Influence of Diffuse Glass on the Growth and Production of Tomato

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Abstract

There is a great deal of interest for diffuse glass in Dutch horticulture ever since higher light transmission values and the diffusing characteristics of diffuse glass have increased production for some crops. Thus an experiment was designed to examine the effects of a variation in haze factors and light transmissions for diffuse glass or a diffuse coating on the growth and production of tomato. The influence of diffuse glass with a haze factor of 45, 62 and 71% and light transmission equal to or greater than that of standard glass, as well as standard glass with a commercial coating with a haze factor of 50% and 6% less light transmission than that of standard glass was compared to that of standard glass. The crops were planted mid-December 2010 and grown to the middle of November 2011. The influence of diffuse light on light interception, crop morphology, photosynthesis and growth was measured and analysed. Light penetrated deeper into the crop resulting in a higher photosynthetic capacity in the lower canopy, but only in winter. Tomato grown under diffuse glass was more generative, transferring more into fruit production than vegetative growth, in comparison to standard glass or coated glass. The production under the three diffuse glass coverings showed a 7-9% increase in June relative to that under standard glass, and retained this increased production to the end of the year, ending with 8-11% more production. The most important reason for the increased production was an increase in individual fruit weight by 5-8 g. Plants grown under diffuse glass or coating were less susceptible to *Botrytis* spp. during the last months of the crop, possibly due to a higher dry matter content. The coating was applied in the beginning of May and the treatment continued through August when the global radiation diminished and more light was necessary in the crop and the coating was removed. The overall production under the coating was 5% higher than that under standard glass. An estimation of the benefits and consequences of diffuse light characteristics on the growth, development and production of tomato under Dutch conditions are discussed, along with recommendations for the optimal characteristics for diffuse glass.

INTRODUCTION

Recent research on the influence of diffuse light on greenhouse crops has indicated that the use of greenhouse coverings which scatters light can increase the production of cucumber by as much as 10% (Dueck et al., 2009). The effects of diffuse light on plant growth and production are promising (Brodersen et al., 2008; Markvart et al., 2010). However, in the choice of glass, a high degree of light transmission is important. Greenhouse crops require a great deal of light in winter, and can utilize a large degree of haze (scattered light) in the summer, when high peaks of light energy may result in photoinhibition, reduced photosynthesis and even crop damage. In addition, complaints have been received about the need for additional heat in the morning hours under diffuse glass as a result of light loss, increasing the costs of heating the greenhouse. Thus, more knowledge about the characteristics of glass is necessary when choosing new glass. The production of diffuse glass has often resulted in a reduction in light transmission in the past, but diffuse glass is now available with the same or even higher light transmission than standard glass due to the use of more pure material (low iron) and the application of anti-reflection coatings.

Light that is scattered as it enters the greenhouse is likely to be better distributed in a vertical and horizontal plane reducing the amount of high light spots and shadows in the crop resulting from greenhouse construction (Hemming et al., 2007). The result of an even light distribution is that light will penetrate deeper into the crop and increase the photosynthetically active leaf area. Due to the homogenous light distribution (Brodersen et al., 2008) the occasions with extremely high amounts of light energy reaching and affecting the top of the crop (canopy) resulting in photoinhibition and decreased photosynthesis (Muraoka et al., 1998; Johnson and Smith, 2006) are likely to be reduced.

Diffuse glass is usually applied when building a new horticultural complex, but when that is not imminent, the application of temporary coatings might offer similar advantages to crop growth and production, even though their use is accompanied by light reduction. In order to investigate this and the effects of diffuse light on greenhouse crops, an experiment was designed using a tomato crop grown from December 2010 to November 2011. During this time, the influence of diffuse glass with various degrees of haze and light transmission was compared to that of standard greenhouse glass with and without the application of a temporary glass coating.

MATERIALS AND METHODS

Tomato plants were planted on 16 December 2010 in five compartments of 144 m^2 each at the Wageningen UR Glasshouses in Bleiswijk (52°N), The Netherlands. The tomato cultivar used was 'Komeett', a large truss tomato, grafted onto Maxifort. The experiment ended 15 November 2011. Three types of diffuse glass were compared to standard greenhouse glass, the latter both with and without a coating applied during the summer months, all of which resulted in five treatments. The characteristics of the control, diffuse glass types (Diff45, Diff62, Diff71) and the coated glass are given in Table 1.

The plant density at planting was 2.55 m^{-2}. Additional auxiliary stems were retained in week 10 (March), resulting in a stem density of 3.4 m^{-2}. The CO_2 concentration was maintained at approximately 1000 ppm (max. dosing capacity 230 kg ha^{-1} h^{-1}). Watering, leaf pruning and temperature set points were adjusted to the needs of the crop in each individual treatment in order to realize optimal growth and production. Crop growth and production was measured and monitored on a regular basis. The light intensity above and in the crop was measured with 1 m long LiCor Line quantum sensor (LI-191, Licor, USA).

Leaf photosynthesis and photoinhibition was measured with a LI6400 XT (Licor, USA), the photoinhibition measurements with a leaf chamber fluorescence head. Measurements were performed on three fully-grown leaves in the upper and in the lowest part of the canopy. The leaf temperature was measured using thermo-couples on the bottom side of leaves at various levels in the canopy. Crop transpiration was estimated using water uptake, calculated by the water supply minus the daily water drain. The amount of thermal energy supplied by the heating pipes in each treatment was registered throughout the experiment.

RESULTS AND DISCUSSION

Glass Characteristics

Measurements on the perpendicular light transmission do not generally provide a good indication of the amount of light available to the crop. At lower altitudes, the angle of sunlight in relation to the slope of greenhouse roofs is never perpendicular and only approaches perpendicular for only a very short time at solar noon; thus the hemispherical light transmission parameter was used. It is derived from the measured light transmission between 0° to 90° (in steps of 10°) in relation to the glass and calculated with an equation described in Out and Breuer (1995), providing a more balanced estimation of the light transmitted by greenhouse glass throughout the day. The haze factor and hemispherical light transmission measured for all five treatments are shown in Table 1. The data show that with various degrees of light scattering, one type of glass (Diff62) transmitted more light than the others, and the coated glass transmitted less light than the control.

Light Distribution and Penetration

The horizontal light distribution was measured at ca. 50 cm depth into the canopy in the control and Diff71 treatments. Diffuse light entering the canopy is much more evenly distributed than is direct light (Johnson and Smith, 2006), providing leaves in the same horizontal plane with similar amounts of light. Light intensities measured in the canopy in the control treatment (direct light) showed a great deal of variation, from 40-80% of the light intensity just above the canopy, due to greenhouse construction. A more even light distribution contributes to a higher rate of photosynthesis and growth at the crop level (Brodersen et al., 2008). In addition, more light reached lower canopy levels under diffuse glass. While similar light intensities were measured at the top of the crop in each treatment, more light penetrated into the crop when scattered by the glass (Diff71) than in the control: 9% more light at an LAI of 1, 6% more at LAI 2 and 1% more at LAI 3. Sarlikioti et al. (2011) suggested that leaves developing in diffuse light alter their orientation to light, influencing the amount of intercepted light.

Leaf Temperature, Photoinhibition and Transpiration

In order to investigate the effect of diffuse light on the uppermost leaf layer, the leaf temperature was measured on a warm, sunny day (2 Aug.) and related to the greenhouse air temperature at that moment. High leaf temperature peaks occurred under standard glass at solar noon, and were several degrees higher than under diffuse glass (Fig. 1A). More striking however, was the difference between the leaf temperature and the air temperature in the greenhouse (Fig. 1B). There the large increase in leaf temperature in relation to air temperature (up to 6°C) in the control treatment (direct light) suggest that leaves might well be subject to heat stress. Even though the air temperature under diffuse glass increases at midday as well, the difference between the leaf and air temperature remained below 2°C.

At the same time, the photosynthesis efficiency was measured by chlorophyll fluorescence (Fv/Fm ratio) in leaves in the upper canopy during the course of the day. Whereas the Fv/Fm ratio in the morning (9 h) was 0.83 under direct and diffuse light, indicating a good functioning photosystem II, it dropped to 0.70 at 13 h and 0.66 at 14 h under direct light, while under diffuse light the degree of photoinhibition was much less, 0.76 at 13 h and 0.73 at 14 h. This supports Johnson and Smith (2006) who observed that direct sunlight reduced the photosynthetic efficiency of *Abies*-seedlings by 10% in comparison to that on cloudy days. This suggests that leaf physiology and photosynthesis is less subject to light and or heat stress under diffuse light.

Leaf temperature in relation to air temperature strongly influences transpiration and thus crop transpiration under diffuse glass will likely differ as well. The results of water taken up by the crops under diffuse and direct light, of which ca. 90% is transpired, are given in Table 2. Averaged over a longer period in the experiment from March to October, 5% more water was taken up and transpired in the Diff62 treatment, which follows the higher light transmission (85%) of that glass. During a shorter period in early summer when the coating was present (May to July), the difference between the coating and the other treatments was larger, 9% less transpiration than in the control treatment.

The greenhouse air temperature is often thought to be lower under diffuse glass. However, when the light transmission is similar to that of standard glass, temperature changes due to sun energy should be similar as well. The amount of thermal energy (i.e., gas consumption) used under each of the roof types in the experiment is shown in Table 3. It appears that although there is some variation in part due to small differences in optimizing the greenhouse climate (data not shown), there is no conclusive evidence indicating that more energy is necessary to maintain the greenhouse air temperature under diffuse glass.

Crop Growth and Production

Following the first flowering in January 2011, tomatoes were harvested starting in the last week of March. Within a month a difference in production was observed between the crops under diffuse glass and the control, whereby it should be mentioned that the treatment with the coating began in the beginning of May. Within a few weeks more tomatoes were harvested under diffuse glass than the control, increasing in production by approximately 600-1300 g m^{-2} more than the control every 4 weeks (Fig. 2). This resulted in an increase of 7-9% under diffuse glass already by June in relation to the control. The coated treatment only began in spring when normally the intensity of sun light considerably increases. The effect of diffuse light under the coating was thus observed later, after the first fruits developed under the diffuse coating became mature and were harvested. Here too, an increase in production was observed, but averaged at 5% at the end of the experiment. This was less than half the production increase under diffuse glass, with average production increases of 8-11%. Although slightly more fruits per m^2 were produced under diffuse glass (14-24), the largest factor responsible for the increase in production was the individual fruit weight. Tomatoes that developed under diffuse glass each weighed 5-8 g more on average than fruits developed under direct light (standard glass).

Tomato growth and production is strongly related to light. The amount of light the plant requires for the production of a kg tomatoes is the sum of light the plant absorbs from flowering to harvest (Marcelis, 1994). Given the time between flowering and harvest from 8-9 weeks, the tomatoes harvested in a particular week was related to the light sum over a period of the 9 previous weeks. The result (Fig. 3) indicates that the tomato production is related to the light sum and that more tomatoes were produced with the same amount of light when it was scattered (diffuse) than when it was direct light. During the period with the most sun light in 2011, the middle of May to the middle of July, the time between flowering and harvest was 56 to 60 days, the shortest time under diffuse glass. Two dips in production in weeks 29 and 30, and weeks 36 and 37 are probably due to the periods of less light and lower greenhouse temperatures occurring in the weeks previous.

During the last 2 months prior to harvest, the number of healthy tomato stems was scored as some degree of *Botrytis* infection was observed in all treatments (Fig. 4). There was consistently more *Botrytis* infection in the control than the other treatments, suggesting that plants grown under diffuse light were less sensitive to *Botrytis* infection. The crops grown under diffuse glass showed more generative growth and had a higher stem dry weight content. In addition, these plants possibly experience less stress (lower leaf temperature, less photoinhibition), and are thus less sensitive to infection. When evaluating the increase in production (8-11% production increase at harvest) and the impact of the *Botrytis* infection, it should be noted that the production under diffuse glass had already reached a difference of 7-9% at the beginning of the summer, well before week 37 when the infected stems were scored and the differences between treatments were small.

CONCLUSIONS

1. Diffuse light results in a higher production, varying from 9-11% at haze factors of 45-71% for diffuse glass and 5% at 50% haze.
2. Greenhouses with diffuse glass do not require more heat energy than standard glass.
3. Diffuse light penetrates deeper in the crop and is more evenly distributed, resulting in less photoinhibition.
4. Plants growing under diffuse light appear to be less sensitive to *Botrytis* infection.

ACKNOWLEDGEMENTS

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Tables

Table 1. Haze factor (%), hemispherical and perpendicular light transmission (%) of the glass used in the experiment.

Glass type	Haze factor (%)	Hemispherical transmission (%)	Hemispherical transmission % of control	Perpendicular transmission (%)
Control	0	82.7	100	89.8
Diff45	45	82.6	100	82.4
Diff62	62	85.4	103	93.9
Diff71	71	82.9	100	93.6
Coating	50	78.0	94	89.7

Table 2. Water uptake (L m^{-2}) by the crops during a period with the coating (1 May to 1 July), and during a longer period from 1 March to 9 October, including a period without the coating.

	Glass type				
	Control	Diff45	Diff62	Diff71	Coating
1 May-1 July					
Water uptake	3.96	3.99	4.08	3.88	3.62
Uptake % control	100	101	103	98	91
1 March-1 October					
Water uptake	3.10	3.13	3.25	3.07	3.01
Uptake % control	100	101	105	99	97

Table 3. Thermal energy use (m^3 natural gas m^{-2}) to heat the greenhouse during crop growth.

Treatment	Energy use (m^3 gas m^{-2})	Energy use relative to control (%)
Control	21.0	100
Diff45	21.8	103
Diff62	20.5	98
Diff71	20.3	96
Coating	21.4	102

Figures

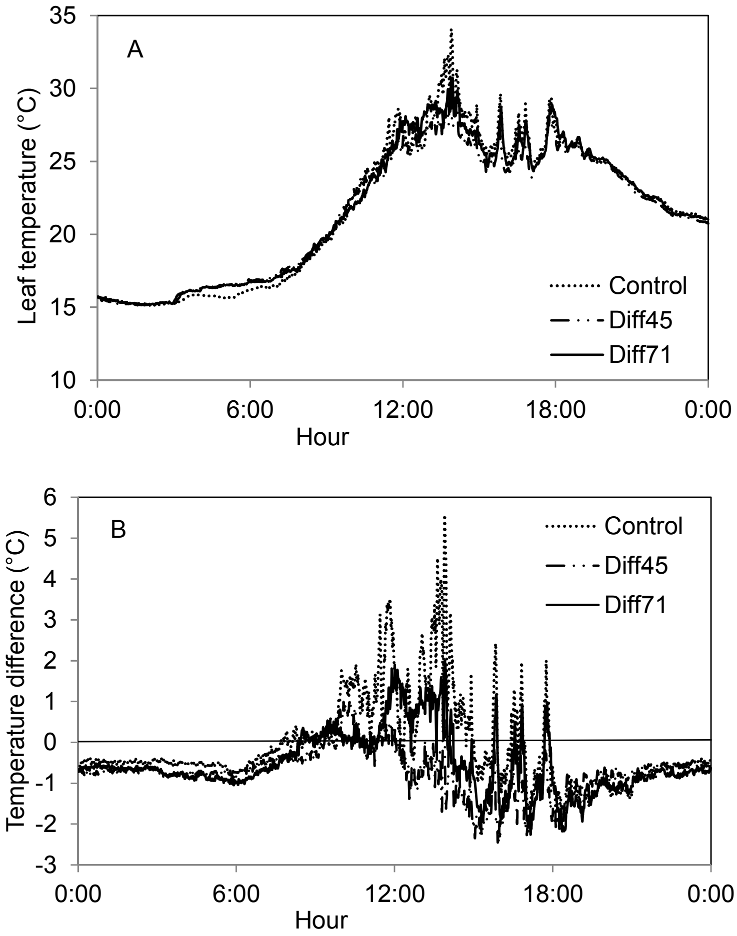

Fig. 1. Leaf temperature (°C) under diffuse glass (Diff45, Diff71) compared to the control (A), and the difference between leaf and air temperature on a sunny day (2 August) (B).

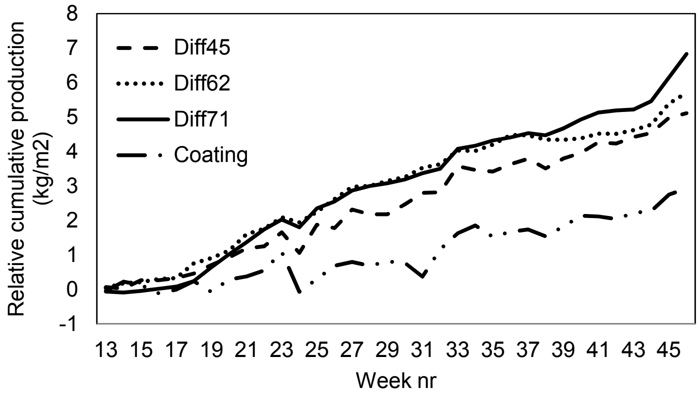

Fig. 2. Cumulative tomato production (kg m^{-2}) under diffuse glass (Diff45, Diff62, Diff71) and coated glass relative to the control.

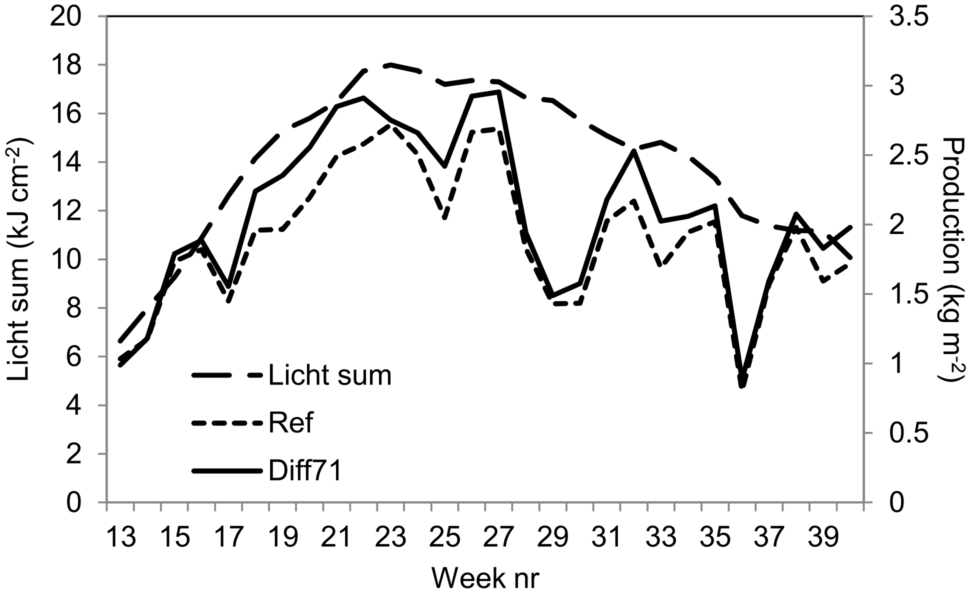

Fig. 3. Tomato production (kg m^{-2}) under diffuse light (Diff71) and the control (Ref) relative to the light sum (kJ cm^{-2}) over the previous 9 weeks.

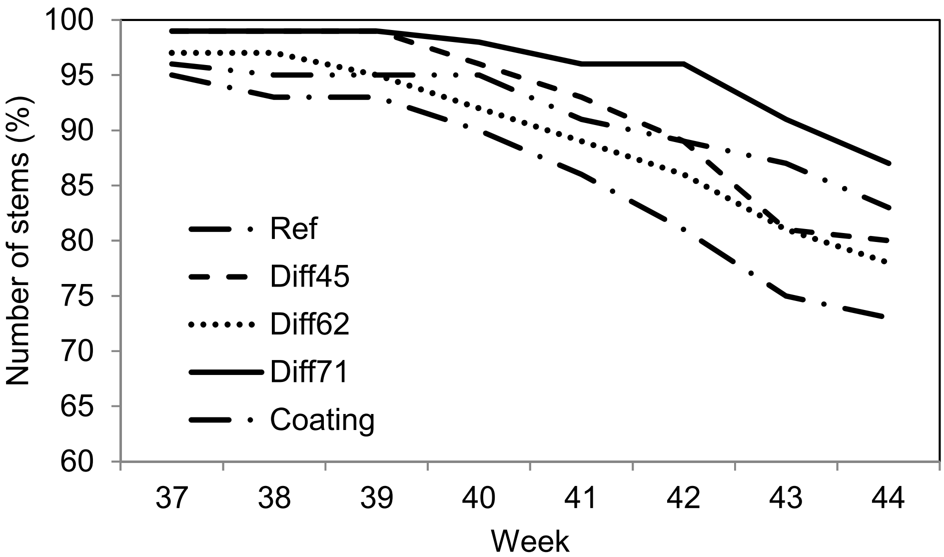

Fig. 4. The number of healthy tomato stems present in each of the treatments during the last 8 weeks of the cropping season.