Rit LbhÍ nr. 94

„Áhrif ljósstyrks á vöxt, uppskeru og gæði „everbearers“ í samanburði við hefðbundna gróðurhúsaræktun jarðarberja að vetri“

FINAL REPORT

Christina Stadler

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Landbúnaðarháskóli Íslands

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Final report of the research project

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Table of contents

List of figures

List of tables

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 everbearers are not yet in place and need to be developed. The objective of this study was to test if the light intensity is affecting growth, yield and quality over the winter of junebearers and everbearers and to evaluate the profit margin.

A strawberry experiment with junebearers (*Fragaria x ananassa* cv. Sonata) and everbearers (*Fragaria x ananassa* cv. Delizzimo) was conducted from the end of October 2016 to the end of February 2017 in the experimental greenhouse of the Agricultural University of Iceland at Reykir. Strawberries were grown in 5 l pots in six replicates with 12 plants/m^2 (Sonata) or 6 plants/m^2 (Delizzimo) under high-pressure vapour sodium lamps (HPS) at two light intensities (150 W/m^2 and 100 W/m^2) for a maximum of 16 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 35 / 45 days (Delizzimo / Sonata) at the higher light intensity and in 41 / 47 days (Delizzimo / Sonata) at the lower light intensity. It seems that more light (150 W/m^2) resulted in more flowers. The treatment with the higher light intensity started some days earlier to give ripe berries of Sonata in comparision to 100 W/m^2, whereas it was the other way round for Delizzimo.

A higher light intensity had a positive effect on marketable yield, the harvest increased by 9-56 % for Delizzimo and by 54-123 % for Sonata compared to the lower light intensity. The higher yield of the higher light intensity was attributed to a higher number of harvested fruits. Differences between light intensities developed at the beginning of the harvest period of Sonata or at the middle of the harvest period for Delizzimo and decreased later in the harvest period. The marketable yield of Delizzimo was 260-340 g/plant and of Sonata 330-350 g/plant with 150 W/m^2 but 210-240 g/plant for Delizzimo and 160-220 g/plant for Sonata with 100 W/m^2. Differences were mostly tendentially between light intensities and between varieties. Sonata gave at the higher light intensity a more than 100 % higher yield (per m^2) and at the lower light intensity a more than 45 % higher yield (per m^2) compared to

Delizzimo. Marketable yield was about 90 % of total yield. More unshaped strawberries were counted in Delizzimo compared to Sonata.

The sugar content was significantly higher at 150 W/m^2 for Delizzimo compared to 100 W/m^2 and also compared to Sonata. However, for Sonata were no differences between light intensities found. This difference was not found in the tasting experiment in the sweetness of the strawberries. The tasting gave no hint to a different taste, but higher grades for the flavour were given at the higher light intensity compared to the lower light intensity for both varieties.

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 yield and growth of the plants. An earlier start of mildew was observed at the lower light intensity and also the intensity of mildew was more pronounced at 100 W/m^2 compared to 150 W/m^2.

With a higher light intensity increased the yield of Delizzimo by 0,7 kg/m^2 (1 % increase of light intensity increased yield by 0,18-1,13 %) and the profit margin by 300 ISK/m^2. With Sonata was the yield at 150 W/m^2 increased by 2,3 kg/m^2 (1 % increase of light intensity increased yield by 1,07-2,46 %) and the profit margin by 3.700 ISK/m^2. A higher tariff did not change profit margin. Also, the position of the greenhouse (urban, rural) did nearly not influence profit margin, however, there was a small advantage for the urban area.

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 as well as the variety Sonata to be able to increase yield and profit margin. The use of the junebearer Delizzimo and come with that around of changing the plants of junebearers after six weeks of harvest are economically not paying off and bringing the risk not to be able to clean the greenhouse in case phytosanitary issues are coming up.

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 everbearers eru ekki til staðar og þarfnast frekari þróunar. Markmiðin voru að prófa, hvort ljósstyrkur hefði áhrif á vöxt, uppskeru og gæði yfir hávetur á junebearers og everbearers og hvort það væri hagkvæmt.

Gerð var jarðarberja tilraun með junebearers (*Fragaria x ananassa* cv. Sonata) og everbearers (*Fragaria x ananassa* cv. Delizzimo) frá lok október 2016 til lok febrúar 2017 í tilraunagróðurhúsi Landbúnaðarháskóla Íslands að Reykjum. Jarðarber voru ræktuð í 5 l pottum í sex endurtekningum með 12 plöntum/m^2 (Sonata) eða 6 plöntum/m^2 (Delizzimo) undir topplýsingu frá háþrýsti-natríumlömpum (HPS) með tvenns konar ljósstyrk (150 W/m^2 og 100 W/m^2) að hámarki í 16 klst. Daghiti var 16 °C og næturhiti 8 °C, CO_2 800 ppm. Jarðarberin fengu næringu með dropavökvun. Áhrif ljósstyrks var prófuð og framlegð reiknuð út.

Það tók 1-2 daga frá blómgun til frjóvgunar. Ávextir voru þroskaðir á 35 / 45 degi (Delizzimo / Sonata) með hærri ljósstyrk og á 41 / 47 dögum (Delizzimo / Sonata) með minni ljósstyrk. Það virðist vera að meira ljós (150 W/m^2) gefi fleiri blóm. Í upphafi uppskerutímabils byrjaði meðferð með hærri ljósstyrk að gefa þroskuð ber af Sonata nokkrum dögum fyrr borið saman við 100 W/m^2, en það var öfugt fyrir Delizzimo.

Hærri ljósstyrkur hefur jákvæð áhrif á markaðshæfa uppskeru, uppskeran var 9-56 % meiri með Delizzimo og 54-123 % meiri með Sonata. Ástæðan fyrir meiri uppskeru við 150 W/m^2 var meiri fjöldi jarðarberja. Mismunur milli ljósstyrkja myndaðist í upphafi uppskeru tímabilsins fyrir Sonata og í miðjuni uppskeru tímabilsins fyrir Delizzimo og munur var lækkaður á síðara uppskerutímabilinu. Þannig fengust 260-340 g/plöntu markaðshæfrar uppskeru með Delizzimo og 330-350 g/plöntu með Sonata við 150 W/m^2 en 210-240 g/plöntu með Delizzimo og 160-220 g/plöntu með Sonata við 100 W/m^2. Munurinn var oftast ekki tölfræðilega marktækur hvorki milli ljósstyrkja né milli yrkja. Hins vegar var uppskera af Sonata við 150 W/m^2 um meira en 100 % hærri (á m^2) og við 100 W/m^2 meira en 45 % hærri (á m^2) samanborið við Delizzimo. Hlutfall uppskerunnar sem hægt var að selja var um 90 %. Hærra hlutfall illa lagaðra jarðarberja var í Delizzimo samanborið við Sonata.

Sykurinnihald var hærra við 150 W/m^2 hjá Delizzimo samanborið við 100 W/m^2 og líka samanborið við Sonata. En fyrir Sonata var engin munur milli ljósstyrk. Hins vegar fannst þessi munur ekki í bragðprófun, en einkunn fyrir bragð var hærri með hærri ljósstyrk samanborið við lægri ljósstyrk fyrir bæði yrki.

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. Sveppasýkingar (mjöldögg) varð fyrr vart við lægri ljósstyrk auk þess sem magn af mjöldögg var meira við 100 W/m^2 samanborið við 150 W/m^2.

Þegar hærri ljósstyrkur var notaður, þá jókst uppskera með Delizzimo um 0,7 kg/m^2 (1 % hækkun í ljósstyrk jók uppskeru um 0,18-1,13 %) og framlegð um 300 ISK/m^2. Við Sonata jókst uppskera við 150 W/m^2 um 2,3 kg/m^2 (1 % hækkun í ljósstyrk jók uppskeru um 1,07-2,46 %) og framlegð um 3.700 ISK/m^2. Hærri rafmagnsgjaldskrá breytir framlegð næstum ekkert. Það skiptir nánast ekki máli hvort gróðurhús er staðsett í þéttbýli eða dreifbýli, framlegð er svipuð, en lítil kostur var fyrir þéttbýli.

Möguleikar til að minnka kostnað, aðrir en að lækka rafmagnskostnað eru ræddir. Frá hagkvæmnisjónarmiði er mælt með því að nota hærri ljósstyrk og Sonata til að auka uppskeru og framlegð jarðarberja. Notkun af everbearer Delizzimo og komast hjá að skipta um plöntur af junebearers eftir sex vikna uppskeru eru ekki hagstæð og þar með myndu koma áhætta um að ekki væri hægt að hreinsa gróðurhús þegar meindýr eða sjúkdóma herja á plöntunar.

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. In the year 2017 were already eight strawberrry growers counted.

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. These varieties are junebearers that produce one harvest in June or early spring. In contrast, everbearers are producing longer than junebearers, but are with less harvest per week. At the International Soft Fruit Conference 2016 in the Netherlands was a new variety of everbearers introduced that is called Delizzimo and is from ABZ Seeds BV from the Netherlands. Delizzimo is very tasty (*ABZ Seeds*, without year) and reached in the Netherlands about 5,25 kg/m² from 20.11.2015 to 05.03.2016 (15 weeks) with a low yield until middle of January and after that 0,4-0,6 kg/m² per week with up to 50 g heavy fruits (*Dings*, personal communication). Assuming the harvest continues until beginning of May would it be possible to get about 8,5 kg/m². Therefore, it would be interesting to test also everbearers in Iceland and get with that around of changing the plants of junebearers after six weeks harvest as it has been done so far in Iceland.

Since several years it is tradition to grow strawberries in heated greenhouses in the Netherlands and Belgium (e.g. *van Delm* et al., 2016). 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.

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). First knowledge in growing berries at different light intensities is available: At the beginning of the harvest were strawberries at the higher light intensity (150 W/m^2) some days earlier ripe than at 100 W/m^2. The higher light intensity had a positive effect on marketable yield. The yield was about 15 % more due to a higher number of “extra class” strawberries. The unmarketable yield seemd to be lower at the higher light intensity (*Stadler*, 2016a, *Stadler* 2016b). However, these results apply to the junebearers Sonata and Elsanta, whereas for everbearers is no knowledge available. Therefore, the effect of light on yield over the high winter (with low levels of natural light) was tested under Icelandic conditons.

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 different strawberry varieties, 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 and variety (junebearers versus everbearers). 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

A strawberry experiment with junebearers (*Fragaria x ananassa* cv. Sonata) and everbearers (*Fragaria x ananassa* cv. Delizzimo) and different light intensities (see chapter “3.2 Treatments”) was conducted at the Agricultural University of Iceland at Reykir during winter 2016/2017.

Delizzimo was sown on rock wool plugs with a diameter of 2 cm on the 11.07.2016 and was covered with plastic until germination. First seeds germinated on the 18.07.2016. Germination was very unequal and thus was the further development of the plants. 6,5 weeks after sowing were plants potted in Ø 9 cm pots and placed in the young production chamber at 150 W/m^2 with 16-18 h light. During the development of the plants were runners regularly taken away. When the first cluster with 1-2 open flowers has developed, were two young plants of Delizzimo planted in 5 l pots on the 25.10.2016. On the 27.10.2016 were these pots with Delizzimo moved into the two chambers with different light intensities.

Four heavy tray plants of Sonata were planted on 24.10.2016 in 5 l pots filled with moist strawberry substrate in two chambers with different light intensities. Harvest of Sonata ended on 02.02.2017. After that were plants moved out of the chamber. On 06.02.2017 were 5 l pots with Sonata, that were planted on 10.01.2017 with four heavy tray plants, moved into the growing chambers with different light intensities.

Fig. 1: Experimental design of cabinets.

The strawberry pots were placed in rows in six 134 cm high beds (Fig. 1) with 8 cm between pots and 96 cm between beds. Beds were divided into two parts and the different varieties put out in a zick zack system (Fig. 1). One bed had 16 pots with eight pots from each variety. Six replicates, one replicate in each bed consisting of one pot (4 plants for Sonata, 2 plants for Delizzimo) acted as subplots for measurements. The plant density for Sonata was 12 plants/m^2 and 6 plants/m^2 for Delizzimo. The temperature was set on 16 °C during day and 8 °C during night. Ventilation started at 20 °C. Carbon dioxide was provided (800 ppm CO_2 with no ventilation and 400 ppm CO_2 with ventilation). Bumblebees were used for pollination. A misting system was installed. Plant protection was managed by beneficial organisms. Paraat was sprayed four days after planting. It was started about 4 weeks after planting to spray Loker once a week (see details in appendix). In the young production of Delizzimo plants was Entonem (*Steinernema feltiae*) used against sciarid fly and Floramite sprayed against spider mites. In addition, Spidex

(*Steinernema feltiae*) was put out against spider mites. Aphiscout (mix of parasitic wasps), Thripor-L (*Orius laevigatus*), Ervipar (*Aphidius ervi*) and Aphipar (*Aphidius colemani*) was used. Mildew was observed and therefore was Savona soap used (see details in appendix).

Sonata got fertilizer according to advice from DLV plant (Tab. 1a) and Delizzimo got fertilizer according to advice from ABZ seeds (Tab. 1b).

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

	Stem solution A (1000 l)			**Stem solution B (1000 l)**									**Irrigation water**	**Relation**
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

Tab. 1b: Fertilizer mixture according to advice from ABZ seeds.

	Stem solution A (1000 l)	**Stem solution B (1000 l)**			**Relation**
Fertilizer (amount in kg) (amount in l) * (amount in g) **	Calciumnitrate liquid *	Magnesium sulfate	Monopotassium phosphate	Potassium nitrate	
	12,8	3,7	1,74	3,88	1:100

Plants were irrigated through drip irrigation (1 tube per bucket). The watering of Sonata 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 general was the rule that the first drip in the morning should not give runoff. 100 ml/drip was irrigated, first one watering per day, then watering in 3 hours intervals, later in 2 hours intervals and then in 1 hour intervals (first at 5.00 and last at 17.00) with E.C. 1,6 and pH 5,8. For Delizzimo was the rule to maintain an even moisture level and with not too wet substrate. For good root development it should be avoided that at the bottom of the container moist is locked. When harvest period starts, watering needs to be intensified up to a drain-percentage of 30 %.

3.2 Treatments

Strawberries were grown from 24.10.2016 - 23.02.2017 (official end due to the fact that results were already clear at this point) 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 16 hours. Half of the lamps went on at 05.00 and the other half at 05.30. Half of the lamps went off at 19.00 and the other half at 19.30. The lamps were automatically turned off when incoming illuminance was above the desired set-point.

The lamps were distributed in the way that strawberries got the most equal light distribution, on average, 222 µmol/m^2/s in the 150 W/m^2 chamber and 155 µmol/m^2/s in the 100 W/m^2 chamber (Tab. 2). In addition, white plastic on the surrounding walls helped to get a higher light level at the edges of the growing area.

Tab. 2: Light distribution in the chambers.

	150 W/m² µmol/m²/s				100 W/m² µmol/m²/s			
bed	**door**	**middle**	**glas**	**average**	**door**	**middle**	**glas**	**average**
A	225	189	156	**190**	108	142	158	**136**
B	230	205	170	**202**	120	127	142	**130**
C	274	270	270	**271**	163	178	198	**180**
D	250	238	204	**231**	161	191	180	**177**
E	255	227	181	**221**	138	145	158	**147**
F	260	219	173	**217**	157	160	171	**163**
average	**249**	**225**	**192**	**222**	**141**	**157**	**168**	**155**

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.

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 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 (green) counted. The marketable yield of the whole chamber 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.

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. The natural light level was low during the whole growing period. From October to the end of the experiment were less than 1 kWh/m^2 reached (Fig. 2).

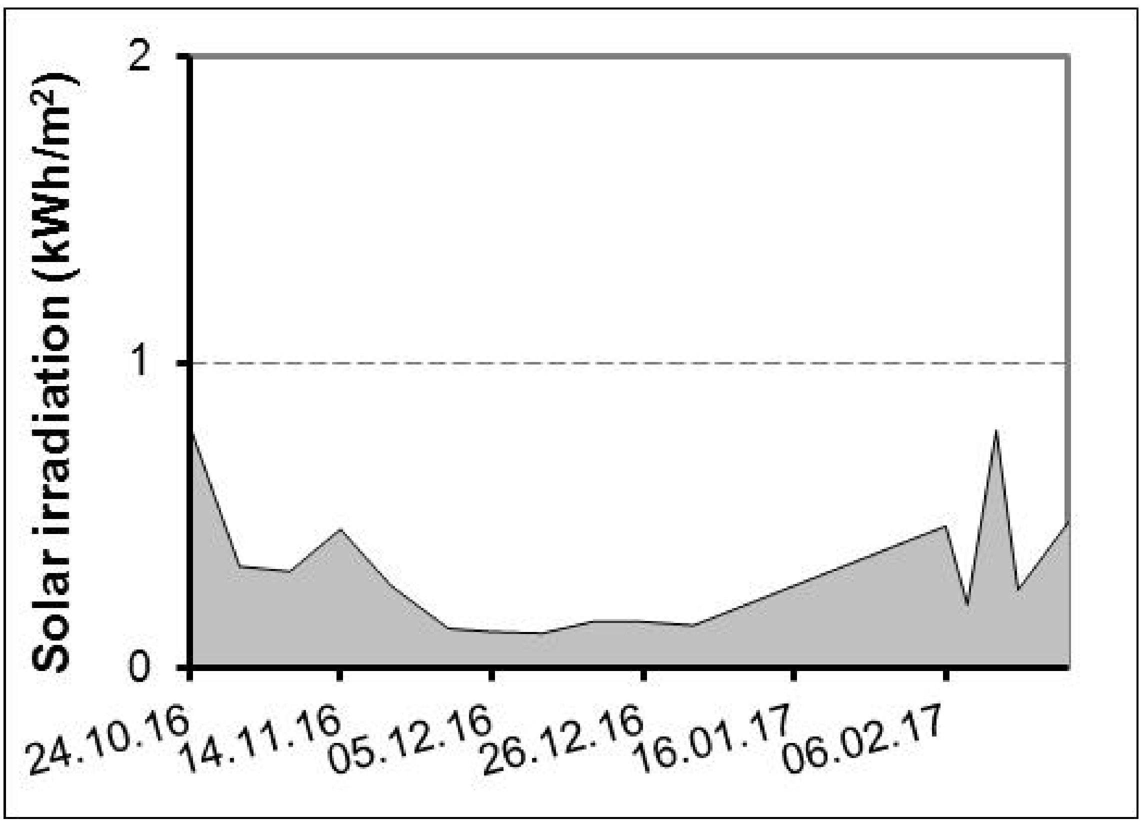


Fig. 2: Time course of solar irradiation.
Solar irradiation was measured every day and values for one week were cumulated.

4.1.2 Chamber settings

The settings in the chambers were regularly recorded. Table 3 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 week 1, 2 and 3 was the CO_2 amount higher at 100 W/m^2 compared to 150 W/m^2. The air temperature was higher at 150 W/m^2 compared to 100 W/m^2, while the floor temperature was lower.

Tab. 3: Chamber settings.

Week	CO_2 (ppm)		Air (°C) (day / night)		Floor (°C)	
	150	100	150	100	150	100
	W/m^2					
1	339	462	16,7 (18,4 / 13,7)	15,3 (17,4 / 11,8)	28,2	37,6
2	345	479	16,0 (18,9 / 11,1)	16,7 (19,3 / 12,6)	28,4	38,7
3	406	537	16,0 (18,7 / 11,3)	16,8 (19,2 / 12,7)	28,9	39,5
4	696	721	14,9 (17,6 / 10,4)	14,8 (17,3 / 10,3)	29,2	31,0
5	784	784	15,1 (17,8 / 10,6)	14,5 (17,0 / 10,3)	29,2	30,7
6	695	708	16,7 (18,7 / 11,8)	16,1 (18,1 / 11,4)	30,6	31,0
7	757	777	17,2 (19,1 / 12,4)	16,5 (18,5 / 11,7)	28,9	30,3
8	761	781	16,7 (18,8 / 11,5)	15,6 (17,6 / 10,8)	30,7	31,1
9	787	786	15,8 (17,7 / 10,9)	14,6 (16,5 / 10,0)	30,5	31,3
10	797	789	15,5 (17,4 / 10,4)	14,8 (16,7 / 10,0)	28,8	32,0
11	771	779	16,2 (18,4 / 11,0)	15,4 (17,4 / 10,2)	30,7	31,2
12	784	784	15,0 (16,9 / 10,6)	14,0 (15,9 / 9,7)	31,3	31,8
13	796	793	16,0 (17,7 / 11,9)	14,6 (16,3 / 10,4)	31,6	31,7
14	787	782	17,9 (19,5 / 13,9)	14,9 (16,8 / 10,1)	32,9	31,6
15	785	781	18,6 (20,5 / 14,2)	15,1 (17,3 / 10,0)	32,2	31,5
16	781	773	19,3 (21,2 / 14,7)	16,0 (18,1 / 10,7)	31,7	31,0
17	680	774	18,5 (20,5 / 13,5)	16,5 (18,6 / 11,4)	31,0	31,0
18	748	781	16,6 (18,7 / 11,4)	15,6 (17,6 / 10,5)	30,7	31,0

4.1.3 Soil temperature

Soil temperature was measured weekly at low solar radiation in the morning (at about 08.30). Soil temperature was most of the time higher at the higher light intensity. Soil temperature fluctuated between 14-21 °C. It seems that the soil temperature was a bit higher in the pots with Delizzimo compared to pots with Sonata (Fig. 3).

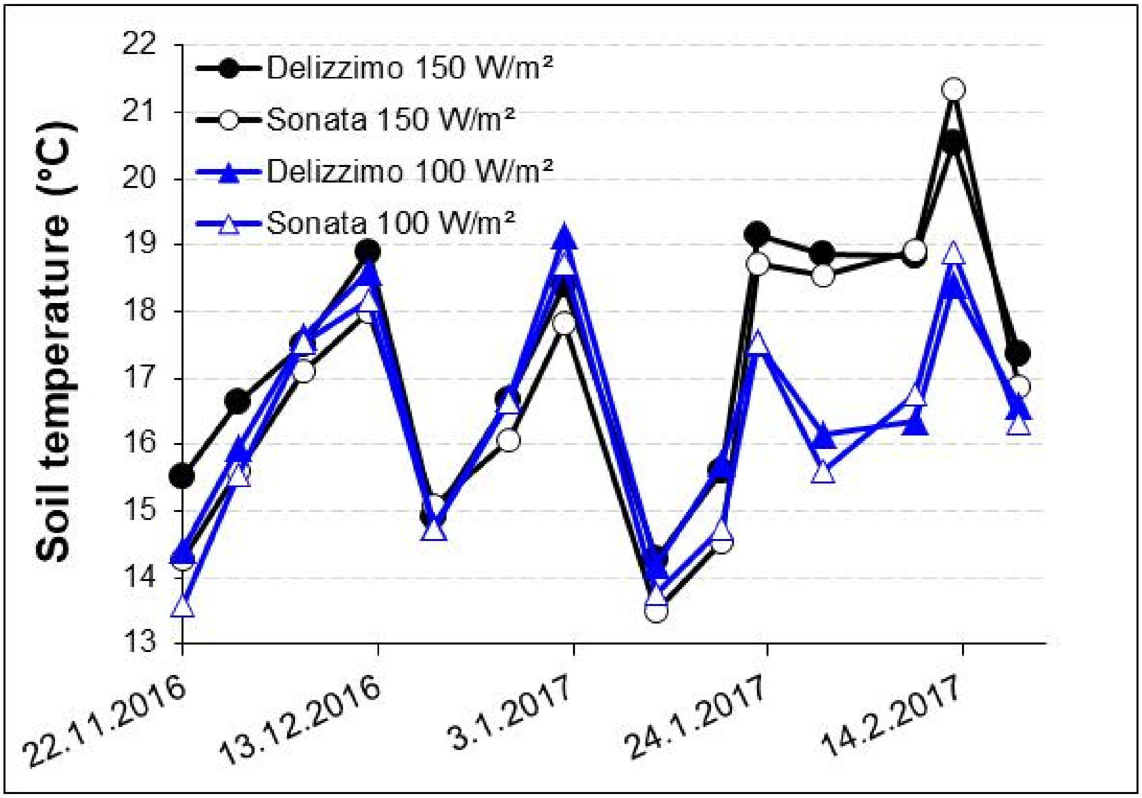


Fig. 3: Soil temperature.
The soil temperature was measured at little solar irradiation early in the morning.

4.1.4 Leaf temperature

Leaf temperature was measured weekly at low solar radiation in the morning (at about 08.30). Leaf temperature was higher at the higher light intensity. It seems that leaf temperature was a bit higher for Delizzimo compared to Sonata. Leaf temperature fluctuated between 11-22 °C (Fig. 4).

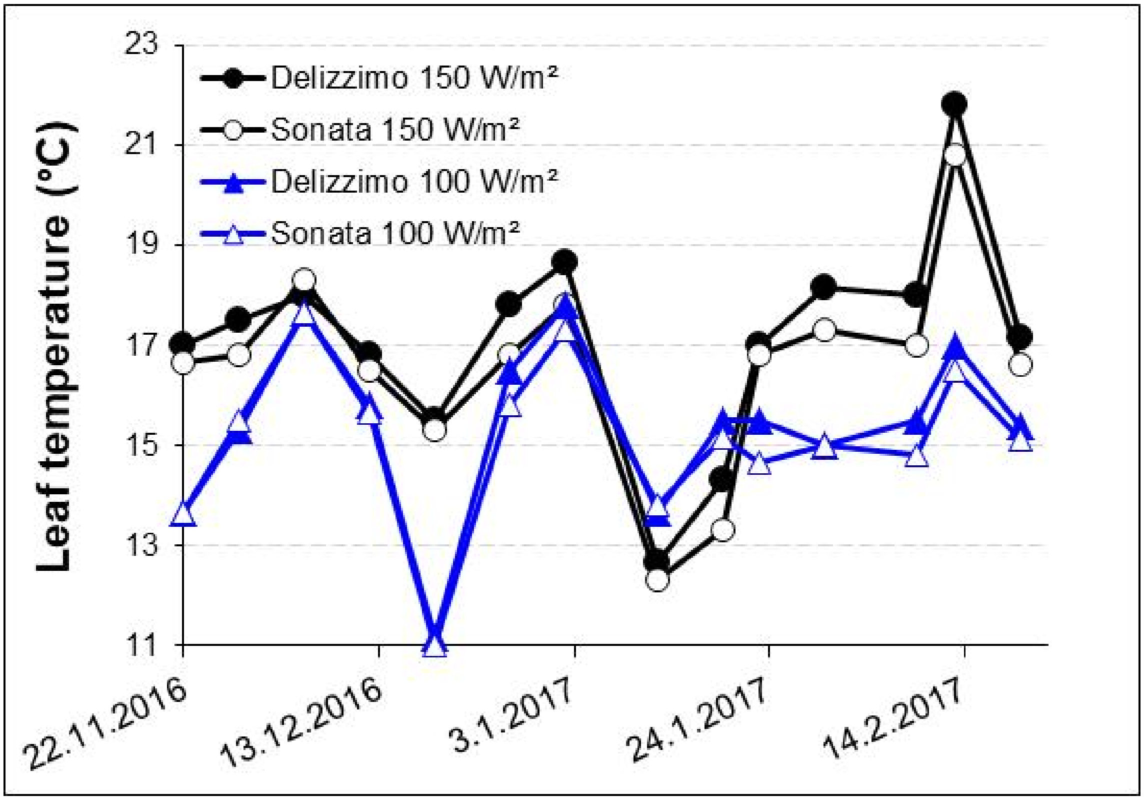


Fig. 4: Leaf temperature.
The soil temperature was measured at little solar irradiation early in the morning.

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 400 ml/plant (Fig. 5).

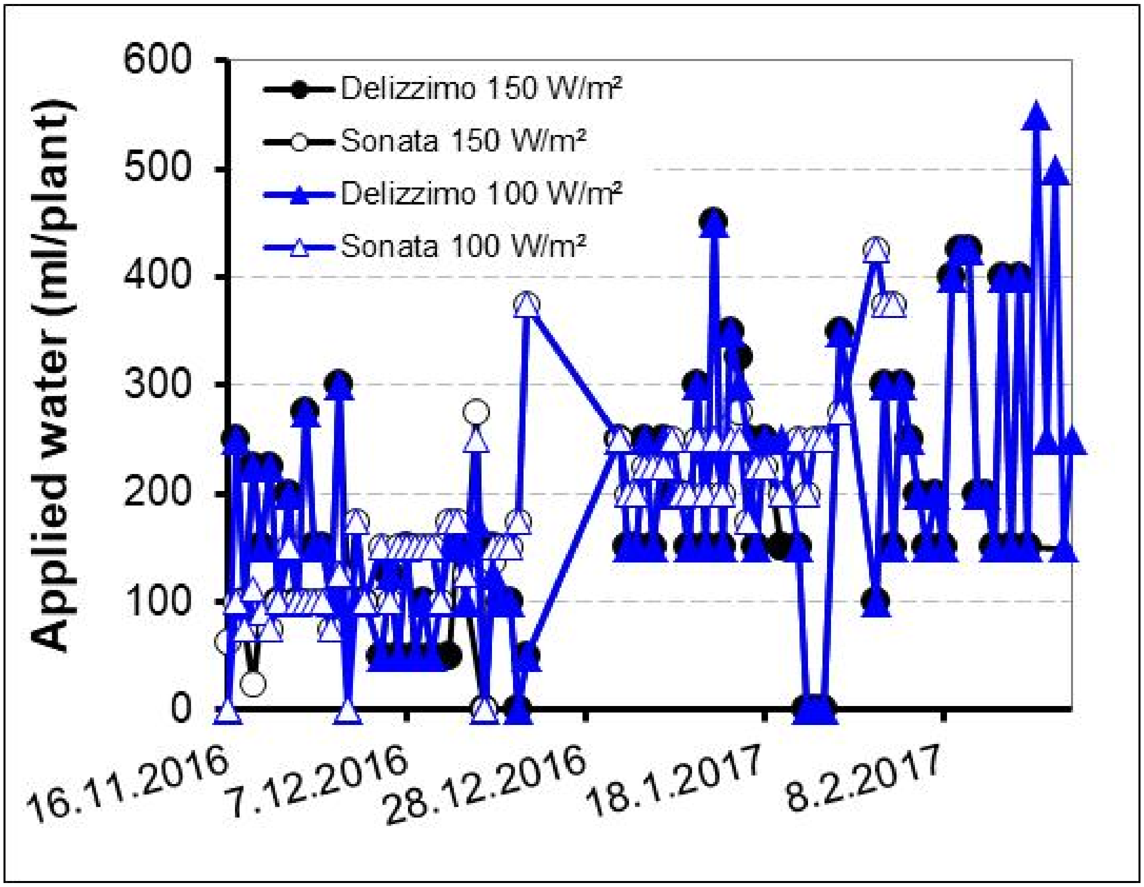


Fig. 5: Daily applied water.

E.C. and pH of irrigation water was fluctuating much (Fig. 6). The E.C. of applied water ranged most of the time between 1,2-2,0 and the pH between 4,5-6,5. The E.C. of runoff stayed most of the time between 1,4-2,4 and the pH 6,0-7,0.

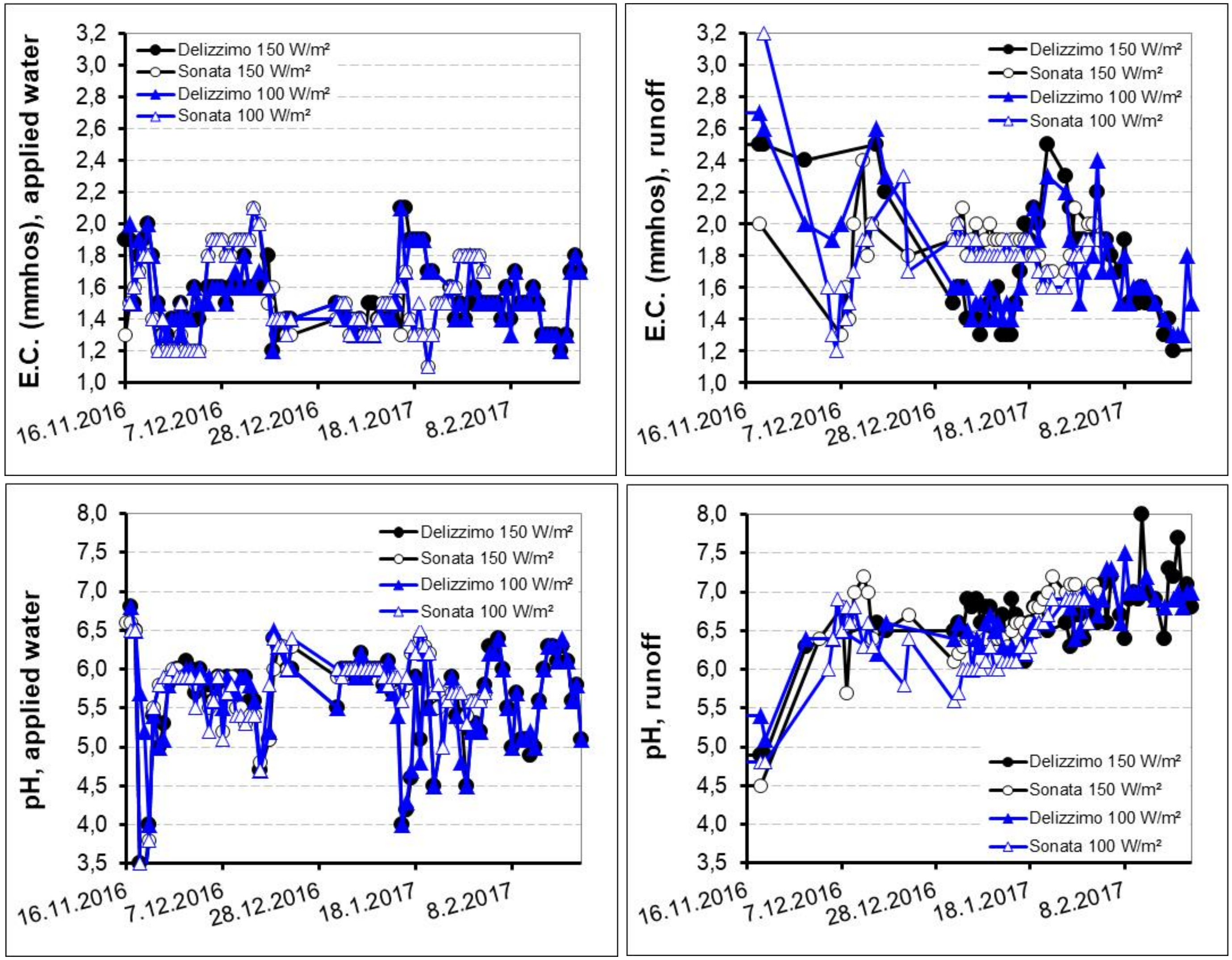


Fig. 6: E.C. and pH of irrigation water and runoff.

The amount of runoff from applied irrigation fluctuated very much, especially for Delizzimo. This variety had very often no runoff at the earlier part of the growing period and at the latter part up to 100 % runoff, followed by no runoff. Also Sonata had at the beginning of the growing period often no runoff. Runoff increased up to 50 % and decreased at the end of the growing period again (Fig. 7). The runoff seems to be lower for the higher light intensity.

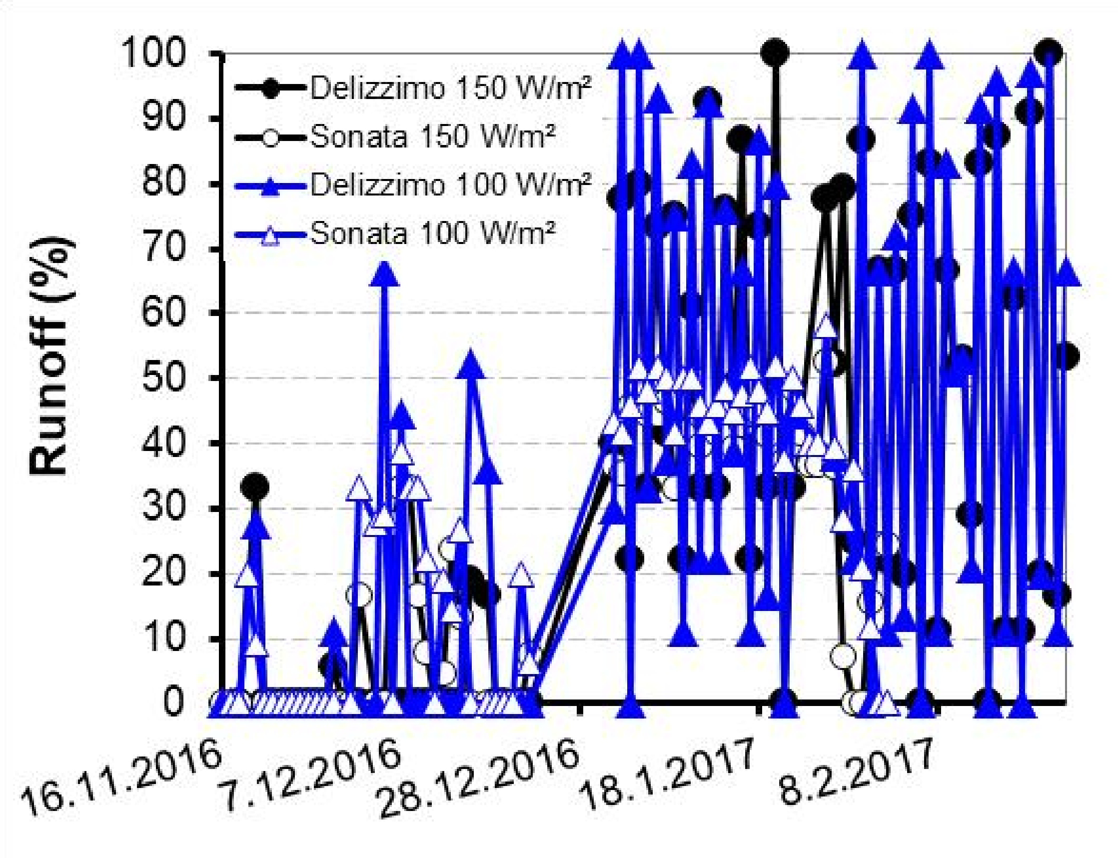


Fig. 7: Proportion of amount of runoff from applied irrigation water.

4.2 Development of strawberries

4.2.1 Plant diseases

Some strawberry plants of Sonata were infected with phytopthora (*Phytopthora cactorum*). Infected plants were removed. Symptoms started to appear about one month after planting. In addition, mildew (*Sphaerotheca macularis*) was observed on 22.11.2016. While on Sonata both leaves and fruits were covered, on Delizzimo were only fruits infected. Mildew was more pronounced at the lower light intensity. At the beginning of January was on Delizzimo leaf scorch (*Diplocarpon earliana*) observed.

4.2.2 Number of leaves

The number of leaves increased for Sonata from 12 to 24 and for Delizzimo from 14 to 26 (Fig. 8). No significant differences in the number of leaves regarding the two light intensities and the varieties were found.

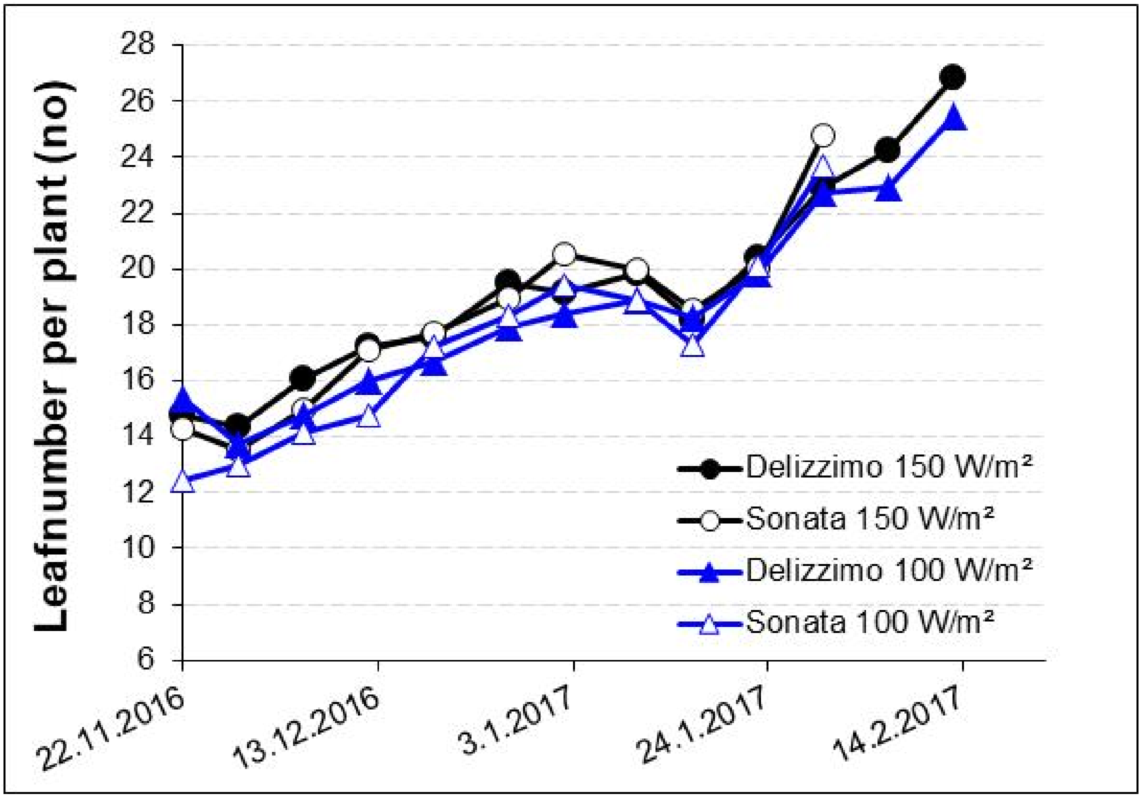


Fig. 8: Number of leaves at strawberry plants.

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

4.2.3 Number of runners

Strawberry plants of the variety Sonata had more runners than Delizzimo. However, Delizzimo developed a lot of runners in the stage of the young production, that were not counted as the experiment started when plants moved into the different chambers. The light intensity seems not to influence the number of runners (Fig. 9).

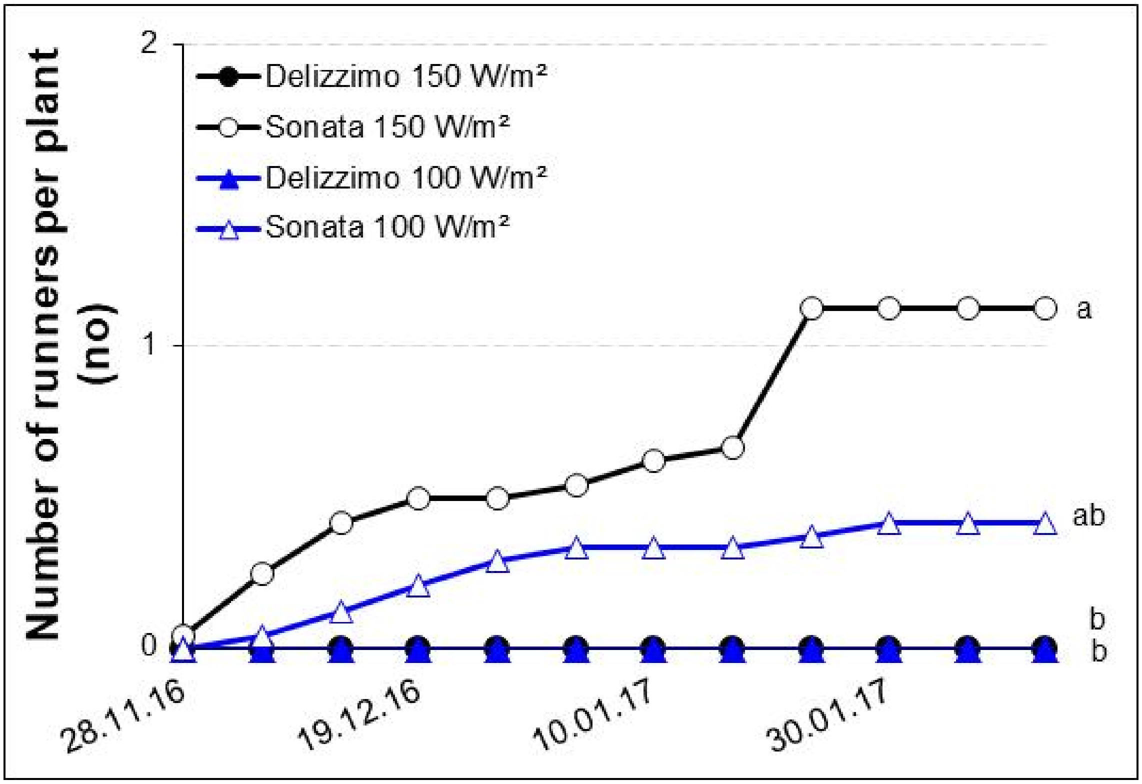


Fig. 9: Number of runners at strawberry plants.

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

4.2.4 Number of clusters

The number of clusters with flowers and / or fruits increased for Sonata until the beginning of harvest and decreased after that when all fruits from a cluster were harvested. A similar patten could be found for Delizzimo, however here were also new clusters developed. Plants at the higher light intensity seem to have a higher number of clusters compared to plants at the lower light intensity (Fig. 10).

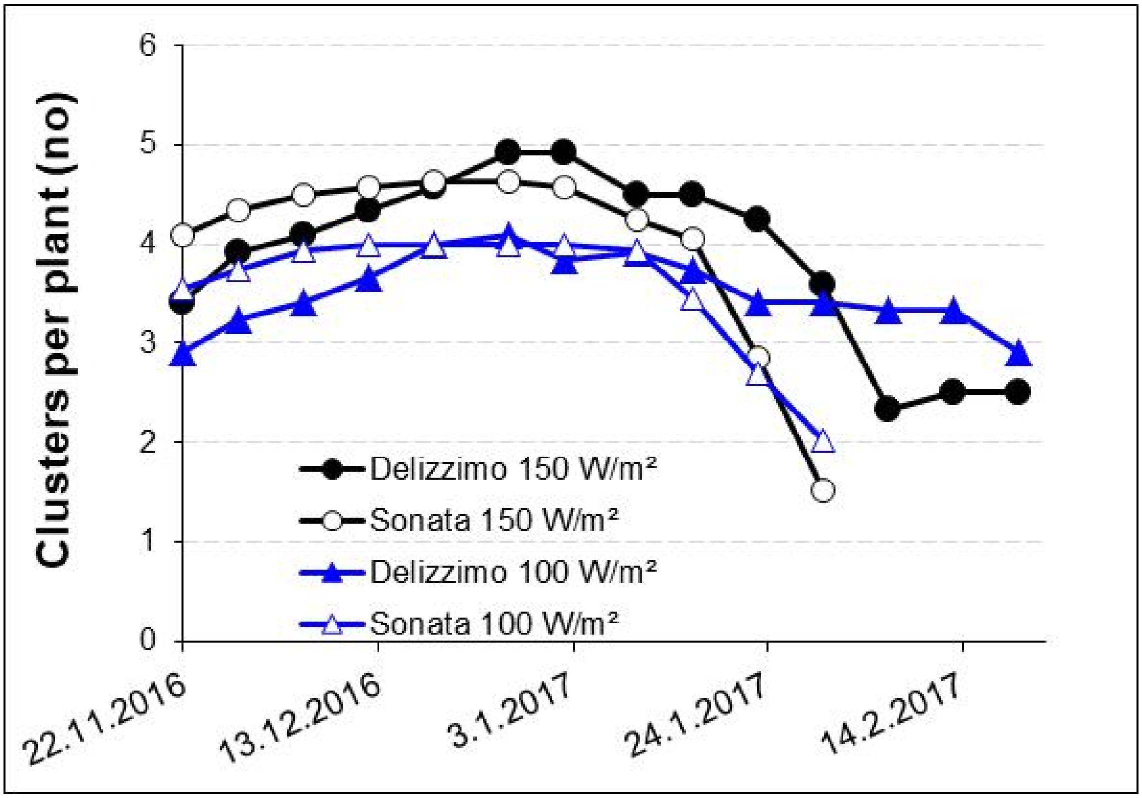


Fig. 10: Number of clusters.

4.2.5 Open flowers / fruits per cluster

The number of open flowers / fruits per cluster reached about 8 for Sonata (Fig. 11). After that, the number decreased naturally due to harvested fruits. The peak was higher at the higher light intensity. There seem to be a steeper inclination, both for the increase and decrease at the higher light intensity. For Delizzimo were about 4 open flowers / fruits per cluster reached (Fig. 11).

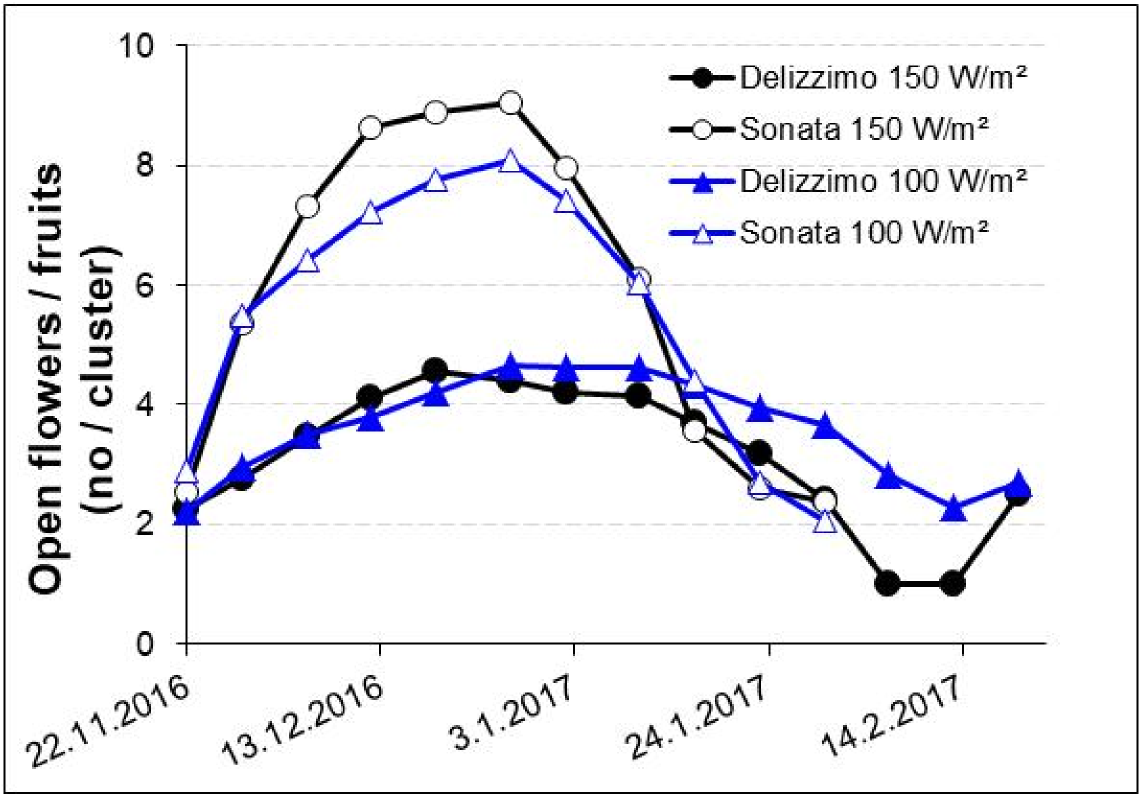


Fig. 11: Number of flowers / fruits per cluster.

4.2.6 Open flowers / fruits per plant

The number of open flowers / fruits of the Sonata plant reached about 40 for the higher light intensity and about 30 for the lower light intensity before harvest started (Fig. 12). Thereafter, decreased this number naturally due to harvested fruits. The decrease seems to be more pronounced at the higher light intensity. The number of open flowers / fruits of Delizzimo was about 20. The higher light intensity had a slightly higher number. After that decreased also here the number, but is supposed to increase again later (Fig. 12).

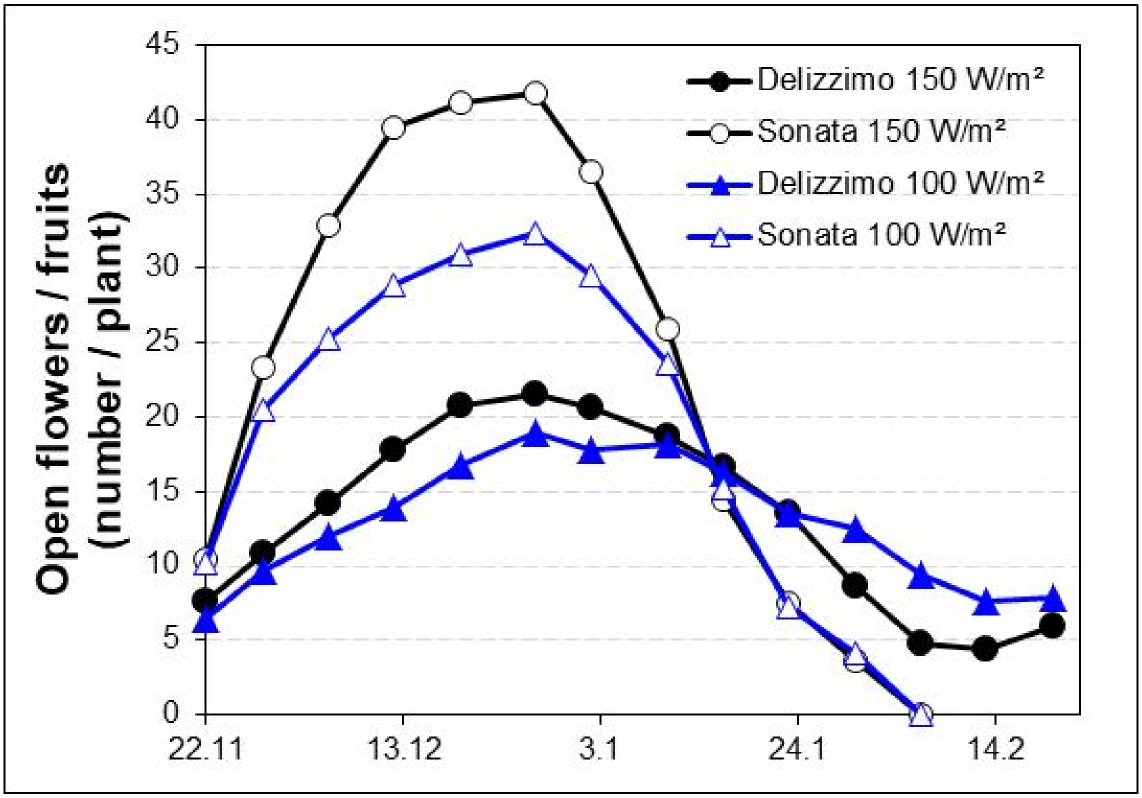


Fig. 12: Open flowers / fruits per cluster.

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), misshaped fruits, moldy fruits and green fruits at the end of the harvest period).

Cumulative total yield of strawberries ranged between 0,21-0,39 g/plant (Fig. 13). A higher light intensity increased tendentially, respectively significantly total yield. The total yield of Sonata was at the higher light intentensity higher compared to Delizzimo.

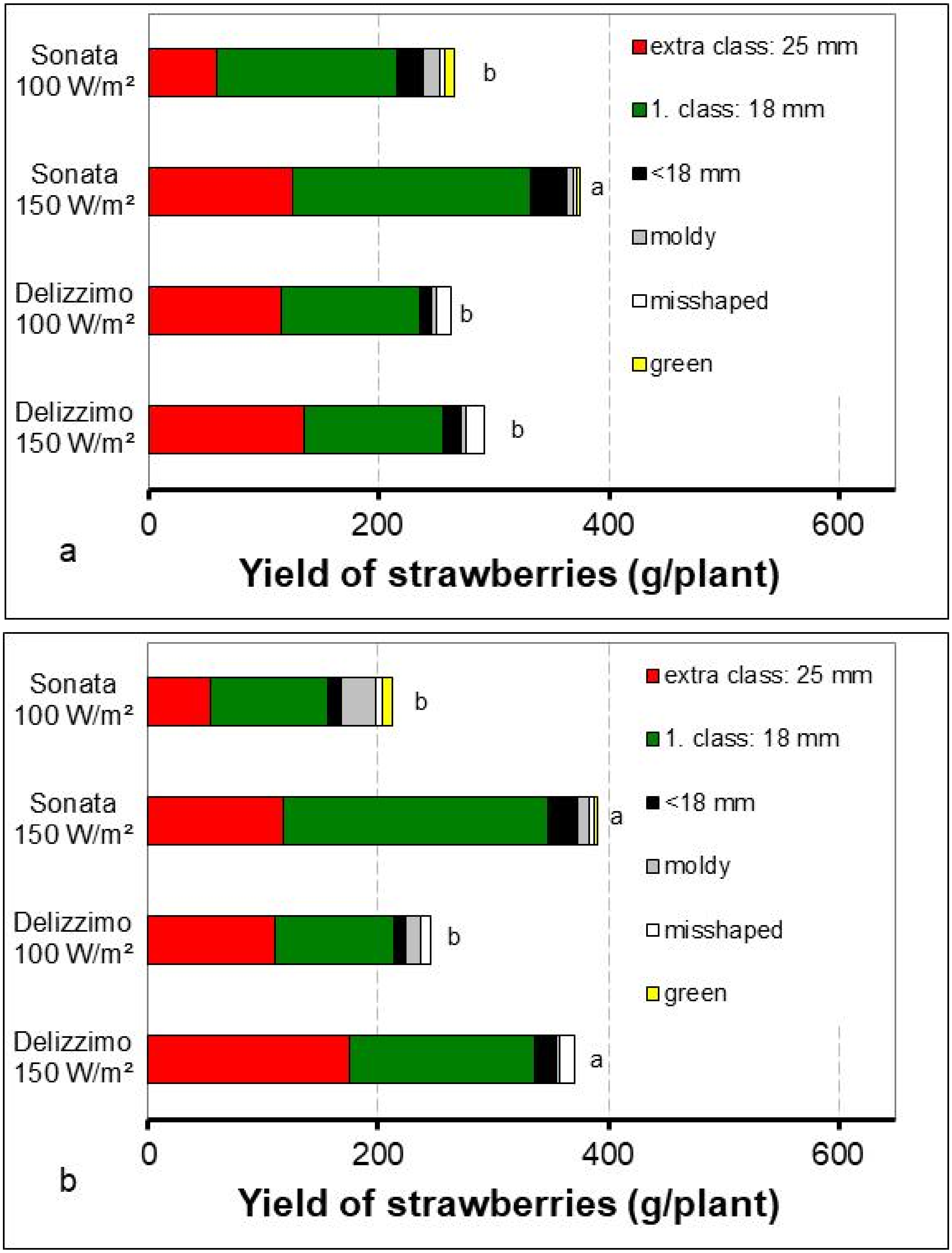


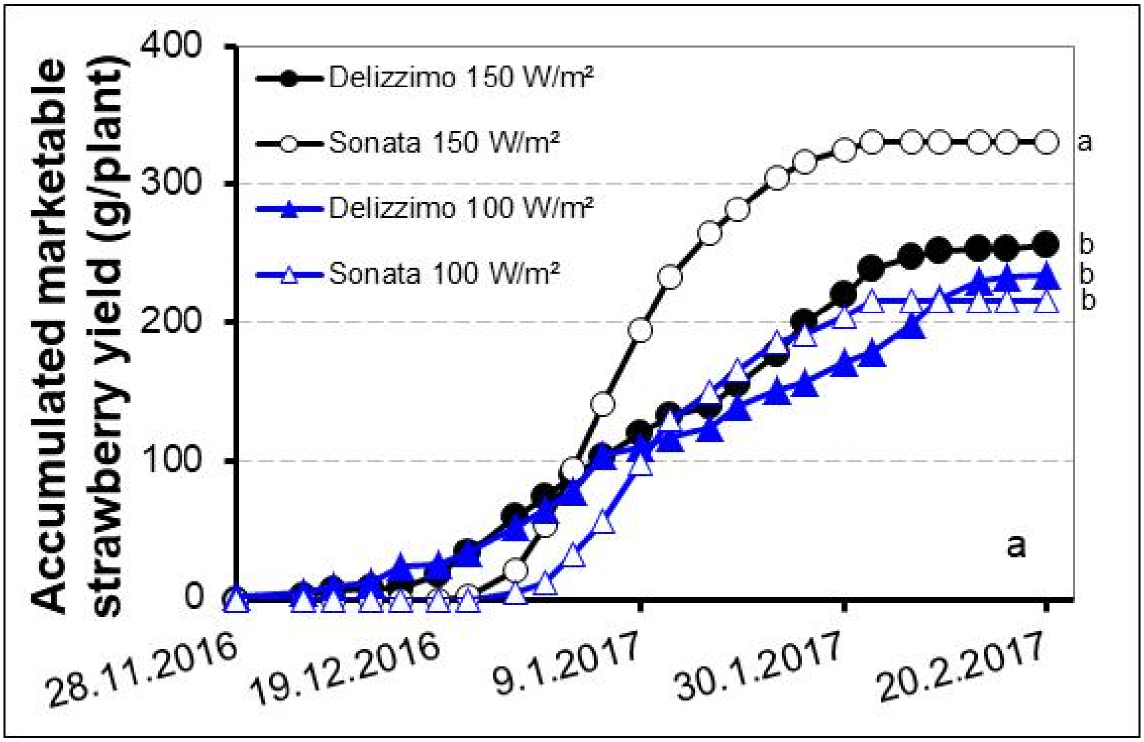
Fig. 13: Cumulative total yield of strawberries.
"a" is the yield of the measurement plants, "b" the yield of the plants, where only the yield was measured.

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

4.3.2 Marketable yield of strawberries

At the end of the harvest period amounted yield of strawberries 0,16-0,35 g/plant (Fig. 14a, Fig. 14b). A higher light intensity resulted in a tendentially, respectively significantly higher marketable yield compared to the lower light intensity. A 50 % increase in light intensity resulted in an increase in yield of 9 % (Fig. 14a) / 56 % (Fig. 14b) for Delizzimo and 54 % (Fig. 14a) / 123 % (Fig. 14b) for Sonata. This is equivalent to a yield increase of 0,18 % / 1,13 % for Delizzimo and 1,07 % / 2,46 % for Sonata at 1 % increase in light intensity. Differences between different light intensities developed at the middle of the harvest period of Delizzimo and at the beginning of the harvest period for Sonata. Differences between these two light intensities decreased later in the harvest period (Fig. 14). The harvest at the higher light intensity started few days earlier (about half week) for Sonata compared to the lower light intensity. In contrast, were the first fruits of Delizzimo earlier ripe at the lower light intensity. At the end of the harvest period was the yield per plant at the higher light intensity tendentially or significantly higher for Sonata (330 / 350 g/plant) compared to Delizzimo (260 / 340 g/plant), while at the lower light intensity was a tendentially higher yield reached for Delizzimo (240 / 210 g/plant) compared to Sonata (220 / 160 g/plant).

Also, the marketable yield of the whole chamber was measured. A higher marketable yield was reached with a higher light intensity (Fig. 15). Due to the fact that 4 plants of Sonata were in one pot compared to two Delizzimo plants, was the marketable yield per chamber higher at Sonata. After taking the removed plants into account and observing just the marketable amount per plant, was it advantageous for Delizzimo (150 W/m^2: 225 g/plant, 100 W/m^2: 283 g/plant) compared to Sonata (150 W/m^2: 175 g/plant, 100 W/m^2: 193 g/plant). In addition, a 28 % higher yield was reached at 150 W/m^2 compared to 100 W/m^2 for Delizzimo and a 47 % higher yield for Sonata at 150 W/m^2 compared to 100 W/m^2.



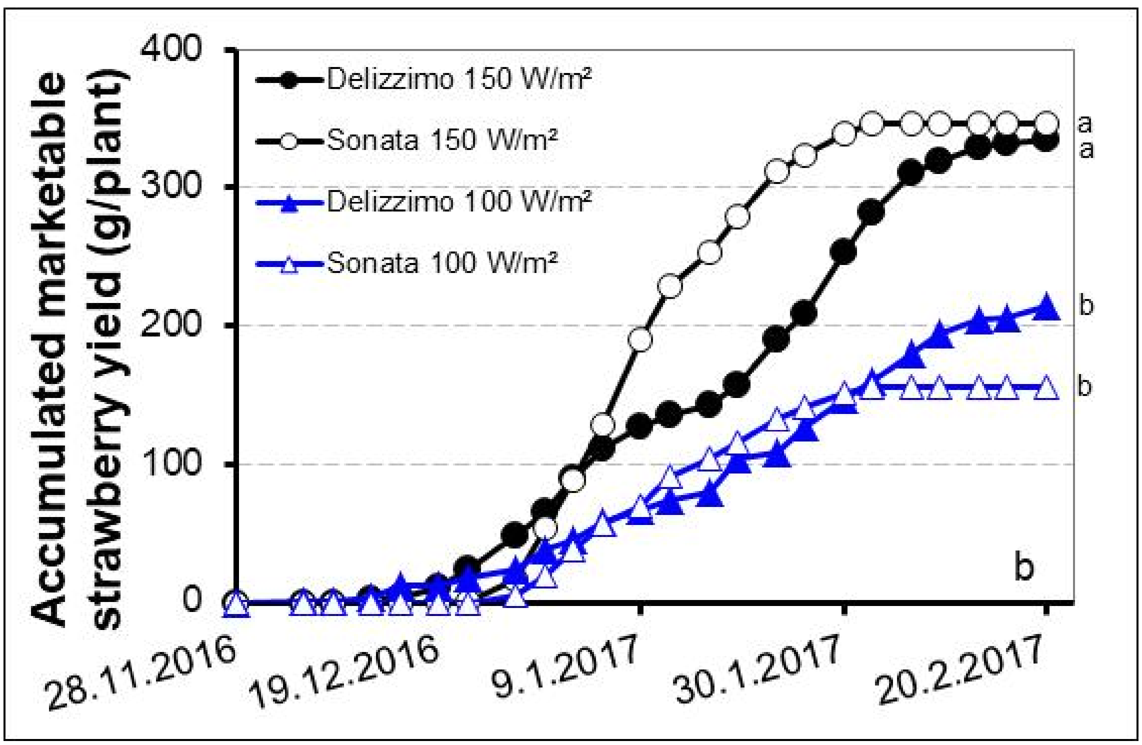


Fig. 14: Time course of accumulated marketable yield of strawberries.
"a" is the yield of the measurement plants, "b" the yield of the plants, where only the yield was measured.

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

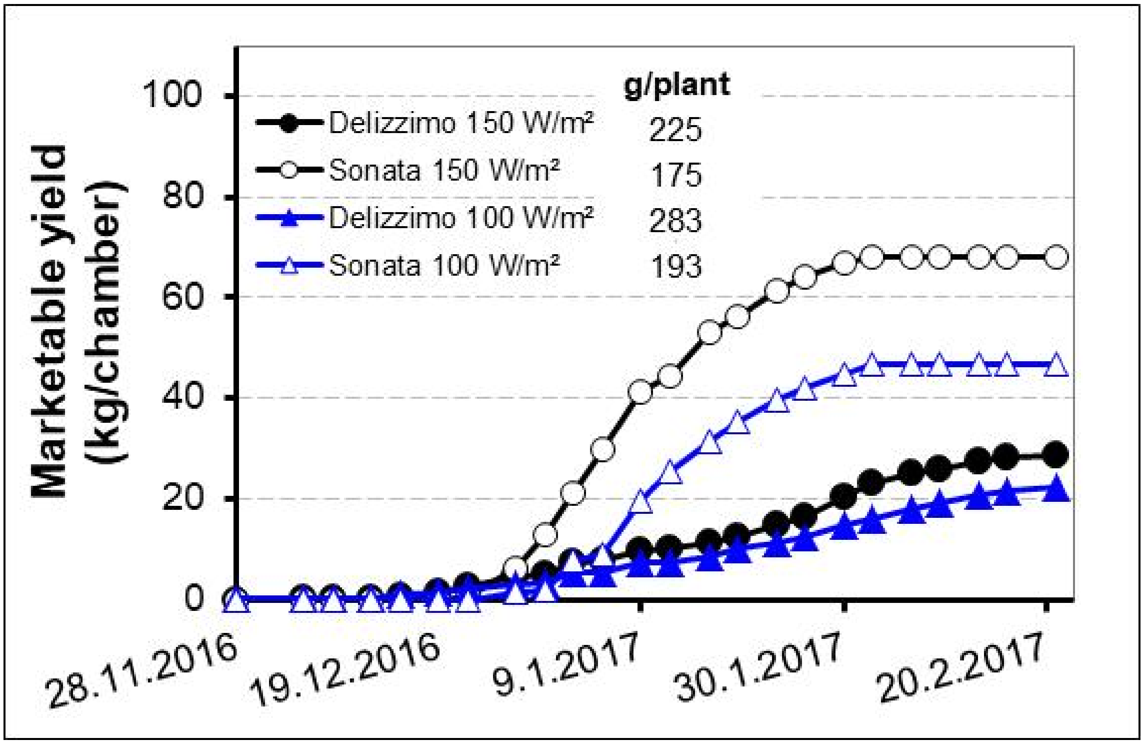


Fig. 15: Time course of accumulated marketable yield of strawberries for the whole chamber.

The marketable strawberry yield was nearly always higher at the higher light intensity. Delizzimo started earlier to ripe, resulting in a higher first yield and gave also longer harvestable fruits compared to Sonata. However, the level of the marketable strawberries of Delizzimo was during the whole harvest period low, but more or less stable in the middle of the harvest period. In contrast, Sonata gave longer a higher yield. The harvested amount of strawberries of Sonata increased until the first third of the harvest period and decreased thereafter (Fig. 16).

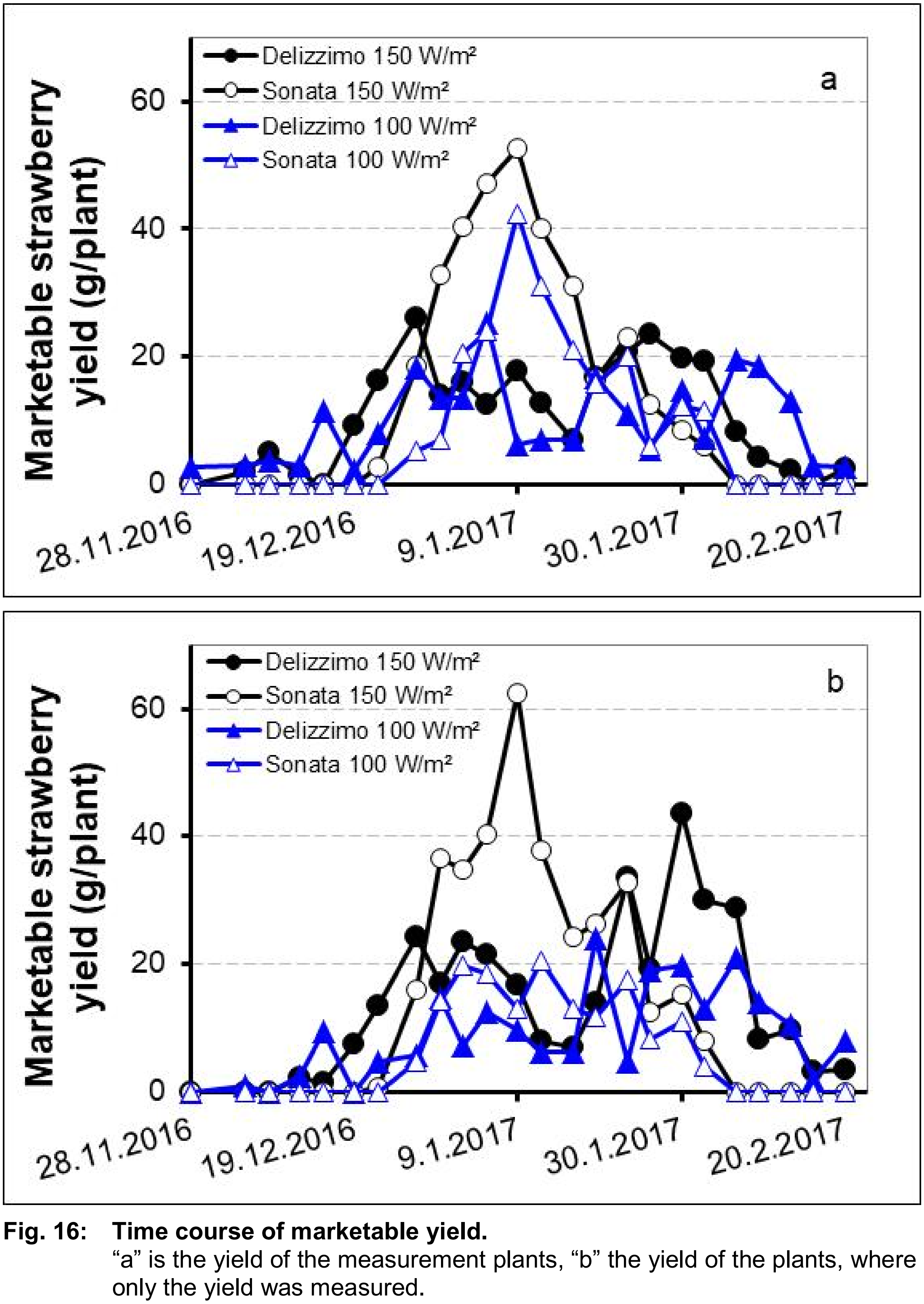


Fig. 16: Time course of marketable yield.
"a" is the yield of the measurement plants, "b" the yield of the plants, where only the yield was measured.

The number of extra class fruits was tendentially or significantly higher for the higher light intensity (Tab. 4). Also, for "class I + II" was most of the time a significantly higher number of fruits counted for the higher light intensity compared to the lower light intensity. While in the extra class fruits no differences between varieties were observed, was the number of class I + II fruits most of the time significantly higher at the variety Sonata compared to Delizzimo.

Tab. 4: Cumulative total number of marketable fruits.

Treatment	**Number of marketable fruits**	
	extra class (no/plant)	class I + II (no/plant)
Delizzimo 150 W/m^2	7 a	12 c
Sonata 150 W/m^2	7 a	22 a
Delizzimo 100 W/m^2	6 ab	13 c
Sonata 100 W/m^2	3 b	17 b
Delizzimo 150 W/m^{2*}	9 a	17 b
Sonata 150 W/m^{2*}	6 ab	25 a
Delizzimo 100 W/m^{2*}	5 b	11 c
Sonata 100 W/m^{2*}	3 b	10 c

* for the plants, where only the yield was measured

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

Average fruit size of marketable fruits was more or less stable during the harvest period (Fig. 17a, 17b). The strawberries at the higher light intensity were in average 0,8 g heavier (Fig. 17 a). However, this difference was not statistically significant. In contrast, with the less touched strawberries was this not observed (Fig. 17 b). It was obvious that Delizzimo fruits were tendentially, respectively significantly heavier than Sonata fruits. This difference amounted around 2 g.

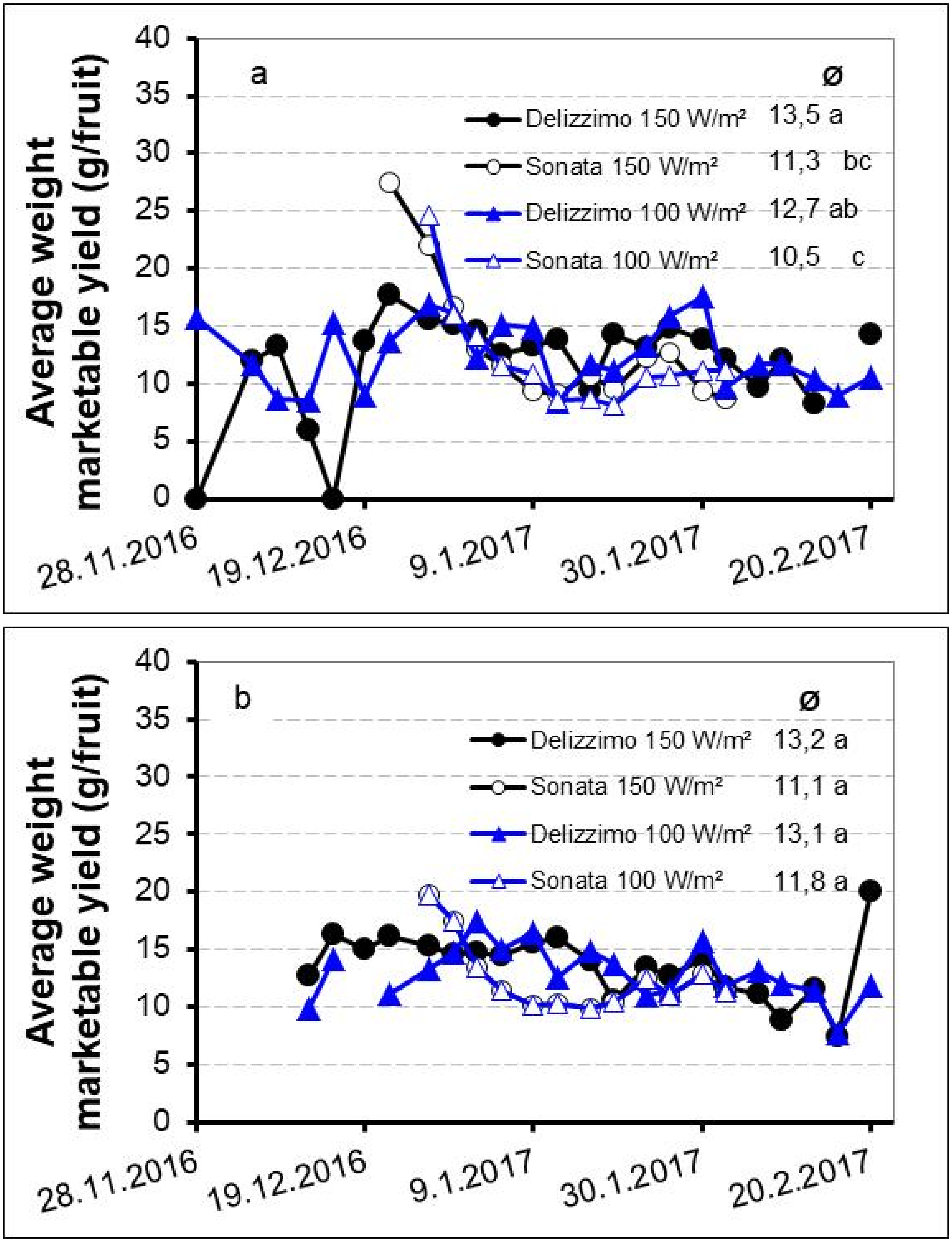


Fig. 17: Average weight of strawberries.
"a" is the average weight of the measurement plants, "b" the yield of the plants, where only the yield was measured.

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). Due to the fact, that nearly all Delizzimo flowers in the higher light intensity were pollinated directly after flower opening, was it only possible to mark very few flowers. It was clearly, that Delizzimo needed fewer days to ripe than Sonata. Also, a higher light intensity reduced the number of days to get ripe fruits. Number of days from pollination to harvest of Delizzimo was about 26-44 days (average: 35 days) for the higher light intensity and 32-48 (average: 41 days) for the lower light intensity and for Sonata 35-51 (average: 45 days) for the higher light intensity and 38-55 (average: 47 days) for the lower light intensity (Fig. 18). No relationship was found between the number of days from pollination to harvest and the weight of the fruit.

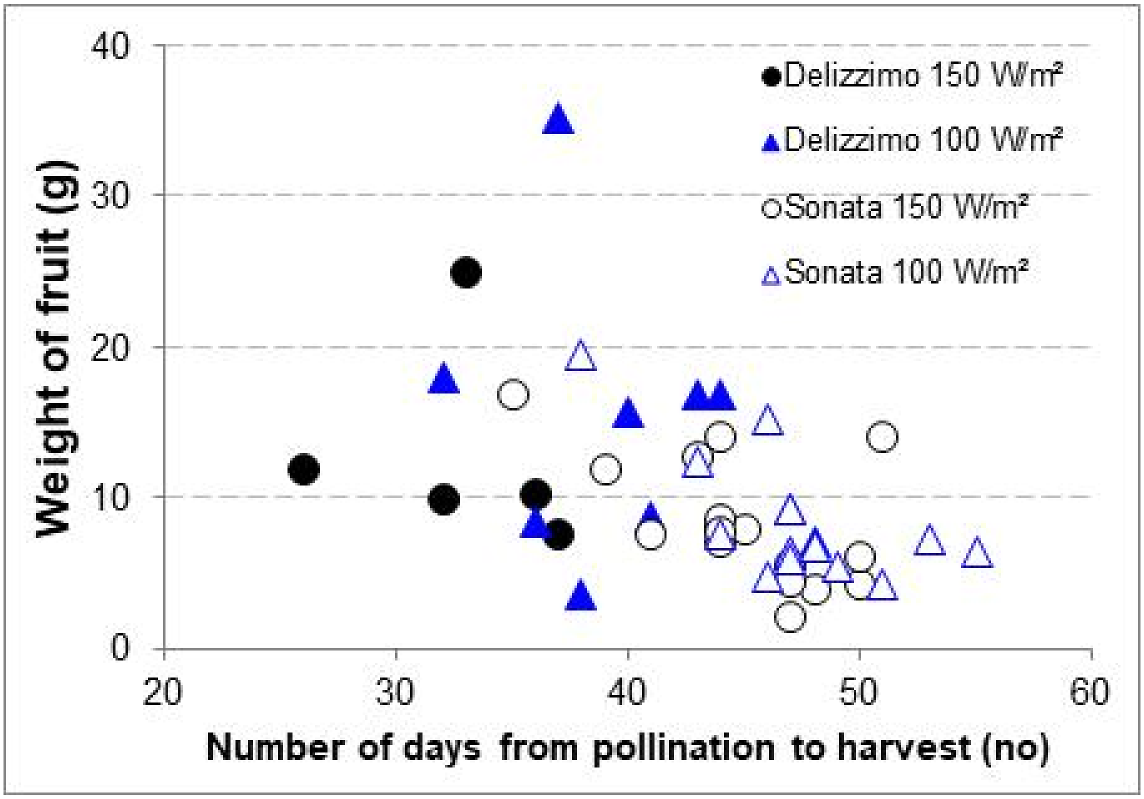


Fig. 18: Number of days from pollination to harvest and weight of the harvested fruit.

In the middle of the harvest of Sonata were most ripe fruits per week counted compared to the beginning (about first two weeks) and the end of the harvest period (about last two weeks). Around 10 fruits were weekly harvested when harvest reached its maximum (Fig. 19). In contrast, for Delizzimo was the harvest more or less even during the 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 about

30 flowers / fruits for Delizzimo and 40 flowers / fruits for Sonata. The number of flowers / fruits was a bit higher at 150 W/m² compared to 100 W/m² (Fig. 19).

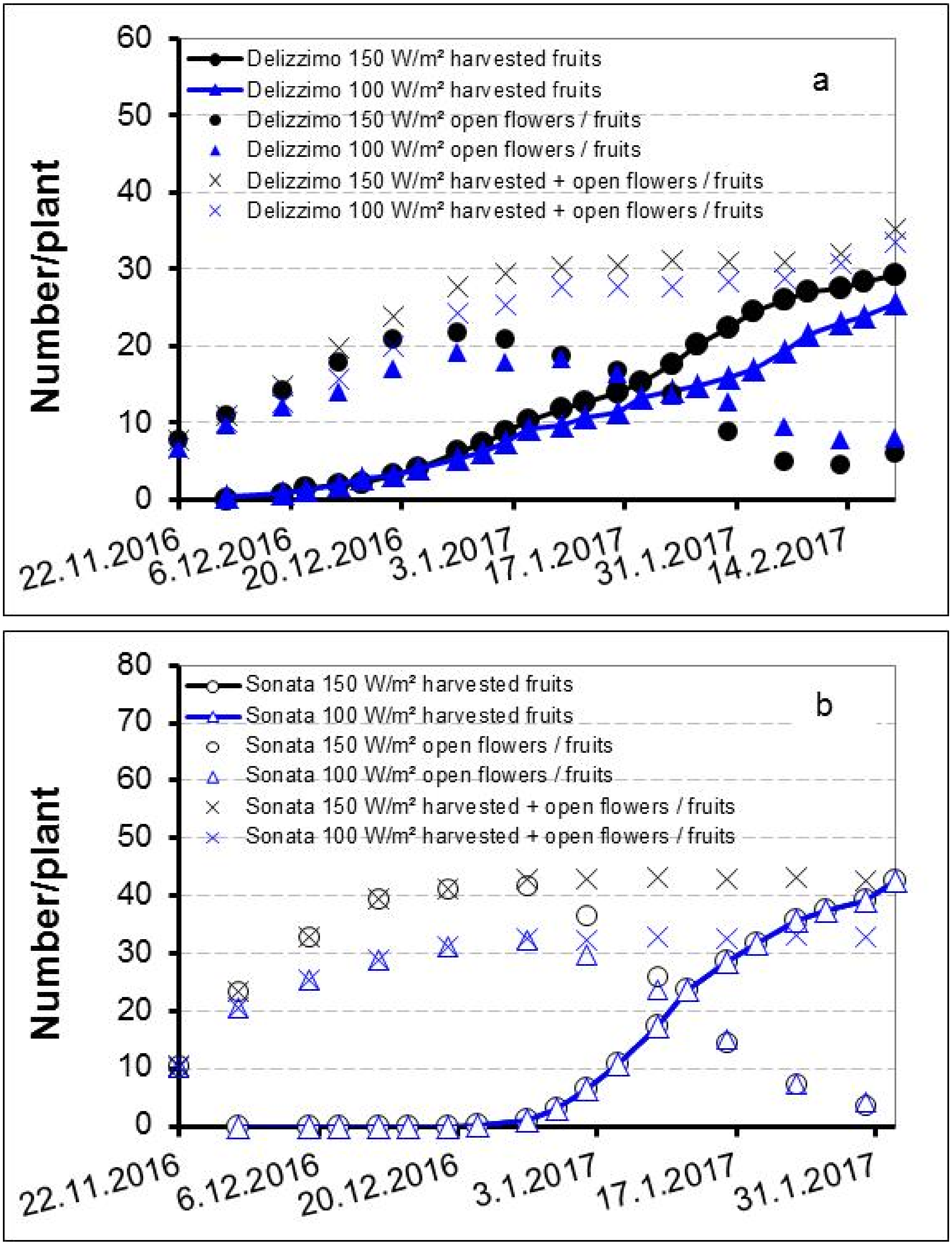


Fig. 19: Development of open flowers / fruits, harvested fruits and their sum during the growth of the strawberries.

4.3.3 Outer quality of yield

Marketable yield was about 90 % except for Sonata at the lower light intensity due to a high amount of moldy fruits (Tab. 5). There seem to be no differences in the proportion of marketable and unmarketable yield between light intensities and varieties. However, the extra class yield was with the variety Sonata compared to Delizzimo tendentially or significantly lower and the 1. class yield was with Delizzimo compared to Sonata tendentially lower. The proportion of moldy fruits was significantly highest with Sonata at the lower light intensity. Tendentially more misshaped fruits were counted for Delizzimo.

Tab. 5: Proportion of marketable and unmarketable yield.

Treatment	Marketable yield		Unmarketable yield			
	extra class > 25 mm	1. class > 18 mm	too little weight	moldy	mis-shaped	green
	%		%			
Delizzimo 150 W/m^2	46 a	42 b	5 a	2 b	5 ab	0 b
Sonata 150 W/m^2	33 ab	55 ab	9 a	1 b	1 b	1 b
Delizzimo 100 W/m^2	43 a	47 ab	4 a	1 b	5 ab	0 b
Sonata 100 W/m^2	22 b	60 a	8 a	6 a	2 b	2 a
Delizzimo 150 W/m^{2*}	47 a	43 a	5 a	1 b	4 a	0 b
Sonata 150 W/m^{2*}	30 ab	58 a	7 a	2 b	2 a	1 a
Delizzimo 100 W/m^{2*}	42 ab	45 a	4 a	5 b	4 a	0 b
Sonata 100 W/m^{2*}	25 b	48 a	6 a	16 a	1 a	4 a

* for the plants, where only the yield was measured

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

4.3.4 Interior quality of yield

4.3.4.1 Sugar content

Sugar content of strawberries was measured on 16.01.2017. Sugar content was with 12 significantly highest for Delizzimo at the higher light intensity. At the lower light intensity and Sonata at both light intensities were much lower values of 8-10 reached (Fig. 20).

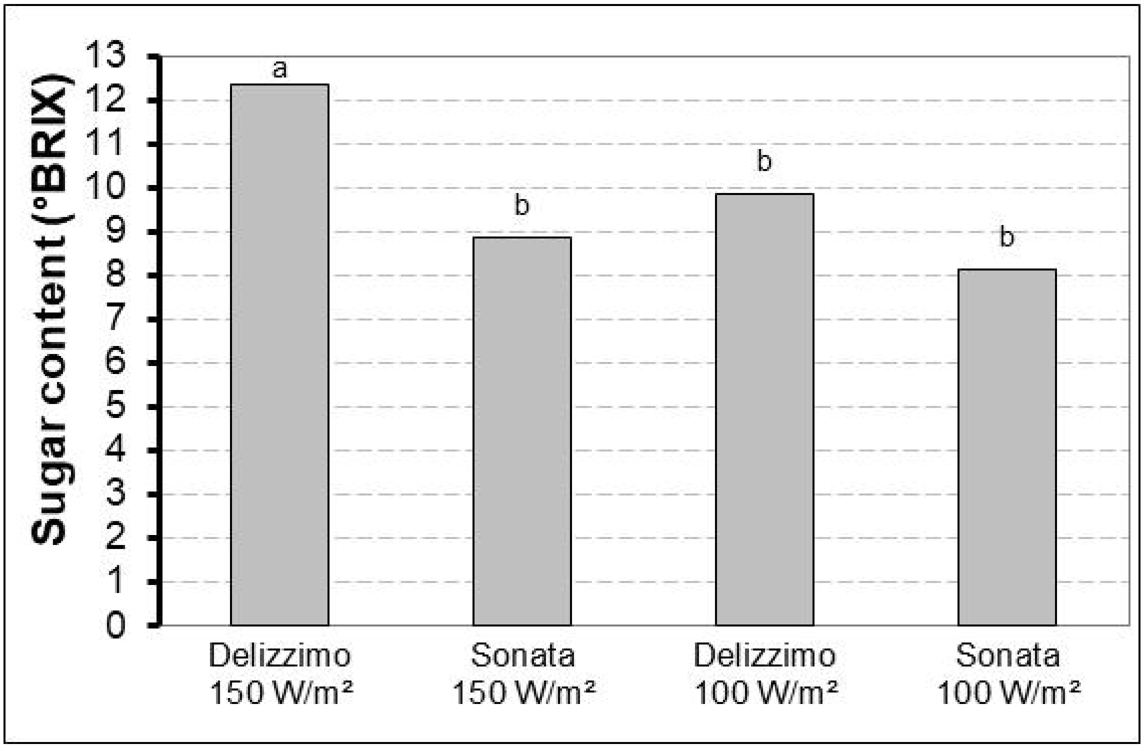


Fig. 20: Sugar content of strawberries.

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

4.3.4.2 Taste of strawberries

The taste of strawberries, subdivided into sweetness, flavour, juiciness and firmness was tested by untrained assessors on 17.01.2017. The rating within the same sample was varying very much and therefore, same treatments resulted in a high standard deviation. It seems that a higher light intensity did not influence the sweetness, juiciness and firmness of strawberries, while the flavour seems to be better at a higher light intensity. It seems that Delizzimo and Sonata got similar grades (Fig. 21a).

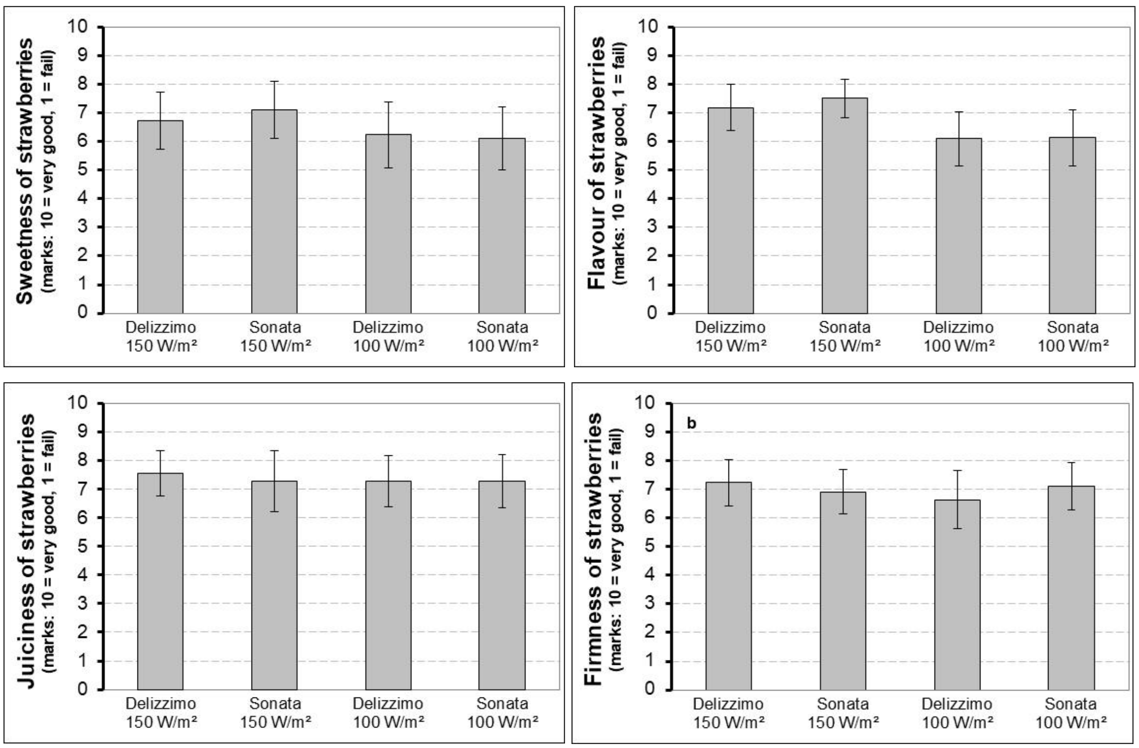


Fig. 21: Sweetness, flavour, juiciness and firmness of strawberries.

4.3.4.3 Dry substance of fruits

Dry substance (DS) of strawberries was measured on 16.01.2017. Delizzimo at the higher light intensity reached with 12 the highest dry substance content. The dry substance content of Delizzimo at the lower light intensity and of Sonata was with 9-10 significantly lower (Fig. 22).

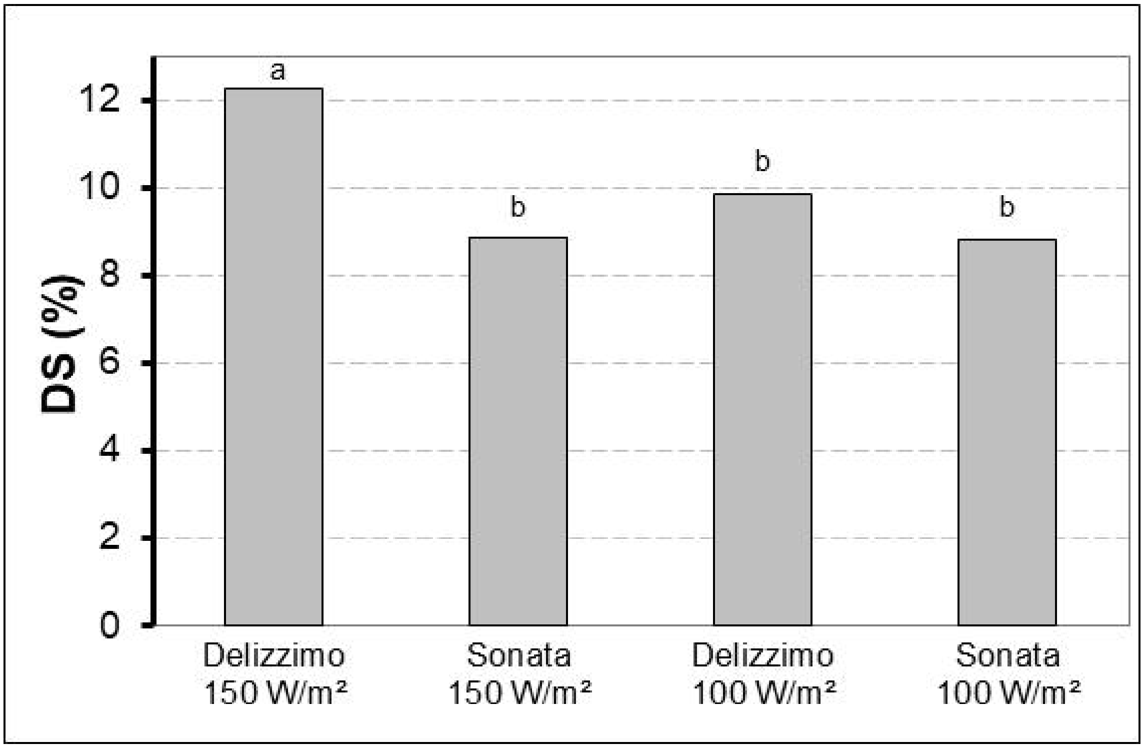


Fig. 22: Dry substance of strawberries.

4.3.4.4 Relationship between dry substance and sugar content of fruits

There was observed a relationship between dry substance and sugar content of fruits. A higher dry substance was involved with a higher sugar content (Fig. 23).

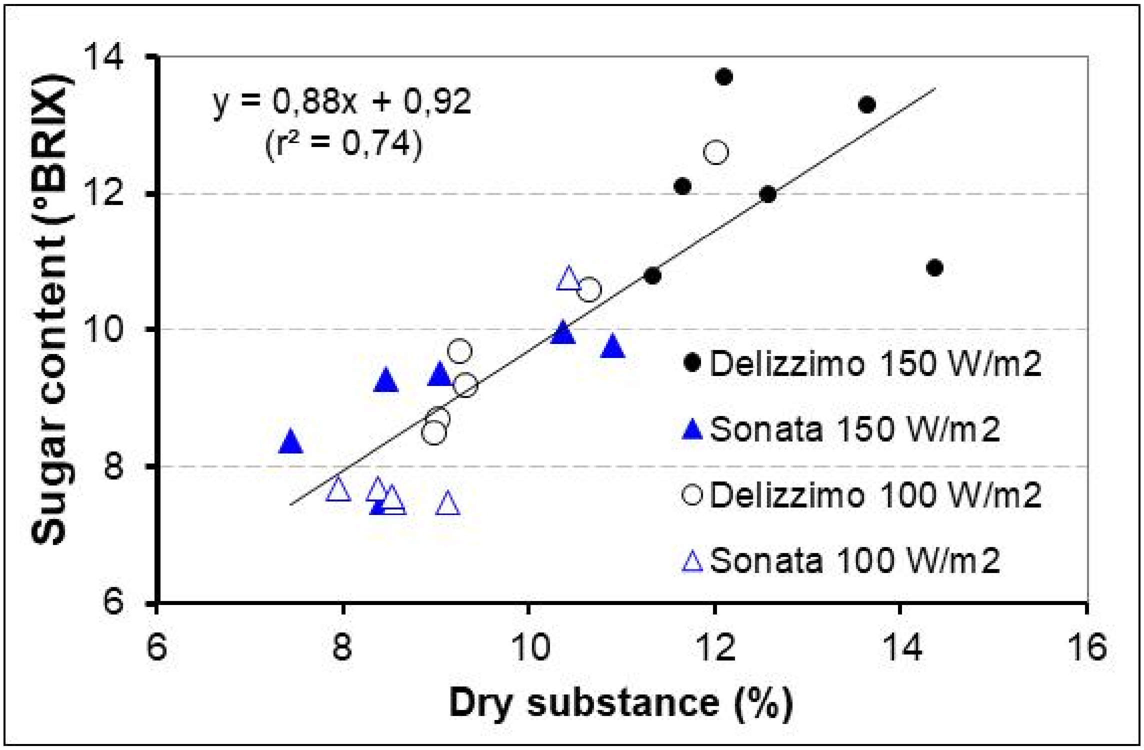


Fig. 23: Relationship between dry substance and sugar content of fruits.

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. 6). Therefore, the simulated value was higher. 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 higher for the measured values than for the simulated ones.

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

Treatment	Hours	Power	Energy	Energy/m²
	h	W	kWh	kWh/m²
HPS 150 W/m²				
Measured values	1.730	216	18.668	373
Simulated values				
0 % more power consumption (nominal)	1.888	150	14.159	283
6 % more power consumption	1.888	159	15.008	300
10 % more power consumption	1.888	165	15.575	311
HPS 100 W/m²				
Measured values	1.698	145	12.311	246
Simulated values				
0 % more power consumption (nominal)	1.888	100	9.439	189
6 % more power consumption	1.888	106	10.006	200
10 % more power consumption	1.888	110	10.383	208

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 64,8 % (before 87 %) and 69,2 % (before 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. 6), for the cabinets the energy costs per m^2 during the time of the experiment for the growers were calculated (Tab. 7).

The energy costs per kWh are for distribution after subsides 1,77-1,85 ISK/kWh for „VA210“ and 2,99-3,12 for „VA230“, 1,53-1,63 ISK/kWh for „VA410“ and 2,13-2,34 ISK/kWh for „VA430“. The energy costs for sale are for „Afltaxti“ 6,09-6,29 ISK/kWh and for „Orkutaxti“ 7,99-8,16 ISK/kWh.

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

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

Treatment	Costs for consumption							
	Energy ISK/kWh				Energy costs with subsidy per m² ISK/m²			
	Delizzimo 150 W/m² Sonata 150 W/m²		Delizzimo 100 W/m² Sonata 100 W/m²		Delizzimo 150 W/m² Sonata 150 W/m²		Delizzimo 100 W/m² Sonata 100 W/m²	
	real	calculated	real	calculated	real	calculated	real	calculated
DISTRIBUTION								
RARIK Urban					64,8 % subsidy from the state			
VA210						501		334
	1,85	1,77	1,87	1,77	692	531	461	354
						552		368
VA410						434		289
	1,61	1,53	1,63	1,53	603	460	402	307
						477		318
RARIK Rural					69,2 % subsidy from the state			
VA230						848		565
	3,10	2,99	3,12	2,99	1.157	899	769	599
						932		622
VA430						602		401
	2,20	2,13	2,21	2,13	821	638	545	426
						662		422
SALE								
Afltaxti	6,29	6,09	6,34	6,09		1.724		1.149
Orkutaxti	8,15	7,99	8,16	7,99	2.350	1.828	1.561	1.218
						1.897		1.264

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 January 2018.

4.4.3 Costs of electricity in relation to yield

Costs of electricity in relation to yield for wintergrown strawberries were calculated (Tab. 8). While for the distribution several tariffs were possible, for the sale only the cheapest tariff was considered. The yield of the plants, where only the yield (and no other measurements were done) was used for the calculation, because it seems that the yield was decreased when plants and clusters were touched very often due to measurements.

The costs of electricity per kg yield decreased by around 2/3 for Sonata with a higher light intensity. However, with Elsanta the cost of electricity per kg yield were nearly not influenced by light intensity (Tab. 8).

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

	Variable costs of electricity per kg yield ISK/kg							
Treatment	Delizzimo 150 W/m²		Sonata 150 W/m²		Delizzimo 100 W/m²		Sonata 100 W/m²	
Yield kg/m²	2,0		4,2		1,3		1,9	
	real	calculated	real	calculated	real	calculated	real	calculated
Urban area (Distribution + Sale)								
VA210	1.512	1.106 1.172 1.217	730	534 566 588	1.571	1.153 1.222 1.268	1.083	794 842 874
VA410	1.467	1.073 1.137 1.180	709	518 549 570	1.526	1.118 1.185 1.230	1.051	770 816 847
Rural area (Distribution + Sale)								
VA230	1.743	1.278 1.355 1.406	842	617 655 679	1.811	1.332 1.412 1.466	1.248	918 973 1.010
VA430	1.576	1.156 1.225 1.272	761	559 592 614	1.637	1.205 1.278 1.326	1.128	830 880 913

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. 23). A higher light intensity increased the revenues and Sonata had higher revenues than Delizzimo.

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. 7). Among others, this are e.g. the costs for the plant itself (≈ 1.200 ISK/m^2), soil (≈ 550 ISK/m^2), gutters and other material (≈ 50 ISK/m^2), costs for plant protection (≈ 100 ISK/m^2) and beneficial organism (≈ 1.160 ISK/m^2), plant nutrition (≈ 50 ISK/m^2), CO_2 transport (≈ 150 ISK/m^2), liquid CO_2 (≈ 1.000 ISK/m^2), the rent of the tank (≈ 150 ISK/m^2), the rent of the green box (≈ 50 ISK/m^2), material for packing (≈ 120 ISK/m^2) and transport costs from SfG (≈ 40 ISK/m^2) (Fig. 24).

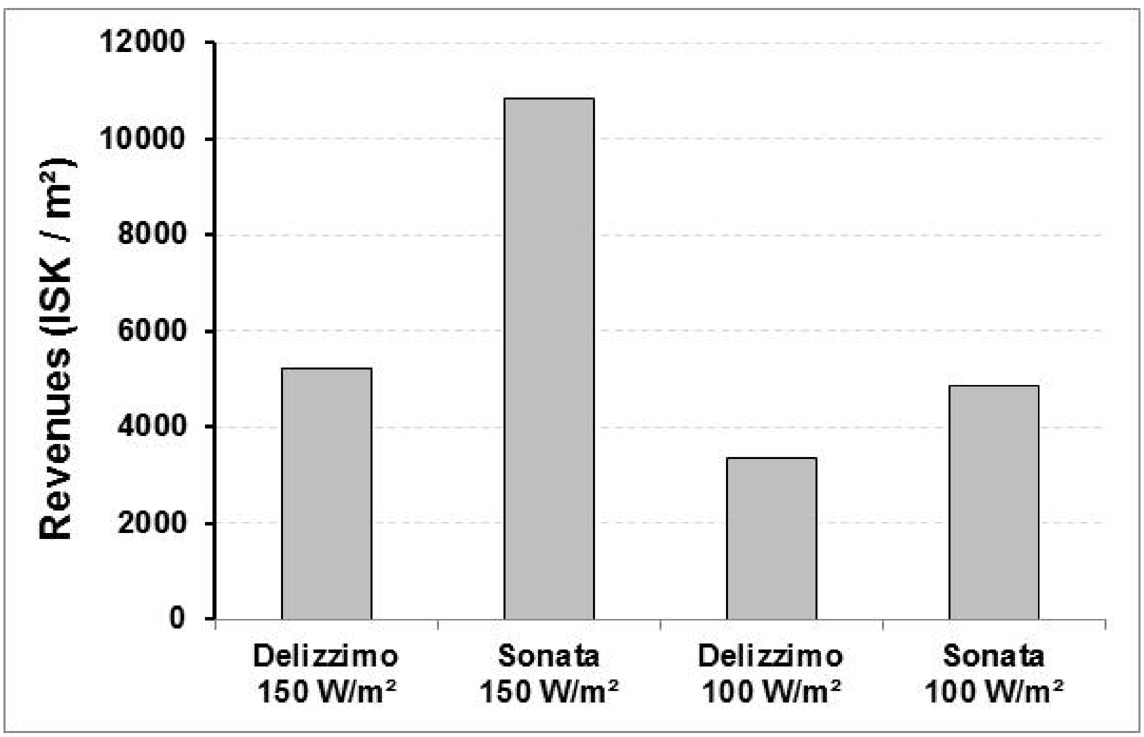


Fig. 24: Revenues at different treatments.

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

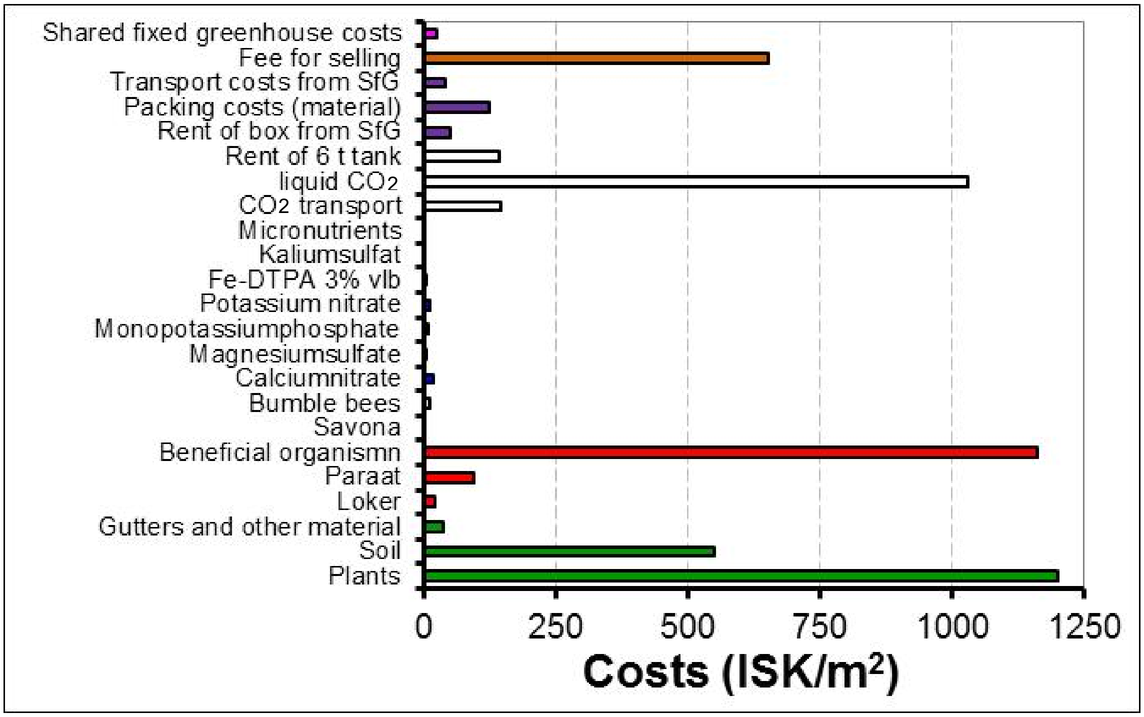


Fig. 25: Variable and fixed costs (without lighting and labour costs).

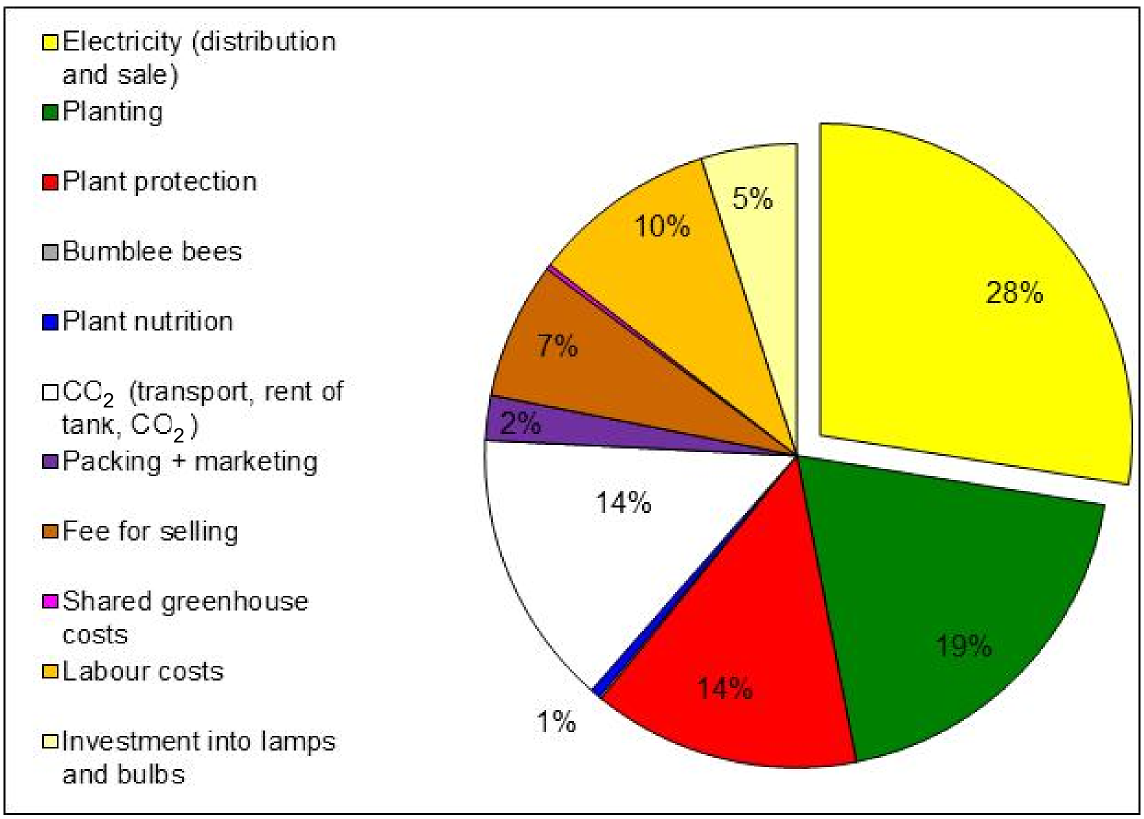


Fig. 26: Division of variable and fixed costs.

planting, plant protection and CO_2 costs. The proportion of the fee for selling the strawberries on the total costs is especially high at high yielding strawberries.

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

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

Treatment	Delizzimo 150 W/m²	Sonata 150 W/m²	Delizzimo 100 W/m²	Sonata 100 W/m²
Marketable yield kg/m²	2,0	4,2	1,3	1,9
Sales				
SfG (ISK/kg) [1]	2.600	2.600	2.600	2.600
Revenues (ISK/m²)	**5.232**	**10.830**	**3.346**	**4.857**
Variable and fixed costs (ISK/m²)				
Electricity distribution [2]	692	692	461	461
Electricity sale	2.350	2.350	1.561	1.561
Strawberry plants [3]	1.197	1.200	1.197	1.200
Soil for strawberries [4]	550	550	550	550
Pots [5]	7	7	7	7
Tape [6]	3	3	3	3
Gutters [7]	28	28	28	28
Loker [8]	14	28	14	28
Paraat [9]	62	146	62	146
Savona soap [10]	1	1	1	1
Beneficial organismn [11]	1.160	1.160	1.160	1.160
Bumble bees [12]	12	12	12	12
Calcium nitrate [13]	23	8	27	9
Potassium sulfate [14]	0	1	0	1
Fe-DTPA 3% vlb [15]	0	7	0	8
Monopotassium phosphate [16]	8	9	9	10
Magnesium sulphate [17]	4	5	5	5
Potassium nitrate [18]	11	12	12	13
Micronutrients [19]	0	1	0	1
CO_2 transport [20]	146	146	146	146
Liquid CO_2 [21]	1.029	1.029	1.029	1.029
Rent of CO_2 tank [22]	144	144	144	144
Rent of box from SfG [23]	42	87	27	39
Packing material [24]	107	221	68	99
Fee for SfG [25]	563	1.166	360	523
Transport from SfG [26]	35	73	23	33
Shared fixed costs [27]	24	24	24	24
Lamps [28]	357	357	238	238
Bulbs [29]	190	190	127	127
∑ variable costs	**8.760**	**9.636**	**7.295**	**7.583**
Revenues -∑ variable costs	**-3.528**	**1.194**	**-3.949**	**-2.726**
Working hours (h/m²)	0,53	0,69	0,48	0,52
Salary (ISK/h)	1.594	1.594	1.594	1.594
Labour costs (ISK/m²)	843	1.095	758	826
Profit margin (ISK/m²)	**-4.371**	**98**	**-4.707**	**-3.552**

[1] price winter 2016/2017: 2.600 ISK/kg
[2] assumption: urban area, tariff “VA210”, no annual fee (according to datalogger values)
[3] 100 ISK / strawberry plant
[4] 66.000 ISK / 4,5 m^3 soil
[5] 54 ISK / pot; assumption: 10 years life time, 3 circles / year
[6] 4.250 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] 25.500 ISK / 5 l Loker; assumption: spraying once per week (~ 8 times per growing season)
[9] 29.950 ISK / bund Paraat; assumption: spraying once per growing season, 400 ml / pot
[10] 8.800 ISK / 5 l Savona soap; assumption: spraying one time per growing season
[11] beneficials: 7.876 ISK / unit Aphidius ervi (parasitic wasp), three times
4.850 ISK / unit Orius laevigatus (predatory bug), two times
2.050 ISK / unit Aphidius colemani (parasitic wasp), once
2.850 ISK / unit mix of the parasitic wasp species Aphidius colemani, Aphidius ervi, Aphelinus abdominalis, Praon volucre and Ephedrus cerasicola, 6 times
1.690 ISK / unit Phytoseiulus persimilis (predatory mite), 7 times
[12] 4.900 ISK / unit bumble bees
[13] 2.750 ISK / 25 kg Calcium nitrate
[14] 3.550 ISK / 25 kg Potassium sulphate
[15] 17.050 ISK / 25 kg Fe-DTPA 3% vlb
[16] 7.050 ISK / 25 kg Monopotassium phosphate
[17] 1.700 ISK / 25 kg Magnesium sulfate
[18] 4.175 ISK / 25 kg Potassium nitrate
[19] 33.900 ISK / 5 kg micronutrients
[20] CO_2 transport from Rvk to Hveragerði / Flúðir: 8,0 ISK/kg CO_2
[21] liquid CO_2: 45,0 ISK/kg CO_2
[22] rent for 6 t tank: 72.000 ISK/month, assumption: rent in relation to 1.000 m^2 lightened area
[23] 90 ISK / box
[24] packing costs (material):
costs for packing of strawberries (0,20 kg): box: 4 ISK / 0,20 kg,
lid: 5 ISK / 0,20 kg,
label: 2 ISK / 0,20 kg
[25] fee for SfG for selling the strawberries: 56 ISK / 0,20 kg
[26] transport costs from SfG: 2.652 ISK / board
[27] 94 ISK/m^2/year for common electricity, real property and maintenance
[28] HPS lights: 30.000 ISK/lamp, life time: 8 years
[29] HPS bulbs: 4.000 ISK/bulb, life time: 2 years

The profit margin was dependent on the treatment (Fig. 27). Due to a low yield, was the profit margin for Delizzimo always negative (around -4.500 ISK/m^2). Also, Sonata had a negative profit margin of -3.500 ISK/m^2 for the lower light intensity and a profit margin of about zero for the higher light intensity. The profit margin was higher for Sonata compared to Delizzimo.

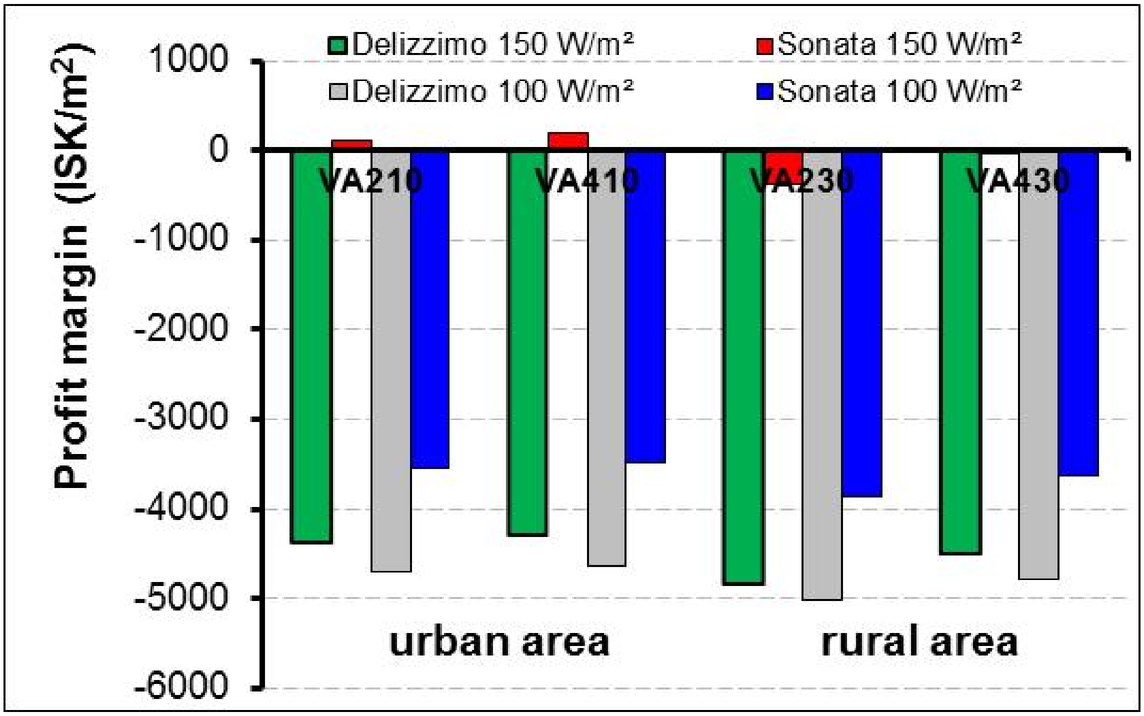


Fig. 27: Profit margin in relation to tariff and treatment.

The profit margin for Delizzimo with about -4.400 ISK/m^2 was higher at the higher light intensity and about 300 ISK/m^2 lower for the lower light intensity. And for Sonata with about 100 ISK/m^2 highest at the higher light intensity and about 3.700 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 300 ISK/m^2 for Delizzimo and by 3.700 ISK/m^2 for Sonata. Also, the use of Sonata instead of Delizzimo increased the profit margin by 4.500 ISK/m^2 at the higher light intensity and by 1.200 ISK/m^2 at the lower light intensity. 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 nearly not matter if the greenhouse is situated in an urban or rural area, however, there was an small advantage for the urban area (Fig. 27).

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 of Delizzimo and Sonata 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. Also, *Stadler* (2016a) counted a higher number of flowers of Sonata at 150 W/m^2 compared to 100 W/m^2. *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 were values of 0,18-1,13 % for Delizzimo and 1,07-2,46 % for Sonata found and are with that in the range of the above mentioned ones. But, in the chamber with the lower light intensity was the infection with mildew higher than in the chamber with the higher light intensity, resulting in a lower marketable yield. However, with a lower value of infection with mildew, mentioned *Stadler* (2016a, 2016c) lower values of 0,2-0,4 % for Sonata for 1 % increase of light intensity.

The reason for the higher yield of more than 10 % at the higher light intensity was a tendentially increased number of harvested fruits. The number of extra class fruits and also the 1st and 2nd class fruits were higher at the higher light intensity. In addition, the marketable fruits at the higher light intensity were 0,85 g heavier than at the lower light intensity. Also, *Stadler* (2016a, 2016c) reported that the reason for the higher yield at 150 W/m^2 compared to 100 W/m^2 was an increased number of harvested extra class strawberries and in addition in the spring / summer experiment, to a smaller extend, a higher average weight of strawberries. Again, 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. Also, *Hidaka* et al. (2013) concluded that accelerated photosynthesis promoted plant growth, as manifested by increases in leaf weight and LAI, leading to increased fruits weight, number of fruits and marketable yield. The LAI was not observed in the presented experiment, but the number of leaves was tendentially higher at the higher light intensity. 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. Indeed, *van Delm* et al. (2016) reported that the total yield of strawberries in Belgium decreased with lower light intensities or reduced operation hours and concluded that the regulation of temperature and lighting strategy seems to be important for plant balance between earliness and total yield.

Van Delm et al. (2016) hypothesized that when total yield of strawberries was comparable between lighted and unlighted plants, was the advancement of the harvest more pronounced. When there is a strong increase in yield between lighted and unlighted plants is the difference in earliness smaller. This is fitting to the results of the presented study, as a more than 10 % higher yield was reached at the higher light intensity, but in contrast was there only a small difference of few days in the earliness of the ripening of the strawberries between light intensities.

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 due to moldy fruits, 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 16 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. For Sonata resulted the higher light intensity 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 50 W/m² resulted in a yield increase of 2,3 kg/m² and this was reflected in an increase of profit margin of 3.700 ISK/m². However, for Delizzimo resulted an increase of the light intensity from 100 W/m² to 150 W/m² in a yield increase of 0,7 kg/m² and this was reflected in an increase of profit margin of 300 ISK/m².

When the yield of the higher light intensity would have been 1,7 kg lower for Sonata, 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 1,8 kg/m^2 higher yield for Sonata at 150 W/m^2 compared to 100 W/m^2 (Fig. 28).

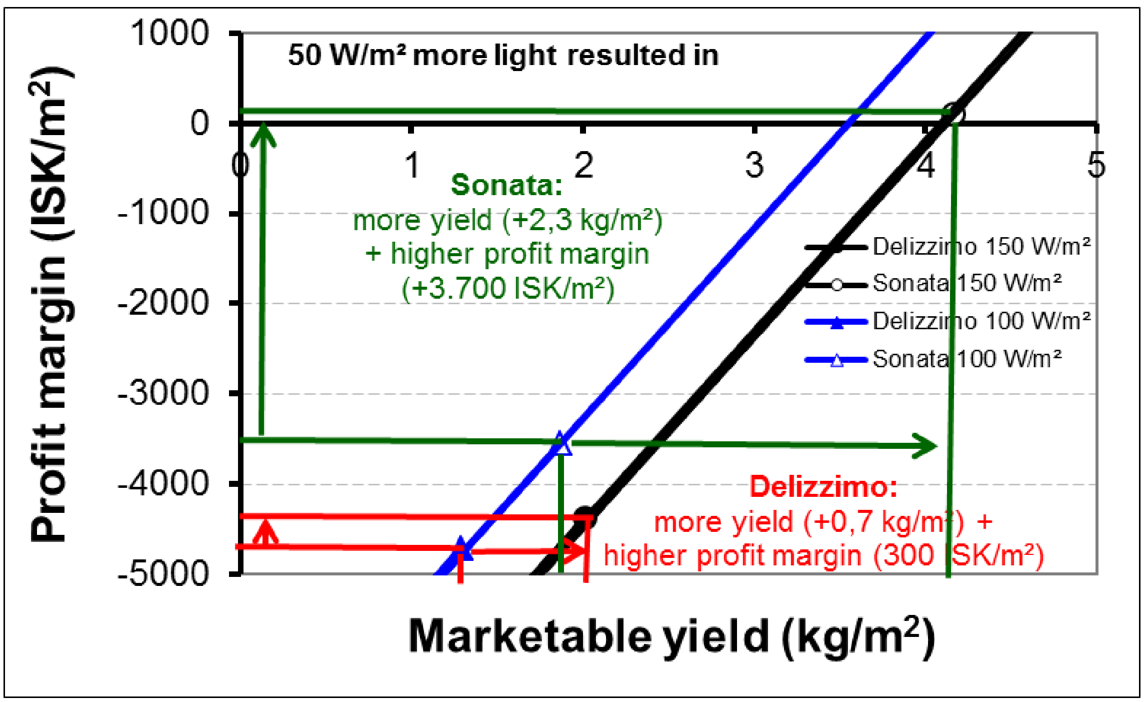


Fig. 28: Profit margin in relation to yield with light intensity – calculation scenarios (urban area, VA210).

When the yield of the higher light intensity would have been 0,3 kg lower for Delizzimo, 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 0,4 kg/m^2 higher yield for Delizzimo at 150 W/m^2 compared to 100 W/m^2 (Fig. 28).

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.

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/m²). These yield increases were achieved without adversely affecting mean fruit size.

In addition, at higher light intensity was for Delizzimo a higher sugar content and a higher dry matter content found compared to the lower light intensity. However, this was not confirmed with Sonata, where the sugar content seemd to be independent of the light intensity.

5.2 Yield in dependence of the variety

It is known, that different varieties of strawberries naturally result in different yield levels. Sonata is the most used variety for winter greenhouse cultivation under lights in Iceland. In contrast, Delizzimo and everbearers in general have never been tested in commercial production in Iceland.

Due to the fact that Sonata is a junebearer and Delizzimo an everbearer, it is obvious that their behaviour towards the production of flowers and fruits is different. During the time of the experiment, produced Delizzimo less fruits compared to Sonata. Fruits of Delizzimo were about one week earlier ripe than Sonata. In addition, was an advantage reached, when the higher light intensity was choosen, however, this was more pronounced for Delizzimo (41 days at the lower light intensity, 35 days at the higher light intensity) compared to Sonata (45 days at the lower light intensity, 47 days at the higher light intensity). *Stadler* (2016c) found comparable values for Sonata.

For everbearer is the yield period longer than with junebearers, however with less harvest per week. At the higher light intensity was the marketable yield per plant higher for Sonata compared to Delizzimo, while at the lower light intensity was a tendentially higher yield reached with Delizzimo. However, it has to be taken into account that Delizzimo had half of the amount of the Sonata plants in the pot. Therefore, if the yield is evaluated on the basis of plants per squaremeter, is the yield of Sonata higher. Over the whole harvest period gave Sonata at the higher light intensity a more than 100 % higher yield (per m^2) and at the lower light intensity a more than 45 % higher yield compared to Delizzimo. The yield level of Delizzimo was with 0,15 kg/m^2/week much below the one that was measured in the Netherlands of 0,4-0,6 kg/m^2/week (*Dings*, personal communication).

It also has to be mentioned that everbearers do not grow well in constant wet substrate, which has been the case during part of the experiment. This might also have been attributed to the low yield of Delizzimo. After the water level has been changed to normal values, an increase in yield of Delizzimo was observed, however, much below the values that were reported in the Netherlands from *Dings* (personal communication).

Due to this low yield of Delizzimo, even the waiting period for Sonata to get ripe fruits after changing the plants would not justify the use of Delizzimo instead of Sonata. It seems therefore not recommended to change to plant everbearers instead of junebearers and come with that around of changing the plants of junebearers after six weeks harvest as it has been done so far in Iceland.

While there were no differences between the varieties in the extra class fruits, was the number of 1^{st} and 2^{nd} flass fruits most of the time significantly higher for Sonata compared to Delizzimo. However, Delizzimo had 2 g heavier fruits than Sonata. (Delizzimo: 45% fruits larger than 25 mm, 44 % fruits smaller then 25 mm; Sonata: 28 % fruits larger than 25 mm, 55 % fruits smaller then 25 mm). There were more misshapened fruits at Delizzimo than at Sonata, whereas Sonata had more moldy fruits.

By the selection of Sonata instead of Delizzimo can the yield and the profit margin be increased: At the lower light intensity resulted the use of Sonata in a 0,6 kg/m^2 higher yield, which was reflected in a 1.200 ISK/m² higher profit margin (Fig. 29). Again, when a higher light intensity together with Sonata instead of Delizzimo is selected, a

2,2 kg/m^2 higher yield and a 4.500 ISK/m^2 higher profit margin is possible. This means, it is not only paying of to select a higher light intensity, but also to choose the junebearer Sonata. The advantage of Sonata compared to the everbearer Delizzimo was especially paying of at a higher light intensity.

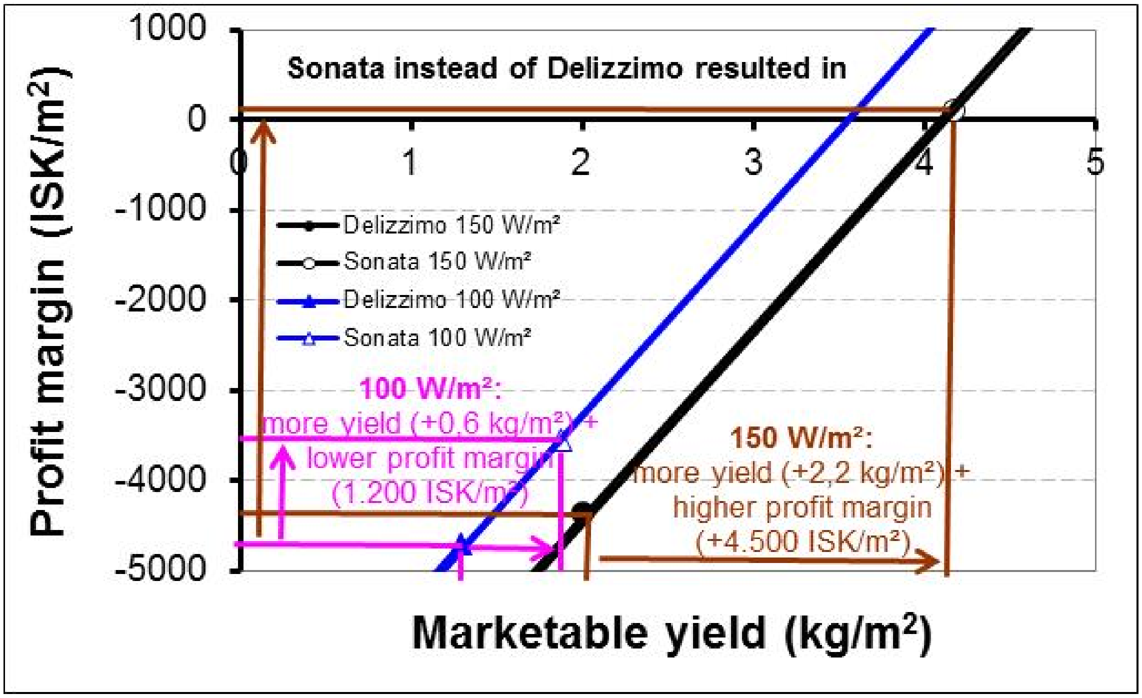


Fig. 29: Profit margin in relation to yield with different varieties – calculation scenarios (urban area, VA210).

Proefcentrum Hoogstraten (2016) measured an increasing sugar content from 7,4 to 8,7 with an average of 7,6°Brix for Sonata, while the Brix content decreased to the middle of the harvest period and increased again to the end of the harvest period and with an average of 6,3°Brix. The changes in the Brix content might also be the reason, why in the present experiment were no differences found between Sonata and Delizzimo at the low light intensity. This makes it necessary to take more regulary samples in further experiments to be able to detect possible differences in the sugar content between varieties. However, at the higher light intensity was the sugar content of Delizzimo significantly higher than of Sonata. The reason for that may lay in the higher DS content at Delizzimo compared to Sonata at the higher light intensity.

Even though Sonata is evaluated with high grades (In total got the fruit assessment of Sonata a high score of 82,3 % with high grades particularly at “bruising skin”, “colouring” and “regularity (shape)”) compared to other junebearers (*Proefcentrum Hoogstraten*, 2016), was the everbearer Delizzimo evaluated with higher grades (*ABZ Seeds,* without year).

5.3 Future speculations concerning energy prices

In terms of the economy of lighting it is also worth to make some future speculations about possible developments also regarding the fact that the subsidy has been decreased by more than 20 %. So far, the lighting costs (electricity + bulbs) are contributing to a big part 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. 30).

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 -5.600 to -1.200 ISK/m^2 (black columns, Fig. 30). 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 -5.200 to 700 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 -4.200 to 900 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. Referring to the reduction of the subsidity of 20 % from the year 2017 to the year 2018, it is obvious that actions must be taken, that growers are also producing during the winter at low solar irradiation. It is also showing clearly, that it is only paying of to produce strawberries during the winter in Iceland, when a high yield is guarantied.

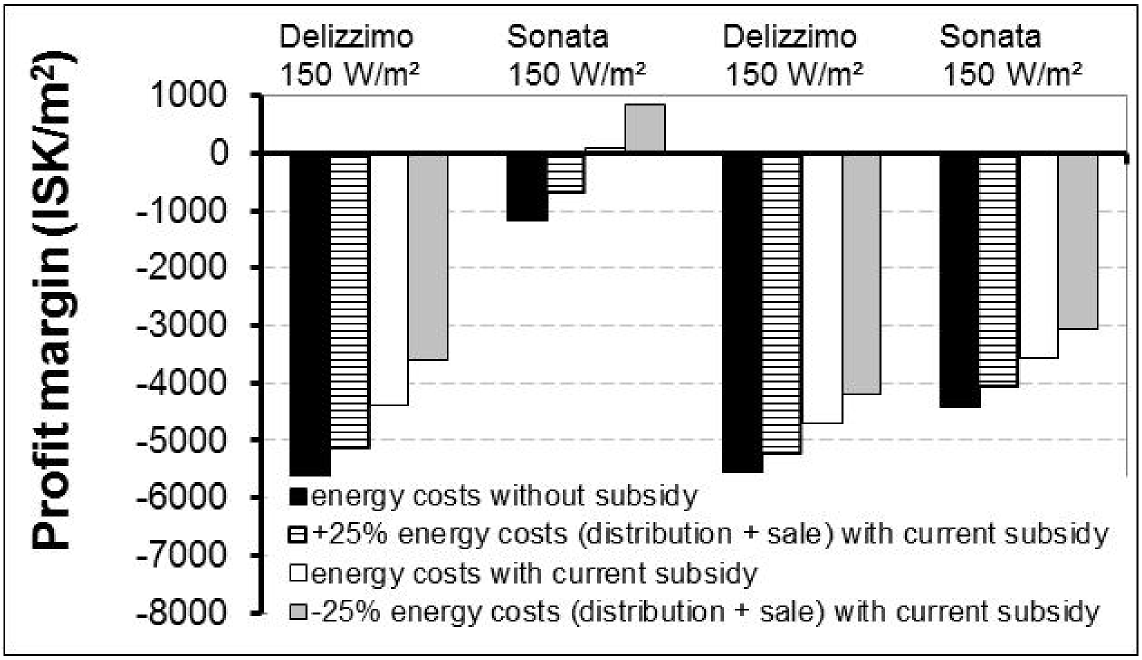


Fig. 30: Profit margin in relation to treatment – calculation scenarios (urban area, VA210).

5.4 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. This is especially important when a high yield is expected, because then the proportion of the fee for selling the strawberries through SfG is contributing to ¼ of the production costs. Therefore, it would be profitable for the grower to choose other channels of distribution.

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.

   According to the presented results, seems it not to pay off to use everbearers, and with that decreasing the planting costs by making it unnecessary to plant strawberries in about three months intervals as for junebearers due to a low yield. Also, with using everbearers it would not be possible to clean the greenhouse in between which is especially important if the crop has aphids or plant diseases.

3 Selection of a good plants

   Not only the variety, but also within a variety yield differences are possible. Therefore, it is necessary to select first of all plants with a high yield guaranty. Beside that is the choose of the variety also important and can result in a profit margin that is more than 1.500 ISK/m^2 higher.

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 0,7 kg/m^2 and an increase of profit margin of 300 ISK/m^2 for Delizzimo and a yield increase of 2,3 kg/m^2 and an increase of profit margin of 3.700 ISK/m^2 for Sonata. Therefore, from the economic side it seems to be recommended to provide 50 W/m^2 more light. Due to the low yield of the everbearer Delizzimo compared to the junebearer Sonata seems it to be not recommended to change to everbearers and come with that around of changing the plants of junebearers after six weeks harvest. Also, from the point of phytosanitary issues seem everbearers not recommended.

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	
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**	**tasks**	**observations / problems**
24. okt	planting Sonata		planting Sonata			
25. okt					planting Delizzimo (2 plants per pot, clusters showing to the end of the pot)	plants are very different in quality, brownish roots, few white roots
26. okt						
27. okt	moving Delizzimo into chamber, light: 05.00-19.00, 03.00 floor heat on (35 °C), 16 °C day		moving Delizzimo into chamber, light: 05.00-19.00, 03.00 floor heat on (35 °C), 16 °C day			
28. okt	Paraat		Paraat			
29. okt						
30. okt						
31. okt		plants starting to root		plants starting to root		
1. nov						
2. nov	Spidex		Spidex			
3. nov						
4. nov		Delizzimo plants light green, Sonata darker		Delizzimo plants light green, Sonata darker		
5. nov						
6. nov						
7. nov		roots developing, Sonata starting to show flowers, more flowers are coming at Delizzimo		roots developing, Sonata starting to show flowers, more flowers are coming at Delizzimo		
8. nov	Spidex		Spidex			
9. nov						
10. nov						
11. nov						

	150 W/m²		100 W/m²		Chamber for the first 4 weeks	
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**	**tasks**	**observations / problems**
12. nov						
13. nov						
14. nov						
15. nov	new hives	Sonata developing very well, nearly no development at Delizzimo	new hives	Sonata developing very well, nearly no development at Delizzimo		
16. nov						
17. nov						
18. nov						
19. nov						
20. nov						
21. nov	misting system set up		misting system set up			
22. nov	Spidex, measurements	many dead bumblee bees on the floor, plants wet under humidity sprinklers, Sonata developing very well, not much development in Delizzimo, powdery mildew starting	Spidex, measurements	many dead bumblee bees on the floor, plants wet under humidity sprinklers, Sonata developing very well, not much development in Delizzimo, powdery mildew starting		
23. nov						
24. nov	Loker		Loker			
25. nov						
26. nov						
27. nov	light for 16 h			light for 16 h		
28. nov	measurements		measurements	one bulb not working		
29. nov	Spidex		Spidex			
30. nov						
1. dec	harvest Delizzimo, Loker		harvest Delizzimo, Loker			

	150 W/m²		100 W/m²		Chamber for the first 4 weeks	
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**	**tasks**	**observations / problems**
2. dec						
3. dec						
4. dec						
5. dec	measurements, harvest Delizzimo, Savona	mildew has increased	measurements, harvest Delizzimo, Savona	mildew has increased, ventilation not working		
6. dec						
7. dec	Orius laevigatus		Orius laevigatus			
8. dec	Loker		Loker			
9. dec						
10. dec						
11. dec						
12. dec	measurements, harvest Delizzimo	mildew has increased, Delizzimo is getting better, leaves have stretched	measurements, harvest Delizzimo	mildew has increased, Delizzimo is getting better, leaves have stretched		
13. dec						
14. dec						
15. dec	Spidex, harvest		Spidex, harvest			
16. dec	Loker		Loker			
17. dec						
18. dec						
19. dec	measurements, harvest Delizzimo, watering increased in the morning	Sonata pots are very dry	measurements, harvest Delizzimo, watering increased in the morning	Sonata pots are very dry		
20. dec	Spidex		Spidex			
21. dec						
22. dec	harvest Delizzimo, first harvest Sonata	mildew seems to get better, Sonata plants look better	harvest Delizzimo	mildew seems to get better, Sonata plants look better		
23. dec	Loker		Loker			

	150 W/m²		100 W/m²		Chamber for the first 4 weeks	
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**	**tasks**	**observations / problems**
24. dec						
25. dec						
26. dec						
27. dec	harvest, measurements	Delizzimo seems wet, mildew is getting better	harvest, measurements	Delizzimo seems wet, mildew is getting better		
28. dec						
29. dec						
30. dec	harvest, Loker	mildew much better	harvest, Loker	mildew much better		
31. dec						
1. jan						
2. jan	harvest, measurements	mildew has increased again	harvest, measurements	mildew has increased again		
3. jan						
4. jan						
5. jan	harvest		harvest			
6. jan	Loker		Loker			
7. jan						
8. jan						
9. jan	harvest		harvest			
10. jan	measurements	leaf scorch	measurements	leaf scorch	planting new Sonata	
11. jan						
12. jan	harvest		harvest			
13. jan						
14. jan						
15. jan						
16. jan	harvest, measurements, water samples taken		harvest, measurements, water samples taken			
17. jan	new hives, aphiscout		new hives, aphiscout			
18. jan						
19. jan	harvest		harvest			

	150 W/m^2		100 W/m^2		Chamber for the first 4 weeks	
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**	**tasks**	**observations / problems**
20. jan						
21. jan						
22. jan						
23. jan	harvest, measurements		harvest, measurements			
24. jan						
25. jan						
26. jan	harvest		harvest			
27. jan	Loker		Loker			
28. jan						
29. jan						
30. jan	harvest, measurements		harvest, measurements			
31. jan	Spidex		Spidex			
1. feb						
2. feb	harvest, throwing old Sonata plants out of chamber		harvest, throwing old Sonata plants out of chamber			
3. feb						
4. feb						
5. feb						
6. feb	harvest, measurements, moving new Sonata plants into chamber		harvest, measurements, moving new Sonata plants into chamber			
7. feb						
8. feb						
9. feb	harvest		harvest			
10. feb						
11. feb						
12. feb						
13. feb	harvest, measurements		harvest, measurements			
14. feb						
15. feb						
16. feb	harvest		harvest			
17. feb						

	150 W/m²		100 W/m²		Chamber for the first 4 weeks	
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**	**tasks**	**observations / problems**
18. feb						
19. feb						
20. feb	harvest, measurements		harvest, measurements			
21. feb						
22. feb						
23. feb	harvest		harvest			