Horticultural Lighting in the Netherlands: New Developments

E. Heuvelink and M.J. Bakker
Wageningen University
Horticultural Production Chains group
Marijkeweg 22, 6709 PG Wageningen
The Netherlands

L. Hogendonk, J. Janse, R. Kaarsemaker and R. Maaswinkel
Applied Plant Research
P.O. Box 8, 2670 AA Naaldwijk
The Netherlands

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Abstract

In the Netherlands about 2000 ha of glasshouses is equipped with supplementary assimilation light (SL), which is about 19% of the total glasshouse area. Besides increased production, SL results in improved product quality, a better control of yield and quality, possibilities for earlier or year-round production and a more regular labor requirement. In this paper several recent experiments with different strategies of SL (33 up to 210 µmol m^{-2} s^{-1}) for tomato, sweet pepper, cucumber and eggplant are presented and discussed. In general, it was concluded that SL was not economically feasible. For cucumber SL can only be attractive if the crop is grown at high plant density and according to the high-wire system. Based on 3 plantings per year, a production of 147 kg m^{-2} (360 cucumbers) is possible with 210 µmol m^{-2} s^{-1} SL during 3000 h/year. Application of 50% of the light within the crop (interlighting) by fluorescent tubes instead of only HPS-lamps above the crop, did not improve production but improved fruit quality in cucumber. Mobile lamps are sometimes used instead of fixed lamps. For sweet pepper and tomato, a fixed-lamp installation was economically more feasible than mobile lamps when compared at the same light intensity. A dynamic simulation model was used to predict effects of different lighting strategies at 500 and 1000 ppm CO_2 on potential production. Maximum levels of 110, 64 and 168 kg m^{-2} $year^{-1}$ were calculated for tomato, sweet pepper and cucumber, respectively.

INTRODUCTION

The glasshouse industry in the Netherlands is the largest worldwide with 10.500 ha and a production value of 5.9 billion euro. About 40% of the glasshouse area is used for vegetable production, mainly tomato, sweet pepper and cucumber. Ornamentals, both cut flowers and pot plants are grown on the remaining 60%. Main cut flowers are roses and chrysanthemum, whereas ficus, kalanchoe and begonia are the most important pot plants considering cultivation area. Although the total glasshouse area is rather constant, the area of individual companies is growing fast. For vegetables, in 1995 442 companies (9% of the total) were larger than 2 ha, whereas in 2004 this was 686 (26% of the total). Among these are several companies larger than 20 ha. Annual production levels in the Netherlands belong to the highest in the world, e.g. for tomato (up to 70 kg m^{-2}), cucumber (up to 90 kg m^{-2}), large-sized cut roses under supplementary assimilation light (SL; 270 stems m^{-2}) and cut chrysanthemum under SL (250 stems m^{-2}). A major threat to the glasshouse industry is its high energy use. The equivalent of 4.3×10^9 m^3 of natural gas is used annually to heat the glasshouses, resulting in an average gas input of 41 m^3 m^{-2} $year^{-1}$. In 2002 the energy input per m^2 glasshouse was equal to the input in 1980, but the energy efficiency, i.e. the energy use per unit of produce doubled, as a result of increased yields per m^2 (Van der Knijff et al., 2004).

More than 2000 ha of glasshouses are equipped with SL, which substantially increases yield, but also energy use per m^2. This area is increasing by about 1%-point each year. SL is almost exclusively used in the production of ornamentals and in both vegetable and ornamental propagation. However, recently we see a rapid increase in the use of SL in vegetable production. Tomato production under SL is already more than 120 ha, for sweet pepper this is 60 ha, and for cucumber this is about 10 ha (Boonekamp, 2005). In this paper we focus on the use of SL in glasshouse vegetable production.

There are several reasons for the use of SL, besides an increase in production. SL makes year-round production possible, which is demanded by the markets and stimulates an efficient use of the investments in glasshouses. In winter, natural light levels are too low for production of fruit vegetables. Typically, a tomato or sweet pepper crop is planted mid-December, production starts early March and continues until mid-November. Natural light level around 21 December is about ten times lower than around 21 June, caused by a 5 times lower light intensity and a day length of only 7.5 h instead of 16.5 h. Therefore SL, representing a much larger part of total light in winter than in summer, results in a more regular production (Fig. 1) and labor demand year-round. Finally, SL can improve product quality (more assimilates produced) and it provides one more means to control yield and quality (Marcelis et al., 2002).

The number of crops produced with SL is still increasing, whereas also higher light intensities are applied compared to five years ago. When application of SL in vegetable production started, 600W/230V lights were used, just like in cut flower production. A big step forward was the development of 600W/400V lights. With the same input wattage, these produce 10% more photosynthetically active radiation (PAR; Visser, 2005). With such a modern installation it is possible to obtain an efficiency of about 30%, whereas in the early times of SL 1 W m^{-2} electric power going into the SL installation would result in only 0.22 W m^{-2} PAR. The most recent development is the use of 1000W lights. These are not more efficient, but fewer fixtures are needed per ha, hence reducing investment costs. A high glasshouse is needed, as 40% less lamps per ha can only result in a good horizontal light distribution if there is enough distance between lights and crop (Visser, 2005). Another development is the use of mobile lamps, where fewer lights and fixtures per ha are used. Lamps move along a line and thus plants receive a high light intensity for a short period, several times per day. It makes earlier fruit set possible (e.g. in sweet pepper; Heijboer en Selman, 2005), but light levels are too low for year-round production. As rather low average light levels are applied, effects of mobile lamps are very small in a dark year (minimum amount of light for early fruit set is not reached).

In this paper we present recent experimental data on the application of SL (fixed and mobile lamps). We also give results on interlighting in cucumber, where part of the SL is supplied between the plants instead of on top of the canopy. A simulation model is used to investigate potential production levels under different lighting strategies.

FIXED LAMPS IN SWEET PEPPER, EGGPLANT AND CUCUMBER

In the season 2001-2002 the following strategies were compared for sweet pepper ‘Special’ and ‘Oblix’ (Enza Seeds): control (no SL), 125 or 188 µmol m^{-2} s^{-1} high pressure sodium lamps (HPS) during 13 or 17 h. The crop was planted on 3 October (3.3 plants m^{-2}; 2 stems per plant) and SL was applied from the day of planting. This resulted in a too strong vegetative growth, and a plant completely out of balance. The same problem was observed for eggplant ‘Combo’ (Rijk Zwaan) receiving 188 µmol m^{-2} s^{-1} SL. Plants developed too vegetative, flower quality and fruit set was insufficient and yield between week 47 and week 8 was 600 g m^{-2} whereas 800 g m^{-2} per week was expected (Kaarsemaker and Van Steenpaal, 2004). Despite these sub-optimal conditions, sweet pepper yield increased with more hours of SL or higher intensity, as expected. Plants were less elongated and had more internodes, when SL was applied in fewer hours and with a higher intensity. SL did not influence average fruit weight, but the crop appeared to be more sensitive to mildew and a faster development of pest organisms was observed.

In the following season the same two light intensities were tested on sweet pepper ‘Special’ and ‘Fiesta’ (Enza Seeds), but lights were only used between sun rise and sun set. The crop was planted on 4 September and SL was applied from 18 October until 20 March. It was concluded that a better plant balance was maintained this time, with SL only during daytime. Higher light intensity improved yield by better fruit set (more fruits produced) and average fruit weight was hardly affected (Table 1). Economic calculations, based on the yields obtained in the experiment resulted in a cost price, even with an electricity price as low as € 0.04/kWh, of at least € 2.90 per kg sweet pepper harvested during the period in which SL was applied. This is substantially higher than what Dutch growers are expected to receive during that period.

In the season 2002-2003 SL was practiced in cucumbers with 125 or 188 µmol m^{-2} s^{-1} HPS for a maximum of 20 h per day. The planting dates in the traditional umbrella system were 1 October and 7 January and the second crop ended on 14 April. In the first planting 'Mystica' and 'Euphoria' (Rijk Zwaan) and in the second planting 'Balance' (Rijk Zwaan) and 'Phoenix' (Enza Seeds) were grown. The last two are partially resistant to powdery mildew. The densities in the first planting were 1.4 and 1.8 plants m^{-2} and in the second planting 1.8 and 2.2 plants m^{-2}. These were combined with plant load treatments, realised by retaining different numbers of fruit on the main stem. In the first and second planting the lighting hours were on average 14.6 and 13.7 h, respectively. Due to powdery mildew, the yield was too low in the first planting. By growing partially resistant cultivars in the second planting, powdery mildew could be avoided almost completely. The cumulative yields in the best treatments of each of the plantings were 50 and 63 kg m^{-2} for SL at 125 or 188 µmol m^{-2} s^{-1}. In both crops an increase in planting density of 1% improved the yield with 0.5% without reduction of quality. Keeping 5 more fruits on the main stem lead to a yield increase for each of the crops of 3 fruits m^{-2}.

In the season 2003-2004 cucumbers grown in a high-wire cultivation system gave 15-20% higher yields than in the traditional umbrella system, both under HPS at 210 µmol m^{-2} s^{-1}. Especially in a planting in spring, also fruit quality was much higher for the high-wire system. Yield increased almost proportionally with increased stem density up to 4.0 stems m^{-2} for this growing system, whereas for the traditional umbrella system 2.0 and 2.6 plants m^{-2} did hardly differ in yield. Details on the experiment are presented further on in the paragraph on interlighting. Based on the results of these experiments for 3000 h of SL per year at 210 µmol m^{-2} s^{-1} an annual cucumber yield of 360 pieces per m^2, being 147 kg m^{-2}, was calculated (Table 2). Nearly 81 kg m^{-2} in the darkest six months of the year is about the same or even a higher yield than cucumber growers realize in a whole year without SL. Important conclusions are that optimal use of SL in cucumbers requires the use of (partially) mildew-resistant cultivars, increased plant densities and cultivation according to the high-wire system.

MOBILE LIGHTING IN SWEET PEPPER AND TOMATO

Until recently no scientific reports on mobile lighting were available, whereas strong claims on its profitability were made. For example, Verbruggen (2001) claimed for roses that with such a system, with a much lower installed wattage, almost the same yield could be obtained as for a standard fixed-lamp installation. These claims resulted in substantial interest among growers, because the investment is much lower than for a fixed installation, as fewer lamps are used.

We compared fixed lamps with mobile lamps for sweet pepper (Hogendonk et al., 2004) and tomato (Kaarsemaker et al., 2004) in experiments conducted at commercial glasshouses. Sweet pepper 'Ferrari' (Enza Seeds) was planted on 10 November 2003 and the experiment ended on 1 November 2004. Lights were on during 1700 h (0-2 h before sunrise until 0-1 h before sun set; lights were switched off when natural radiation was higher than 350 W m^{-2}). Besides fixed or mobile lamps, a third treatment combining fixed and mobile lights was applied. In all 3 treatments SL level was 60 µmol m^{-2} s^{-1}. Under mobile or combined lighting fruit set started one week earlier, and also harvest started one week earlier compared to fixed lighting. However, the cumulative production was higher from May onwards under fixed lamps compared to the other two treatments (Fig. 2). Final production was 31.8 kg m^{-2} under fixed lamps, whereas this was 30.6 kg m^{-2} for mobile lighting and 29.2 kg m^{-2} for combined lighting.

Heijboer and Selman (2005) compared mobile lights in sweet pepper (19 µmol m^{-2} s^{-1}) with a control (no SL), based on expected production levels of 27.5 and 25.5 kg

m^{-2}, respectively. These values came from estimates by growers and were not based on scientifically sound experiments. They assumed also a € 0.10/kg higher average price for sweet peppers from the plants under mobile lights, as these plants were believed to produce 2-3 weeks earlier and production was therefore shifted from periods with lower prices to periods with higher prices. Mobile lights were also believed to save 0.5 m^3 gas per m^2, as less heating was needed because of the heat produced by the lamps (Heijboer and Selman, 2005). In that case, cultivation under mobile lights would have an annual profit of € 3,-/m^2 compared to the control (no SL). However, under the more realistic assumptions of 0.5 kg m^{-2} production increase (based on measurements reported by Visser, 2004) and no increase of average price for the annual production, mobile light would give a negative profit compared to no SL.

For tomato 'Aranca' (Enza Seeds) grafted on rootstock 'Eldorado' (Enza Seeds), 4 treatments were compared: control (no SL), fixed lamps and mobile lamps (2 or 4 lamps per unit), all at 34 µmol m^{-2} s^{-1}. The crop was planted on 22 December 2004. Lights were on between sunrise and sunset, when global radiation was less than 400 Wm^{-2}. Early yield (till week 16 of the year) was about 400 g m^{-2} higher for the SL treatments compared to the control (Fig. 3A). However, this effect gradually diminished and final production (till week 32) was not different (Fig. 3B). Also no difference in yield between plants under mobile and fixed lamps was observed, nor between plants under the line of lamps or in between two lines.

In conclusion, special positive effects of mobile lighting were not observed for sweet pepper or tomato. The same conclusion has been drawn for cut roses (Marissen et al., 2006). These results also mean that mobile light with less lamps per ha can not result in comparable yields to a fixed installation, as claimed by Verbruggen (2001). Since mobile lighting is more expensive per µmol m^{-2} s^{-1} or installed wattage, fixed lighting should be preferred, when comparing at the same light intensities.

INTERLIGHTING IN CUCUMBER

SL is almost exclusively applied on top of a crop canopy. However, this might not be the most optimal, as most light will then be intercepted by top leaves that also receive most natural light and are therefore already closer to or completely at saturating light intensities. Therefore Hovi et al. (2004) applied part of the SL between the plants instead of on top of them. This resulted in improved yield, probably because of a better vertical light distribution and therefore a more efficient use of SL. At first glance one may think that it is suboptimal to illuminate leaves low in the canopy, as their maximum photosynthetic capacity is very low (acclimated to low light levels). However, if these leaves are experiencing every day higher light levels because of interlighting, their maximum photosynthetic capacity is also expected to remain at a higher level.

In the season 2003-2004 the following lighting strategies were compared for cucumber 'Aviance' (Rijk Zwaan): SL with 100 % fixed HPS lamps on top of the crop canopy of 210 µmol m^{-2} s^{-1} and a combination of 50% fixed HPS lamps at the top and 50% interlighting with fluorescent tubes (totally 194 µmol m^{-2} s^{-1}). Both systems had the same wattage of 135 W m^{-2}. The fluorescent lamps were hanging horizontally between the plant rows, except for the first crop of the high wire system (lamps vertically). The lighting period was at a maximum of 20 h. A first and second crop were planted on 4 November and 3 February, respectively. The traditional umbrella system (planting density 2.0 and 2.6 plants m^{-2}) was compared with the high wire system (stem densities in the first planting of 2.4 and 3.0 stems m^{-2} and in the second planting 3.0 and 4.0 stems m^{-2}). In the first and second crop the lighting hours were on average respectively 16.5 and 13.6 h. In the first crop the reduction in yield due to interlighting for the traditional and high wire system was 5 and 23%, respectively. In the second crop this was 3 and 2 %, respectively. The reduction of 23% was probably due to the vertical position of the fluorescent tubes, as in that case less light was intercepted by the crop. With interlighting, cucumber fruits had a darker green color.

Hovi et al. (2006) reported a 9% increase in annual cucumber yield (117 instead of

108 kg m^{-2}) for Southern Finland, when 24% of the SL (170 Wm^{-2} installed; lights on between 04:00 and 24:00) was supplied between the plants instead of all light on top of the plants. That we did not observe such an expected yield increase may be due to the use of fluorescent tubes for interlighting, whereas Hovi et al. (2006) used 250 W HPS lamps for interlighting. The use of tubes makes it difficult to make a fair comparison (same wattage results in less PAR, as efficiency of tubes is lower than for HPS). However, Hovi et al. (2006) observed, just like in our experiment, an improved fruit quality for interlighting (increased fruit skin chlorophyll content, darker color at harvest and better ability to maintain color and structure during 24 d storage).

WHAT PRODUCTION LEVELS CAN BE OBTAINED WITH SL?

For the decision whether or not to invest in SL, reliable yield expectations for specific situations (e.g. glasshouse location, transmissivity of the glasshouse, planting date(s), plant density, SL intensity, and lighting strategy) are needed. Crop models can supply such yield predictions, and are certainly more accurate than rather wild estimates (e.g. 360 kg m^{-2} $year^{-1}$ for tomato, as mentioned by Nichols, 2003). We used the model TOMSIM (Heuvelink, 1999) to predict potential production levels, i.e. under ample supply of water and nutrients and in a pest, disease and weed free environment.

Global radiation outside the glasshouse (representative data for De Bilt in the centre of the Netherlands; Breuer and Van de Braak, 1989), inside temperature (20°C) and CO_2 concentration (500 and 1000 ppm CO_2) are model inputs. The model consists of modules for glasshouse radiation transmission (here set at 71% for diffuse radiation), radiation interception by the crop, leaf and canopy photosynthesis and dry matter production. Maintenance respiration was calculated based on dry mass of 190, 223, 324 and 120 g m^{-2}, for leaves, stem, fruits and roots, respectively. In agreement with Challa and Bakker (1999) we assumed a year-round leaf area index of 3 (90% light interception) and a fixed partitioning of 70% to the tomato fruits, hence theoretical maxima rather than yield predictions for an actual cultivation are obtained. Applying 188 µmol m^{-2} s^{-1} with a 6 h dark period and lights switched off above 300 W m^{-2} global radiation resulted in 5348 h SL per year and a predicted tomato yield roughly twice as high as a cultivation without SL (Fig. 4). The yield increase from SL is higher under high CO_2; however, the relative effect of SL did not depend on the CO_2 concentration. A year-round CO_2 level of 1000 ppm is impossible in conventional glasshouses because of the need for ventilation in summer; however, this is very realistic for a closed glasshouse (De Gelder et al., 2005).

Based on the calculated total biomass production for the scenario with the highest yield, we also estimated potential yields for sweet pepper and cucumber, both for the Netherlands and for Quebec (Canada; Table 3). Also for these crops potential yield was roughly twice current actual yield (without SL), and for Quebec potential yields were 15% higher than for the Netherlands, because of 15% higher natural light sum compared to the Netherlands. This fits well with the 1%-rule, a rule-of-thumb stating that 1% more light will result in 1% more production (Marcelis et al., 2006).

CONCLUDING REMARKS

Despite calculations showing that the use of SL in vegetable production is in general not economically feasible, the glasshouse area equipped with SL is increasing fast. This contradiction may be caused e.g. by the importance of year-round production for growers and by the possibility of delivering electricity to the public grid at high prices during peak loads. In fact, several grower-specific factors make it very difficult to conclude on profitability in general. It is clear, that both electricity price and product price are decisive parameters in these calculations (e.g. Heuvelink and Challa, 1989).

The increase in application of SL has also increased the amount of questions. It is important to find ways to increase efficiency of SL, especially when increasing the number of hours with SL. It seems that in tomato e.g. 18 h SL instead of 15 h SL hardly improves yield, whereas these or even higher natural light levels in summer still improve yield more or less proportional to the light integral (Marcelis et al., 2006). Also the balance between vegetative and generative growth is important. Just adding SL with no adjustments in the climate setpoints and crop management may result in improved vegetative growth but little or no yield improvement. The adjustments in temperature, plant density and other factors needed to optimally transfer SL into production are still not fully understood. The impact of SL depends on many factors, therefore experiments are necessary, but also model calculations are needed to generalise the results from experiments.

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Tables

Table 1. Yield and average fruit weight for sweet pepper ‘Special’ and ‘Fiesta’ grown with SL (125 or 188 µmol m^{-2} s^{-1} HPS used from 8 October until 20 March only between sunrise and sun set). Cultivation period from 4 September (planting date) until 23 June. Calculated cost price for the period that SL was applied, assuming an electricity price of € 0.07/kWh (public grid) or € 0.04/kWh (co-generation of heat and power).

Cultivar	SL intensity (µmol m^{-2} s^{-1})	Yield (kg m^{-2})	Average fruit weight (g)	Cost price[1] (€/kg) assuming € 0.07/kWh	€ 0.04/kWh
‘Special’	125	14.4	171	3.36	2.90
‘Special’	188	16.3	179	3.69	3.10
‘Fiesta’	125	14.6	163	3.53	3.05
‘Fiesta’	188	17.4	164	3.53	2.96

[1]Cost price is total production costs divided by total yield; Calculation based upon: 1329 h lights on, 1 luminaire+cables etc. € 200; light € 26 and a depreciation period of 7 years.

Table 2. Calculation of annual cucumber yield under SL, based on 3 plantings per year and measured yields in experiments (3 high wire cultivations; 3000 h, 210 µmol m^{-2} s^{-1})

Cultivation	Planting week	End week	Yield # m^{-2} $week^{-1}$	# m^{-2}	kg m^{-2}
Autumn/Winter[1]	45	5	9.1	91	33.3
Spring[1]	6	18	12.1	121	47.5
Summer[2]	19	44	6.4	147	66.2
Total			8.4	360	147

[1]Yield observed in experiment 2003-2004.
[2]Yield from commercial crop in 1997.

Table 3. Potential annual production levels calculated with TOMSIM (Heuvelink, 1999), at 1000 ppm CO_2 and 5348 h 188 µmol m^{-2} s^{-1} SL, for the Netherlands and for Quebec (Canada). For details on the simulation see text. Cumulative total dry mass produced was 8.6 kg m^{-2} $year^{-1}$ for the Netherlands and 10.0 kg m^{-2} $year^{-1}$ for Quebec.

Crop	HI[1]	DMC[2]	Potential annual production (kg m^{-2}) Netherlands	Quebec (Canada)
Cucumber	0.70	0.035	168	199
Sweet pepper	0.65[3]	0.085	64	76
Tomato	0.70	0.055	110	127

[1]Harvest index (Heuvelink and Challa, 1989)
[2]Dry matter content of fruits (Heuvelink and Challa, 1989)
[3]Value from B. Houter (pers. comm.)

Figures

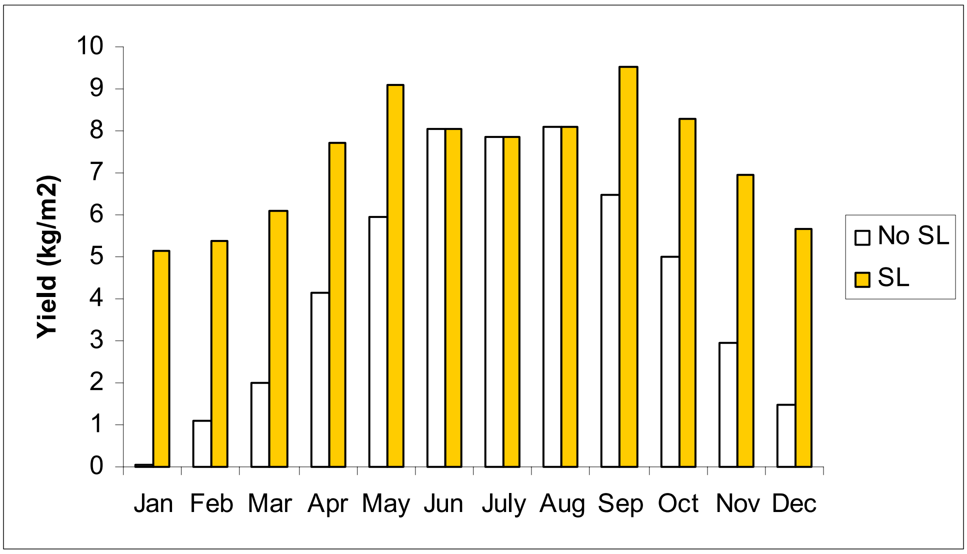

Fig. 1. Monthly yields for a tomato crop in the Netherlands, simulated with TOMSIM (Heuvelink, 1999; for details on the simulation see text), when grown with or without SL (188 µmol m^{-2} s^{-1} HPS, lights were off when global radiation outside exceeded 300 W m^{-2}, a minimum dark period of 6 h was imposed, and lights were not used at all in June, July and August). Coefficient of variation is 0.65 for no SL, and 0.20 for SL. Simulations assumed constant 500 ppm CO_2 in the glasshouse.

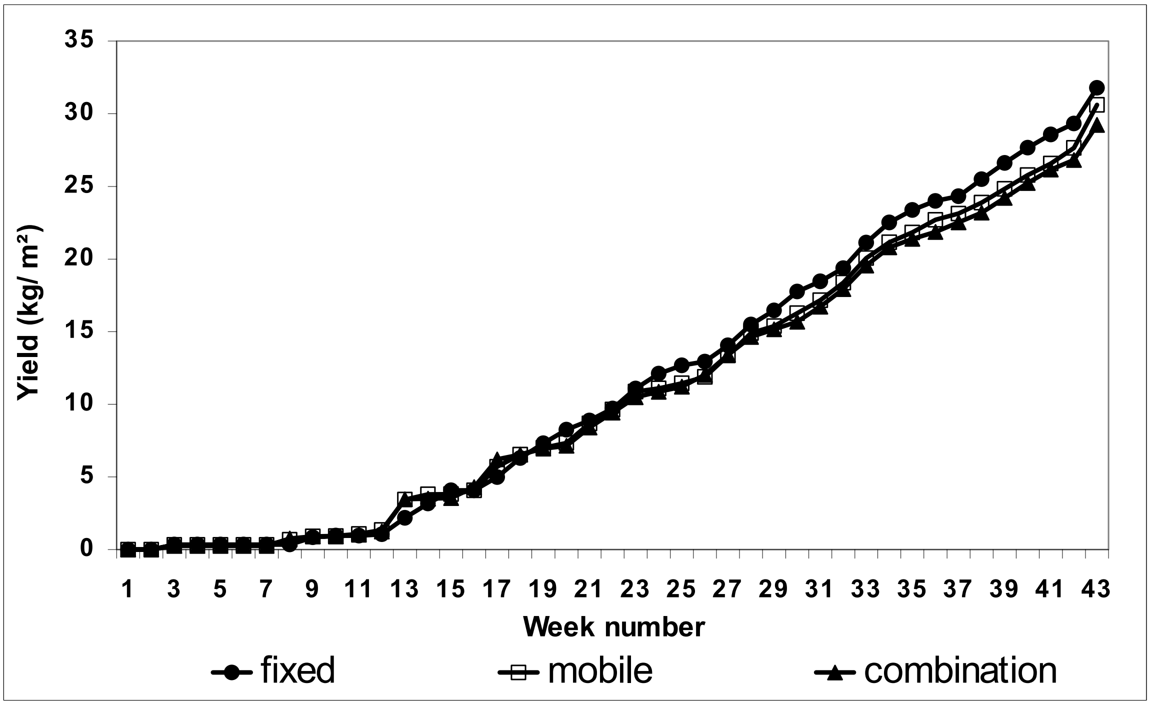

Fig. 2. Cumulative production for sweet pepper 'Ferrari', planted on 10 November 2003. SL (60 µmol m^{-2} s^{-1}) was applied with fixed lights, mobile lights (moving over 3.2 m; 3 min forward, 3 min backward) or as a combination (44 µmol m^{-2} s^{-1} fixed + 16 µmol m^{-2} s^{-1} mobile moving over 17 m; 27 min forward – 3 min backward). In total lights were used during 1700 h.

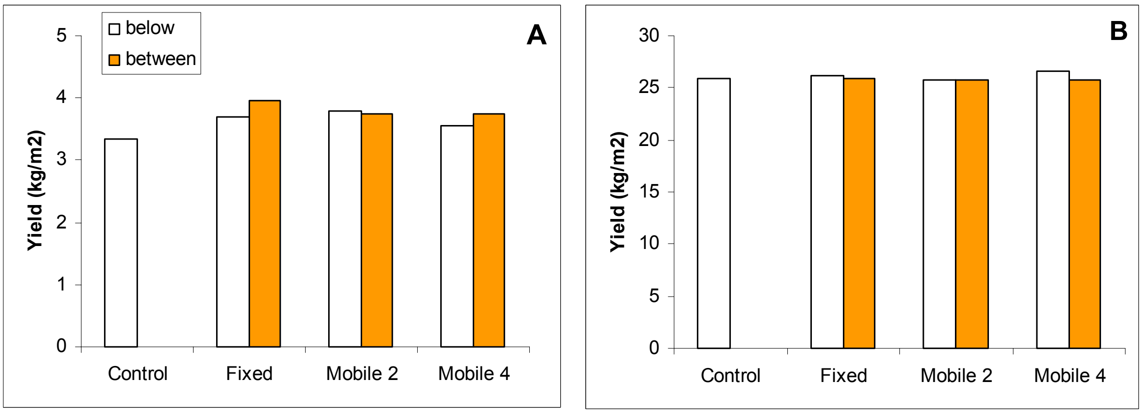

Fig. 3. Yield of tomato 'Aranca' grafted on 'Eldorado' up to week 16 (A) or week 32 (B) when no SL was applied or when 34 µmol m^{-2} s^{-1} HPS was applied with fixed lights or mobile lights (2 or 4 lamps per unit, moving 20 m; 26 min forward – 2 min. backward). Planting date was 22 December 2003 and lamps were on between sunrise and sunset, when global radiation was less than 400 W m^{-2}.

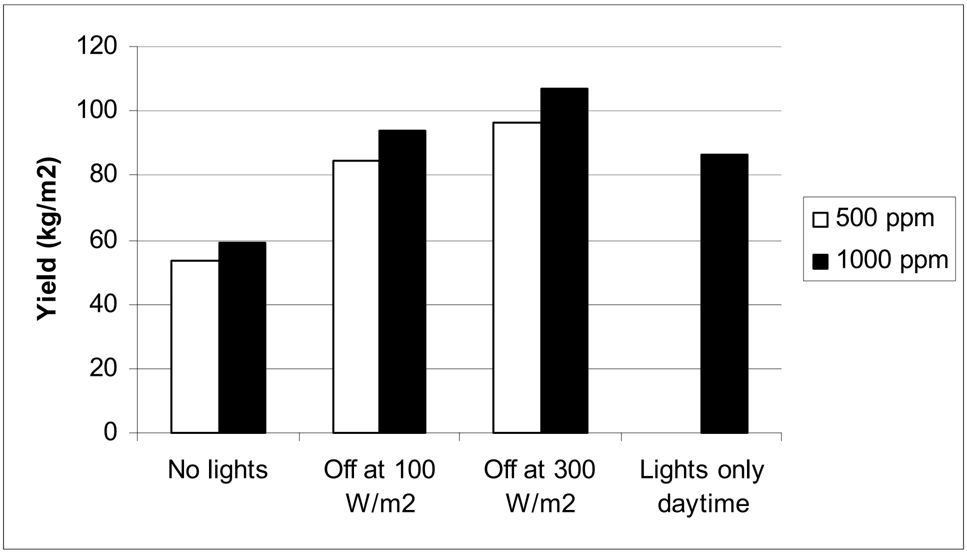

Fig. 4. Potential annual tomato yield calculated with TOMSIM (Heuvelink, 1999) at 500 or 1000 ppm CO_2. Lights were used 0, 3743, 5348 or 3156 h respectively. For details on the simulation see text.