Quantification of the Growth Response to Light Quantity of Greenhouse Grown Crops

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Abstract

Growers have often assumed that a 1% increment in light results in a 1% yield increase. In this study, this rule of thumb has been evaluated for a number of greenhouse grown crops: fruit vegetables (cucumber, tomato, sweet pepper), soil grown vegetables (lettuce, radish), cut flowers (rose, chrysanthemum), bulb flowers (freesia, lily), flowering pot plants (poinsettia, Kalanchoe), and non-flowering pot plants (Ficus, Dracaena). A literature survey was first carried out on the effects of light on growth, dry matter production and partitioning, dry matter content and harvestable yield. Subsequently, yield data for cucumber, poinsettia and rose from commercial growers were analysed. Finally, growers were interviewed to assess their crop management in relation to the available light. For most crops a 1% light increment results in 0.5 to 1% increase in harvestable product. As a rule of the thumb the following values may be used: 0.8-1% for soil grown vegetables, 0.7-1% for fruit vegetables, 0.6-1% for cut flowers, 0.25-1.25 for bulb flowers, 0.5-1% for flowering pot plants and 0.65% for non-flowering pot plants. These are average values, which depend on several factors. For instance, the relative effect of light on growth is greater at lower light levels, at higher CO_2 concentrations and at higher temperatures. Consequently, the relative effect is larger in winter than in summertime. The effect of light on growth also depends on the duration and moment that the light level is changed. Besides a positive effect on yield quantity, light usually has a positive effect on quality as well. Light should not be considered as a separate growth factor in greenhouse horticulture, as it forms an integral part of the total farm management. Many growers, for instance, choose a higher temperature and adapt their plant density and cultivar choice when the light level is increased.

INTRODUCTION

The growth rate of a crop largely depends on the radiation it receives. Considering a given solar radiation, the grower has several options to increase the amount of incident light on a crop, such as building a greenhouse with high light transmissivity, or using assimilation light. On the other hand, the use of some measures such as screens may reduce the amount of incident light on the crop.

In order to judge whether a measure affecting the light intensity is profitable, the grower needs to estimate its effect on production. For more than 20 years Dutch growers have usually taken a 1% additional light results in 1% additional growth and production as a rule of thumb. For cut flowers and pot plants there are indications that effects of light on production are less strong than in vegetable crops; for these crops 1% additional light it is often assumed to result in 0.5% additional growth and production.

Light is the driving force for photosynthesis, while it may also affect plant development, morphology, dry matter partitioning and water content. Despite the assumed proportionality between light and production, it is well known that leaf photosynthesis shows a non-linear relation to light. Moreover, effects of light are affected by many other factors, e.g. CO_2 concentration, temperature and leaf area index.

In this study, the 1% rule of thumb has been evaluated for a number of greenhouse grown crops. The following groups of crops were studied: fruit vegetables, soil grown vegetables, cut flowers, bulb flowers, flowering pot plants, and non-flowering pot plants. A literature survey was first carried out on the effects of light on growth, dry matter production and partitioning, dry matter content and harvestable yield. Subsequently, yield data for cucumber, poinsettia and rose from commercial growers were analysed. Finally, growers were interviewed to assess their crop management in relation to the available light.

RESULTS AND DISCUSSION

Literature Survey

Although the results of about 100 publications were analysed, the scope of this paper does not allow the citation of all these references.

The cumulative production or plant weight is often plotted against cumulative radiation. In many cases this results in a linear relationship starting at the origin, which indicates that 1% additional light results in 1% additional growth. However, plotting cumulative values against each other did not appear to be sufficiently accurate to estimate the effects of 1% additional light (e.g. see Demetriades-Shah et al., 1994).

Soil grown Vegetables (Lettuce, Radish)

A 1% decrease in radiation leads to a reduction in both the fresh and dry weight of lettuce heads by about 0.8% (e.g. De Pinheiro Henriques and Marcelis, 2000). The formation of radish tubers is strongly dependent on radiation. The effects of light are stronger on tuber weight than on sprout weight, and consequently, the shoot/tuber ratio increases at low light (Marcelis et al., 1997). Light in the final stage of tuber development has a stronger effect on the final tuber weight than light during the initial phase of the crop (Marcelis, unpublished data). Effects of a 1% difference in light on the production of radish vary from 0.6 to 1.4, thus an average reduction of 1% seems reasonable.

Fruit Vegetables (Cucumber, Tomato, Sweet Pepper)

The literature on fruit vegetables yields interactions between the effects of light and other growth conditions (e.g. Nilwik, 1981; De Koning, 1989; Heuvelink, 1995; Cockshull et al., 1992). The effect of a reduction in radiation during a prolonged period has a relative stronger effect on cucumber yield than duration during a short period, due to changes in dry matter partitioning and water content (Marcelis, 1993). Furthermore, the relative effect of radiation decreases at low temperatures, low CO_2 concentrations and at high light levels. The reduction in cucumber yield due to 1% less radiation varied in most cases between 0.6 and 1.2%, for tomato between 0.6 and 1.1%, while in sweet pepper it varied between 0.8 and 1.3%. These data seem to indicate that pepper is slightly more sensitive to light than are tomato and cucumber, but the data on sweet pepper were too limited to draw strong conclusions. For fruit vegetables in general, a 1% light reduction leads to an average yield reduction in the range of 0.8 to 1%.

Cut Flowers (Rose, Chrysanthemum)

A decrease in radiation results in less shoots, lower shoot weights and less quality in rose (e.g. Zieslin and Mor, 1990; Gislerød and Mortensen, 1997; Kim and Lee, 2002). Furthermore, flower buds may abort at low radiation levels, resulting in blind shoots. A reduction of 1% radiation reduced yield between 0.4 and 1.2%, but in most cases it was in between 0.8 and 1.0%. The effects of light in winter can be greater, but at high light levels the effects can be substantially smaller. In chrysanthemum, the effects of a 1% reduction in radiation led to yield reductions varying between 0.3 and 1.0%, but in most cases a yield reduction of 0.6% fitted reasonably with the observations (e.g. Lee et al., 2003). Quality is a much more important item in cut flowers than in vegetables, and quality usually is reduced by lowering the radiation. However, there is little quantitative information on these quality effects.

Bulb Flowers (Freesia, Lily)

The fresh weight of freesia shoots is reduced by 0.1 to 0.5% by a 1% light reduction, while the number of shoots decreased by 0.0 to 1.2%. Consequently, total fresh weight production was reduced by 0-1.7% by 1% light reduction. These data were based on summer experiments. In winter the effects of light are likely to be stronger. In lily a 1% light reduction resulted in dry weight reductions of 0 to 1.4% and for bulb flowers the number of available data were too limited to draw general conclusions.

Flowering Pot Plants (Poinsettia, Kalanchoe)

There are only very few quantitative data available on the effects of light on growth of flowering pot plants. A decrease of 0.8-1% dry weight at 1% light reduction was found for Kalanchoe (e.g. Gislerød et al., 1989; Mortensen, 1994; Carvalho et al., 2005). In flowering pot plants other factors like plant morphology, leaf colour and shelf life are more important for the grower than weight, and light also has clear effects on these quality aspects. Some examples are that the number of flowers decrease at low radiation (e.g. Carvalho et al., 2005), while leaves may become pale at high light levels (e.g. Andersson, 1994).

Non-flowering Pot Plants (Ficus, Dracaena)

In non-flowering pot plants as well, quality is more important for the grower than plant weight. High radiation may have negative effects on leaf colour in Dracaena. Literature data for Ficus benjamina and Dracaena indicate on average a 0.65% reduction in plant weight (fresh and dry) at 1% reduction in light (e.g. Mortensen & Grimstad, 1990; Sarracino et al., 1992).

Analysis of Data from Commercial Growers

A data set for cucumber was used with weekly values of harvested weight and the climate conditions of 14 growers during the period January 1996 to May 1997. The relative effect of radiation clearly depended on the radiation level (Figs. 1, 2). At the lowest radiation levels the effect of 1% light reduction on yield was much higher than 1%. At 3500 J cm^{-2} $week^{-1}$ solar radiation (typical for February in Holland) this percentage was 1%, while at radiation levels higher than 10,000 J cm^{-2} $week^{-1}$ it was about 0.5%. Averaged over the whole year 1% light reduction resulted in about 0.7% yield reduction. Note that in contrast to most of the literature data, other climate variables changed in these growers' data, together with the radiation. The temperature was often higher and the CO_2 concentration was lower at higher radiation. Regression analyses indicated that the effect of 1% additional light on yield would have been 0.9% if there were no negative correlations between radiation and CO_2 concentration.

The monthly production values for rose during October, November, December from 40 growers were available. Differences in the light level were mainly due to differences in supplemental lighting. The relation between production and radiation showed a lot of variation, indicating that many more factors than light affect the production rate.

Production values for poinsettia for three periods (5-7 weeks per period) during September to December of 33 growers were available. Differences in light level were due to variation in natural light, transmissivity of the greenhouse and screens. These data showed that 1% additional light resulted in an increase in growth by 0.5-0.7%.

Interviews of Growers

Dutch growers of lettuce, cucumber, rose, freesia, poinsettia and Ficus (3 growers per crop species) were asked about their expectations concerning additional light on crop performance, and in what way the light levels might affect their (crop) management. Almost all growers think it is important to have high light levels in their greenhouses. All are convinced that the relative effect of light is larger in winter than in summer. However, the opinions varied quite a bit about the magnitude of the light effect on yield. In some crops screens are closed in the summer time, or the greenhouse is whitewashed at high radiation levels. This is mainly done to prevent too high temperatures. Growers stress that besides the quantity of the yield, product quality largely depends on the radiation level. This holds for all crops, despite the fact that each crop has different quality aspects.

Most growers adapt their crop management to the amount of incoming light.

Many growers increase plant density and temperature when light levels increase and choose a different variety. The interviews clearly stated that light should not be considered as a separate growth factor, but that it forms an integral part of the total farm management.

CONCLUSIONS

This study aimed to evaluate the rule of thumb that a 1% light increment results in a 1% yield increase. For most crops a 1% light increment results in a 0.5 to 1% increase in harvestable product. The average yield increases with increasing light levels for the different crops are summarised in Table 1. These values on yield increase may be used as a rule of thumb. However, it should be noted that these values only indicate quantitative effects on yield but not on product quality, while quality usually increases with increasing light level. Furthermore, the values presented in Table 1 are average values and depend on several factors. The relative effect of light on growth for instance, increases at lower light levels, higher CO_2 concentration and higher temperatures. Consequently, the relative effect is larger in winter than in the summer. The values are probably a few tenths of a per cent higher in the winter and a few tenths of a per cent lower in the summer compared to the average values for the whole year. Despite the fact that effects of light in summer are smaller than in winter, this study also revealed that even in summer additional light usually has a positive effect on production. However, under some conditions, additional light is not desired (especially pot plants). However, this is mainly because additional light results in an undesired increase in temperature. The effect of light on growth also depends on the duration and moment that the light level is changed.

Many climate conditions change in greenhouses when the light intensity changes. Especially the negative correlation between CO_2 concentration and radiation may result in a reduction of the positive effects of light on growth.

Lighting in the greenhouse should not be considered as a separate growth factor as it forms an integral part of the total farm management. Many growers for instance, adapt their plant density, cultivar choice and choose a higher temperature when light level is increased.

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Tables

Table 1. Summary of the average effects of a 1% decrease in light level on the yield (harvestable biomass) of several greenhouse crops. Data were based on a literature survey, data from growers and interviews with growers).

Group of crops	Crop	Yield reduction at 1% less light	Remarks
Soilgrown vegetables	Lettuce	0.8%	Equal effects on fresh and dry weight
	Radish	1%	Effects on tuber stronger than on shoot. Shoot/tuber ratio increases at low light
Fruit vegetables	Cucumber	0.7-1%	Dry-matter percentage of fruit decreased at low light. Effect of light on fruit fresh weight is smaller than on fruit dry weight
	Tomato	0.7-1%	Effect on fruit fresh weight stronger than on plant dry weight
	Sweet pepper	0.8-1%	
Cut flowers	Rose	0.8-1%	Light affects number of shoots as well as shoot weight. Effects in summer smaller than in winter
	Chrysanthemum	0.6%	
Bulb flowers	Freesia	0.25-1.25%	Too few data available to draw general conclusions
	Lily	0.25-1.25%	Too few data available to draw general conclusions
Flowering pot plants	Poinsettia	0.5-0.7%	Quality aspects are more important than biomass
	Kalanchoe	0.8-1%	Quality aspects are more important than biomass
Non-flowering pot plants	*Ficus benjamina*, Dracaena	0.65%	Equal effects on fresh and dry weight. In winter sufficient light is essential to prevent leaf abscission

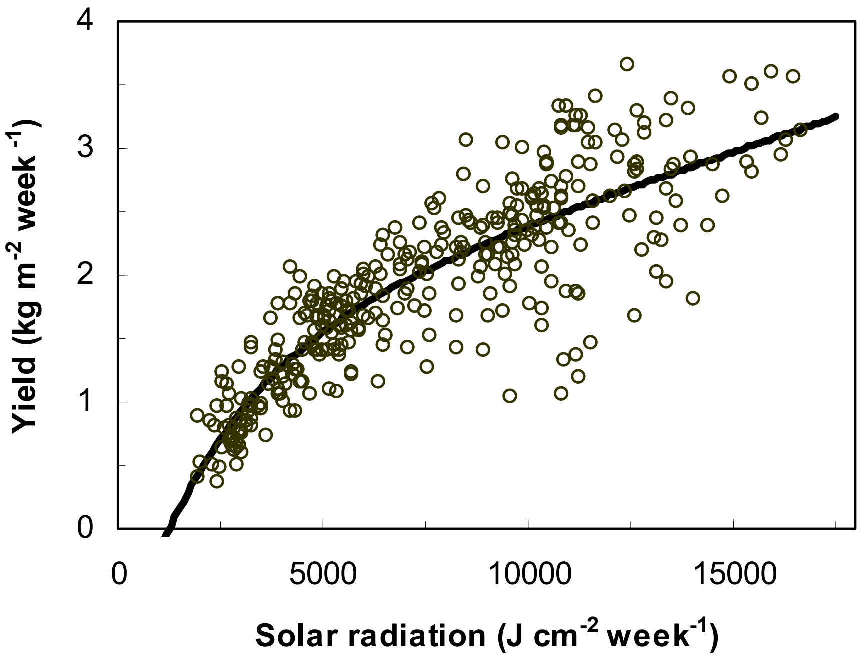

Fig. 1. Fresh weight of cucumber harvest in relation to global radiation outside the greenhouse. Each data point is the average of 3 weeks. Data are based on 14 growers in the period from January 1996 to May 1997.

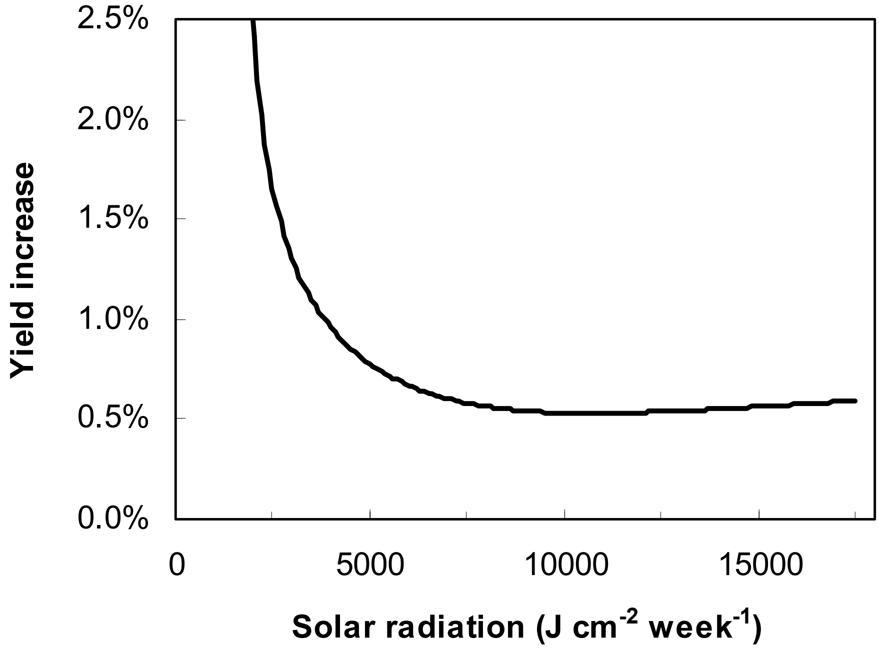

Fig 2. The relative effect of 1% additional light on yield increase (fresh weight) of cucumber in relation to global radiation outside the greenhouse. The curve is based on the first derivative of the regression line in Fig. 1.