The Latest Developments in the Lighting Technologies in Dutch Horticulture

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Abstract

The use of lamps for improvement of CO2-assimilation of greenhouse crops has increased enormously during the last 15 years in The Netherlands. The main reasons for the use of assimilation lighting are not only to increase crop production and product quality, especially in winter time, but also more and more to ensure a year round production and quality level which meets market demands.

Assimilation lighting is often used for plant propagation and rose production, while its use in other ornamental crops is increasing rapidly. In addition, few producers of vegetables started to apply assimilation lighting. Some new trends are higher light intensities during longer periods, techniques to improve light output per lamp by enlarging the voltage and moveable lamps with high light intensities. The coming years the use of artificial lighting in the Netherlands will be affected by liberalization and legislation of the trade of energy (gas and electricity).

Nowadays explanatory crop models are available that can predict crop growth quite accurately. These models in combination with models simulating the greenhouse climate are powerful tools to analyse effects of artificial lighting. Some results of a combined model for crop growth and greenhouse climate are shown with respect to different strategies for the operation of artificial lighting. It is shown that the light use efficiency (unit production per unit of PAR from lamps) decreases when intensive lighting regimes are applied. Besides light, lamps produce heat. Therefore, the energy demand of the heating system decreases when lights are turned on. This simulation study showed that it is possible to increase the energy use efficiency (unit production per unit of energy input from lamps and heating system together) by the use of lighting.

DEVELOPMENTS IN DUTCH HORTICULTURE

Introduction

Glasshouse horticulture is an important industry in The Netherlands, with a total area of glasshouses of almost 11 000 ha. The five most important crops are cut roses, cut chrysanthemums, sweet pepper, tomato and cucumber. The Dutch cultivation system can be characterised as being very intensive and sophisticated. Production levels are high (e.g. 80 kg m^{-2} cucumbers per year, 60 kg m^{-2} tomatoes per year, 180 stems m^{-2} large sized cut roses and 240 stems m^{-2} of cut chrysanthemums), and the input of natural resources is large (e.g. annual consumption of natural gas is 50-60 m^3 m^{-2} for fruit vegetables and 70-80m^3 m^{-2} for cut roses).

Rapid innovations are the key to the competitiveness of the Dutch greenhouse horticulture. Some of the latest developments in the glasshouse industry in The Netherlands will be discussed here. The farm size is increasing rapidly. At the moment many farms have a size of 1-2 ha. However, the number of farms with a size of 3-6 ha is increasing rapidly and even bigger farms are formed. Each farm used to be run by one family (man, his wife and children). The increase in farm size demands now a different, more modern, farm management. In the past many growers have immigrated to countries all over the world. Recently, an increasing number of growers semigrate, i.e. they start a farm abroad (e.g. in Spain) and keep also their farm in the Netherlands. The main aim of semigration is to be able to have a continuous production throughout the year. The production can be considered as market driven, i.e. growers produce that what is demanded by the market. In order to meet the demands of the market and for efficient production, growers have recognized that they participate in a production chain. A chain from breeding to consumption and flexible networks with other companies is being formed. Growers strive to fully control the production process. They try to predict and to plan their production in advance. Monitoring of the status of the crop is of increasing interest of growers; examples are monitoring of canopy temperature and sap flow or counting numbers of fruits set. Food safety is a very important issue. Accordingly, tracing and tracking, HACCP (hazard analysis critical control point), Eurep-GAP rules set out by supermarkets are gaining interest from the growers. Productions systems are forced to be sustainable and acceptable to consumers. This implies minimum use of nutrients, chemicals and energy, minimizing waste products, no ‘light pollution’ (during four hours a night emission of light from greenhouses is forbidden). Legislation has put limits to the use of nutrients, chemicals and energy for the horticultural sector as a whole. Now limits will be applied to each individual farm. In order to create acceptable production systems, social aspects have also to be considered. There must be good labour conditions and the glasshouse should fit in with the landscape. Farms may be isolated companies, but they may also produce in clusters of glasshouses or forming a cluster with other industries. In general, internet techniques and other e-technologies are developing rapidly. In the near future we may expect a rapid increase in internet applications in horticulture as well. In general intensification of production can be observed, with many technological innovations and automation. Nevertheless, there is also an increasing interest in organic farming in glasshouses (modern organic farming uses many technological innovations).

The use of lamps in greenhouses has increased enormously during the last 15 years in The Netherlands. This paper will discuss some developments in lighting technology in The Netherlands and the efficiency of the use of lamps will be analysed by using a simulation model.

Developments in Lighting Technology

In greenhouse horticulture lamps have already been applied for many years for controlling photoperiodic reactions in ornamental crops, such as flowering control in chrysanthemum. The use of lamps for improvement of CO_2-assimilation of greenhouse crops has increased enormously during the last 15 years in The Netherlands. The main reasons for the use of assimilation lighting are not just to increase crop production and product quality, especially in winter time, but also to ensure the year-round production and quality level which meets the market demands. Lamps provide the grower one more tool to control the production process. Furthermore, a year-round production may also improve the efficiency of expensive investments and may lead to a more regular labour requirement.

First assimilation lighting was used for plant propagation, then rose growers also started to use assimilation lighting. At present approximately 90% of rose growers use assimilation lighting, while the use in other ornamental crops is increasing rapidly (e.g. in cut chrysanthemums approximately 25% of growers use assimilation lighting; Vernooij and Ploeger, 1999) and pot plants. In addition, few producers of vegetables started to use assimilation lighting as a commercial test (in total about 4 ha in the year 2000). Greenhouse assimilation lamps are used on a surface area of 1460 ha, which represents 13% of the total greenhouse area; this percentage is increasing each year by 1% per year (R. Bakker, LEI personal communication).

Growers are continuously intensifying the lighting by increasing the light intensity as well as the operational hours per year. In the early nineties 30-40 µmol m^{-2} s^{-1} were common light intensities, presently 50-100 µmol m^{-2} s^{-1} are common intensities and it is expected that in the near future the intensities will be further raised to 100-200 µmol m^{-2} s^{-1}. Neither optimal light intensity nor the limits to the light intensity are known exactly yet. Present intensities and operational hours of lamps are shown for several crops in Table 1. Some new trends are techniques to improve light output per lamp by enlarging the voltage and the use of moveable lamps with high light intensities. Several years ago 400 W high pressure sodium lamps were the most common lamps used. Now in most cases 600 W high pressure sodium lamps are being installed. Increasing the voltage on the lamps is believed to increase light intensities, but serious doubts about the longevity of the lamps (especially for the 600 W lamps) can be raised when the voltage is increased. Light output may seriously reduce during the lifetime of a lamp due to dirt on the reflector (which is outside, just above the lamp). There are new lamps with a reflector inside the lamp, which might yield higher light output without problems of decreasing reflection. However, it is yet too early to predict the prospects of this technique. To reduce costs of investments in expensive lamps and fixtures some growers installed moveable lamps. The system has two 600 W lamps mounted next to each other and hanging close to the top of the canopy (1.2 meter, whereas normally the distance between canopy and lamps will be at least 2.5 m for cut flowers). This double-lamp moves along a line (e.g. 47 m long) and thus plants receive a very high light intensity for a short period, several times per day. It is claimed for roses that with this system, with a much lower installed wattage, almost the same yield can be obtained as for a standard fixed-lamp installation (Verbruggen, 2001), but no scientific reports are available yet. Sometimes moveable lamps are combined with a standard fixed-lamp installation (Verbruggen, 2001).

The rapid increase in heat/power co-generation engines (total energy systems) at individual farms ensured growers of electricity at a relatively low price. As the trade of energy (gas and electricity) in The Netherlands will be liberalized, peaks in electricity use should be avoided (because this affects the energy price) and the use of total energy systems might become less interesting for individual growers. Consequently, the costs of artificial lighting might increase and hence affect its use in commercial practice.

Until recently it was believed that lighting vegetables was not profitable in The Netherlands. As discussed before few producers of vegetables started to use assimilation lighting as a commercial test. Spectacular increases in productivity have been reported for tomato (yearly production increased by 55%). However, independent tests are not yet available, nor a thorough economic evaluation. For optimal use of assimilation lighting not just lamps should be installed but also the cropping system and climate control should be adapted. In this respect the commercial tests with lighting in tomato are good examples, because here not just lamps were installed, but many modifications to the cropping system were adopted. Examples of modifications of the cropping system are an increased stem density, two instead of one crop cycle a year, interplanting (during two months both the old and new crop were simultaneously growing in the greenhouse) and plants grown on hanging troughs. Lights are not just being used in winter time, but also in summer time when outside light levels are low. As the use of assimilation lighting in vegetables has just started, further improvements in production and quality are likely. For a widespread application of assimilation lighting in vegetables, beside economic evaluation it is also important whether or not growers do believe in the system. Furthermore it is not yet sure what the consumer acceptance of lighted vegetables is. In addition if all growers start assimilation lighting, this could lead to overproduction and price reductions. In conclusion the use of assimilation lighting in vegetables might be profitable, but there are still many questions related to this topic.

Light Spectrum and Plant Development

In several ornamental crops grown in greenhouses chemicals are used to control plant morphology, which is an important quality attribute. There is an increasing pressure to minimize the use of chemicals. Lighting the plants with lamps with the proper spectrum (e.g. high red/far red ratio, much blue, or much UV) in combination with adapted temperature regimes may become good alternatives for chemical growth control and to improve product quality.

In greenhouses, crops are usually grown at high planting densities, resulting in low red to far red ratios in the canopy, while it is well known that the ratio between red and far red radiation strongly affects plant morphology (Kendrick and Kronenberg, 1994). When the greenhouse is covered by glass, the UV-B radiation level inside the greenhouse is very low. There are many claims that UV-B radiation may increase beneficial metabolites such as anthocyanins and flavonoids, which may lead to improved colour, hardiness and stress tolerance of the plant or be beneficial for human health (Duthie et al., 2000). However, there are few scientific proofs yet. When assimilation lighting is intensively used, the relative contribution of sunlight, which has a wide spectrum decreases. Therefore, the spectrum of the assimilation lighting is becoming more important under intensive lighting conditions. The most commonly used lamps in greenhouses are high pressure sodium lamps. These lamps have a rather limited spectrum. For instance, it contains only little blue light, while it is well known that reductions in blue light lead to increased elongation (Maas and Bakx, 1995, Maas et al., 1995). Furthermore, red light (Kasperbauer and Hamilton, 1984) and very long daily light periods increase accumulation of starch in the leaves (Dorais et al., 1996). Excess starch accumulation may occur when daily night periods become too short (< 4h) for the breakdown of starch and export of sucrose out of the leaves. This may hamper normal plant development. Too long daily photoperiods of blue-deficient high pressure sodium lighting also caused a disturbed stomatal regulation which negatively affects postharvest performance of cut roses (Blom-Zandstra et al., 1995). Demers et al. (1998) and Demers and Gosselin (2001) showed negative effects of assimilation lighting in greenhouse grown tomato and sweet pepper when too long photoperiods were applied. They related these negative effects to changes in carbohydrate metabolism. These negative effects were stronger for high pressure sodium lamps than for metal halide lamps, the latter yielding more blue light. There seem to be some similarities between these effects of long duration of assimilation lighting and the effects of low levels of blue light on starch content. Therefore, the negative effects of long photoperiods, when applying assimilation lighting, might partly be attributed to the light spectrum of the lamps.

MODELS AS A TOOL FOR ANALYSING THE EFFICIENCY OF LIGHTING

There are still many uncertainties about the efficiency of different lighting strategies and whether assimilation lighting is profitable for production of greenhouse vegetables. Explanatory simulation models are powerful tools to represent and combine knowledge in a generic way and to analyse quantitatively the effects of lighting on crop production and energy use. A number of descriptive and explanatory models for greenhouse climate and crop growth has been developed during the last 20 years (reviewed by Critten, 1993 and Marcelis et al., 1998). A few models (e.g. Rijsdijk and Houter, 1993; Van Henten, 1994; Jones et al., 1995; Gary et al., 1998; Gijzen et al., 1998) simulate both greenhouse climate and crop growth. In this study the model HORTISIM (Gijzen et al., 1998) was used, for a preliminary analysis of effects of some lighting strategies on energy use and crop production in tomato. HORTISIM (Fig. 1) contains seven sub models (Weather, Greenhouse Climate, Soil, Crop, Greenhouse Manager, Soil Manager and Crop Manager) plus a simulation process manager (the “Engine”). The model can simulate climate conditions inside the greenhouse from outdoor weather. The use of energy, CO_2 and water is calculated, as well as crop photosynthesis, dry matter production and dry matter partitioning. HORTISIM can be used for simulating cucumber, tomato and sweet pepper. This study was performed for tomato.

Materials and Methods

A simulation study was performed to compare three different lighting strategies to a standard crop strategy without lighting: lights were switched on when outside global radiation was less than 50, 100 or 300 W m^{-2}, while light intensities (PAR) from the lights was 30, 120 or 240 μmol m^{-2} s^{-1}. Lights were always off during 4 hours at night. It was assumed that 25% of the energy use for lighting was converted into PAR. Plants were grown in a Venlo-type glasshouse with 70% transmission of diffuse light. Weather data were taken from a reference year for The Netherlands (latitude: 52°N) (Breuer and Van de Braak, 1989). Average outside global radiation was 9.5 MJ m^{-2} d^{-1} and average greenhouse air temperature was 20°C for the control treatment. For CO_2 concentration of the greenhouse air a constant value of 400 ppm was assumed. The crop was planted December 1 and production was continued until November 20 the next year. Plant density was 2.1 plants m^{-2}.

Results and Discussion

Simulated total plant dry weight increased by assimilation lighting, and was higher the more assimilation light was provided (Fig. 2). The light use efficiency for assimilation light (unit production per unit of PAR from lamps) slightly decreased when light intensity increased or when outside radiation level below which the lamps turn on increased (Fig. 3). This slight decrease in light use efficiency can be attributed to the saturation type of curve of leaf photosynthesis. Besides light, the lamps produce heat. Therefore, the energy demand of the heating system decreases when lights are turned on and in some periods the temperature inside the greenhouse increases. In all scenarios where assimilation lighting was applied the total energy use per m^2 greenhouse area increased (data not shown), which might limit the commercial use of assimilation lighting in future because of legislation with respect to reducing energy use per greenhouse area. Interestingly, for several lighting strategies the energy use efficiency (unit production per unit of energy input from lamps and heating system together) was higher than for the control without assimilation lighting (Fig. 4). This agrees with Vernooij and Ploeger (1999), who reported that in the Netherlands greenhouses with supplementary light, despite a higher energy use per square meter, showed a 9-18% more efficient energy use (expressed in m^3 of gas per financial value of sold flowers) than greenhouses without supplementary light.

The energy use efficiency was higher for assimilation lighting with 120μmol m^{2} s^{-1} PAR than for 30 μmol m^{-2} s^{-1} PAR. When intensity was further increased to 240 μmol m^{-2} s^{-1} PAR, the energy use efficiency decreased to values less than for the control without assimilation lighting. Especially when lamps (240 μmol m^{-2} s^{-1} PAR) were turned off only when outside global radiation exceeded 300 W m^{-2}, the energy use efficiency dropped considerably below that of the control. The above described results can be explained by the fact that at low intensities of assimilation lighting almost all the energy input into the lamps can be used for heating the greenhouse, while it also provides some PAR which boosts plant growth. At higher intensities not all the energy input is needed for heating of the greenhouse, leading to a reduction in energy use efficiency. When considering these results, it should be noted that the efficiencies of light and energy use depend on the cropping system and many other growth conditions, such as CO_2 concentration, plant density, leaf area development, interplanting, etc. (data not shown) as well as assumptions with respect to the efficiency of the lamps itself. Nevertheless, it can be concluded from this preliminary simulation study that it is possible to increase the energy use efficiency by the use of lighting, but this depends on the strategy of lighting.

CONCLUSIONS

The use of assimilation lighting by growers is still rapidly increasing and there are several interesting new technological developments. In the Netherlands liberalization and legislation of the trade of energy (gas and electricity) may affect the use of assimilation lighting in the coming years. There are still many uncertainties about the efficiency of different lighting strategies. Simulation models, validated with data from practice, are valuable tools to analyse what lighting strategy is optimal. For optimal use of assimilation lighting, cropping systems might need adaptation.

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Tables

Table 1. Light use in several greenhouse crops in The Netherlands in the year 2000.

	Intensity (μmol m^{-2} s^{-1})	Hours per year
Rose	50-90	4500
Chrysanthemum	50-70	3000
Orchid	50-60	
Tomato	>120	

Figures

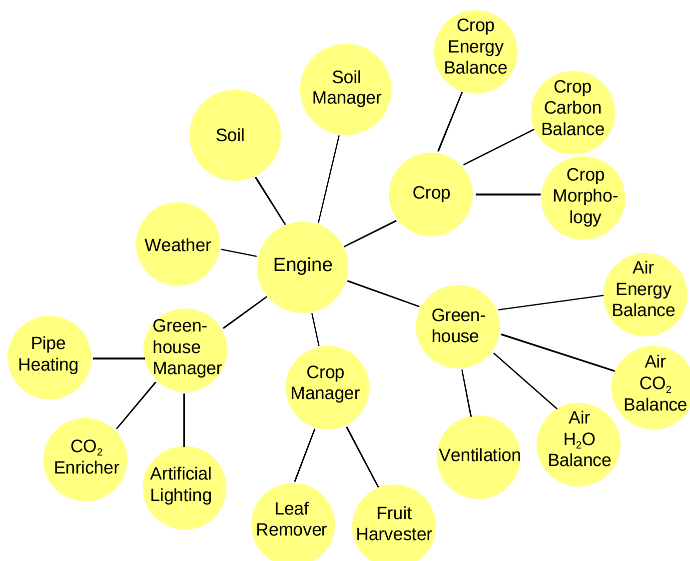

Fig. 1. Schematic representation of Submodels, Tasks and the simulation process manager (the "Engine") in the model HORTISIM (from Gijzen et al., 1998).

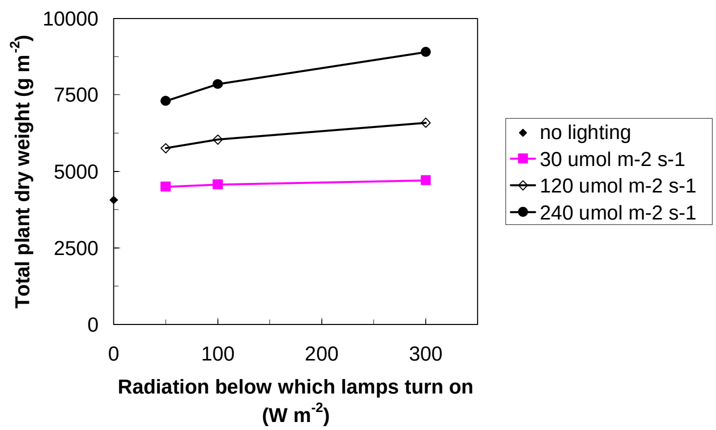

Fig. 2. Simulated effect of different lighting strategies on cumulative dry weight of tomato plants (01 December until 20 November). Lights were switched on when outside global radiation was less than 50, 100 or 300 W m^{-2}; operational hours of the lamps were 3810, 4474 and 5941 hours per year, respectively. Intensity of assimilation lighting was 30, 120 or 240 μmol m^{-2} s^{-1}.

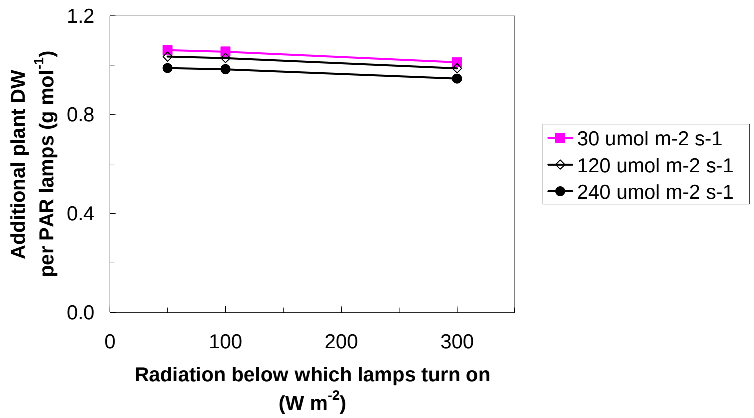

Fig. 3. Simulated effect of different lighting strategies on light use efficiency for assimilation lighting (unit dry weight production per unit of PAR from lamps). Details as in Fig. 2.

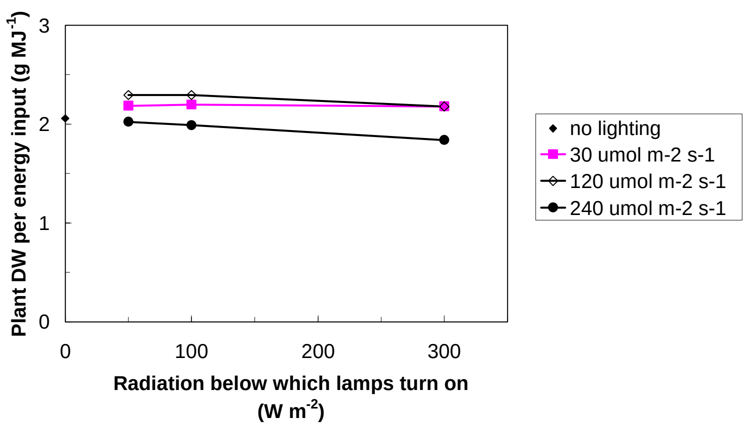

Fig. 4. Simulated effect of different lighting strategies on energy use efficiency (unit production per unit of energy input from lamps and heating system together). Details as in Fig. 2.