Rit LbhÍ nr. 63

„Áhrif ljósstyrks á vöxt, uppskeru og gæði gróðurhúsajarðarberja að vetri“

FINAL REPORT

Christina Stadler

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Landbúnaðarháskóli Íslands

January 2016

Final report of the research project

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Abbreviations

DM	dry matter yield
DS	dry substance
E.C.	electrical conductivity
HPS	high-pressure vapour sodium lamps
kWh	kilo Watt hour
LAI	leaf area index
N	nitrogen
pH	potential of hydrogen
ppm	parts per million
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 winterproduction of strawberries are not yet in place and need to be developed. The objective of this study was to test if winterproduction of strawberries is possible in Iceland and if the light intensity is affecting growth, yield and quality of strawberries and to evaluate the profit margin.

Two experiments with strawberries (*Fragaria x ananassa* cv. Sonata) were conducted, the first (A) from January to May 2015 and the second (B) from the middle of May to the end of July 2015, in the experimental greenhouse of the Agricultural University of Iceland at Reykir. Strawberries were grown in pots in five replicates with 12 plants/m^2 under high-pressure vapour sodium lamps (HPS) at two light intensities (150 W/m^2 and 100 W/m^2) for a maximum of 18 hours light. The day temperature was 16° C and the night temperature 8° C, CO_2 800 ppm. Strawberries received standard nutrition through drip irrigation. The effect of light intensity was tested and the profit margin calculated.

It took 1-2 days from flowering to pollination. The fruits were ripe in 42 days for part A and 33-35 days for part B. It seems that more light (150 W/m^2) resulted in more flowers, but later was the effect lower in part A. In part B were from the middle of the growth period on more flowers / fruits counted at 100 W/m^2. The treatment with the higher light intensity started some days earlier to give ripe berries in comparision to 100 W/m^2.

A higher light intensity had a positive effect on marketable yield, the harvest increased by 13 % in part A and by 19 % in part B compared to the lower light intensity. The higher yield was attributed to a higher number of „extra class“ fruits, while the avarage weight was only in part B higher at 150 W/m^2, but not in part A. It seems that unmarketable yield was decreased at a higher light intensity. In part A was marketable yield 600 g/plant with 150 W/m^2 but 500 g/plant with 100 W/m^2. However, the difference was not statistically significant. In part B were 450 g/plant marketable yield at 150 W/m^2 and more than 350 g/plant at 100 W/m^2, which was also not statistically different. Marketable yield was 90-94 % of total yield in part A

and 86-88% in part B. The reason for the higher unmarketable yield in part B was a higher amount of unshaped strawberries due to overpollination.

It seems that sugar content was a bit higher at 150 W/m^2. However, this difference was not found in the tasting experiment in the sweetness of the strawberries. The tasting gave a hint that a higher light intensity improved taste and firmness but not the juiciness.

In the chamber with 150 W/m^2 was a higher air temperature, a higher leaf temperature and a higher soil temperature measured compared to the chamber with 100 W/m^2. This could also have a positive influence on the yield and growth of the plants. For example was a tendency for a higher amount of runners found at 150 W/m^2, whereas the number of leaves was comparable between different light intensities.

With a higher light intensity increased the yield by 0,8 kg/m^2 (1 % increase of light intensity increased yield by 0,3-0,4 %) and the profit margin by 900 ISK/m^2 for part A and 1.500 ISK/m^2 for part B. A higher tariff did not change profit margin. Also, the position of the greenhouse (urban, rural) did not influence profit margin.

Possible recommendations for saving costs other than lowering the electricity costs are discussed. From an economic viewpoint it is recommended to use a higher light intensity to be able to increase yield and profit margin.

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 vegna vetrarræktunar á jarðarberjum eru ekki til staðar og þarfnast frekari þróunar. Markmiðin voru að prófa, hvort vetrarræktun gróðurhúsajarðarberja er möguleg á Íslandi og hvort ljósstyrkur hefði áhrif á vöxt, uppskeru og gæði jarðarberja og hvort það væri hagkvæmt.

Gerðar voru tvær tilraunir með jarðarberjum (*Fragaria x ananassa* cv. Sonata), sú fyrri (A) frá janúar til maí 2015 og sú síðari (B) frá miðjum maí til loka júlí 2015, í tilraunagróðurhúsi Landbúnaðarháskóla Íslands að Reykjum. Jarðarber voru ræktuð í pottum í fimm endurtekningum með 12 plöntum/m^2 undir topplýsingu frá háþrýsti-natríumlömpum (HPS) með tvenns konar ljósstyrk (150 W/m^2 og 100 W/m^2) að hámarki í 18 klst. Daghiti var 16° C og næturhiti 8° C, CO_2 800 ppm. Jarðarberin fengu næringu með dropavökvun. Í hluta A og hluta B voru áhrif ljósstyrks prófuð og framlegð reiknuð út.

Það tók 1-2 daga frá blómgun til frjóvgunar. Ávextir voru þroskaðir í 42 daga í hluta A og í hluta B 33-35 daga. Það virðist vera að meira ljós (150 W/m^2) gefi fleiri blóm en síðan eru áhrifin minni í hluta A. Í hluta B voru frá miðju vaxtarskeiði fleiri blóm / aldin við 100 W/m^2. Í upphafi uppskerutímabils byrjaði meðferð með hærri ljósstyrk nokkrum dögum fyrr að gefa þroskuð ber í samanburði við 100 W/m^2.

Hærri ljósstyrkur hefur jákvæð áhrif á markaðshæfa uppskeru, uppskeran var 13 % meiri í hluta A og 19 % meiri í hluta B. Ástæðan var fleiri jarðarber sem voru í úrvalsflokki, en meðalþyngd var aðeins hærri við 150 W/m^2 í hluti B en ekki í hluti A. Það virðist að ómarkaðshæf uppskera hafi minnkað við hærri ljósstyrk. Þannig fengust 600 g/plöntu markaðshæfrar uppskeru við 150 W/m^2 en 500 g/plöntu við 100 W/m^2 í hluta A, sem var samt ekki tölfræðilega marktækur munur. En í hluta B fengust 450 g/plöntu við 150 W/m^2 og meira en 350 g/plöntu við 100 W/m^2 sem var heldur ekki tölfræðilega marktækur munur. Hlutfall uppskerunnar sem hægt var að selja var 90-94 % í hluta A og 86-88% í hluta B. Hærra hlutfall ómarkaðshæfrar uppskeru í hluta B var vegna hærri hluta af jarðarberjum sem voru illa löguð vegna ófrjóvgunar.

Það virðist að sykurinnihald væri örlítið hærra við 150 W/m^2. Hins vegar fannst þessi munur ekki í bragðprófun á sætu í jarðarberjum. Smökkun gaf í skyn að hærri ljósstyrkur yki bragð og þéttleika en ekki safa.

Í klefa með 150 W/m^2 mældist hærri lofthiti, hærri laufhiti og hærri jarðvegshiti samanborið við klefa með 100 W/m^2. Það getur líka haft jákvæð áhrif á uppskeruna og vöxt plantna. Til dæmis virðist tilhneiging til fjölgunar hlaupara við 150 W/m^2, þótt fjöldi laufa væri hinn sami við mismunandi ljósstyrk.

Þegar hærri ljósstyrkur var notaður, þá jókst uppskera um 0,8 kg/m^2 (1 % hækkun í ljósstyrk jók uppskeru um 0,3-0,4 %) og framlegð um 900 ISK/m^2 í hluta A og 1.500 ISK/m^2 í hluta B. Hærri rafmagnsgjaldskrá breytir framlegð næstum ekkert. Það skiptir ekki máli hvort gróðurhús er staðsett í þéttbýli eða dreifbýli, framlegð er svipuð.

Möguleikar til að minnka kostnað, aðrir en að lækka rafmagnskostnað eru ræddir. Frá hagkvæmnisjónarmiði er mælt með því að nota hærri ljósstyrk til að auka uppskeru og framlegð jarðarberja.

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 production. This could replace imports from lower latitudes during the winter months and make domestic vegetables and fruits even more valuable for the consumer market.

Árni Magnús Hannesson from Fluðir is the pioneer in growing strawberries in Iceland. He has started with the production in the year 1985. Eiríkur Ágústsson and Olga Lind Guðmundsdóttir started to grow strawberries at Silfurtún in the year 2002 and in 2011 more growers joined producing strawberries.

The possibilities for strawberry production are based on growing under vegetation covers for the market in June-August or cultivate strawberries in heated greenhouses with preferably supplementary lighting. The harvest period was so far from May to October and therefore, are Icelandic strawberries not available in winter and spring. However, a demand exists because relative cheap strawberries are imported and the Icelandic producers can hardly compete with the price of imported strawberries. Strawberry production in the greenhouse is based on producing strawberries at times where cheap strawberries are not available. "Sonata" and "Elsanta" are the most common strawberry varieties abroad and also in Iceland.

Since several years is it tradition to grow strawberries in heated greenhouses in the Netherlands and Belgium. Also, the Norwegians are experimenting with greenhouse cultivation of strawberries during winter (e.g. *Verheul* et al., 2007). The question is whether this can also be pursued in Iceland. It is difficult to cultivate strawberries on high latitudes like in Iceland, because there are short days and little daylight from middle of September to middle of April and the low natural light level is the main limiting factor for a production in winter in greenhouses. Therefore, supplemental lighting is necessary to maintain an equal harvest over the year and this could make imports from lower latitudes unnecessary. Vegetables are grown during winter with supplemental lighting and the question is whether it is possible to extend the growing season of strawberries in the same way. Therefore, it should be considered if it is possible to use supplemental lighting when active radiation (PAR) falls below the critical value in production of strawberries.

In strawberries is it necessary to use supplemental lighting for 12 to 13 hours (*Verheul* et al., 2007). Longer lighting reduced the number of flowers. A day temperature of 18 °C and / or a night temperature of 12 °C was the best to get flowers and also at the shortest time.

At the nursery Kvistar were good results reached with minimal heating (day temperature of 16 °C and night temperature of 8 °C) in a plastic greenhouse in summer production. Under that conditions were 4 kg/m^2 of strawberries possible and sold for 3.000 ISK / kg.

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 (*Stadler*, 2012) or in only a slightly higher yield (*Stadler*, 2013a). Knowledge in growing berries at different light intensities is not yet available. Therefore, two light intensities will be tested to investigate if growing strawberries in winter is possible.

Incorporating lighting 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 strawberries.

The objective of this study was to test if (1) the light intensity is affecting growth, yield and quality of strawberries, if (2) this parameter is converted efficiently into yield, and if (3) the profit margin can be improved by the chose of the light intensity. This study should enable to strengthen the knowledge on the best method of growing strawberries and give strawberry growers advice how to improve their production by modifying the efficiency of strawberry production.

3 MATERIALS AND METHODS

3.1 Greenhouse experiment

An experiment with strawberries (*Fragaria x ananassa* cv. Sonata) and different light intensities was conducted at the Agricultural University of Iceland at Reykir during winter / spring (part A) and spring / summer (part B).

Four heavy tray plants were planted on 19.12.2014 for part A and on 13.04.2015 for part B in 5 l pots filled with moist strawberry substrate. The plants stayed into the young plants production chamber with 150 W/m^2 until 19.01.2015 (part A) respectively until 12.05.2015 (part B). The temperature was adjusted to 16 °C / 12 °C (day / night) and the ventilation started with 20 °C.

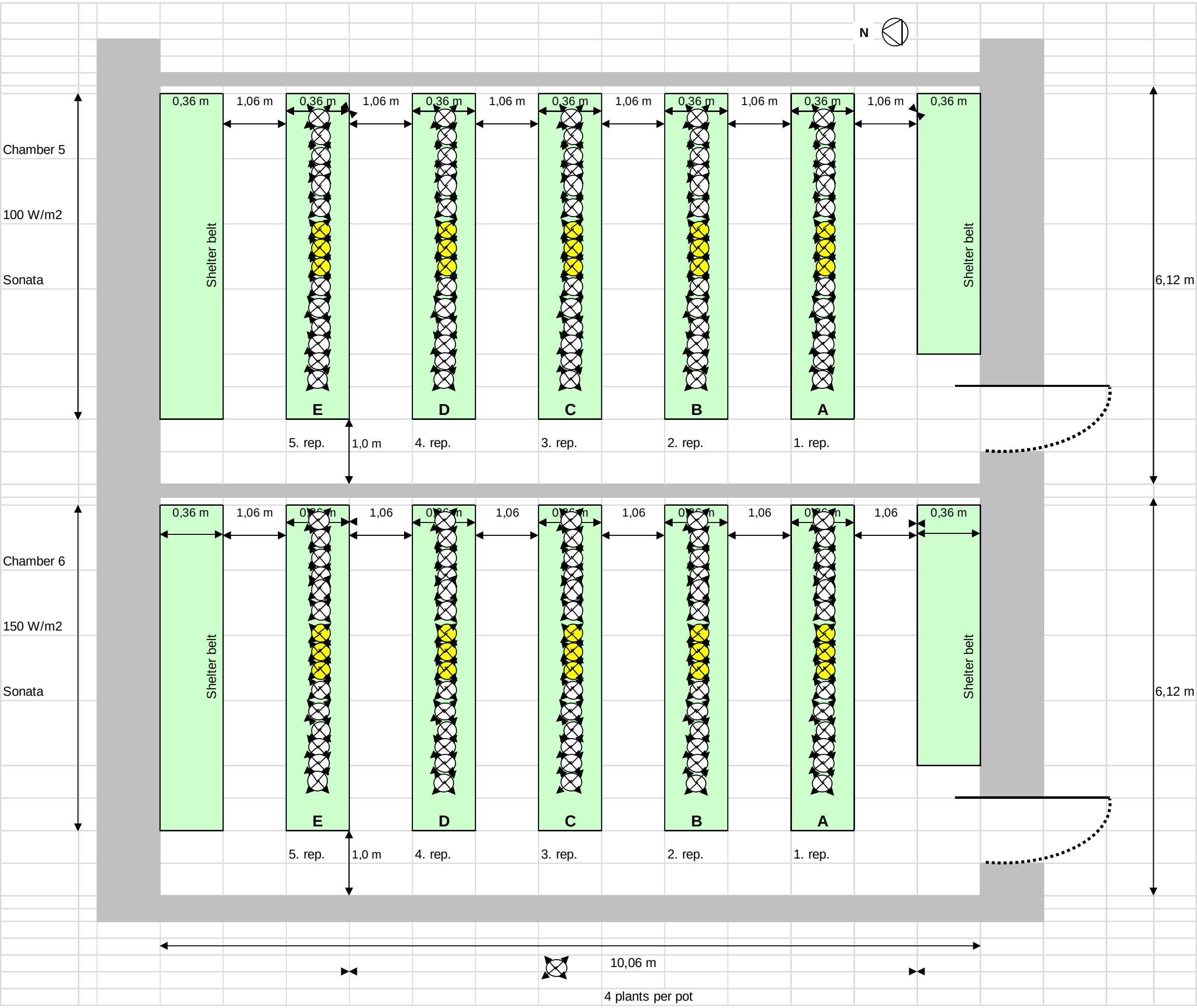

Fig. 1: Experimental design of cabinets.

After four weeks in the young plants production chamber were pots moved into the growing chambers with different light intensities (see chapter "3.2 Treatments"). The strawberry pots were placed in rows in five 70 cm high beds (Fig. 1) with 8 cm between pots and 1,06 m between beds. One bed had 16 pots. Five replicates, one replicate in each bed consisting of one pots (4 plants) acted as subplots for measurements. The temperature was set on 16 °C during day and 8 °C during night. Carbon dioxide was provided (800 ppm CO_2 with no ventilation and 400 ppm CO_2 with ventilation). In part A was at the latter part of the harvest the amount increased to 1.200 ppm CO_2. Bumblebees were used for pollination. A misting system was installed. Plant protection was managed by beneficial organisms. In part A was Rovral sprayed once after planting and about two weeks later Paraat against phythopthora. In part B was Paraat sprayed after planting and again after 10 days. After moving plants into the chambers with different light intensities was in both parts Loker sprayed once a week (see details in appendix).

In part A was the first 6 weeks after moving plants into the different chambers the fertilizer plan accoring to Azelis used (Tab. 1a) and after that the fertilizer plan according to DLV plant (Tab. 1b). In part B was during the whole growth period the fertilizer plan according to DLV plant used.

Tab. 1a: Fertilizer mixture according to advice from Azelis.

	Stem solution A (1000 l)	**–––– Stem solution B –––– (1000 l)**						**Irrigation water**	**Rela-tion**
Fertilizer (amount in kg) (amount in l)*	Calcium nitrate	Pioner NPK Red 9-5-30	Pioner NPK Yellow 10-4-25	Potassium sulfate	Pioner Mikro Plus *	Pioner Iron Chelate EDDHA 6 %	Resistim (as needed)*	E.C. (mS/cm)	
Planting – 10 white fruits / plant (growth)	75	50	50	25	14	0,5	10	1,6	1:150
10 white fruits / plant – harvest end (fruit development)	75	100		25	14	0,5		1,6	1:150

Tab. 1b: Fertilizer mixture according to advice from DLV plant.

	Stem solution A (1000 l)			–––––– Stem solution B –––––– (1000 l)									Irri-gation water	Rela-tion
Fertilizer (amount in kg) (amount in l) * (amount in g) **	Calciumnitrate liquid *	Calciumnitrate	Fe-DTPA 3 % vlb	Potassium sulfate	Magnesium sulfate	Monopotassium phosphate	Potassium nitrate	Mangansulfat 32,5 % Mn **	Borax 11,3 % B **	Koparsulfat 24 % Cu **	Zinksulfat 23 % Zn **	Natriummolybdat 40 % Mo **	E.C. (mS/cm)	
Planting – 10 white fruits / plant (growth)	21,8	62,5	6,45	0,5	35,9	17	29,1	510	140	27	210	12	1,5	1:100
10 white fruits / plant – harvest end (fruit development)	74,1		7,16	3,2	35,2	17	41,8	590	140	25	260	14	1,5	1:100

Plants were irrigated through drip irrigation (1 tube per bucket). The watering was set up that the plants could root well down, which means no runoff after planting and a low amount of runoff in the first 2-3 weeks. At the growing stage was the irrigation arranged to 10-20 % runoff on sunny days and 0-5 % on cloudy days with an E.C in the drip of 1,5-1,7. At flowering and carrying green fruits was the runoff supposed to be 25-30 % on sunny days and 10-15 % on cloudy days with a lowering of E.C. from 1,7 to 1,5 one week before harvest. The E.C. of the input and runoff water is supposed to be adjusted that their sum is 3,2-3,3 during growth and flowering and 3,0-3,1 during harvest. In geneneral was the rule that the first drip in the morning should not give runoff. 100 ml/drip was irrigated in 2,5 h intervals (first at 5.00 and last at 17.00) with E.C. 1,6 and pH 5,8.

3.2 Treatments

Strawberries from part A were grown from 19.01-04.05.2015 and strawberries from part B from 12.05-22.07.2015 under high-pressure sodium lamps (HPS) in two chambers with different light intensities:

1. HPS top lighting 150 W/m^2
   HPS, 150 W/m^2
2. HPS top lighting 100 W/m^2
   HPS, 100 W/m^2

HPS lamps for top lighting (600 W bulbs) were mounted horizontally over the canopy. Light was provided for 18 hours. Half of the lamps went on at 03.00 and the other half at 03.30. Half of the lamps went off at 19.00 and the other half at 19.30. When lights went off it was 16 °C, at 9.00 10 °C, when half of the lamps went on it was 16 °C, when other half went on 18 °C. The lamps were automatically turned off when incoming illuminance was above the desired set-point.

3.3 Measurements, sampling and analyses

Soil temperature and leaf temperature was measured once a week.

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

To be able to determine plant development, the number of leaves, the number of clusters and the number of open flowers was counted each week. This gave information regarding the total amount of flowers per plant and the number of flowers per cluster.

During the growth period were runners regularly taken away and the number per plant was registered. During the harvest period were berries regularly collected (2-3 times per week) in the subplots. Total fresh yield, number of fruits, fruit category (extra-class (> 25 mm), 1.class (18 mm) and not marketable fruits (too little fruits (< 18 mm), damaged fruits, misshaped fruits, moldy fruits) were determined. At the end of the harvest period was on each plant the number of immature fruits counted. The marketable yield of the whole chamber at each light intensity was also measured.

The interior quality of the berries was determined. A brix meter (Pocket Refractometer PAL-1, ATAGO, Tokyo, Japan) was used to measure sugar content in the strawberries during the growth period. From the same harvest, the flavour of fresh fruits was examined in tasting experiments with untrained assessors. Also, subsamples of the fruits were dried at 105 °C for 24 h to measure dry matter yield (DM).

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

3.4 Statistical analyses

SAS Version 9.4 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 $p \leq 0{,}05$.

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. Solar irradiation was lower for part A than for part B. For part A increased the natural light

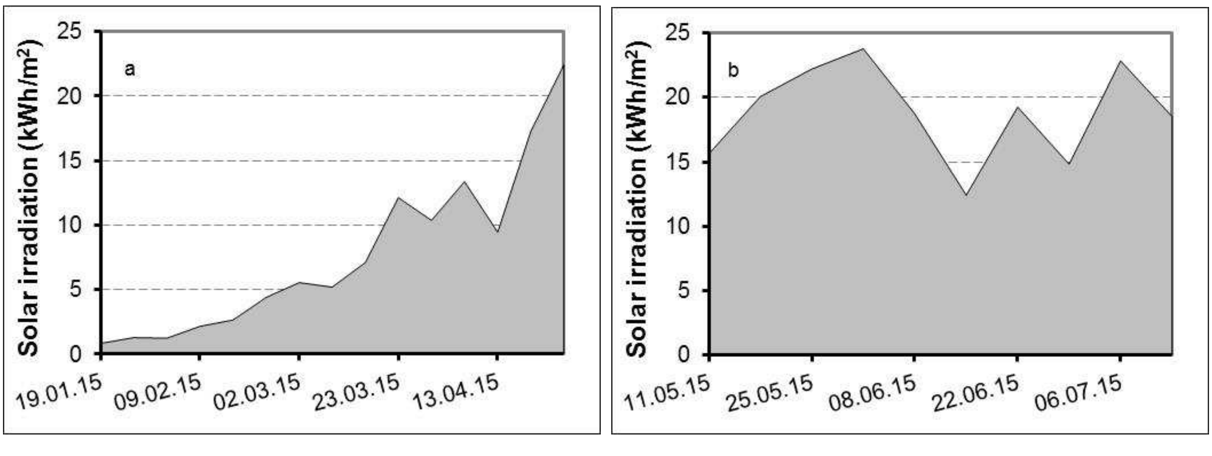

Fig. 2: Time course of solar irradiation for part A (a) and part B (b). Solar irradiation was measured every day and values for one week were cumulated.

level with proceeding growth period. At the beginning of March were 5 kWh/m^2 reached, at the end of March more than 10 kWh/m^2 and at the end of the experiment more than 20 kWh/m^2. In contrast, part B was conducted during longer days and solar irradiation stayed during the whole growth period at around 15-25 kWh/m^2 (Fig. 2).

4.1.2 Chamber settings

The settings in the chambers were regularly recorded. Table 2 shows the weekly average of the CO_2 amount, the air and floor temperature. The settings were mainly equal between the different light intensities. However, in part A was in week 1 the CO_2 amount higher and the air temperature lower at 100 W/m^2 compared to 150 W/m^2. Also, in week 5 was the floor temperature lower at the lower light intensity. In part B was the CO_2 amount in week 1, in week 4-7, week 9 and week 10 higher in the chamber with the lower light intensity. In addition, the temperature on the floor was in week 9 and week 10 also higher at 100 W/m^2 compared to 150 W/m^2.

Table 2: Chamber settings for part A and part B.

	Part A						Part B					
	CO_2 (ppm)		Air (°C)		Floor (°C)		CO_2 (ppm)		Air (°C)		Floor (°C)	
Week*	150	100	150	100	150	100	150	100	150	100	150	100
no	––––––––– W/m^2 –––––––––						––––––––– W/m^2 –––––––––					
1	621	669	17,2	16,5	28,8	29,5	720	782	16,7	16,7	32,4	33,3
2	755	759	16,5	16,1	28,3	28,8	505	512	16,6	16,5	27,0	27,6
3	809	817	16,9	16,8	29,6	30,2	575	587	17,3	17,3	28,7	29,1
4	869	878	16,5	16,5	32,1	32,6	424	505	18,0	17,9	27,1	27,9
5	884	904	16,5	16,6	34,6	32,8	467	495	18,0	18,1	27,4	27,1
6	871	884	16,5	16,4	37,5	37,1	453	483	17,9	18,0	28,7	29,4
7	833	854	16,9	16,6	39,0	39,1	449	476	19,7	19,6	30,0	30,3
8	582	602	18,0	17,7	37,2	37,0	447	464	20,4	20,5	28,5	29,0
9	847	824	17,3	17,2	38,7	38,7	463	486	19,7	19,9	22,3	23,4
10	773	781	17,0	16,8	38,7	38,8	433	484	19,3	19,3	18,5	19,8
11	781	793	16,5	16,4	38,7	38,7						
12	879	883	16,5	16,4	34,6	35,2						
13	1047	1045	16,1	16,2	31,5	32,5						
14	1124	1126	15,2	15,3	30,5	31,5						
15	1080	1079	15,5	15,4	30,8	31,6						

* week after moving pots into chambers with different light intensities

4.1.3 Soil temperature

Soil temperature was measured weekly at low solar radiation in the morning (at about 08.30). In part A and part B was soil temperature most of the time higher at the higher light intensity. In part A fluctuated soil temperature most of the time between 15-18° C, while in part B increased soil temperature from 17 °C to 19 °C (Fig. 3).

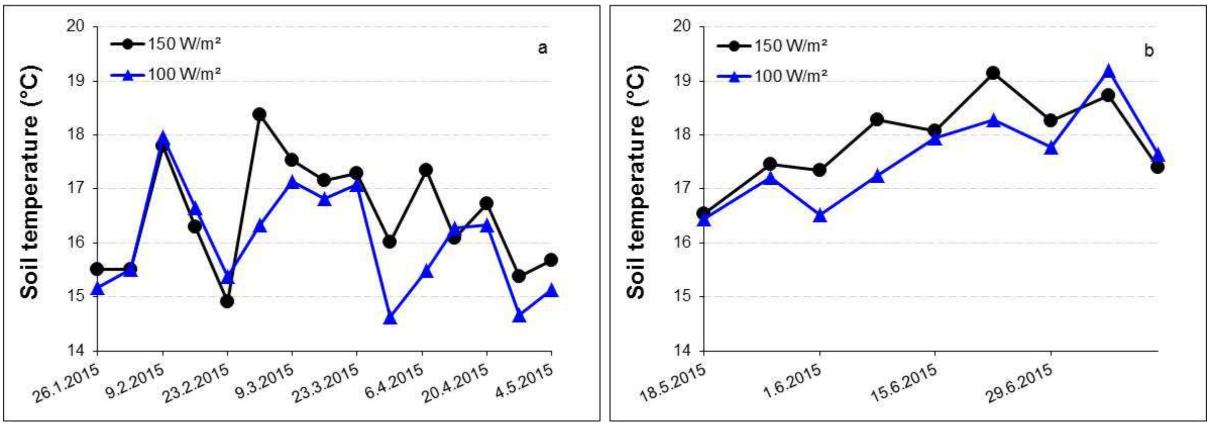

Fig. 3: **Soil temperature for part A (a) and part B (b). The soil temperature was measured at little solar irradiation early in the morning.**

4.1.4 Leaf temperature

Leaf temperature was measured weekly at low solar radiation in the morning (at about 08.30). In part A and part B was leaf temperature most of the time higher at the higher light intensity. In part A increased leaf temperature from 12 °C to 20 °C, while for part B fluctuated leaf temperature between 14-22 °C (Fig. 4).

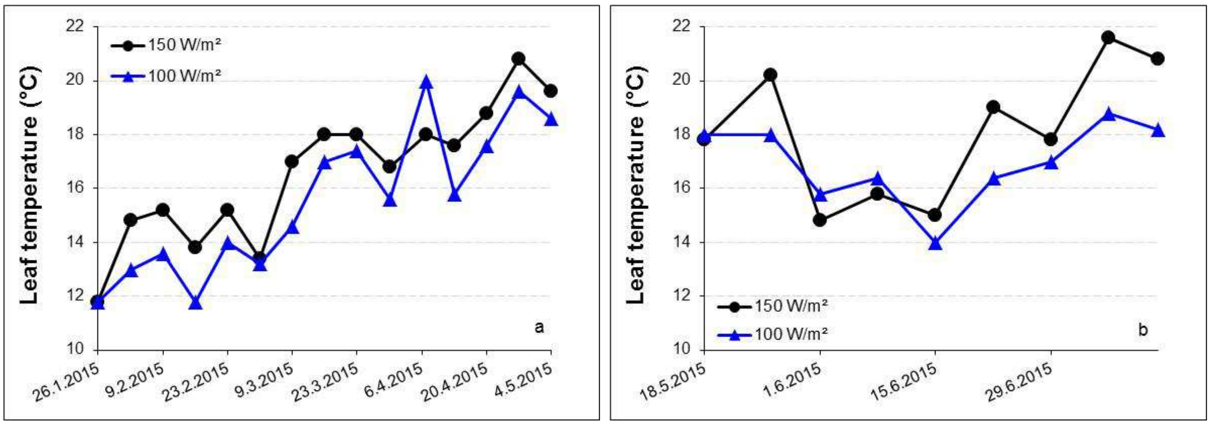

Fig. 4: **Leaf temperature for part A (a) and part B (b). The soil temperature was measured at little solar irradiation early in the morning.**

4.1.5 Irrigation of strawberries

The amount of applied water increased with longer growth of the strawberries from about 100 ml/plant to about 500 ml/plant in part A and from 200 ml/plant to about 500 ml/plant in part B. The amount of applied water was higher at the higher light intensity (Fig. 5).

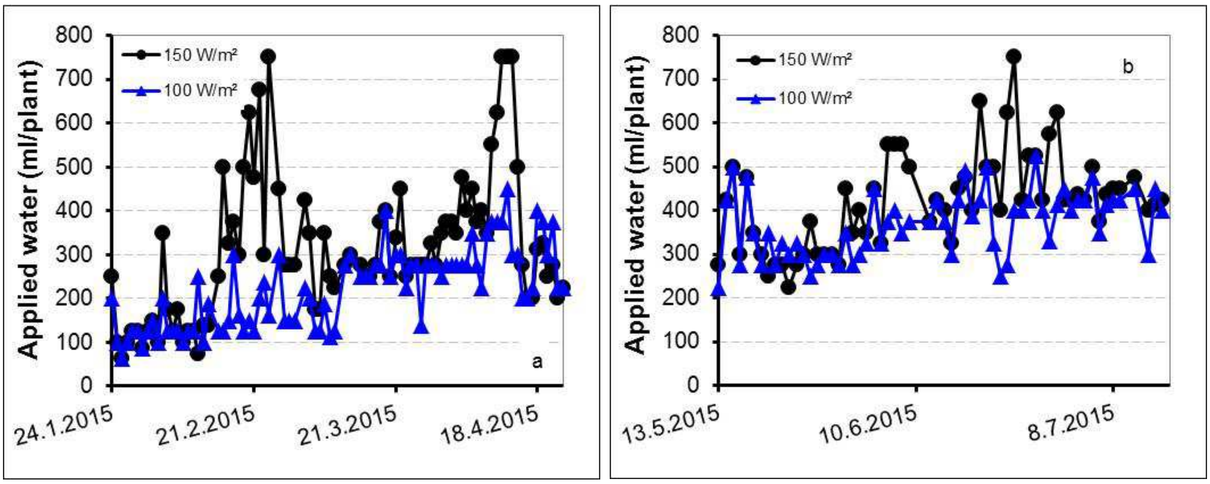

Fig. 5: Daily applied water for part A (a) and part B (b).

E.C. and pH of irrigation water was fluctuating much (Fig. 6a, b). The E.C. of applied water ranged most of the time between 1,2-1,8 and the pH between 5,0-6,5. The E.C. of runoff stayed mostly between 1,4-2,4 and the pH of runoff between 4,5-7,5. The pH of runoff seems to decrease during the growth period (Fig. 7a, b).

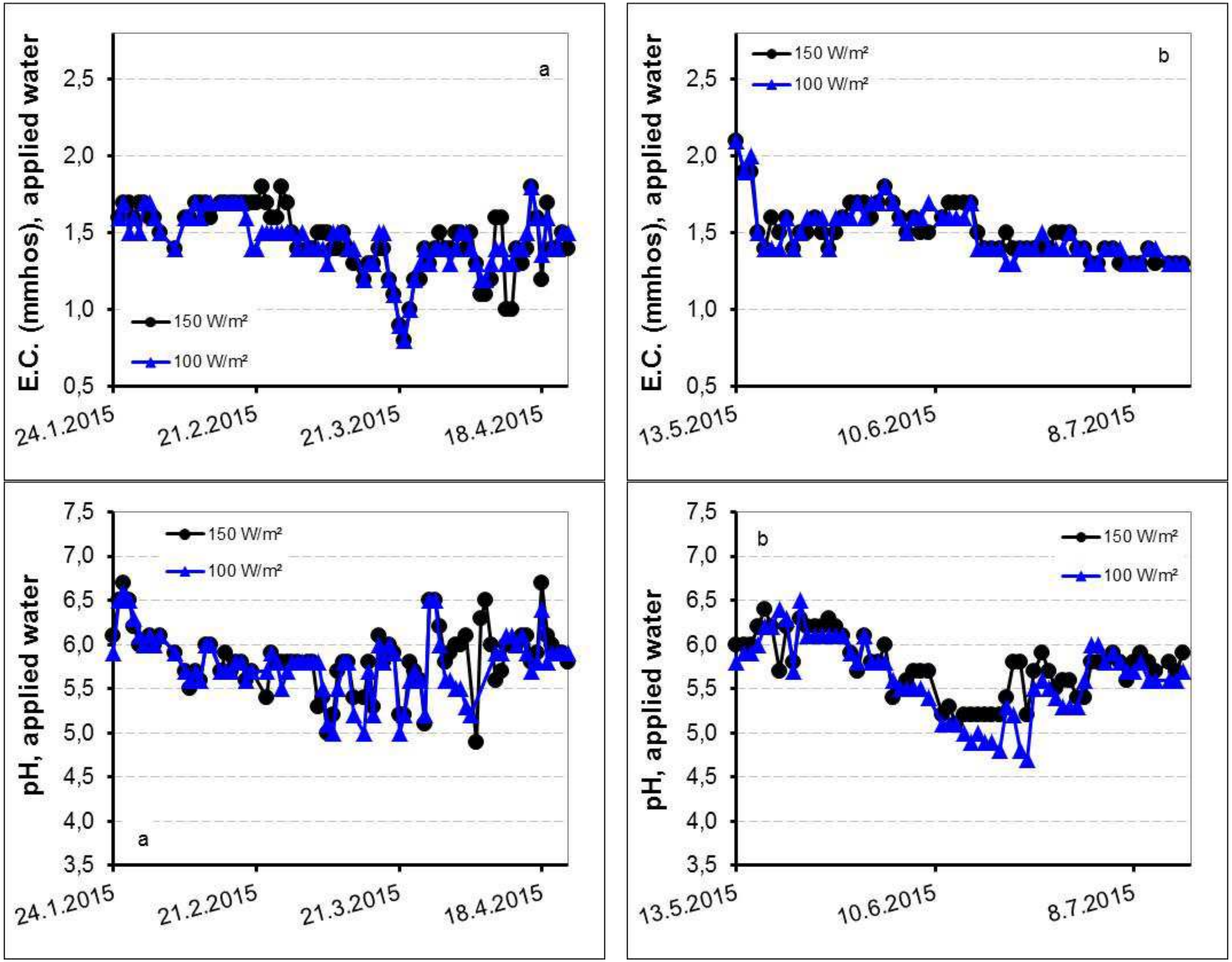

Fig. 6: E.C. and pH of irrigation water for part A (a) and part B (b).

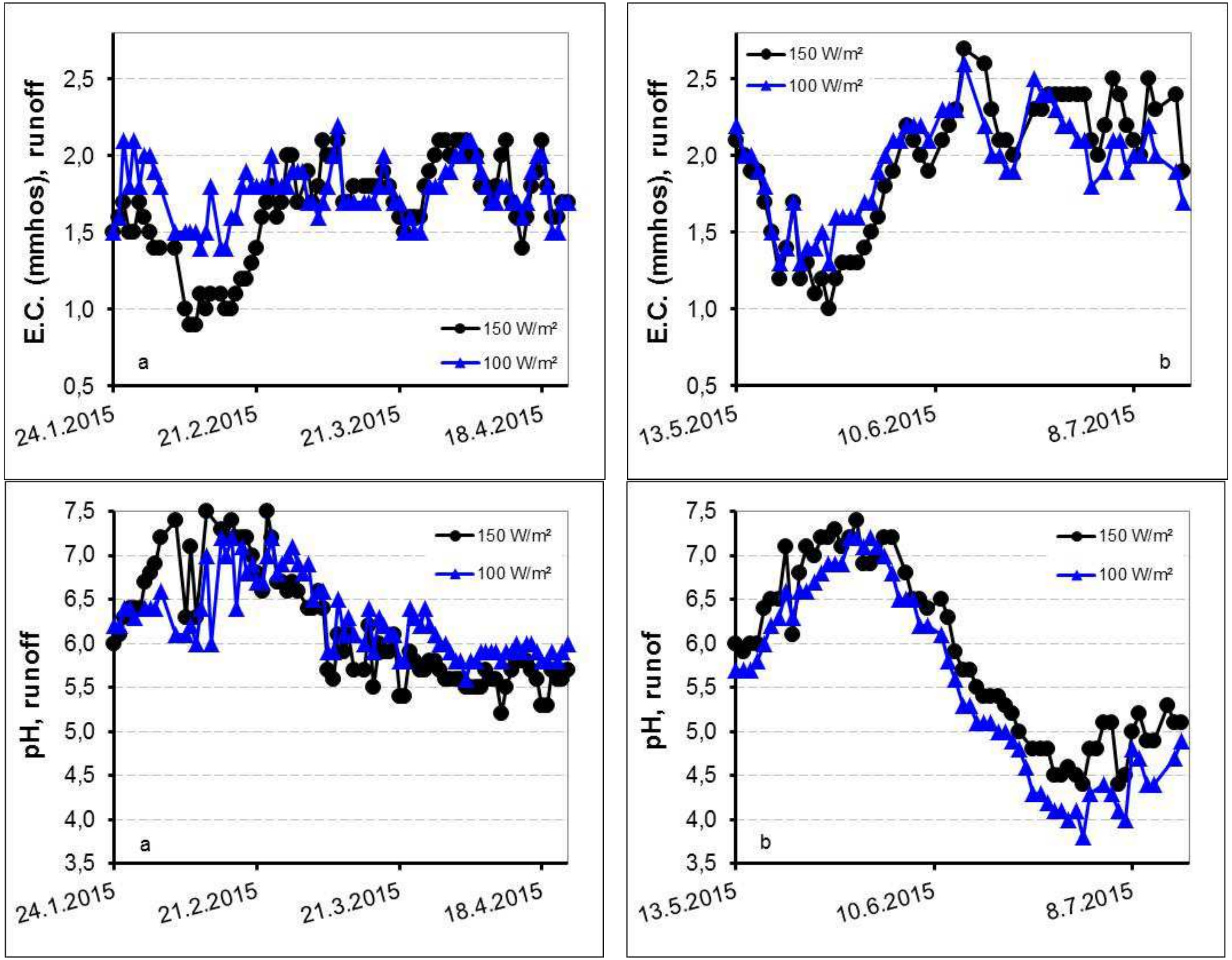

Fig. 7: E.C. and pH of runoff of irrigation water for part A (a) and part B (b).

The amount of runoff from applied irrigation water was about 5-25 % (Fig. 8). The runoff seems to be lower for the higher light intensity.

Water samples taken from the drip and the runoff water provide an information basis on which nutrients are close to the target of the drain water. Samples taken on the 16.02.2015 showed a high pH and a high S content and Cu content, while the Mn and Mo content was low, independent of chambers (data not shown).

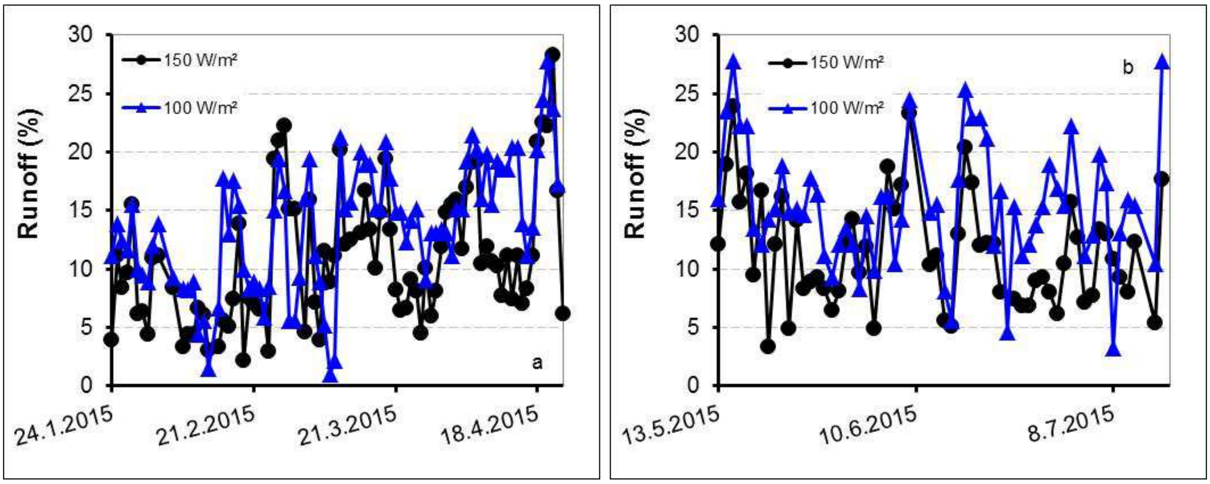

Fig. 8: **Proportion of amount of runoff from applied irrigation water for part A (a) and part B (b).**

4.2 Development of strawberries

4.2.1 Number of leaves

Strawberry plants had more leaves in the winter / spring crop, while the number of leaves was lower in the spring / summer crop. The number of leaves stayed more or less stable between 18-20 in part A (Fig. 9a), while the number of leaves increased from 12-19 in part B (Fig. 9b). No differences in the number of leaves regarding the two light intensities were observed.

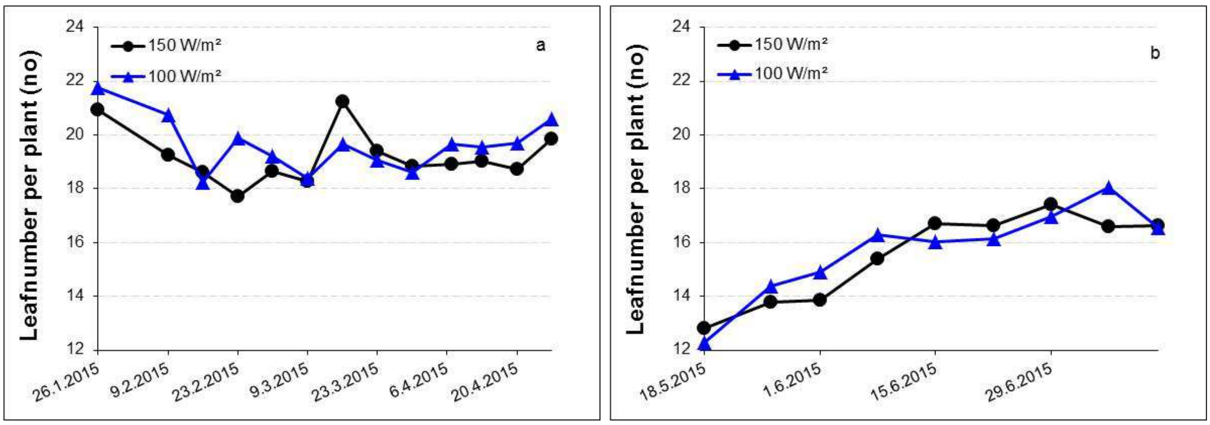

Fig. 9: **Number of leaves at strawberry plants for part A (a) and part B (b).**

4.2.1 Number of runners

Strawberry plants had more runners in the winter / spring crop, while the number of runners was lower in the spring / summer crop. The number of runners was tendentially (Fig. 10a) respectively significantly (Fig. 10b) increased at the higher light intensity.

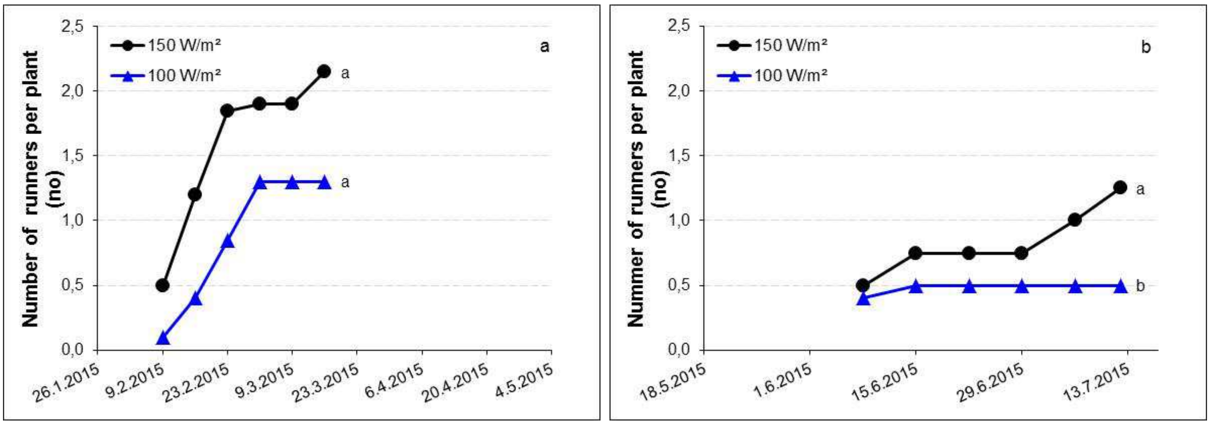

Fig. 10: Number of runners at strawberry plants for part A (a) and part B (b).
Letters indicate significant differences at the end of the experiment (HSD, p ≤ 0,05).

4.2.2 Number of clusters

The number of clusters with flowers and / or fruits increased until the beginning of harvest and decreased after that when all fruits from a cluster were harvested. No differences in the number of clusters were observed between different light intensities (Fig. 11).

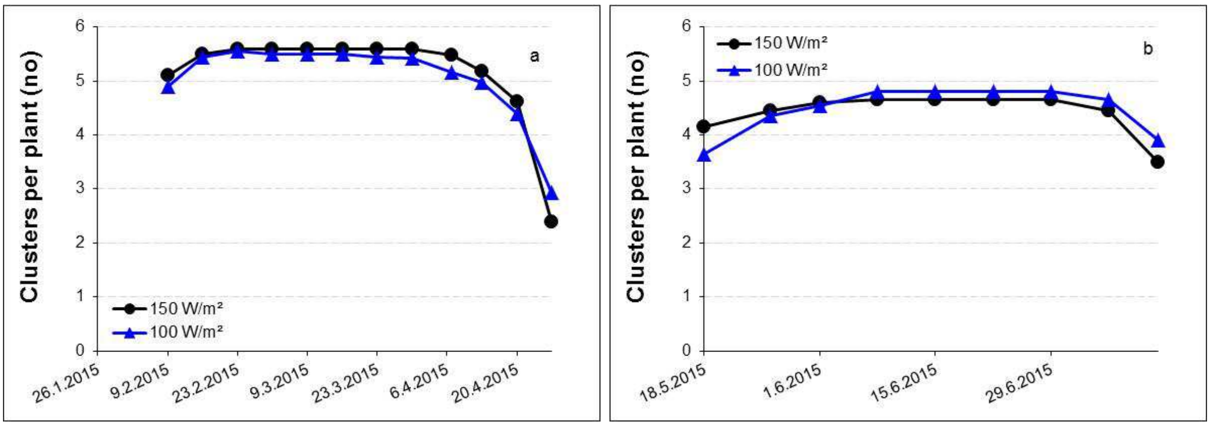

Fig. 11: Number of clusters for part A (a) and part B (b).

4.2.3 Open flowers / fruits per cluster

The number of open flowers / fruits per cluster reached 10-12 when harvest started. After that the number decreased naturally due to harvested fruits. It seems that the number of open flowers / fruits per cluster was a bit higher for the higher light intensity for part A, while this was not observed for part B. In part A, it seems that the number of open flowers / fruits decreased with the same spead (Fig. 12a). In contrast, in part B was this behaviour delayed for the lower light intensity compared to the higher light intensity (Fig. 12b).

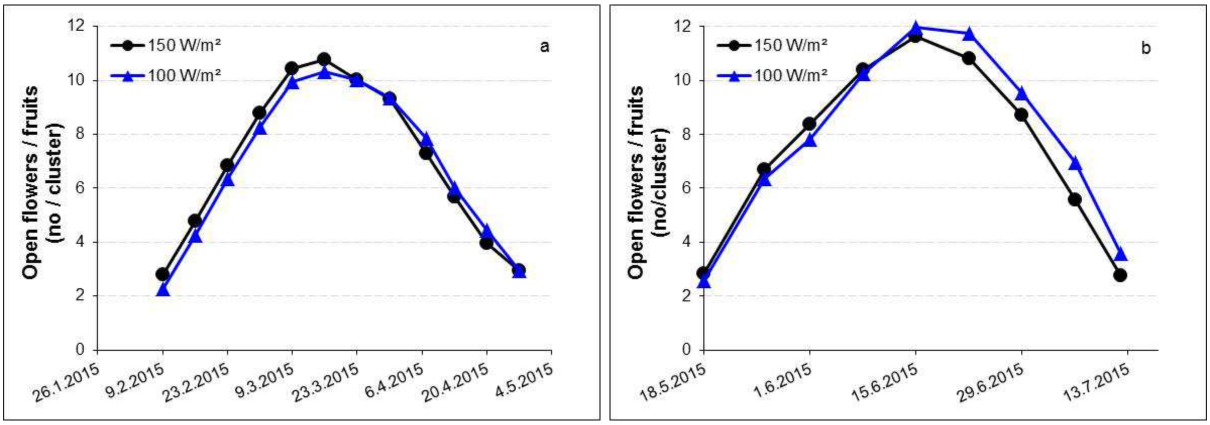

Fig. 12: Number of clusters per cluster for part A (a) and part B (b).

4.2.4 Open flowers / fruits per plant

The number of open flowers / fruits per plant reached about 60 for the higher light intensity and about 55 for the lower light intensity in part A before harvest started (Fig. 13a). However, in part B was it the other way round: The lower light intensity had nearly 60 open flowers / fruits per plant, while the higher light intensity had nearly 55 (Fig. 13b). Thereafter decreased this number naturally due to harvested fruits. In

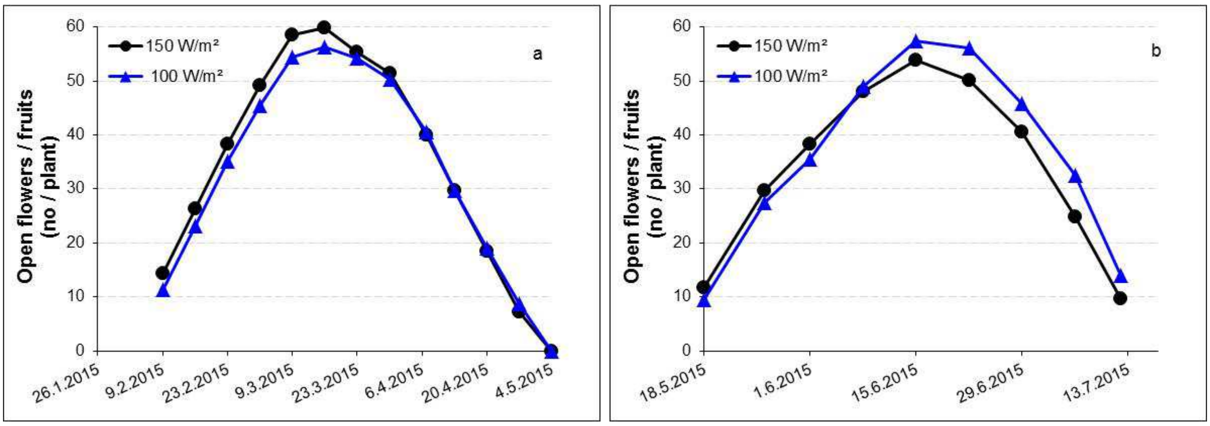

Fig. 13: Open flowers / fruits per cluster for part A (a) and part B (b).

part A, it seems that the number of open flowers / fruits decreased with the same spead (Fig. 13a). In contrast, in part B was this behaviour delayed for the lower light intensity when compared to the higher light intensity (Fig. 13b).

4.3 Yield

4.3.1 Total yield of strawberries

The yield of strawberries included all harvested red fruits during the growth period. The fruits were classified in extra-class (> 25 mm), 1. class (18 mm) and not marketable fruits (too little fruits (< 18 mm), damaged fruits, misshaped fruits, moldy fruits and green fruits at the end of the harvest period).

Cumulative total yield of strawberries ranged between 0,57-0,63 g/plant for part A (Fig. 14a) and 0,43-0,50 g/plant for part B (Fig. 14b). A higher light intensity increased tendentially total yield in both croppings.

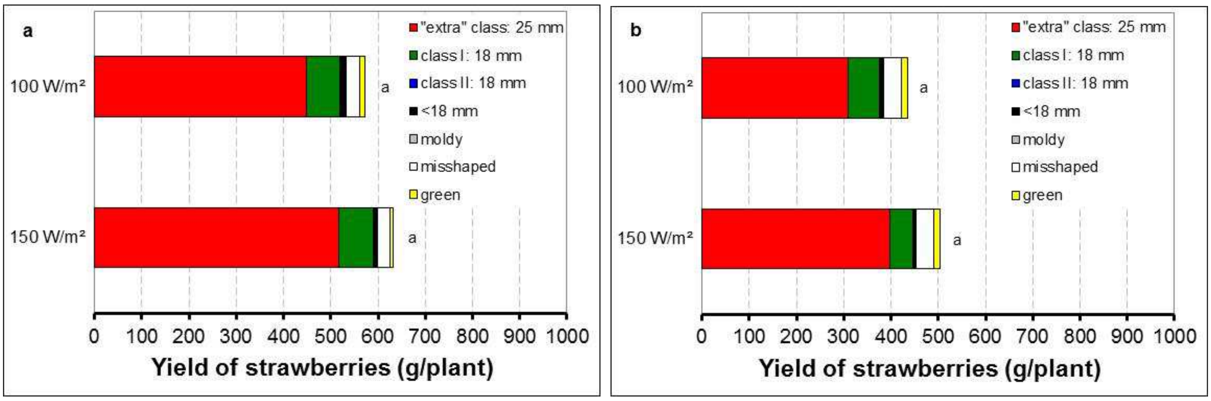

Fig. 14: Cumulative total yield of strawberries for part A (a) and part B (b).
Letters indicate significant differences at the end of the experiment (HSD, $p \leq 0,05$).

4.3.2 Marketable yield of strawberries

Both light intensities had a higher yield at the winter / spring crop (part A) than in the spring / summer crop (part B). At the end of the harvest period amounted yield of strawberries 0,5-0,6 g/plant for part A (Fig. 15a) and 0,35-0,45 g/plant for part B (Fig. 15b). No significant yield differences between the two light intensities were observed. However, the marketable yield was tendentially higher at the higher light intensity. A 50 % increase in light intensity resulted in an increase in yield of 13 % / 19 % (part A / part B), which is equivalent to a yield increase of 0,27 % / 0,38 % (part A / part B) at 1 % increase in light intensity. Differences between different light intensities developed at the beginning of the harvest period, both for the winter / spring crop as well as for the spring / summer crop. Differences between the two light intensities decreased later in the harvest period (Fig. 15).

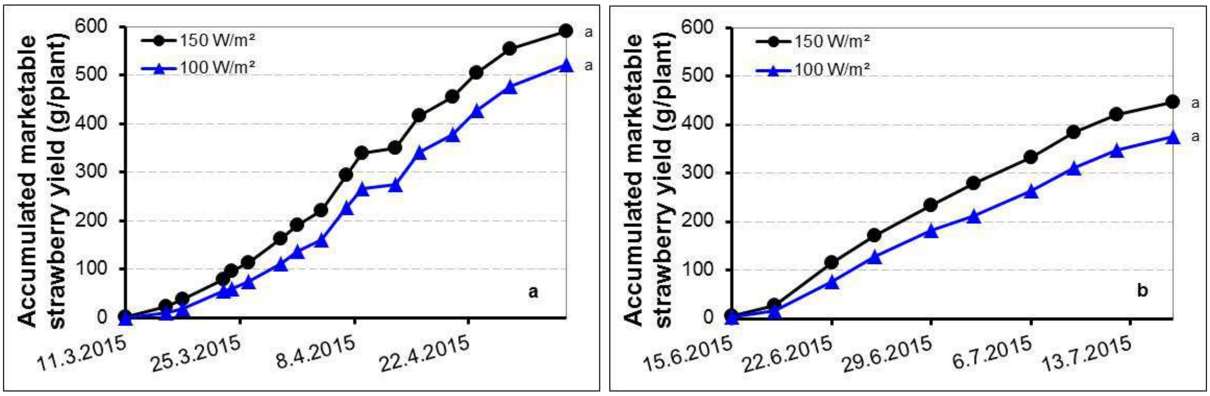

Fig. 15: Time course of accumulated marketable yield of strawberries for part A (a) and part B (b).

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

Also the marketable yield of the whole chamber was measured. In both parts was a higher marketable yield reached with a higher light intensity (Fig. 16). The yield increase of 150 W/m^2 compared to 100 W/m^2 was 21 % / 14 % (part A / part B).

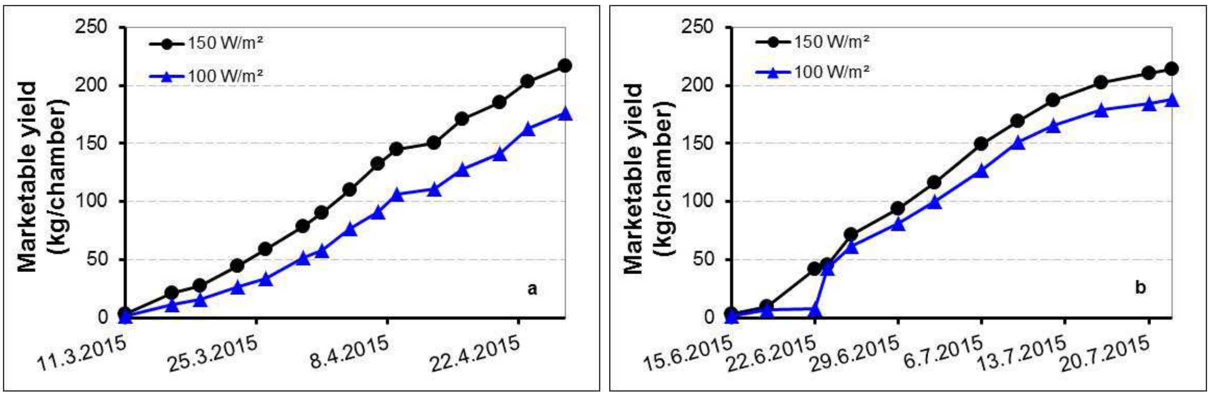

Fig. 16: Time course of accumulated marketable yield of strawberries for the whole chamber for part A (a) and part B (b).

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

In part A and part B increased the harvested amount of strawberries until the middle of the growth (part A) respectively until the first third of the harvest period (part B) and decreased thereafter (Fig. 17). In part A was the marketable strawberry yield until the middle of the harvest period higher at the higher light intensity, while after that, yield was comparable between the two tested light intensities (Fig. 17a). In part B, was the higher yield of the higher light intensity until two thirds of the harvest period even more obvious and after that was yield more or less comparable between light intensities (Fig. 17b).

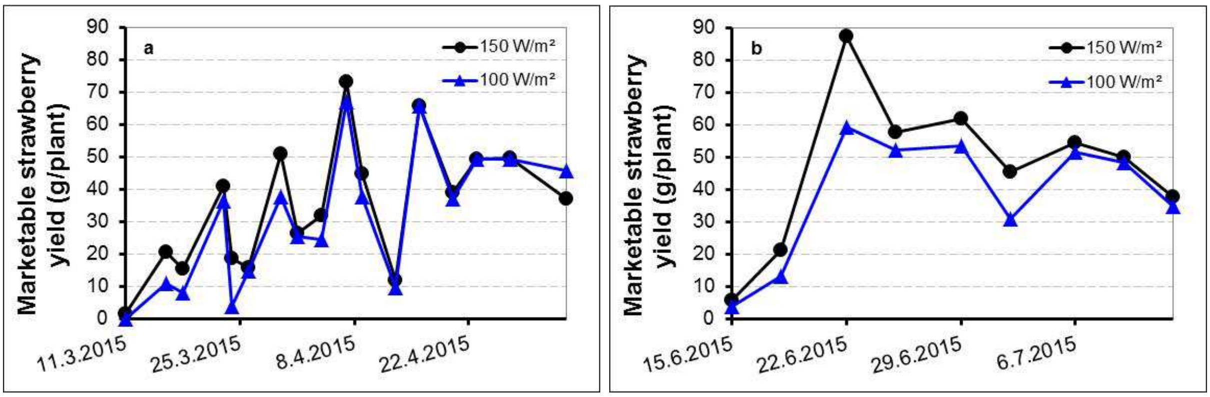

Fig. 17: Time course of marketable yield for part A (a) and part B (b).

The number of extra class fruits was significantly higher for the higher light intensity for both, part A and part B (Tab. 3). In contrast, in the first and second class fruits were no statistically differences between the tested light intensities found.

Tab. 3: Cumulative total number of marketable fruits for part A and part B.

Treatment	**Number of marketable fruits**	
	extra class (no/plant)	class I + II (no/plant)
Part A		
150 W/m^2	45 a	14 a
100 W/m^2	38 b	14 a
Part B		
150 W/m^2	30 a	9 a
100 W/m^2	25 b	13 a

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

Average fruit size of marketable fruits decreased with a longer harvest period from 15-23 g/fruit to about 7 g/fruit. While in part A no differences in the average weight between different light intensities were measured (Fig. 18a), was in part B in average a higher average fruit yield determined for the higher light intensity (Fig. 18b).

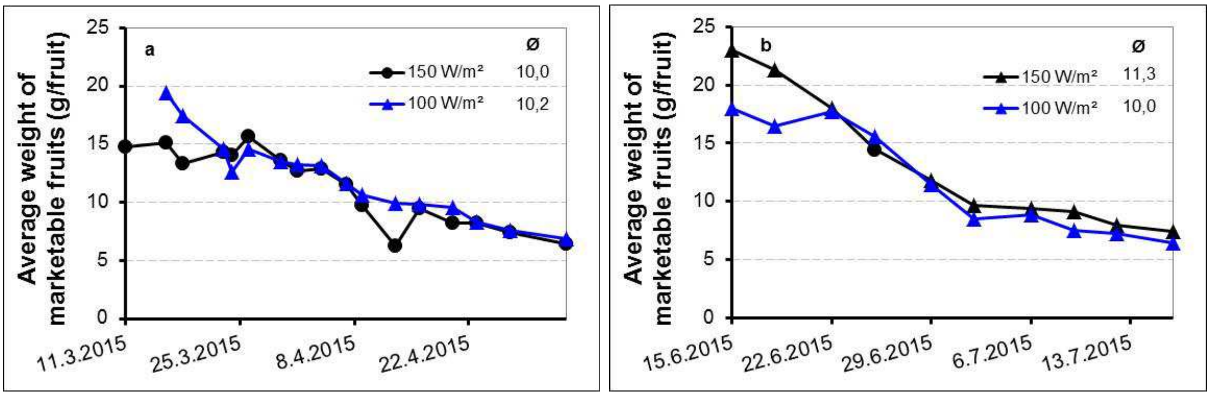

Fig. 18: Average weight of strawberries for part A (a) and part B (b).

To observe the success of flowering until harvest, flowers were marked and followed from pollination until harvest. Flowers were within 1-2 days pollinated (data not shown). Number of days from pollination to harvest was about 30-50 days in part A (Fig. 19a) and about 30-40 days in part B (Fig. 19b). In average took it 42 days up to harvest in part A while in part B passed 35 days at the higher light intensity and 33 days at the lower light intensity. No relationship was found between the number of days from pollination to harvest and the weight of the fruit.

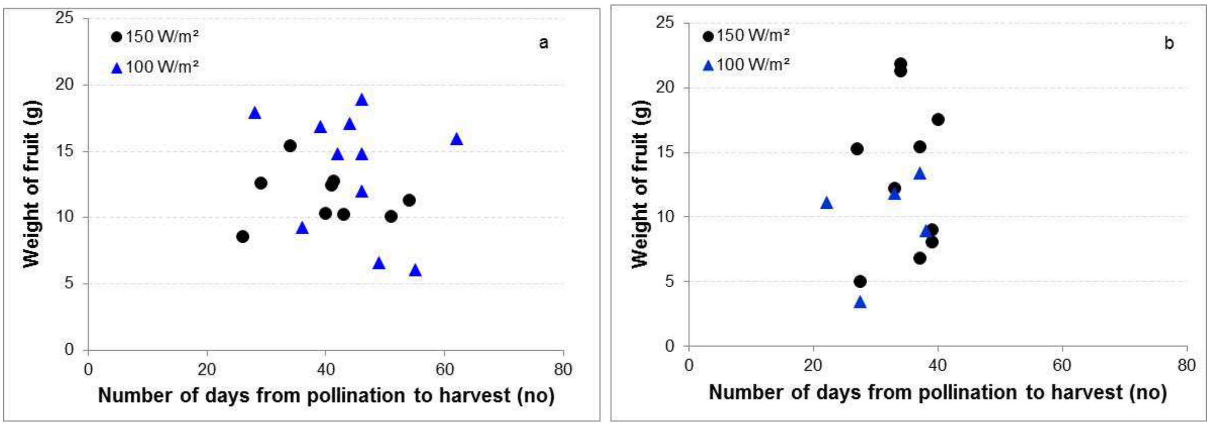

Fig. 19: Number of days from pollination to harvest and weight of the harvested fruit for part A (a) and part B (b).

The first 1-2 weeks of harvest were less fruits ripe compared to the weeks after that. After the second week increased the harvest and stayed constantly at about 10 fruits per week in part A. In contrast, in part B increased the number of weekly harvested fruits week after week during the whole harvest period. Naturally, with the beginning of the harvest, decreased the number of open flowers and fruits. The number of "harvested and open flowers / fruits" is the sum of the harvested fruits and the number of open flowers / fruits that was registered at weekly measurements. This number was fluctuating at about 60 flowers / fruits in part A, while there was a decline from about 60 to 50 in part B (Fig. 20).

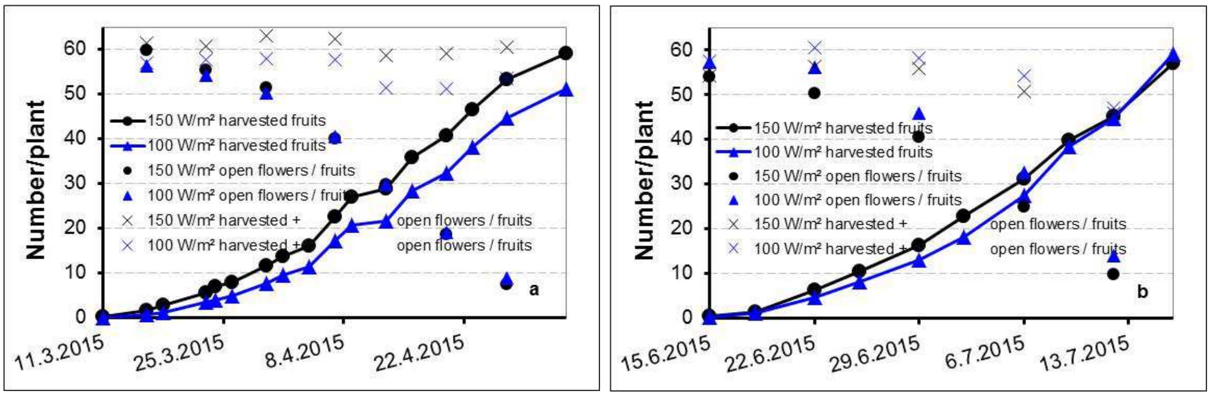

Fig. 20: Development of open flowers / fruits, harvested fruits and their sum during the growth of the strawberries for part A (a) and part B (b).

4.3.3 Outer quality of yield

Marketable yield was about 90 % in part A and less than 90 % in part B (Tab. 4). The proportion of fruits in "extra class" was higher with a higher light intensity. The proportion of misshaped fruits was higher in part B, due to a problem with overpollination.

Tab. 4: Proportion of marketable and unmarketable yield for part A and part B.

Treatment	Marketable yield			Unmarketable yield			
	extra class	1. class	2. class	too little weight	moldy	mis-shaped	green
	%			%			
Part A							
150 W/m²	82	12	0	1	0	4	1
100 W/m²	78	12	1	2	0	5	2
Part B							
150 W/m²	79	9	0	1	0	8	3
100 W/m²	71	15	0	2	0	9	3

4.3.4 Interior quality of yield

4.3.4.1 Sugar content

Sugar content of strawberries was measured once during the harvest period (part A: 16.04.2015, part B: 29.06.2015) and was around 7. The higher light intensity had a tendentially higher value (Fig. 21).

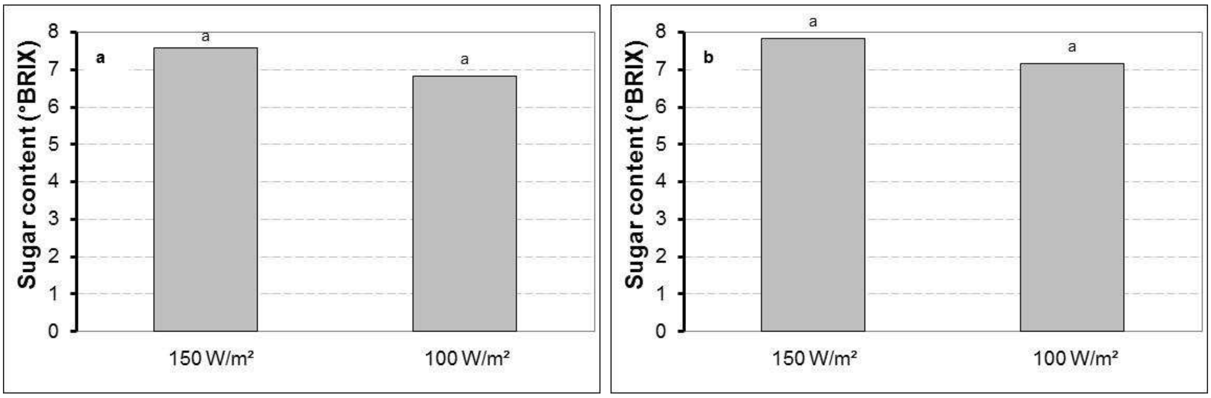

Fig. 21: Sugar content of strawberries for part A (a) and part B (b).
Letters indicate significant differences at the end of the experiment (HSD, p ≤ 0,05).

4.3.4.2 Taste of strawberries

The taste of strawberries, subdivided into sweetness, flavour, juiciness and firmness was tested by untrained assessors on 16.04.2015 in part A and on 30.06.2015 in part B. The rating within the same sample was varying very much and therefore, same treatments resulted in a high standard deviation. It seems that with a higher light intensity the flavour and the firmness of the strawberries increased tendentially in part A (Fig. 22a). Also, in part B was the firmness tendentially increased with a higher light intensity (Fig. 22b). Between the other treatments were no obvious differences observed.

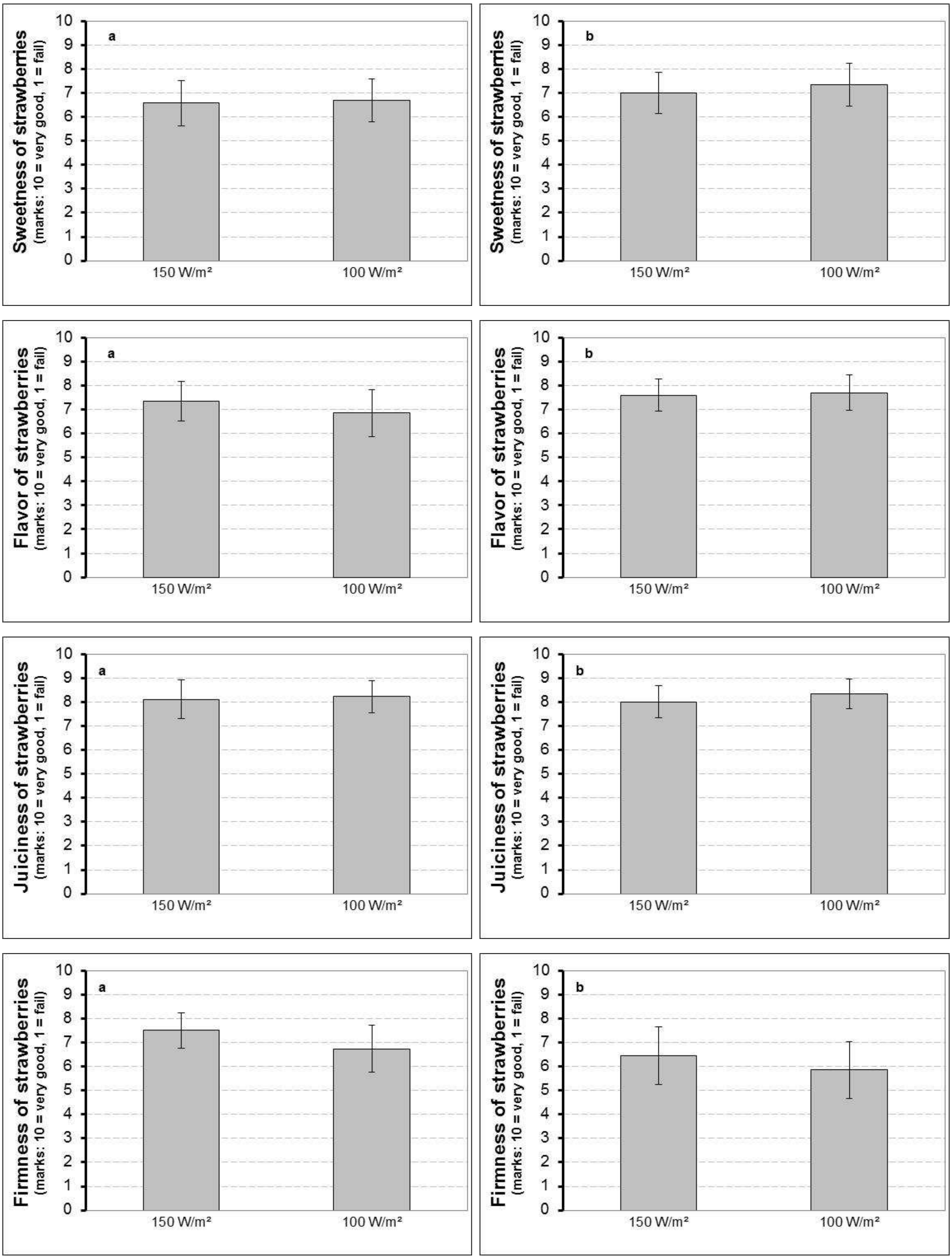

Fig. 22: Sweetness, flavour, juiciness and firmness of strawberries for part A (a) and part B (b).

4.3.4.3 Dry substance of fruits

Dry substance (DS) of strawberries was measured once during the harvest period and amounted 7-8 % (Fig. 23). It seems that the treatment with the higher light intensity had a slightly higher dry substance content.

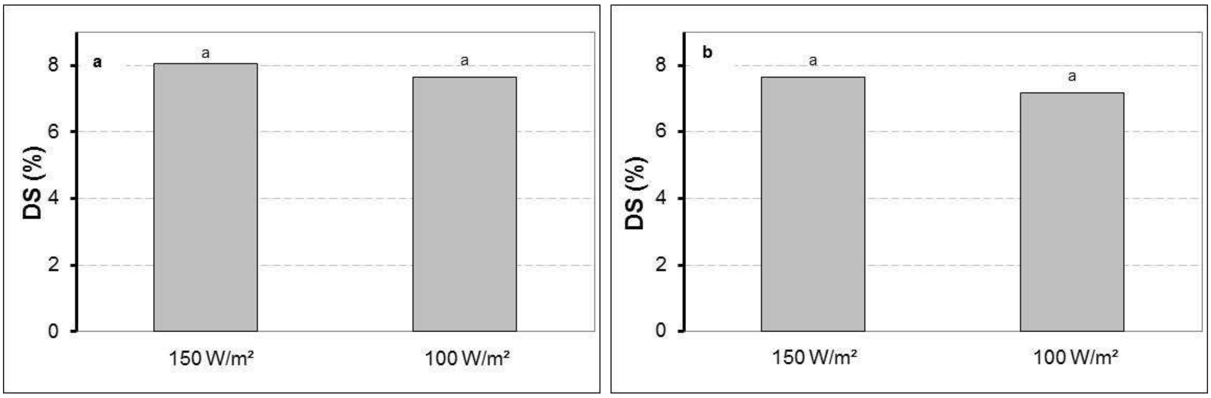

Fig. 23: Dry substance of strawberries for part A (a) and part B (b).

4.4 Economics

4.4.1 Lighting hours

The number of lighting hours is contributing to high annual costs and needs therefore special consideration to consider to decrease lighting costs per kg marketable yield. The total hours of lighting during the growth period of strawberries were both simulated and measured with dataloggers.

The simulated value was calculated according to the lighting hours written down. However, there it was not adjusted for automatic turn off, when incoming solar radiation was above a set-point (Tab. 5a, 5b). The measured lighting hours were higher for the chamber with the higher light intensity, because the set-point was reached later compared to the chamber with the lower light intensity.

For calculation of the power, different electric consumptions were made, because the actual consumption is higher than the nominal value of the 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. The power was in part A lower for the measured values than for the simulated ones, while this value was comparable for part B.

Tab. 5a: Lighting hours, power and energy in the cabinets for part A.

Treatment	Hours	Power	Energy	Energy/m²
	h	W	kWh	kWh/m²
HPS 150 W/m²				
Measured values	1.241	218	13.526	271
Simulated values				
0 % more power consumption (nominal)	1.592	150	11.940	239
6 % more power consumption	1.592	159	12.656	253
10 % more power consumption	1.592	165	13.134	263
HPS 100 W/m²				
Measured values	1.209	145	8.775	175
Simulated values				
0 % more power consumption (nominal)	1.592	100	7.960	159
6 % more power consumption	1.592	106	8.438	169
10 % more power consumption	1.592	110	8.756	175

Tab. 5b: Lighting hours, power and energy in the cabinets for part B.

Treatment	Hours	Power	Energy	Energy/m²
	h	W	kWh	kWh/m²
HPS 150 W/m²				
Measured values	501	150	3.765	75
Simulated values				
0 % more power consumption (nominal)	1.120	150	8.400	168
6 % more power consumption	1.120	159	8.904	178
10 % more power consumption	1.120	165	9.240	185
HPS 100 W/m²				
Measured values	460	99	2.268	45
Simulated values				
0 % more power consumption (nominal)	1.120	100	5.600	112
6 % more power consumption	1.120	106	5.936	119
10 % more power consumption	1.120	110	6.160	123

4.4.2 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 (tímaháður taxti, Orkutaxti TT000) with high prices during the day (09.00-20.00) at working days (Monday to Friday) but much lower during the night and weekends and summer, and
c) demand based tariffs (afltaxti AT000), for larger users, who pay according to the maximum power demand.

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 87 % and 92 % 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. 5), for the cabinets the energy costs per m^2 during the time of the experiment for the growers were calculated (Tab. 6).

In part A are the energy costs per kWh for distribution after subsides around 0,67-0,80 ISK/kWh for „VA210“ and „VA230“, around 0,58-0,71 ISK/kWh for „VA410“ and 0,47-0,55 ISK/kWh for „VA430“. The energy costs for sale are for „Afltaxti“ around 6,51-7,36 ISK/kWh and for „Orkutaxti“ around 5,85-7,24 ISK/kWh.

In part B are the energy costs per kWh for distribution after subsides around 0,91-1,65 ISK/kWh for „VA210“ and „VA230“, around 0,84-1,55 ISK/kWh for „VA410“ and 0,63-1,07 ISK/kWh for „VA430“. The energy costs for sale are for „Afltaxti“ around 1,86-11,13 ISK/kWh and for „Orkutaxti“ around 2,61-3,16 ISK/kWh.

Cost of electricity was lower for the calculated values (Tab. 6). In general, tariffs for large users rendered lower cost.

Tab. 6a: Costs for consumption of energy for distribution and sale of energy for part A.

	Costs for consumption							
	Energy ISK/kWh				**Energy costs with subsidy per m²** ISK/m²			
Treat-ment	150 W/m²		100 W/m²		150 W/m²		100 W/m²	
	real	calculated	real	calculated	real	calculated	real	calculated
DISTRIBUTION								
RARIK Urban					87 % subsidy from the state			
VA210	0,78	0,67	0,80	0,67	211	160 169 176	140	107 113 117
VA410	0,69	0,58	0,71	0,58	187	139 147 153	124	92 98 102
RARIK Rural					92 % subsidy from the state			
VA230	0,78	0,68	0,79	0,68	211	162 172 178	139	108 115 119
VA430	0,54	0,47	0,55	0,47	146	275 291 302	96	75 80 83
SALE								
Afltaxti	7,26	6,51	7,36	6,51		1.260		840
Orkutaxti	7,20	5,85	7,24	5,85	1.624	1.336	1.057	891
						1.386		924

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 April 2015.

Tab. 6b: Costs for consumption of energy for distribution and sale of energy for part B.

Treatment	Costs for consumption: Energy ISK/kWh, 150 W/m² real	150 W/m² calculated	100 W/m² real	100 W/m² calculated	Energy costs with subsidy per m^2 ISK/m^2, 150 W/m² real	150 W/m² calculated	100 W/m² real	100 W/m² calculated
DISTRIBUTION								
RARIK Urban					87 % subsidy from the state			
VA210						156		104
	1,54	0,93	1,65	0,93	116	166	75	110
						172		115
VA410						141		94
	1,44	0,84	1,55	0,84	108	149	70	100
						155		103
RARIK Rural					92 % subsidy from the state			
VA230						154		102
	1,46	0,91	1,56	0,91	110	163	71	109
						169		113
VA430						106		71
	1,00	0,63	1,07	0,63	75	112	49	75
						117		78
SALE								
Afltaxti	10,37	1,86	11,13	1,86		312		208
Orkutaxti	2,61	3,16	2,61	3,16	196	331	118	221
						344		229

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 April 2015.

4.4.3 Costs of electricity in relation to yield

Costs of electricity in relation to yield for wintergrown strawberries were calculated (Tab. 7). While for the distribution several tariffs were possible, for the sale only the cheapest tariff was considered. The costs of electricity increased by around 30 % with a higher light intensity in part A and part B (Tab. 7).

Tab. 7: Variable costs of electricity in relation to yield.

	Variable costs of electricity per kg yield ISK/kg							
	Part A				Part B			
Treatment	150 W/m²		100 W/m²		150 W/m²		100 W/m²	
Yield/m²	7,1		6,3		5,4		4,5	
	real	calculated	real	calculated	real	calculated	real	calculated
Urban area (Distribution + Sale)								
VA210	259	200 212 220	191	151 160 166	58	88 93 96	43	69 74 76
VA410	255	197 209 217	189	149 158 164	57	85 90 93	42	67 71 74
Rural area (Distribution + Sale)								
VA230	259	201 213 221	191	151 161 167	57	87 92 96	42	69 73 76
VA430	250	194 205 213	184	146 155 161	51	78 83 86	37	62 66 68

4.4.4 Profit margin

The profit margin is a parameter for the economy of growing a crop. It is calculated by substracting the variable costs from the revenues. The revenues itself, is the product of the price of the sale of the berries and kg yield. For each kg of strawberries, growers are getting about 2.600 ISK from Sölufélag garðyrkjumanna (SfG). Therefore, the revenues increased with more yield (Fig. 24).

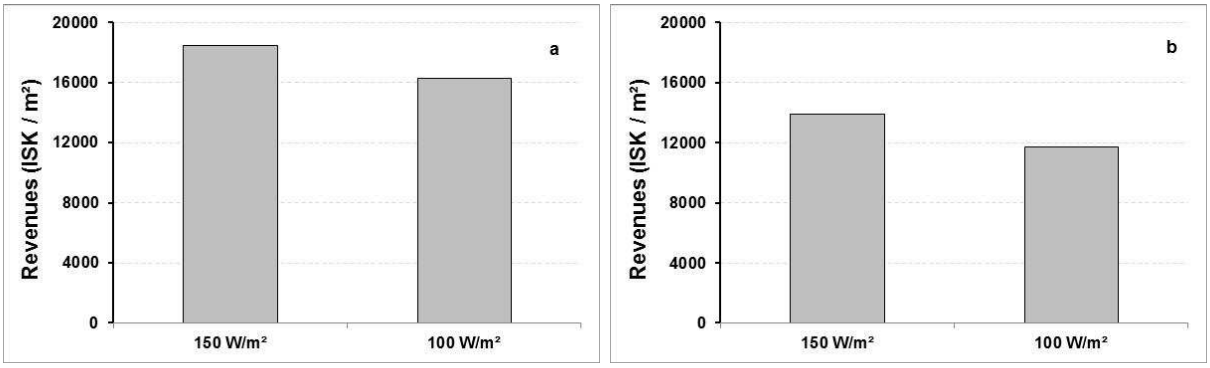

Fig. 24: Revenues at different treatments for part A (a) and part B (b).

When considering the results of previous chapter, one must keep in mind that there are other cost drivers in growing strawberries than electricity alone (Tab. 6). Among others, this are e.g. the costs for the plant itself (≈ 1.500 ISK/m^2), soil (≈ 500 ISK/m^2), gutters and other material (≈ 50 ISK/m^2), costs for plant protection (≈ 300 ISK/m^2) and beneficial organism (≈ 200 ISK/m^2), plant nutrition (≈ 100 ISK/m^2), CO_2 transport (≈ 150 ISK/m^2), liquid CO_2 (≈ 700 ISK/m^2), the rent of the tank (≈ 150 ISK/m^2), the rent of the green box (≈ 150 ISK/m^2), material for packing (≈ 400 ISK/m^2) and transport costs from SfG (≈ 100 ISK/m^2) (Fig. 25).

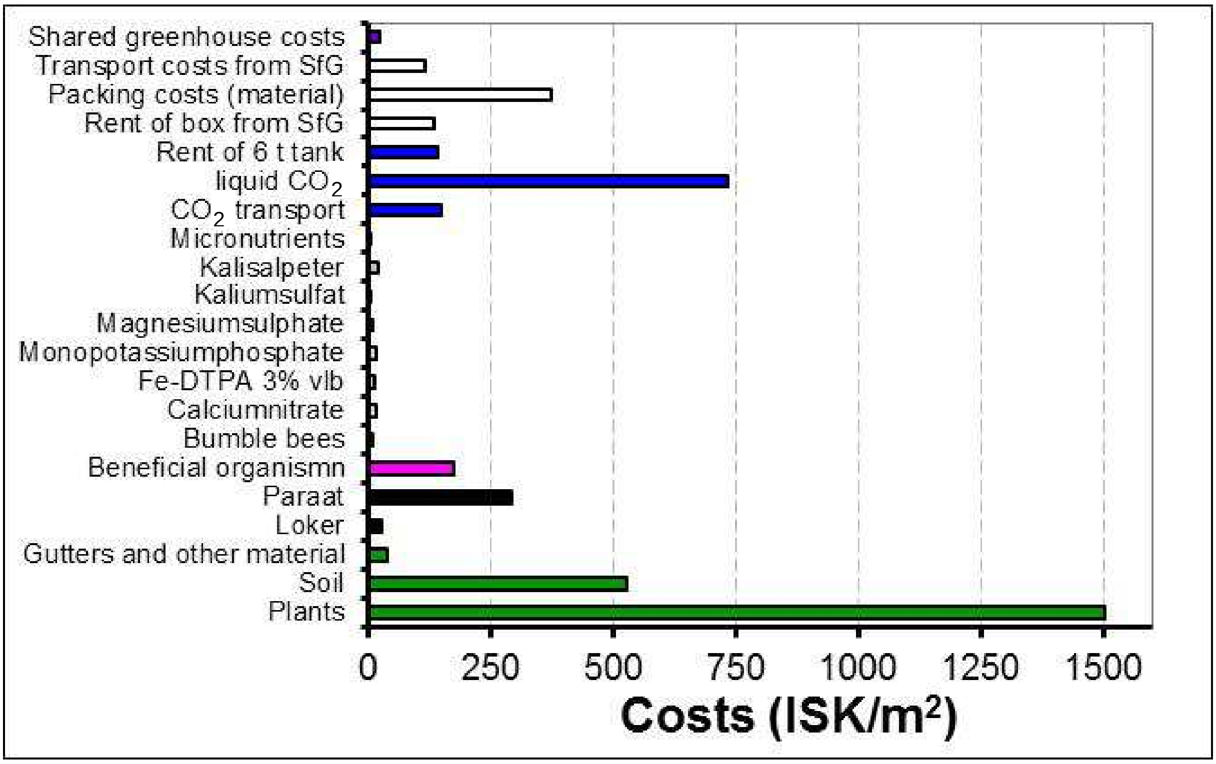

Fig. 25: Variable and fixed costs (without lighting and labour costs).

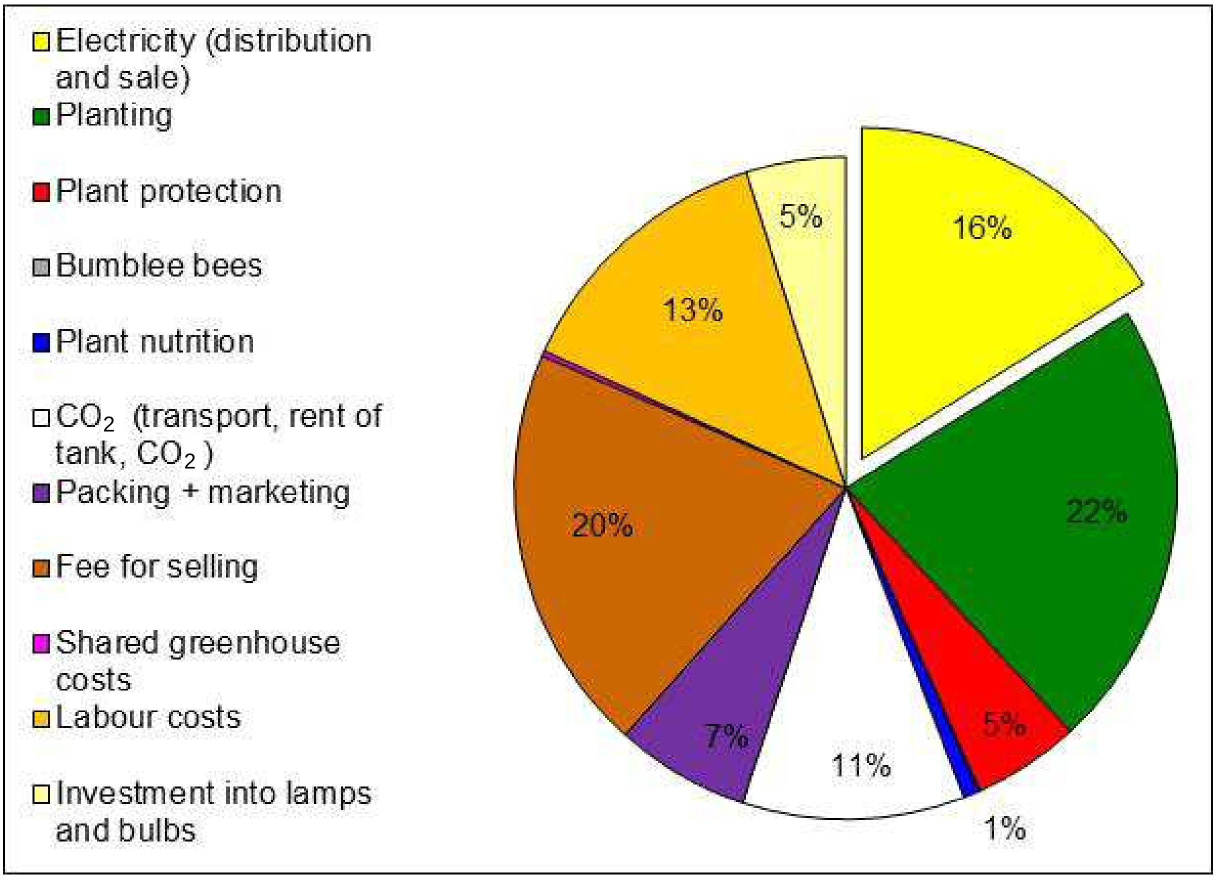

Fig. 26: Division of variable and fixed costs (numbers from part A).

However, in Fig. 25 four of the biggest cost drivers are not included and these are the investment in lamps and bulbs, electricity, labour costs and the fee for SfG for selling the strawberries. These costs are also included in Fig. 26 and it is obvious, that especially the fee for selling the strawberries, the electricity as well as the labour costs are contributing much to the variable and fixed costs beside the costs for planting and CO_2 costs.

A detailed composition of the variable costs at each treatment is shown in Tab. 8.

Tab. 8: Profit margin of strawberries at different light treatments for part A and part B (urban area, VA210).

	Part A		Part B	
Treatment	**150 W/m²**	**100 W/m²**	**150 W/m²**	**100 W/m²**
Marketable yield/m²	7,1	6,3	5,4	4,5
Sales				
SfG (ISK/kg) [1]	2.600	2.600	2.600	2.600
Revenues (ISK/m²)	**18.436**	**16.278**	**13.911**	**11.701**
Variable and fixed costs (ISK/m²)				
Electricity distribution [2]	211	140	116	75
Electricity sale	1.624	1.057	196	118
Strawberry plants [3]	1.500	1.500	1.500	1.500
Soil for strawberries [4]	525	525	525	525
Pots [5]	7	7	7	7
Tape [6]	1	1	1	1
Gutters [7]	28	28	28	28
Loker [8]	27	27	27	27
Paraat [9]	291	291	291	291
Beneficial organismn [10]	174	174	174	174
Bumble bees [11]	6	6	6	6
Calcium nitrate [12]	21	14	19	17
Iron chelate [13]	15	12	14	12
Monopotassium phosphate [14]	23	16	22	19
Magnesium sulfate [15]	12	8	11	10
Potassium sulfate [16]	1	1	1	1
Potassium nitrate [17]	30	21	28	24
Micronutrients [18]	2	2	2	2
CO_2 transport [19]	146	146	146	146
Liquid CO_2 [20]	731	731	731	731
Rent of CO_2 tank [21]	140	140	140	140
Rent of box from SfG [22]	140	123	105	89
Packing material [23]	394	348	298	250
Fee for SfG [24]	1.985	1.753	1.498	1.260
Transport from SfG [25]	121	107	91	77
Shared fixed costs [26]	24	24	24	24
Lamps [27]	357	238	357	238
Bulbs [28]	190	127	190	127
∑ variable costs	**8.707**	**7.555**	**6.531**	**5.902**
Revenues -∑ variable costs	**9.729**	**8.723**	**7.379**	**5.798**
Working hours (h/m²)	0,90	0,84	0,77	0,71
Salary (ISK/h)	1.436	1.436	1.436	1.436
Labour costs (ISK/m²)	1.296	1.208	1.112	1.022
Profit margin (ISK/m²)	**8.433**	**7.515**	**6.268**	**4.776**

[1] price winter 2014/2015: 2.600 ISK/kg
[2] assumption: urban area, tariff “VA210”, no annual fee (according to datalogger values)
[3] 100 ISK / strawberry plant
[4] 63.000 ISK / 4,5 m^3 soil
[5] 54 ISK / pot; assumption: 10 years life time, 3 circles / year
[6] 4.500 ISK / bund of tape; assumption: 10 years life time, 3 circles / year
[7] 660 ISK / m gutter; assumption: 10 years life time, 3 circles / year
[8] 4.790 ISK / 5 l Loker; assumption: spraying once per week (~ 8 times per growing season)
[9] 34.950 ISK / bund Paraat; assumption: spraying twice per growing season, 400 ml / pot
[10] 5.212 ISK / unit aphid predator (aphidoletes)
[11] 4.900 ISK / unit bumble bees
[12] 2.750 ISK / 25 kg Calcium nitrate
[13] 17.050 ISK / 25 kg Iron chelate
[14] 7.050 ISK / 25 kg Monopotassium phosphate
[15] 1.700 ISK / 25 kg Magnesium sulfate
[16] 3.550 ISK / 25 kg Potassium sulfate
[17] 4.175 ISK / 25 kg Potassium nitrate
[18] 33.900 ISK / 5 kg micronutrients
[19] CO_2 transport from Rvk to Hveragerði / Flúðir: 8,0 ISK/kg CO_2
[20] liquid CO_2: 40,0 ISK/kg CO_2
[21] rent for 6 t tank: 70.000 ISK/month, assumption: rent in relation to 1.000 m^2 lightened area
[22] 85 ISK / box
[23] packing costs (material):
costs for packing of strawberries (0,20 kg): box: 3 ISK / 0,20 kg,
lid: 4 ISK / 0,20 kg,
label: 1 ISK / 0,20 kg
[24] fee for SfG for selling the strawberries: 45 ISK / 0,20 kg
[25] transport costs from SfG: 2.575 ISK / board
[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

The profit margin was dependent on the treatment (Fig. 27). In part A, the profit margin was with about 8.400 ISK/m^2 highest with the higher light intensity and about 1.000 lower for the lower light intensity. Again, in part B was the profit margin with about 6.300 ISK/m^2 highest at the higher light intensity and about 1.500 ISK/m^2 lower for the lower light intensity. That means an increase of the light intensity by 50 W/m^2, from 100 W/m^2 to 150 W/m^2, roose the profit margin by 1.000-1.5000 ISK/m^2. For both, part A and part B, a larger use (higher tariff: “VA 410” compared to “VA 210”, “VA 430” compared to “VA 230”), did not influence the profit margin. Also, it did not matter if the greenhouse is situated in an urban or rural area, the profit margin was comparable. However, at a higher tariff there was a surprisingly small advantage of rural areas due to the state subsidies (Fig. 27).

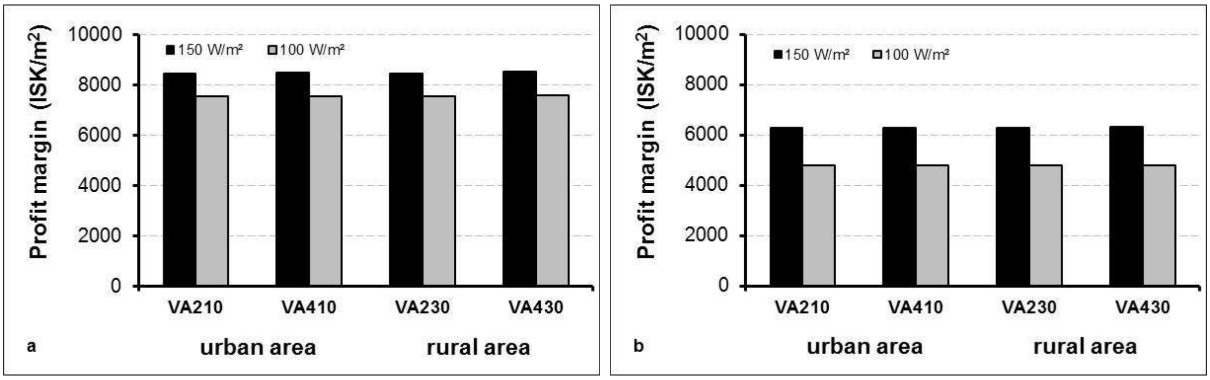

Fig. 27: Profit margin in relation to tariff and treatment for part A (a) and part B (b).

5 DISCUSSION

5.1 Yield in dependence of the light intensity

Strawberry plants need to have strong vegetative growth in order to flower and to produce berries. In winter production is flower induction highly dependent on the supplemental light. At the two tested light intensities was the number of flowers increased at the higher light intensity, which resulted in the possibility to enhance strawberry productivity to a quite big extent by distributing a higher amount of light intensity. *Marcelis* et al. (2006) reported the general rule, that 1 % increase of light intensity results in a yield increase of 0,7-1,0 % for fruit vegetables, 0,8-1,0% for soil grown vegetables, 0,6-1,0 % for cut flowers, 0,25-1,25 % for bulb flowers, 0,5-1,0 % for flowering pot plants and 0,65 % for non-flowering pot plants. No values were indicated for berries. In the present findings, values of 0,3-0,4 % were found and are with that much lower than the above mentioned ones.

The reason for the higher yield at higher light intensity was an increased number of harvested extra class fruits and in addition, to a smaller extend, a higher average weight of strawberries in part B, while no effect of light intensity on average weight was observed in part A. Also, for fruit vegetables the reason for the higher yield at a higher light intensity was attributed to more, rather than heavier fruits of sweet pepper (*Stadler*, 2010) and tomatoes (*Stadler*, 2013a; *Stadler* 2013b).

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. The LAI was not observed in the presented experiment, but the number of leaves was not different. However, more factors than only light intensity might have influenced yield: The higher light intensity resulted in a slightly higher air, soil and leaf temperature and might also have been contributed to a yield increase, but the influence of each factor is unknown.

In tomatoes, it was found that a higher light intensity decreased pollination with about one fruit less pollinated compared to the lower light intensity (*Stadler*, 2013a). However, in the presented experiment were flowers pollinated after 1-2 days, independent of the light intensity. It seems that the unmarketable yield was slightly higher for the lower light intensity, while with a higher light intensity a bigger amount of fruits in “extra class” were counted.

The importance of the photoperiod is shown by studies from *Verheul* et al. (2007), where a daily photoperiod of 12 h or 13 h resulted in the highest number of strawberry plants with emerged flowers and a photoperiod of 14 h or more reduced this number, while no flowers emerged at a photoperiod of 16 h, 20 h or 24 h (*Verheul* et al., 2006). Furtheron, interactions between photoperiod, temperature, duration of short-day treatment and plant age on flowering were documented from *Verheul* et al. (2006). In contrast, the presented experiment was conducted with a photoperiod of 18 h, which induced good flowering of strawberries.

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. The higher light intensity resulted in a higher profit margin than the lower light intensity, meaning that the additional yield was high enough to pay off for the higher use of electricity. An increase of the light intensity from 100 W/m² to 150 W/m² resulted in an yield increase of 0,8 kg/m² and this was reflected in an increase of profit margin of 900 ISK/m² (part A) respectively 1.500 ISK/m² for part B. When the yield of the higher light intensity would have been 0,4 kg lower in part A or 0,7 kg lower in part B, profit margin would have been comparable to the one at the lower light intensity. That means it is only worth to use 50 W/m^2 more light if this would result in an almost 0,5 kg/m^2 or 0,8 kg/m^2 higher yield at 150 W/m^2 compared to 100 W/m^2 (Fig. 28).

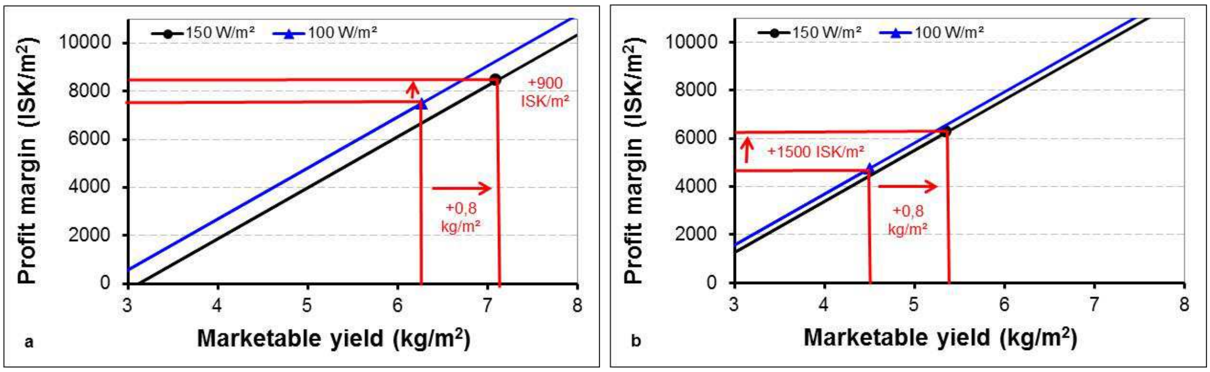

Fig. 28: Profit margin in relation to yield with light intensity – calculation scenarios (urban area, VA210).

In part B were the lights often automatically turned off due to high solar radiation. That resulted in low expenses for sale and distribution of energy. Therefore, the effect of the light intensity on yield can not really be evaluated in part B. *Stadler* (2010) studied the effect of light intensity at low solar irradiation: 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 not different within light intensities. However, this was not confirmed at the presented experiments with strawberries as there was also a gain in yield determined by using a higher light intensity at increasing natural light level. But as stated before, was the use of energy very low at high natural light level (in part B) and therefore may have other factors than the amount of supplemental light contributed to the higher yield at 150 W/m^2 when compared to 100 W/m^2.

A further yield increase of strawberries might be possible with a higher plant density. For example found *Paranjpe* et al. (2008) that early and total marketable yield increased linearly with increasing plant densities (8,8; 9,5; 10,4; 11,4; 17,6; 19,1; 20,8; 22,9 plants/m^2). These yield increased were achieved without adversely affecting mean fruit size.

5.2 Future speculations concerning energy prices

In terms of the economy of lighting it is also worth to make some future speculations about possible developments. So far, the lighting costs are contributing to about 1/6 of the production costs of strawberries. 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 (Fig. 29). The white columns are representing the profit margin according to Fig. 27. 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 6.500-7.000 ISK/m^2 in part A and of 4.200-5.5000 ISK/m^2 in part B (black columns, Fig. 29). Without the subsidy of the state, probably less Icelandic grower would produce strawberries 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 7.200-8.000 ISK/m^2 in part A and between 4.700-6.200 ISK/m^2 in part B (dotted columns). When it is assumed, that growers have to pay 25 % less for the energy, the profit margin would increase to 7.800-9.000 ISK/m^2 in part A and in part B to 4.800-6.3000 ISK/m^2 (gray columns). From these scenarios it can be concluded that from the grower's side it would be preferable to get subsidy to be able to get a higher profit margin and grow strawberries over the winter.

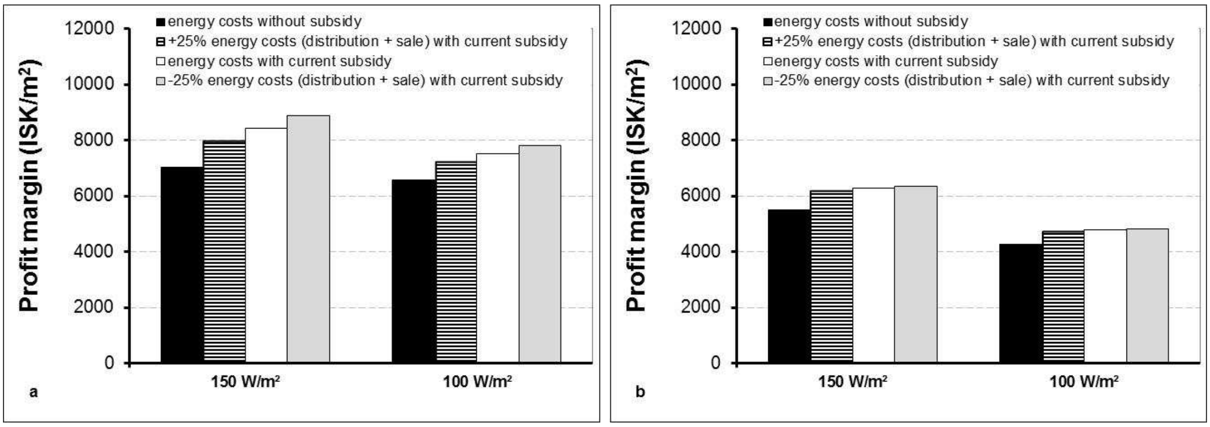

Fig. 29: Profit margin in relation to treatment – calculation scenarios (urban area, VA210).

5.3 Recommendations for increasing profit margin

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

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

1. Getting higher price for the berries

   It may be expected to get a higher price, when consumers would be willing to pay even more for Icelandic berries 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). They could also try to find other channels of distribution (e.g. selling directly to the shops and not over SfG). In doing so, growers could save the very high expences of the fee to SfG for selling the strawberries.

2. Lower planting costs

   The price for the strawberry plant is quite high. By using the strawberry plant not only once, but twice, could costs be decreased. By that, also the costs for the soil would be lowered. However, it is necessary that the yield is staying at a high value when same plants are used more than once.

3. 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. However, this takes more time and it is more difficult to perform this task by employees.

4. 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.

5. Decrease packing costs

   The costs for packing (material) from SfG and the costs for the rent of the box are high. Costs could be decreased by using cheaper packing materials.

6. 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.

7. 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 possibly result in no lower yield (*Stadler* et al., 2010).
   - 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, a tomato 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 strawberry yield was positively influenced by a higher light intensity. The high increase in energy costs by lighting when increasing light intensity from 100 W/m^2 to 150 W/m^2 was accompanied by a yield increase of 0,8 kg/m^2 and in an increase of profit margin of 900-1.500 ISK/m^2. Therefore, from the economic side it seems to be recommended to provide 50 W/m^2 more light.

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

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8 APPENDIX

	150 W/m²		100 W/m²		Chamber for the first 4 weeks		Emails/ phone calls with advisors
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**	**tasks**	**observations / problems**	
19.des					planting, light: 11-15	plants arrived with many leaves and big + small fruits, some fruits with gray mould	
20.des					light: 08-15		
21.des							
22.des					light: 08-16		
24.des							
25.des							
26.des						start drip irriga-tion: 4 x, 10 min.	
27.des					light: 07-19		
28.des							
29.des							
30.des					floor temp.: 30°C, ventilation: 20°C	too much runoff, irrigation stopped	
31.des					irrigation: 2 per day, 2,5 min		
1.jan							
2.jan							
3.jan							
4.jan							
5.jan					light: 05-19	spray Loker	

	150 W/m²		100 W/m²		Chamber for the first 4 weeks		Emails/ phone calls with advisors
Date	tasks	observations / problems	tasks	observations / problems	tasks	observations / problems	
6.jan					light: 03-19		light: change to 03-19, beginning of March to 14 h (when bright outside), and down to 6-7 h at end of March spray 1 x / week Loker, spray in 3. week of January Roveral or Tendor
7.jan							
8.jan							
9.jan							
10.jan							
11.jan							
12.jan					Loker sprayed		
13.jan							
14.jan					Rovral sprayed		
15.jan					night: 10°C		plant on Monday, remove first flowers
16.jan							
17.jan							
18.jan							
19.jan	planted into chambers, old leaves removed	16 °C / 10 °C (day/night)	planted into chambers, old leaves removed	16 °C / 10 °C (day/night)			
20.jan							
21.jan	Loker sprayed	temperature drop	Loker sprayed	temperature drop			

	150 W/m²		100 W/m²		Chamber for the first 4 weeks		Emails/ phone calls with advisors
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**	**tasks**	**observations / problems**	
22.jan	4 waterings		4 waterings				
23.jan							
24.jan							
25.jan							
26.jan	measurements, old leaves removed		measurements, old leaves removed				
27.jan							
28.jan	Loker sprayed		Loker sprayed				
29.jan							
30.jan							
31.jan							
1.feb							
2.feb	19 bad plants marked (Phythopthora), last irrigation: 16.00, Paraat (400 ml/pot)		11 bad plants marked (Phythopthora), last irrigation: 16.00, Paraat (400 ml/pot)				water with Paraat 400 ml/pot and again after 10 days
3.feb							
4.feb	first hives, Loker sprayed		first hives, Loker sprayed				

	150 W/m²		100 W/m²		Chamber for the first 4 weeks		Emails/ phone calls with advisors
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**	**tasks**	**observations / problems**	
5.feb	irrigation interval: 1,5 h, bad plants removed, pots changed so that at shelter beds are pots with removed plants	plants are more stressed	irrigation interval: 1,5 h, bad plants removed, pots changed so that at shelter beds are pots with removed plants	better balance in plants			Sven: • change to 1000 ppm • remove bad plants • water again after 10 to 14 days with Paraat • increase E.C. to 1,7, when fruiting max. 1,4 E.C. • first drainage of the day should be no runoff • pollination next 2 days important • increase Mg by 10 % • decrease night temp. to 7-8°C when fruiting • next time only 3 plants/pot
6.feb	runners removed		runners removed				
7.feb							
8.feb							
9.feb	measurements, bad plants removed	plants have developed much since last week	measurements, bad plants removed	plants have developed much since last week			

	150 W/m²		100 W/m²		Chamber for the first 4 weeks		Emails/ phone calls with advisors
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**	**tasks**	**observations / problems**	
10.feb	irrigation interval: 1:45, runners and old leafes removed		irrigation interval: 2:45, runners and old leafes removed				
11.feb	Loker sprayed		Loker sprayed				
12.feb	bad plants removed, Paraat (400 ml/pot)		bad plants removed, Paraat (400 ml/pot)				
13.feb	irrigation interval: 1:30 , 3:00 min		irrigation interval 2:00, 3:00 min				
14.feb							
15.feb							
16.feb	measurements, bad plantsand runners removed water sample taken	brown spots on the edge of leaves	measurements, bad plants and runners removed water samples taken irrigation interval: 2:30, 3:00 min.	brown spots on the edge of leaves			
17.feb	floor temp.: 35°C						
18.feb	Loker sprayed		Loker sprayed				
19.feb	put ammonium nitrat in mixture, watering 4 min, new big hives, bad plants removed		put ammonium nitrat in mixture, new big hives, bad plants removed				
20.feb							
21.feb							
22.feb							

	150 W/m²		100 W/m²		Chamber for the first 4 weeks		Emails/ phone calls with advisors
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**	**tasks**	**observations / problems**	
23.feb	measurements, bad plants and runners removed		measurements, bad plants and runners removed				
24.feb							
25.feb	Loker sprayed		Loker sprayed				
26.feb							
27.feb							
28.feb							
1.mar							
2.mar	measurements, bad plants and runners removed		measurements, bad plants and runners removed				
3.mar	fertilizer changed to fruit, runners removed, cluster moved to front		fertilizer changed to fruit, runners removed, clusters moved to front				
4.mar	Loker sprayed		Loker sprayed				
5.mar							
6.mar							
7.mar							
8.mar							
9.mar	measurements, bad plants and runners removed		measurements, bad plants and runners removed				
10.mar	bad leaves and runners removed		bad leaves and runners removed				

Date	150 W/m² tasks	150 W/m² observations / problems	100 W/m² tasks	100 W/m² observations / problems	Chamber for the first 4 weeks tasks	Chamber for the first 4 weeks observations / problems	Emails/ phone calls with advisors
11.mar	light: 05-19, first harvest	Loker sprayed	light: 05-19, first harvest	Loker sprayed			
12.mar	aphidoletes mix system		aphidoletes mix system				
13.mar							
14.mar							
15.mar							
16.mar	measurements, bad plants and runners removed, harvest		measurements, bad plants and runners removed, harvest				
17.mar	removing bad leaves, runners		removing bad leaves, runners				
18.mar	Loker sprayed		Loker sprayed				
19.mar							mixture for Sonata, lower E.C. to 1,0-1,2
20.mar							
21.mar							
22.mar							
23.mar	measurements, harvest		measurements, harvest				
24.mar	harvest		harvest				
25.mar	Loker sprayed		Loker sprayed				
26.mar	harvest		harvest				
27.mar							
28.mar							

	150 W/m²		100 W/m²		Chamber for the first 4 weeks		Emails/ phone calls with advisors
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**	**tasks**	**observations / problems**	
29.mar							
30.mar	measurements, harvest		measurements, harvest				
31.mar							
1.apr	harvest		harvest				
2.apr			harvest				
3.apr							
4.apr	harvest		harvest				
5.apr							
6.apr							
7.apr	measurements, harvest		measurements, harvest				
8.apr							
9.apr	harvest, CO_2: 1.200 ppm, night: 8°C		harvest, CO_2: 1.200 ppm, night: 8°C				
10.apr	iron and mangan added		iron and mangan added				
11.apr							
12.apr							
13.apr	measurements, harvest		measurements, harvest		planting strawberries		
14.apr							
15.apr							
16.apr	harvest		harvest				
17.apr					Paraat		

	150 W/m²		100 W/m²		Chamber for the first 4 weeks		Emails/ phone calls with advisors
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**	**tasks**	**observations / problems**	
18.apr							
19.apr							
20.apr	measurements, harvest		measurements, harvest				
21.apr							
22.apr							
23.apr	harvest		harvest				
24.apr							
25.apr							
26.apr							
27.apr	measurements, harvest		measurements, harvest				
28.apr					Paraat		
29.apr							
30.apr					bad leaves and early flowers removed		
1.maí							
2.maí							
3.maí							
4.maí	last harvest, plants thrown out		last harvest, plants thrown out				
5.maí							

	150 W/m²		100 W/m²		Chamber for the first 4 weeks		Emails/ phone calls with advisors
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**	**tasks**	**observations / problems**	
6.maí					light: 05-19, bad leaves and early flowers removed Locker sprayed		
7.maí							
8.maí							
9.maí							
10.maí							
11.maí							
12.maí	new plants put into chambers, bad leaves removed		new plants put into chambers, bad leaves removed				
13.maí	Loker sprayed		Loker sprayed				
14.maí							
15.maí							
16.maí							
17.maí							
18.maí	measurements		measurements				
19.maí	old leaves removed, put strings for leaves		old leaves removed				
20.maí			put strings for leaves				
21.maí							
22.maí							

	150 W/m²		100 W/m²		Chamber for the first 4 weeks		Emails/ phone calls with advisors
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**	**tasks**	**observations / problems**	
23.maí							
24.maí							
25.maí							
26.maí	measurements, bad leaves removed	everything pollinated (hives were open whole weekend)	measurements, bad leaves removed	everything pollinated (hives were open whole weekend)			
27.maí							
28.maí	put tape	bees have been biting fruits, light green leaves	put tape	bees have been biting fruits, light green leaves			add iron + mangan, change light according to solar irradiation
29.maí							
30.maí	iron and mangan added		iron and mangan added				
31.maí							
1.jún	measurements		measurements				
2.jún							
3.jún							
4.jún	Loker sprayed		Loker sprayed				
5.jún							
6.jún							
7.jún							
8.jún	measurements	first fruits colouring	measurements	first fruits colouring			
9.jún	Pirimol sprayed		Pirimol sprayed				

	150 W/m²		100 W/m²		Chamber for the first 4 weeks		Emails/ phone calls with advisors
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**	**tasks**	**observations / problems**	
10.jún	new fertilizer solution (10 fruits white)		new fertilizer solution (10 fruits white)				
11.jún							
12.jún							
13.jún							
14.jún							
15.jún	measurements, first harvest		measurements, first harvest				
16.jún	put clusters in front						
17.jún							
18.jún	1st. harvest, Loker sprayed		1st. harvest, put clusters in front, Loker sprayed				
19.jún							
20.jún							
21.jún							
22.jún	measurements, harvest		measurements				
23.jún			harvest				
24.jún							
25.jún	harvest, Loker sprayed		harvest, Loker sprayed				
26.jún							
27.jún							

	150 W/m²		100 W/m²		Chamber for the first 4 weeks		Emails/ phone calls with advisors
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**	**tasks**	**observations / problems**	
28.jún							
29.jún	measurements, harvest		measurements, harvest				
30.jún							
1.júl							
2.júl	harvest, Loker sprayed		harvest, Loker sprayed				
3.júl							
4.júl							
5.júl							
6.júl	harvest		harvest				
7.júl							
8.júl							
9.júl	harvest, Loker sprayed		harvest, Loker sprayed				
10.júl							
11.júl							
12.júl							
13.júl	measurements, harvest		measurements, harvest				
14.júl							
15.júl							
16.júl	last harvest experimental plants		last harvest experimental plants				
17.júl							

	150 W/m²		100 W/m²		Chamber for the first 4 weeks		Emails/ phone calls with advisors
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**	**tasks**	**observations / problems**	
18.júl							
19.júl							
20.júl	harvest		harvest				
21.júl							
22.júl	last harvest		last harvest				