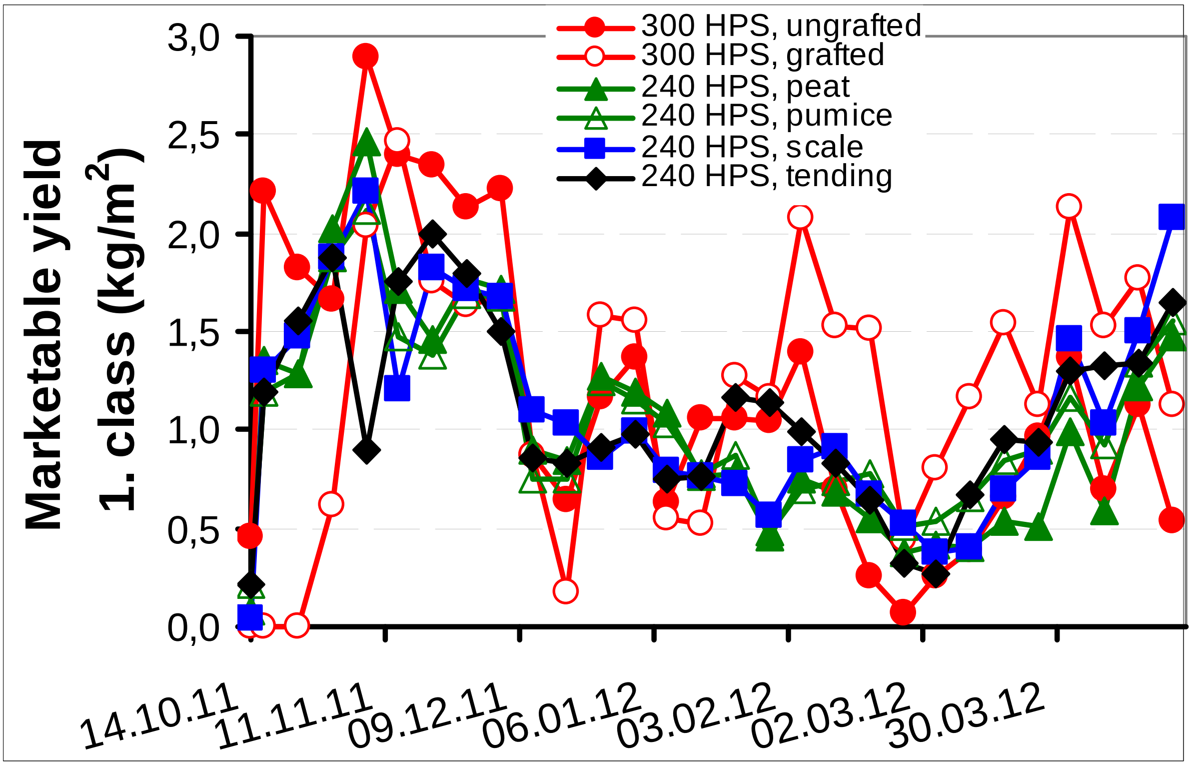

Fig. 24: Time course of marketable yield at different treatments.

Number of 1. class fruits was highest with the highest light intensity (Tab. 4). The total number of marketable fruits of ungrafted tomatoes was comparable in all treatments, except in “240 HPS, pumice” less fruits were harvested. The number of 2. class fruits for grafted tomatoes was low.

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

Lighting regime	**Number of marketable fruits**	
	1. class	2. class
300 HPS, ungrafted	372	184
300 HPS, grafted	359	128
240 HPS, peat	334	207
240 HPS, pumice	343	182
240 HPS, scale	350	205
240 HPS, tending	355	215

Average fruit size of first class tomatoes was varying between 75-115 g / fruit (Fig. 25). A high light intensity (300 HPS) seems to increase the average weight of first class tomatoes. Especially the grafted ones were nearly 10 g heavier than the ungrafted tomatoes grown under 240 W/m^2.

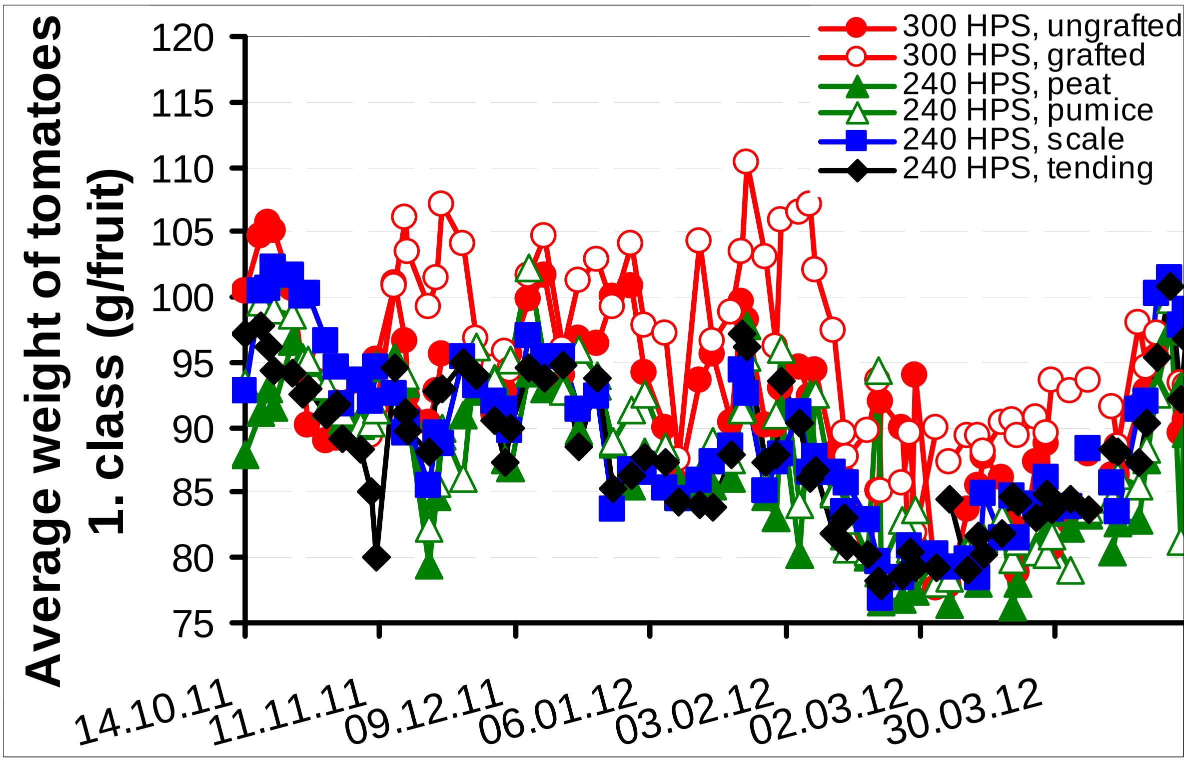

Fig. 25: Average weight of tomatoes (1. class fruits) at different treatments.

To observe the success of fruit setting until harvest, the setting of fruits was classified and the number of “fruits total” (fruits that were supposed to be harvested later) was registered. When a cluster was harvested, the total number of “fruits harvested” was counted. The number of “lost fruits” is marking the difference between the number of fruits that were registered at setting (fruits total) and the number of harvested fruits. “Lost fruits” might have been aborted or did not develop well and stayed small. Much light had no influence on the number of fruits (Fig. 26). The grafted tomatoes showed an increased number of “lost fruits” (Fig. 26 a). “240 HPS, peat” (Fig. 26 c) had in average 0.5 more fruits total and fruits harvested than “240 HPS, pumice” (Fig. 26 d).

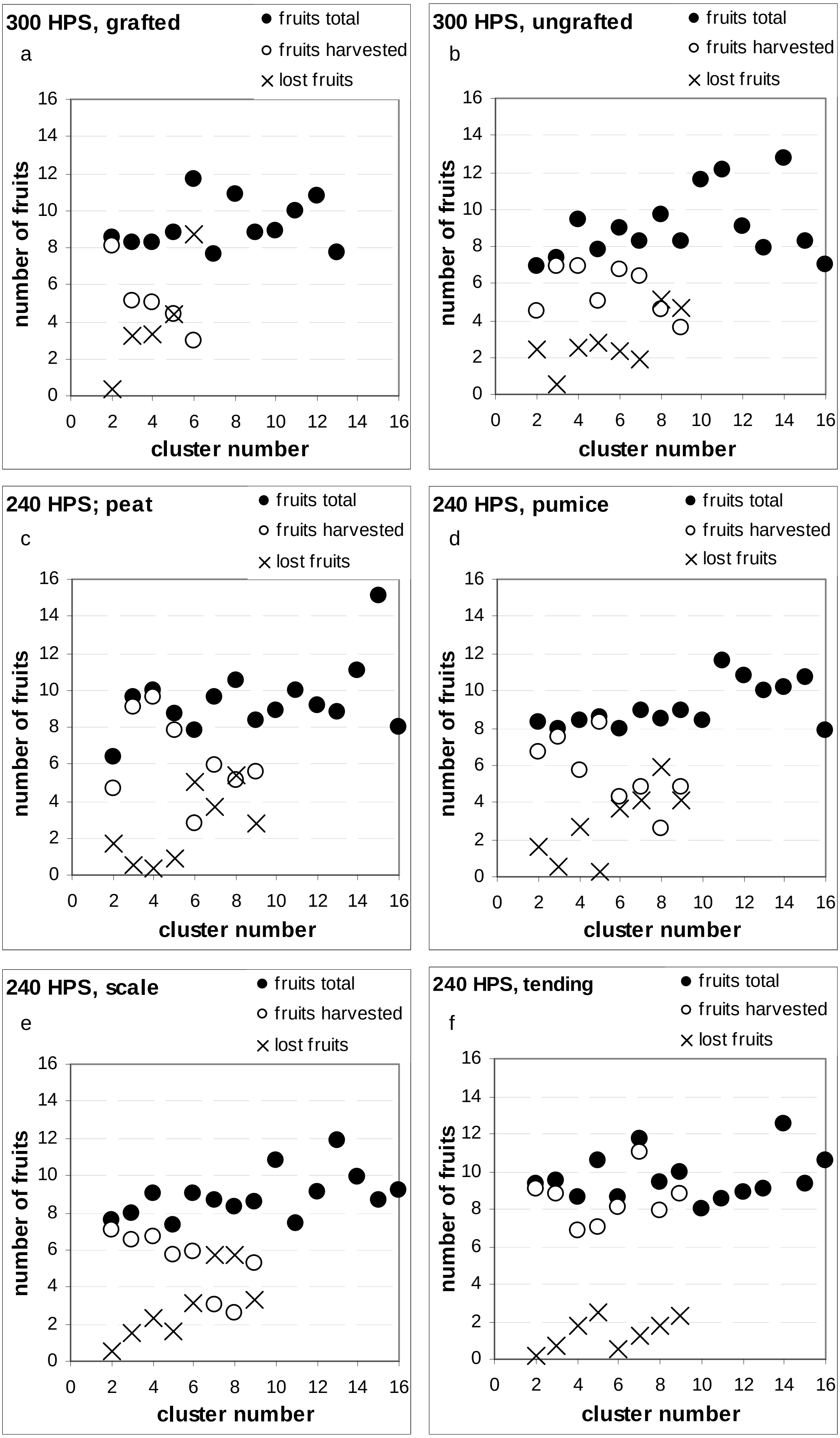

Fig. 26: Number of fruits at setting and harvest at different treatments.

4.3.3 Outer quality of yield

Marketable yield was about 77-91 %. Marketable yield was lowest at the highest light intensity, because of a high amount of flawed and cracked fruits. Grafted tomatoes had less 2. class fruits compared to the other treatments (Tab. 5).

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

Treatments	Marketable yield		Unmarketable yield				
	1. class	2. class	too little weight	blossom end rot	flawed	cracked	not well shaped
300 HPS, ungrafted	60	22	10	0	4	4	0
300 HPS, grafted	61	16	8	0	10	4	0
240 HPS, peat	61	28	9	0	1	0	0
240 HPS, pumice	65	25	8	0	1	0	0
240 HPS, scale	64	27	7	0	1	0	0
240 HPS, tending	62	28	7	0	2	0	0

4.3.4 Interior quality of yield

4.3.4.1 Sugar content

Sugar content of tomatoes was measured three times during the harvest period and varied between 3.7 and 4.5. At the beginning of the harvest period it was obvious that sugar content increased with grafting. However, these differences got smaller at the middle of the harvest period and disappeared at the end of the harvest period. It seems that sugar content was slightly higher with peat compared to pumice (Fig. 27).

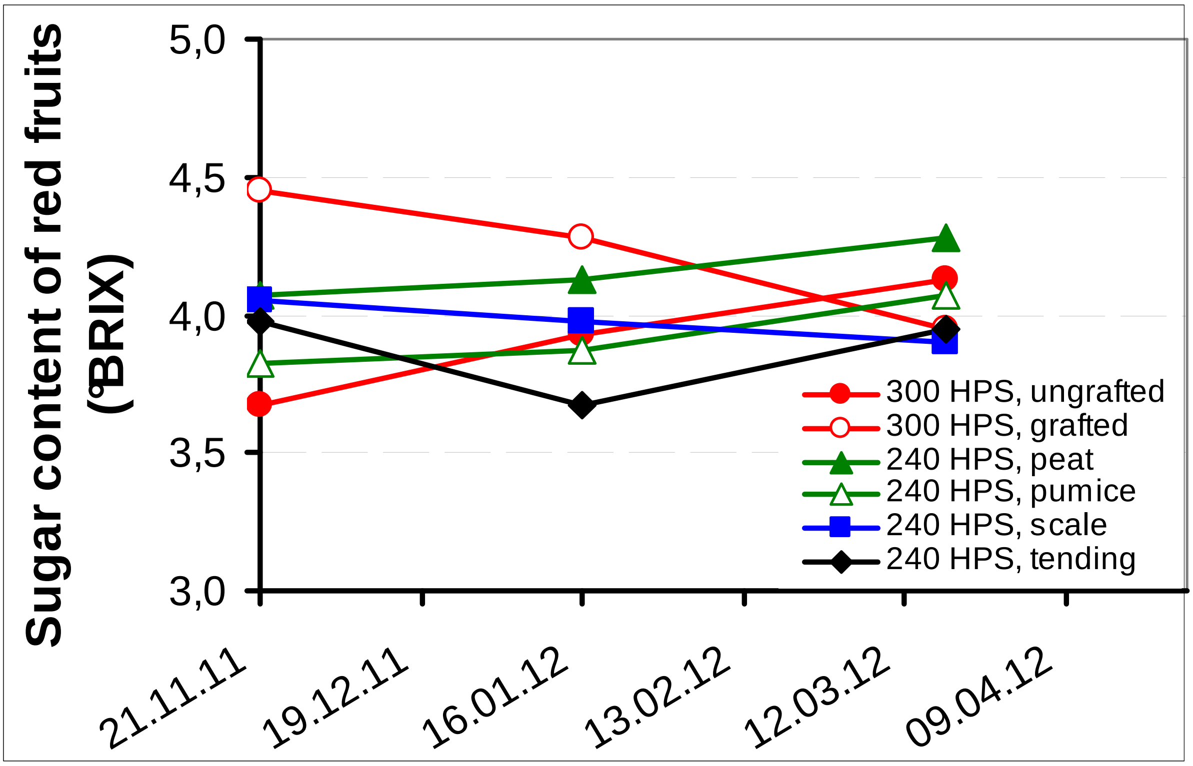

Fig. 27: Sugar content of fruits at different treatments.

4.3.4.2 Taste of fruits

The taste of tomatoes, subdivided into sweetness, flavour and juiciness was tested by untrained assessors at the beginning (22.11.2011), middle (18.01.2012) and at the end (21.03.2012) of the harvest period. Mainly, no differences in taste, sweetness, flavour and juiciness of tomatoes were found between different lighting regimes (data not shown). The rating within the same sample was varying very much and therefore, same treatments resulted in a high standard deviation. The higher sugar content of the grafted tomatoes was not reflected in better marks in sweetness. However, it even seems that grafted tomatoes were rated with lower marks than ungrafted ones for the flavour at the first two tasting dates. There was no relationship between measured sugar content and sweetness of fruits at all tasting dates (data not shown).

4.3.4.3 Dry substance of fruits

Dry substance (DS) of fruits was measured three times during the harvest period. DS increased slightly during the harvest period from 4.4-4.9 % to 4.9-5.2 %. No differences between treatments were observed (Fig. 28).

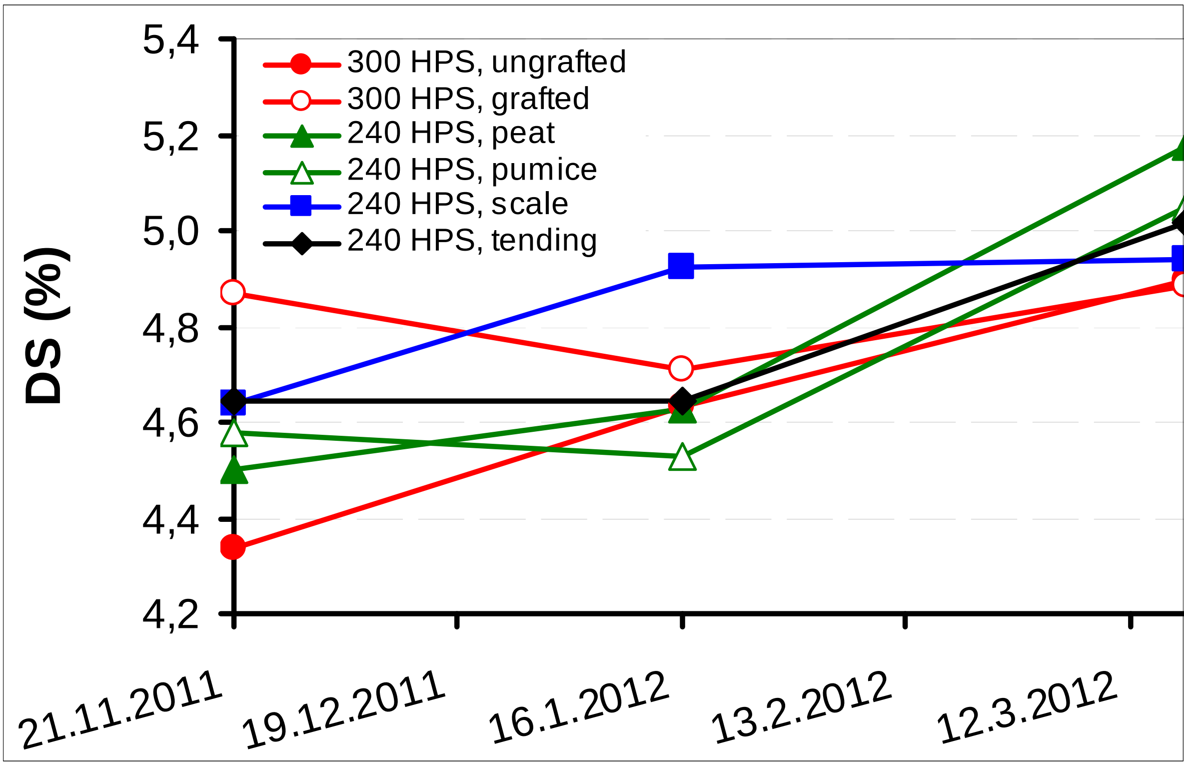

Fig. 28: **Dry substance of fruits at different treatments.**

4.3.5.4 Nitrogen content of fruits

N content of fruits was measured three times and decreased with longer harvest period and varied between 1.8-3.3 %. Grafted tomatoes had highest values (Fig. 29).

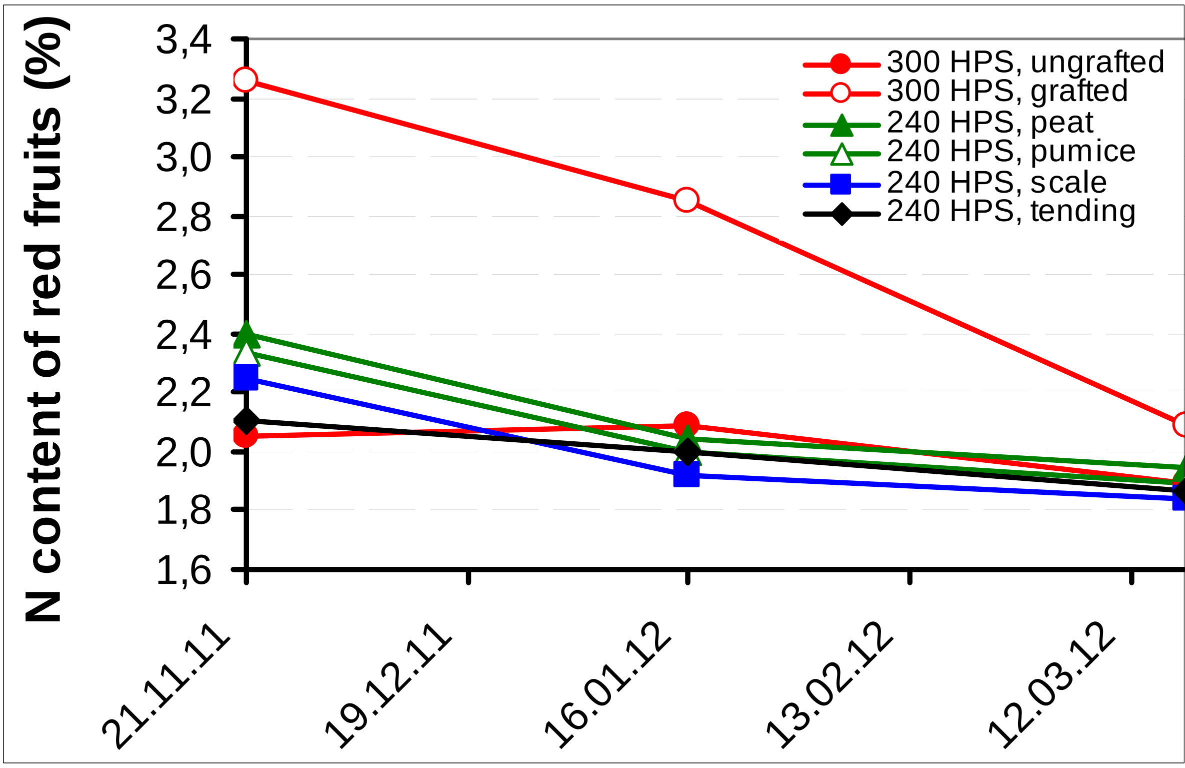

Fig. 29: **N content of fruits at different treatments.**

4.3.5 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. Grafted plants had a higher dry matter yield of stripped leaves than the other treatments (Fig. 30).

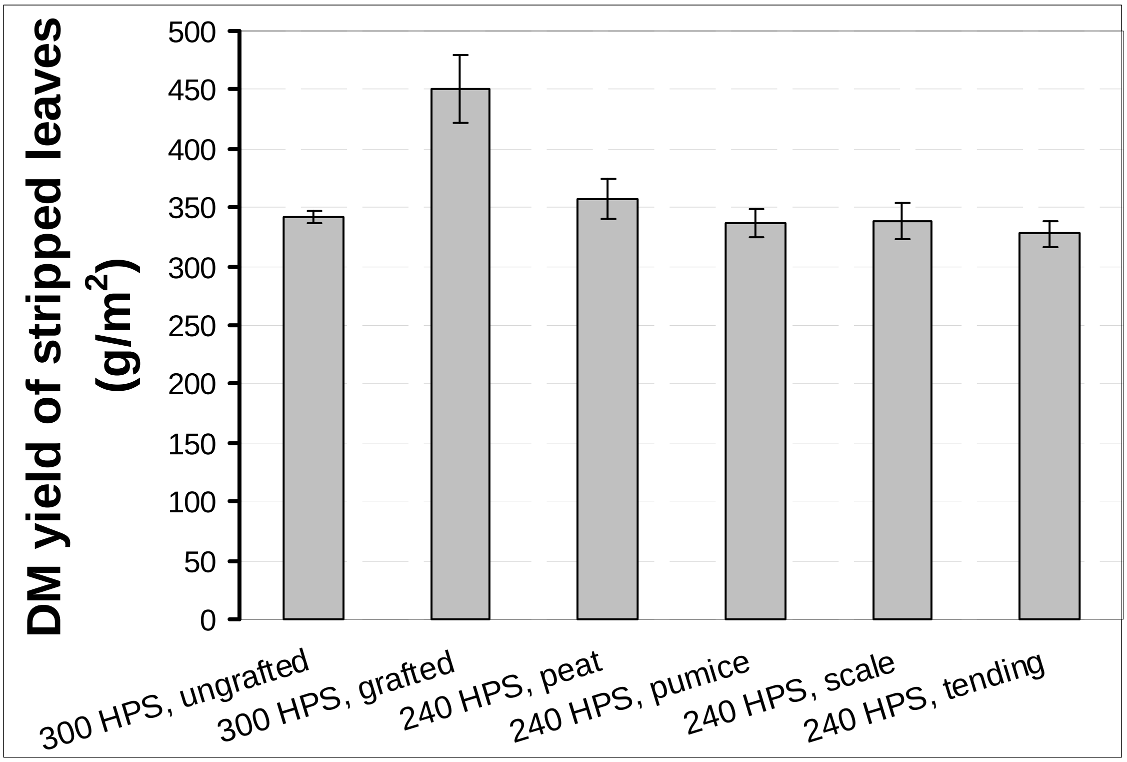

Fig. 30: Dry matter yield of stripped leaves at different treatments.
Error bars indicate standard deviations and are contained within the symbol if not indicated.

4.3.6 Cumulative dry matter yield

The cumulative DM yield included all harvested red fruits, the immature fruits at the end of the growth period, the stripped leaves during the growth period and the shoots. The cumulative DM yield was highest in the chamber with the highest light intensity and higher top density. For the other treatments, cumulative DM yield was pretty much the same (Fig. 31). The ratio fruits on “shoots + leaves” was 75 %, but lower (72 % and 70 %) for the highest light intensity.

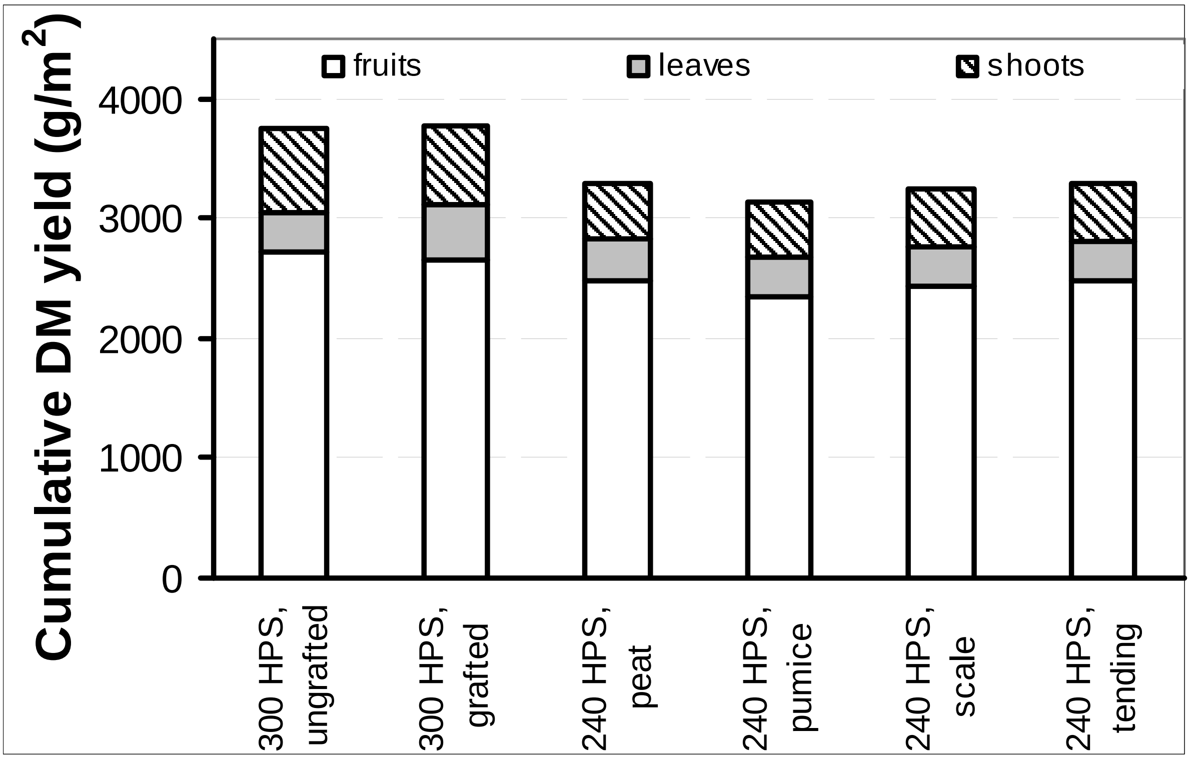

Fig. 31: Cumulative dry matter yield at different treatments.

4.4 Nitrogen uptake and nitrogen left in the growing media

4.4.1 Nitrogen uptake by plants

The cumulative N uptake included N uptake of all harvested fruits, the immature fruits at the end of the growth period, the stripped leaves during the growth period and the shoots. The fruits contributed much more than the leaves and shoots to the cumulative N uptake (Fig. 32). The grafted plants had the highest N uptake. No differences between growing media were calculated.

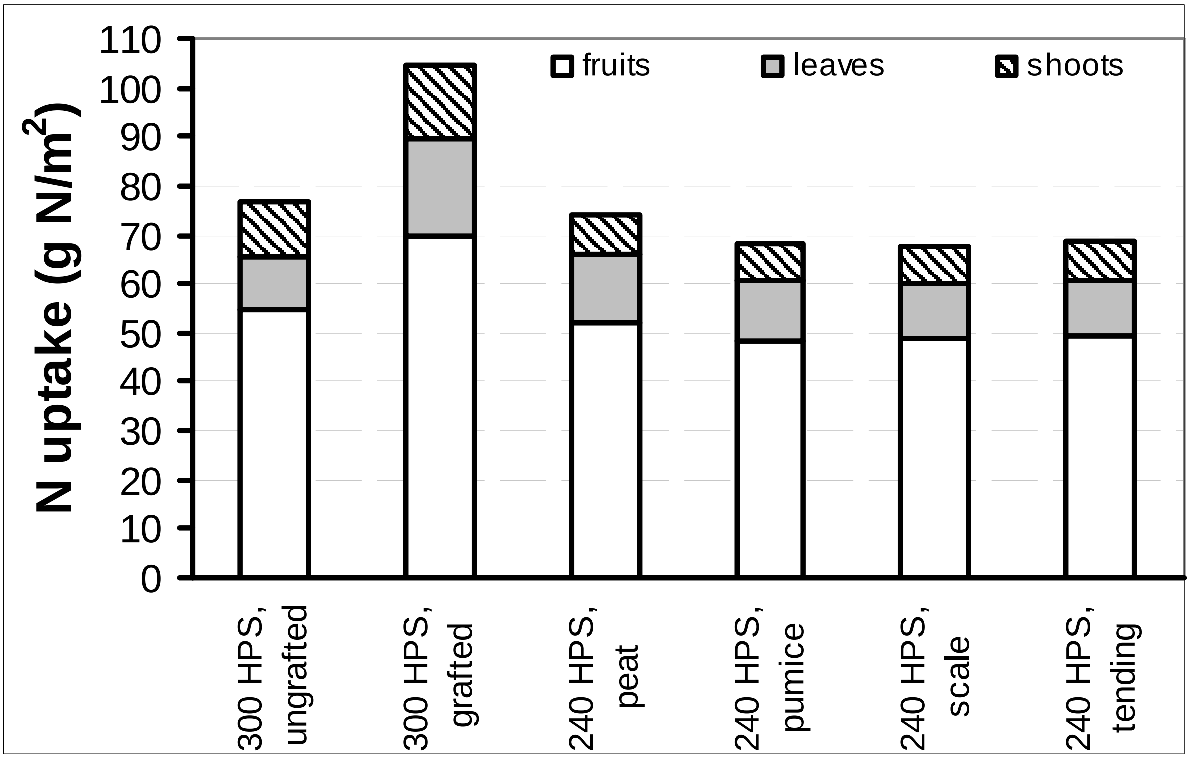

Fig. 32: Cumulative N uptake of tomatoes.

4.4.2 Nitrogen left in the growing media

NH_4-N and NO_3-N in the growing media were measured at the end of the experiment.

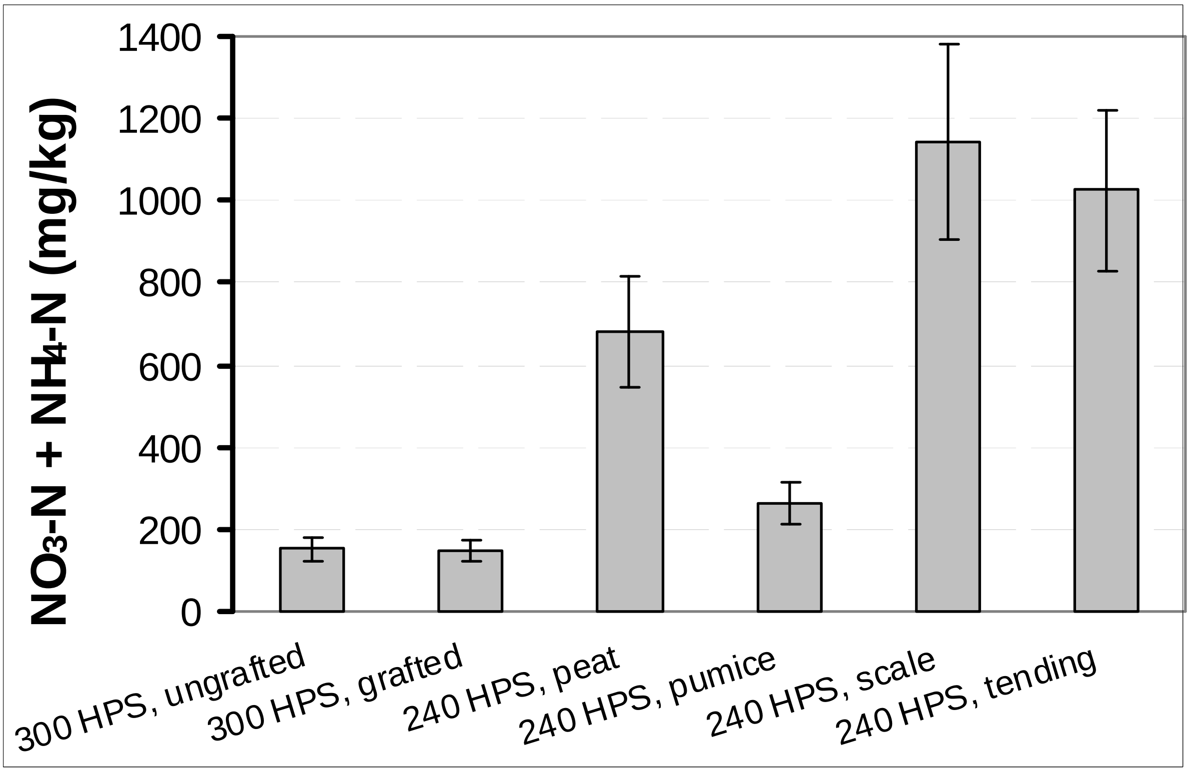

Fig. 33: NO_3-N and NH_4-N in the growing media at the end of the experiment.

The highest light intensity had lowest values. It seems that there was not really a difference in NH_4-N and NO_3-N between pumice and peat. In general, standard deviation was very high (Fig. 33).

4.5 Economics

4.5.1 Lighting hours

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

The total hours of lighting during the growth period of tomatoes were both simulated and measured with dataloggers. Unfortunately, RARIK was only able to read data out of the datalogger measuring in the cabinet “240 HPS, peat” and “240 HPS, pumice”. Therefore, for the other cabinets with 240 W/m^2 same values were assumed and for 300 W/m^2 values were calculated according to the measurements obtained with the lower light intensity.

The simulated value was higher than the measured one, because there it was not adjusted for automatic turn off, when incoming solar radiation was above a set-point (Tab. 6). The calculation of the power was higher for the measured values than for the simulated ones, because lights at the outer beds were also partly contributing to lighten the shelter belt. For calculation of the power, different electric consumptions were made, because the actual consumption is higher than the nominal value of the

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

	Hours	**Power**	**Energy**	**Energy/m^2**
	h	W	kWh	kWh/m^2
300 HPS, ungrafted; 300 HPS, grafted				
Measured values	3,918	340	62,118	1,242
Simulated values				
0 % more power consumption (nominal)	4,354	300	65,310	1,306
6 % more power consumption	4,354	318	69,229	1,385
10 % more power consumption	4,354	330	71,841	1,437
240 HPS, peat; 240 HPS, pumice; 240 HPS, scale; 240 HPS, tending				
Measured values	3,918	272	49,694	994
Simulated values				
0 % more power consumption (nominal)	4,354	240	52,248	1,045
6 % more power consumption	4,354	254	55,383	1,108
10 % more power consumption	4,354	264	57,473	1,149

bulb: one was based on the power of the lamps (nominal Watts, 0 % more power consumption), one with 6 % more power consumption and one for 10 % more power consumption.

4.5.2 Energy prices

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

RARIK offers basically three types of tariffs:

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

In the report, only afltaxti is used as the two other 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.

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

The government subsidises the distribution cost of growers that comply to certain criteria’s. Currently 76.4 % and 84.0 % of variable cost of distribution for urban and rural areas respectively. This amount can be expected to change in the future.

Based on this percentage of subsidy and the lighting hours (Tab. 6), for the cabinets the energy costs per m² during the time of the experiment for the growers were calculated (Tab. 7).

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

	Costs for consumption							
	Energy ISK/kWh				**Energy costs with subsidy per m²** ISK/m²			
Treat-ment	300 HPS, ungrafted 300 HPS, grafted		240 HPS, peat 240 HPS, pumice 240 HPS, scale 240 HPS, tending		300 HPS, ungrafted 300 HPS, grafted		240 HPS, peat 240 HPS, pumice 240 HPS, scale 240 HPS, tending	
	real	calculated	real	calculated	real	calculated	real	calculated
				DISTRIBUTION				
RARIK Urban					76.4 % subsidy from the state			
VA210		0.76		0.76		989		791
	0.81	0.76	0.81	0.76	1,004	1,048	803	839
		0.76		0.76		1,088		870
VA410		0.60		0.60		785		628
	0.65	0.60	0.65	0.60	809	832	647	666
		0.60		0.60		864		691
RARIK Rural					84.0 % subsidy from the state			
VA230		0.68		0.68		884		707
	0.72	0.68	0.72	0.68	891	937	713	750
		0.68		0.68		972		778
VA430		0.44		0.44		574		459
	0.47	0.44	0.47	0.44	585	608	468	487
		0.44		0.44		631		505
				SALE				
Afltaxti	4.55	4.37	4.55	4.37		5,709		4,567
Þrígjalds-taxti TT	5.85	5.53	5.85	5.53	5,651	6,052	4,521	4,841
						6,280		5,024
Þrígjalds-taxti TV	5.48	5.34	5.48	5.34				

Source: Composition from *Eggertsson* (2012)

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

Prices are from December 2012.

The energy costs per kWh for distribution after subsides are around 0.7-0.8 ISK/kWh for „VA210“ and „VA230“, around 0.6 ISK/kWh for „VA410“ and around 0.4-0.5 ISK/kWh for „VA430“. The energy costs for sale are for „afltaxti“ around 4.5 ISK/kWh and for „þrígjaldstaxti TT“ and „þrígjaldstaxti TV“ around 5-6 ISK/kWh.

Cost of electricity was higher for the calculated values (Tab. 7). In general, tariffs for large users rendered lower cost.

4.5.3 Costs of electricity in relation to yield

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

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

	Variable costs of electricity per kg yield ISK/kg											
Treatment	300 HPS, ungrafted		300 HPS, grafted		240 HPS, peat		240 HPS, pumice		240 HPS, scale		240 HPS, tending	
Yield/m²	47.0		43.5		43.3		42.6		45.3		46.1	
	real	calculated	real	calculated	real	calculated	real	calculated	real	calculated	real	calculated
Urban area (Distribution + Sale)												
VA210	142	143 151 157	153	154 163 169	123	124 131 136	125	126 133 138	117	118 125 130	116	116 123 128
VA410	137	138 146 152	149	149 158 164	119	120 127 132	121	122 129 134	114	115 121 126	112	113 120 124
Rural area (Distribution + Sale)												
VA230	139	140 149 154	150	152 161 167	121	122 129 134	123	124 131 136	115	116 123 128	114	114 121 126
VA430	133	134 142 147	143	145 153 159	115	116 123 128	117	118 125 130	110	111 118 122	108	109 116 120

While for the distribution several tariffs were possible, for the sale only the cheapest tariff was considered. The costs of electricity decreased at the lower light intensity and with a higher yield and were about 5 % lower for the treatment “240 HPS, scale” and “240 HPS, tending” compared to “240 HPS, pumice”. Costs of electricity per kg yield increased by nearly 15 % for “300 HPS, ungrafted” and even more than 20 % for “300 HPS, grafted” (Tab. 8).

4.5.4 Profit margin

The profit margin is a parameter for the economy of growing a crop. It is calculated by subtracting the variable costs from the revenues. The revenues itself, is the product of the price of the sale of the fruits and kg yield. For each kg of tomatoes, growers are getting about 400 ISK from Sölufélag garðyrkjumanna (SfG) and in addition about 64 ISK from the government. Therefore, the revenues increased with more yield (Fig. 34).

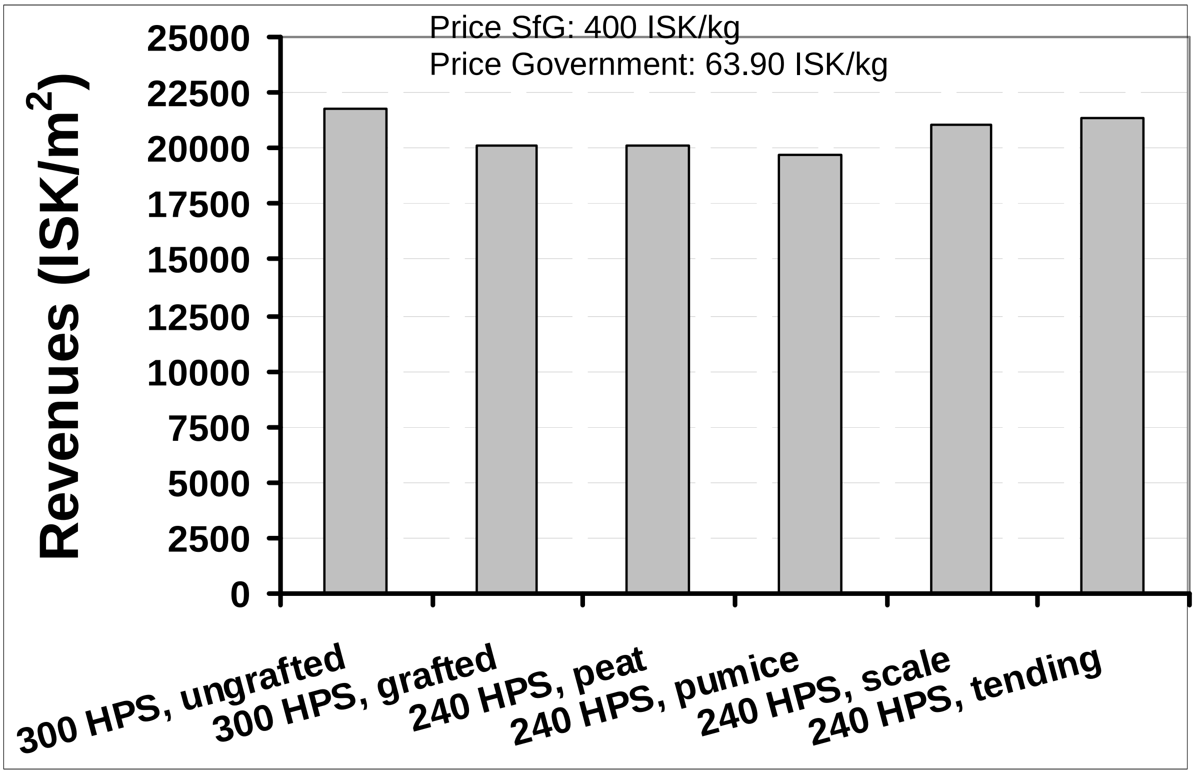

Fig. 34: Revenues at different treatments.

When considering the results of previous chapter, one must keep in mind that there are other cost drivers in growing tomatoes than electricity alone (Tab. 7). Among others, this are e.g. the costs for seeds and seedling production (≈ 350 ISK/m^2) and transplanting (≈ 300 ISK/m^2), costs for plant nutrition (≈ 700 ISK/m^2), CO_2 transport (≈ 300 ISK/m^2), liquid CO_2 (≈ 1,500 ISK/m^2), the rent of the tank (≈ 400 ISK/m^2), the rent of the green box (≈ 300 ISK/m^2), material for packing (≈ 1,000 ISK/m^2), packing costs with the machine from SfG (≈ 550 ISK/m^2) and transport costs from SfG (≈ 300 ISK/m^2) (Fig. 35).

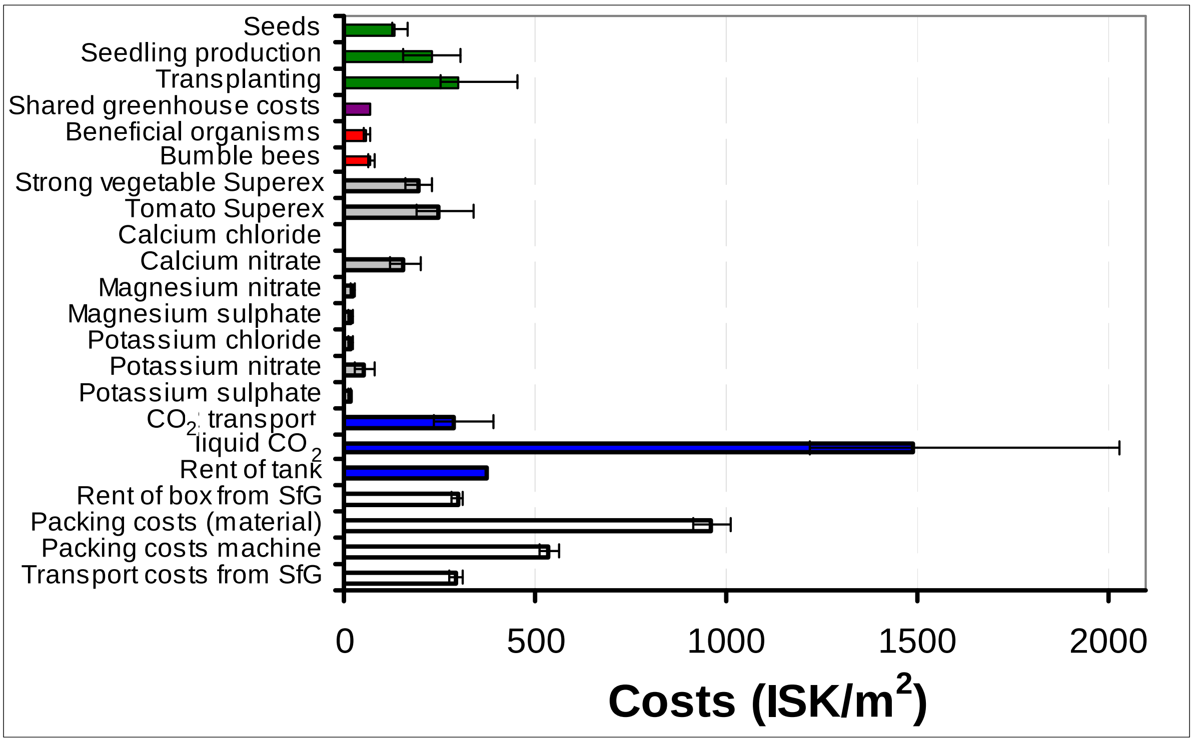

Fig. 35: Variable and fixed costs (without lighting and labour costs).

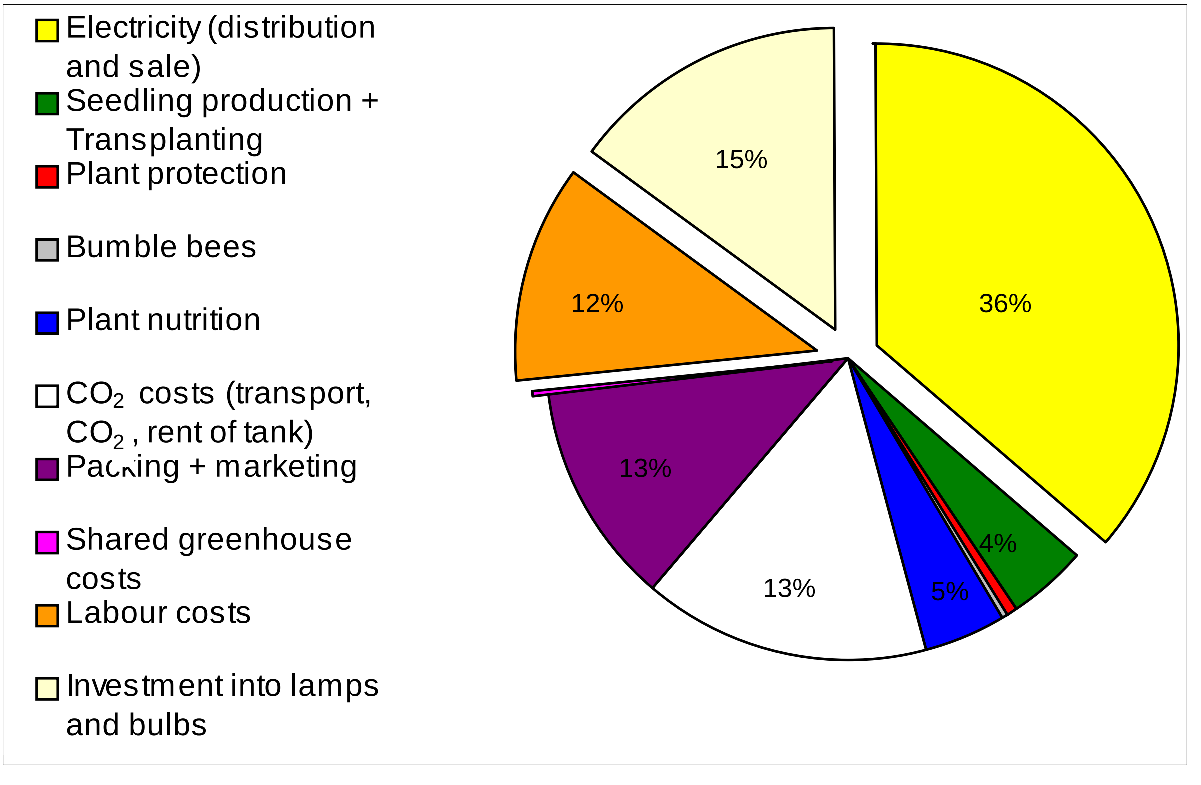

Fig. 36: Division of variable and fixed costs.

However, in Fig. 35 three of the biggest cost drivers are not included and these are investment in lamps and bulbs, electricity and labour costs. These costs are also included in Fig. 36 and it is obvious, that especially the electricity and the investment in lamps and bulbs as well as the labour costs, are contributing much to the variable and fixed costs beside the costs for packing and marketing and CO_2 costs.

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

The profit margin was dependent on the treatment, whereas the tariff was only influencing profit margin slightly (Fig. 37). Profit margin was with about 6,500 ISK/m^2 highest with “240 HPS, tending”, closely followed by “240 HPS, scale”. Compared to “240 HPS, pumice” profit margin was about 1,000 ISK/m^2 higher, when the scale was used for watering. At higher light intensity decreased profit margin by nearly 2,000 ISK/m^2 (Fig. 37). With a larger use (higher tariff) profit margin increased slightly. At a higher tariff there was a surprisingly small advantage of rural areas due to the state subsidies (Fig. 37).

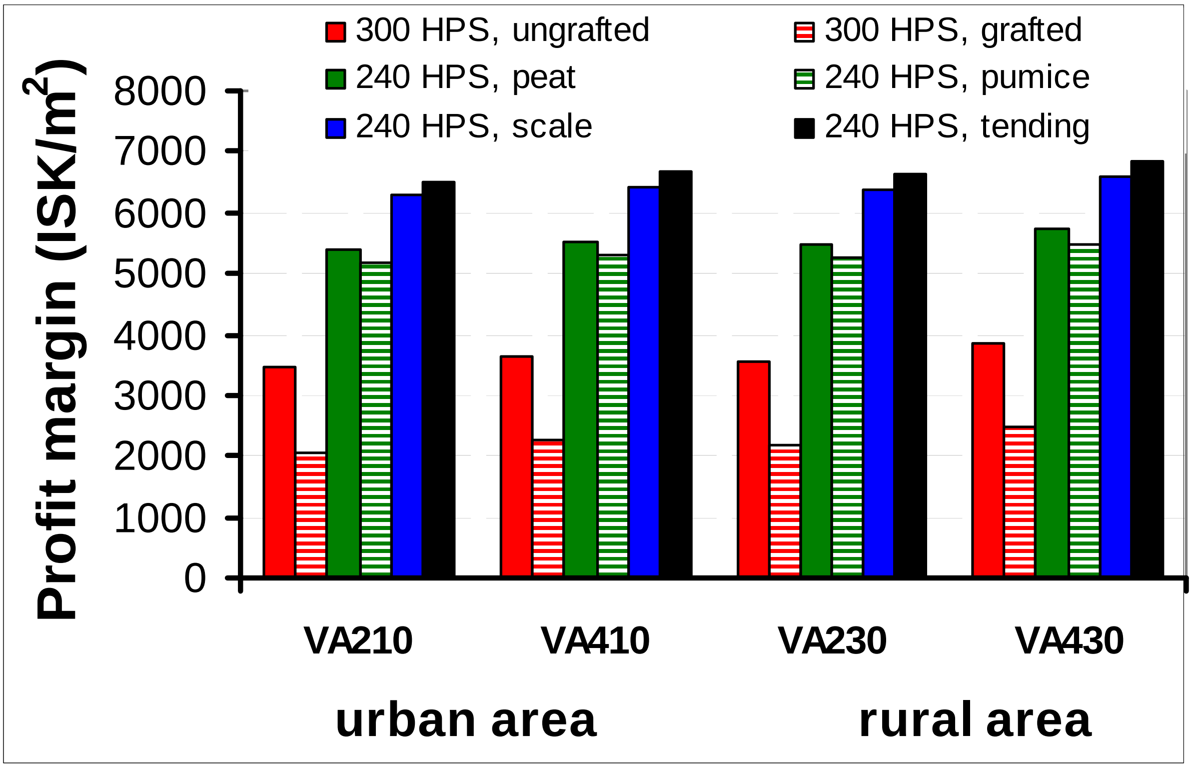

Fig. 37: Profit margin in relation to tariff and treatment.

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

Treatment	300 HPS, ungrafted	300 HPS, grafted	240 HPS, peat	240 HPS, pumice	240 HPS, scale	240 HPS, tending
Marketable yield/m²	47.0	43.5	43.3	42.6	45.3	46.1
Sales						
SfG (ISK/kg) [1]	400	400	400	400	400	400
Government (ISK/kg) [2]	63.76	63.76	63.76	63.76	63.76	63.76
Revenues (ISK/m²)	**21,796**	**20,161**	**20,088**	**19,756**	**21,027**	**21,372**
Variable and fixed costs (ISK/m²)						
Electricity distribution [3]	1,004	1,004	803	803	803	803
Electricity sale	5,651	5,651	4,521	4,521	4,521	4,521
Seeds [4]	165	136	124	124	124	124
Seedling production	307	154	231	231	231	231
Grodan small [5]	29	29	22	22	22	22
Grodan big [6]	136	68	102	102	102	102
Pumice / peat [7]	159	159	324	120	120	120
Predatory bug [8]	41	41	31	31	31	31
Parasitic wasps [9]	27	27	20	20	20	20
Bumble bees [10]	79	79	63	63	63	63
Strong vegetable Superex L 549 [11]	232	213	161	206	171	196
Tómato Superex L 553 [12]	272	337	190	235	219	225
Calcium chloride [13]	2	2	2	2	2	2
Calcium nitrate [14]	174	199	121	151	136	144
Magnesium nitrate [15]	22	29	16	19	17	18
Magnesium sulphate [16]	19	24	13	17	15	16
Potassium chloride [17]	19	24	13	17	15	16
Potassium nitrate [18]	43	49	30	39	77	80
Potassium sulphate [19]	17	20	12	14	14	14
CO_2 transport [20]	393	393	236	236	236	236
Liquid CO_2 [21]	2,030	2,030	1,218	1,218	1,218	1,218
Rent of CO_2 tank [22]	376	376	376	376	376	376
Strings	7	7	7	7	7	7
Rent of box from SfG [23]	313	289	288	283	302	306
Packing material [24]	1012	936	933	917	976	992
Packing (labour + machine) [25]	564	522	520	511	544	553
Transport from SfG	308	285	284	279	297	302
Shared fixed costs [26]	71	71	71	71	71	71
Lamps [27]	1,786	1,786	1,429	1,429	1,429	1,429
Bulbs [28]	952	952	762	762	762	762
∑ variable costs	**16,210**	**15,891**	**12,920**	**12,825**	**12,921**	**13,000**
Revenues -∑ variable costs	**5,586**	**4,270**	**7,167**	**6,931**	**8,107**	**8,372**
Working hours (h/m²)	1.58	1.62	1.32	1.31	1.36	1.37
Salary (ISK/h)	1,352	1,352	1,352	1,352	1,352	1,352
Labour costs (ISK/m²)	2,141	2,196	1,787	1,771	1,833	1,850
Profit margin (ISK/m²)	**3,445**	**2,074**	**5,380**	**5,160**	**6,274**	**6,523**

[1] price winter 2011/2012: 400 ISK/kg
[2] price in October for 2012: 63.76 ISK/kg
[3] assumption: urban area, tariff "VA210", no annual fee (according to datalogger values)
[4] 24,846 ISK / 500 Encore seeds; 16,127 ISK / 500 Maxifort
[5] 36x36x40mm, 25,584 ISK / 2,900 Grodan small
[6] 6.56 42/40, 8,635 ISK / 216 Grodan big
[7] 5,653 ISK/m^3 (2.6 m^3 big pumice, 0.65 m^3 small pumice)
778 ISK / unit Kekkilä GroBoard®, 60 cm x 20 cm x 30 cm
[8] 6,000 ISK / unit predatory bug (*Macrolophus caliginosus*)
[9] 4,000 ISK / unit parasitic wasps (*Encarsia formosa*)
[10] 7,042 ISK / unit bumble bees
[11] 8,664 ISK / 25 kg Strong vegetable Superex L 549
[12] 12,837 ISK / 25 kg Tómato Superex L 553
[13] 2,600 ISK / 25 kg Calcium chloride
[14] 2,934 ISK / 25 kg Calcium nitrate
[15] 6,420 ISK / 25 kg Magnesium nitrate
[16] 1,625 ISK / 25 kg Magnesium sulphate
[17] 4,901 ISK / 25 kg Potassium chloride
[18] 4,380 ISK / 25 kg Potassium nitrate
[19] 8,210 ISK / 25 kg Potassium sulphate
[20] CO_2 transport from Rvk to Hveragerði / Flúðir: 6.25 ISK/kg CO_2
[21] liquid CO_2: 32.30 ISK/kg CO_2
[22] rent for 6 t tank: 46,974 ISK/month, assumption: rent in relation to 1,000 m^2 lightened area
[23] 77 ISK / 12 kg box
[24] packing costs (material):
costs for packing of big tomatoes (0.75 kg): platter: 10.9 ISK / 0.75 kg,
plastic film: 4 ISK / 0.75 kg,
label: 1.25 ISK / 0.75 kg
[25] packing costs (labour + machine): 12 ISK / kg
[26] 94 ISK/m^2/year for common electricity, real property and maintenance
[27] HPS lights: 30,000 ISK/lamp, life time: 8 years
[28] HPS bulbs: 4,000 ISK/bulb, life time: 2 years

5 DISCUSSION

5.1 Yield in dependence of light intensity

The yield of tomatoes was compared at two light intensities. The results show that at a high light intensity it is possible to enhance tomato productivity only to a small extent by distributing an even higher amount of light intensity. *Marcelis* et al. (2006) reported that 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. However, these values are quite high compared to the present findings.

The reasons for the higher yield at higher light intensity were an increased number of harvested fruits and in addition, to a smaller extend, a higher average weight of tomatoes. Also for sweet pepper the reason for the higher yield at higher light intensity was attributed to more, rather than heavier fruits (*Stadler,* 2010). 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. However, more factors than only light intensity might have influenced yield: The higher plant density, higher temperature and higher CO_2 might also have been contributed to a yield increase, but the influence of each factor is unknown.

When a higher light intensity was applied to tomatoes, pollination was decreased. About one fruits less was pollinated compared to the lower light intensity. Also, unmarketable yield was increased with higher light intensity. This means a decrease in the number of marketable fruits per plant, but an increased number of fruits per m^2 due to the higher plant density compared to the one at lower light intensity. In contrast, *Heuvelink* et al. (2006) reported that a higher light intensity (13 h with 188 µmol/m^2/s compared to 17 h and 125 µmol/m^2/s) improved yield of sweet pepper by better fruit set while average fruit weight was hardly affected.

Using a higher light intensity is associated with higher expenses for the electricity. Thus, it is necessary that the higher use of electricity is paying off by obtaining a higher yield. However, the higher light intensity resulted in a lower profit margin than the lower light intensity, meaning that the yield was not high enough to pay off for the higher use of electricity. Only, when the yield would have been nearly 9 kg higher in the cabinet with the higher light intensity, profit margin would have been comparable to the one at the lower light intensity. That means it is only worth to use 60 W/m^2 more light if this would result in an almost 10 kg /m^2 higher yield (Fig. 38).

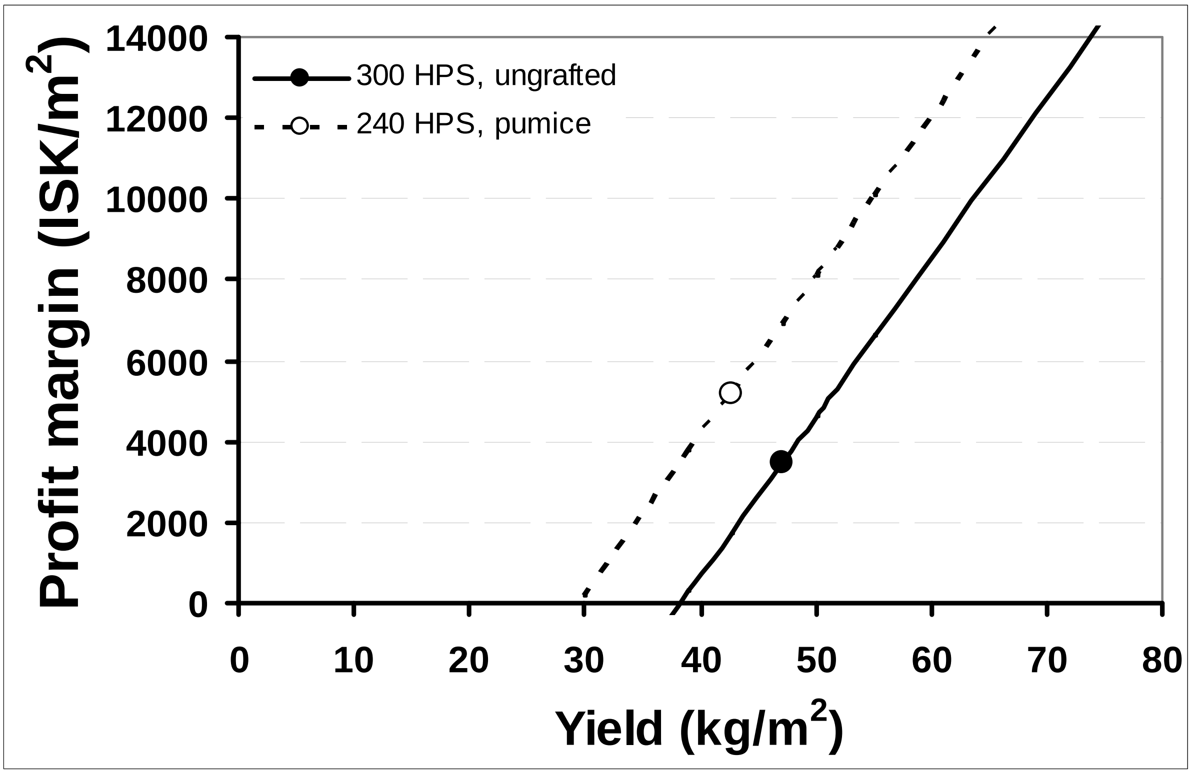

Fig. 38: Profit margin in relation to yield – calculation scenarios (urban area, VA210).

5.2 Yield in dependence of growing media

In the year 1985, pumice was used the first time in Iceland and as far as known in the world as growing media in commercial growing. Today, here it is common to use pumice (*Jóhannesson*, 1991). However, in other countries other growing medias are more popular. In Finland for example, is peat since decades the main growing media for vegetable crops (*Särkkä* et al., 2004). In contrast, in Sweden mostly rock wool, but also pumice and perlite – however both last growing media rather for cucumbers than for tomatoes – are used (*Bohlin* and *Holmberg*, 2004).

In the present experiment, the two growing medias – pumice and peat – resulted in comparable yields. Costs for peat are nearly three times higher than for pumice. However these costs are only contributing to a low percentage to the total costs. On the other hand, plant nutrition costs were lower when peat was used and thus, peat was only about 60 ISK /m^2 more expensive than pumice. Therefore, the choice of the growing media does not really matter. At least, with pumice Icelandic growers can use a local growing media from the volcano Hekla. Also, *Gunnlaugsson* and *Adalsteinsson* (1995) reported that tomatoes, cucumbers and sweet pepper are successfully grown in pumice.

5.3 Yield in dependence of plant treatment (grafted/ungrafted)

So far, it is common to plant ungrafted tomatoes in Iceland. Grafted tomatoes are only used by few Icelandic growers. However, in the literature, grafted tomatoes are evaluated as positive (e.g. *Pogonyi* et al., 2005; *Kowalczyk* and *Gajc-Wolska*, 2011): *Pogonyi* et al. (2005) reported higher tomato yields when tomatoes were grafted, which was on the one hand caused by more fruits per cluster and on the other hand by a higher average fruit weight. Also, *Kowalczyk* and *Gajc-Wolska* (2011) observed a yield advantage of cherry tomatoes after grafting. However, yield was only significantly increased with grafted tomatoes of the variety Organza. Grafted plants of the variety Dasher produced much more fruits than not grafted ones with a comparable average weight.

It seems that when tomatoes are grown longer, there could be imaginated an advantage of grafted tomatoes. However, grafting of tomatoes was not as sucessful as described in the literature. This can be attributed to the two weeks later transplanting of grafted tomatoes caused by the slower development at seedling production. Also, during the first two months got grafted plants a plant nutrition that was adjusted to ungrafted plants, but plant nutrition was after that corrected to the needs of grafted plants. Beside that, showed grafted tomatoes a stronger vegetative growth that has to be counteracted by additional stripping of leaves. However, this was only sufficiently done in the latter part of the growth period. Therefore, also the higher amount of flawed fruits can be attributed to the unsufficiently stripping of leaves and therefore worse conditions for air circulation. That means that results obtained with grafted tomatoes are only limited conclusive and need to be observed in further experiments where grafted plants would need to be treated from the beginning according to their needs.

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 white columns are representing the profit margin according to Fig. 37. Where to be assumed, that growers would get no subsidy from the state for the distribution of the energy, that would result in a profit margin of zero even a negative one for the high light intensity chamber and about 2,500-4,000 for the other treatments (black columns, Fig. 39). In this case it would partly not be economic to grow tomatoes in Iceland during the winter. Without the subsidy of the state, probably less Icelandic grower would produce tomatoes over the winter months. When it is assumed that the energy costs, both in distribution and sale, would increase by 25 %, but growers would still get the subsidy, then the profit margin would range between 0-5,000 ISK/m^2 (dotted columns). When it is assumed, that growers have to pay 25 % less for the energy, the profit margin would increase to 3,500-8,000 ISK/m^2. From these scenarios it can be concluded that from the grower's side it would be necessary to get subsidy to be able to grow tomatoes over the winter. The current subsidy should therefore not be decreased.

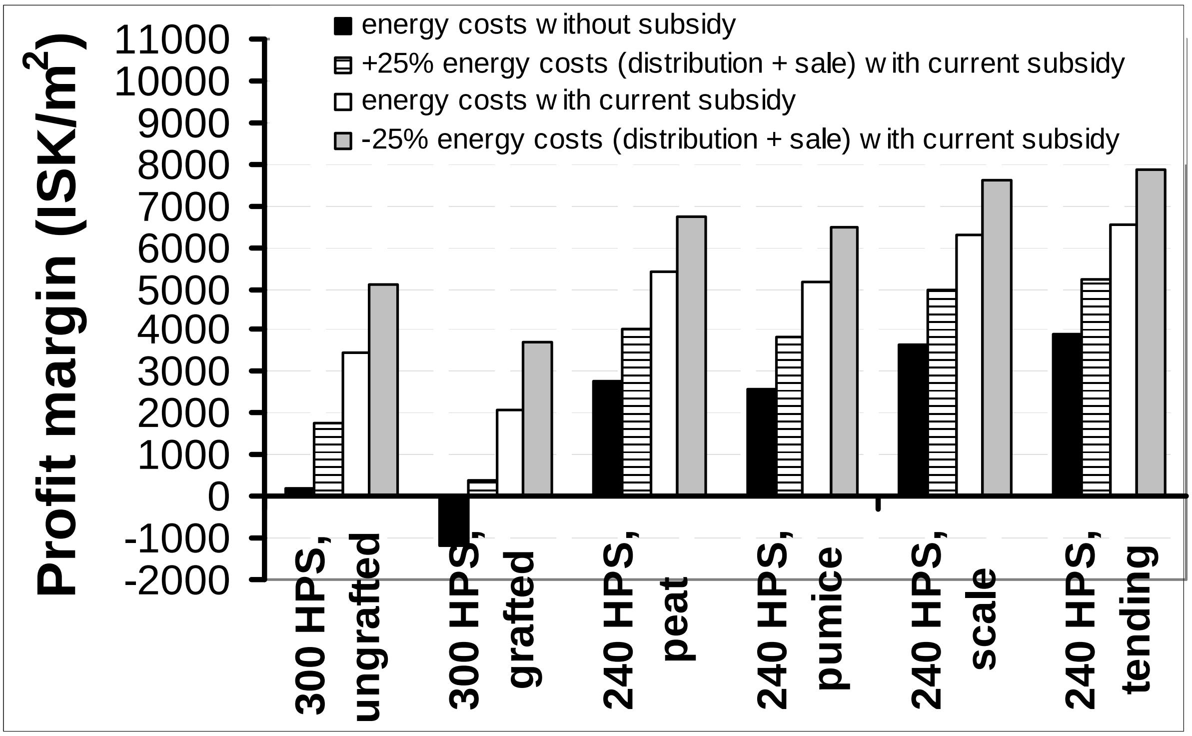

Fig. 39: Profit margin in relation to treatment – calculation scenarios (urban area, VA210).

5.5 Recommendations for increasing profit margin

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

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

1. Getting higher price for the fruits

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

2. Decrease plant nutrition costs

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

   At low solar irradiation, watering with a scale can save up to 20 % of water – and with that plant nutrition costs – with same yield when compared to automatic irrigation. It is profitable to adjust the watering to the amount of last water application (*Yeager* et al., 1997).

3. Lower CO_2 costs

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

4. Decrease packing costs

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

5. Efficient employees

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

6. Decrease energy costs

   - Lower prices for distribution and sale of energy (which is not realistic)
   - Growers should decrease artificial light intensity at increased solar irradiation, because this would result in no lower yield (*Stadler* et al., 2010).
   - Also, growers could decrease the energy costs by about 6 % when they would lighten according to 100 J/cm^2/cluster and 100 J/cm^2 for plant maintenance (*Stadler*, 2012). This would mean that especially at the early stage after transplanting, plants would get less hours light. Also at high natural light, lamps would be turned off. In doing so, compared to the traditional lighting system, profit margin could be increased by about 10 % (assuming similar yield).
   - Light during nights and weekends from the beginning of November to the end of February is not recommended due to the lower yield and lower profit margin (*Stadler*, 2012).
   - Growers should check if they are using the right RARIK tariff and the cheapest energy sales company tariff. Unfortunately, it is not so easy, to say, which is the right tariff, because it is grower dependent.
   - Growers should check if they are using the power tariff in the right way to be able to get a lowered peak during winter nights and summer (max. power -30 %). It is important to use not so much energy when it is expensive, but have a high use during cheap times.
   - Growers can save up to 8 % of total energy costs when they would divide the winter lighting over all the day. That means growers should not let all lamps be turned on at the same time. This would be practicable, when they would grow in different independent greenhouses. Of course, this is not so

easy realisable, when greenhouses are connected together, but can also be solved there by having different switches for the lamps to be able to turn one part of the lamps off at a given time. Then, plants in one compartment of the greenhouse would be lightened only during the night. When yield would be not more than 2 % lower with lighting at nights compared to the usual lighting time, dividing the winter lighting over all the day would pay off. However, the last experiment showed that the yield was decreased by about 15 % when tomatoes got from the beginning of November to the end of February light during nights and weekends (*Stadler*, 2012). This resulted in a profit margin that was about 18 % lower compared to the traditional lighting system and therefore, normal lighting times are recommended.

- For large growers, that are using a minimum of 2 GWh it could be recommended to change to “stórnotendataxti” in RARIK and save up to 35 % of distribution costs.
- It is expected, that growers are cleaning their lamps to make it possible, that all the light is used effectively and that they are replacing their bulbs before the expensive season is starting.
- *Aikman* (1989) suggests to use partially reflecting material to redistribute the incident light by intercepting material to redistribute the incident light by intercepting direct light before it reaches those leaves facing the sun, and to reflect some light back to shaded foliage to give more uniform leaf irradiance.

6 CONCLUSIONS

The choice of the growing media, pumice or peat, did not affect yield. Further experiments are needed to make a statement to grafting of tomatoes.

The very high increase in energy costs by lighting when increasing the light intensity from 240 W/m^2 to 300 W/m^2 was accompanied by only a small yield increase. From the economic side it seems to be not recommended to provide 60 W/m^2 more light. To have the same profit benefit with more use of electricity nearly 10 kg higher yield must be obtained.

Growers should pay attention to possible reduction in their production costs for tomatoes other than energy costs. One of them could e.g. be to use a scale for watering at low solar irradiation and save by that 20 % of water and with that also plant nutrition costs.

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