Quantifying the effects of hortiscatter in greenhouse cover materials on crop yield

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Quantifying the effects of hortiscatter in greenhouse cover materials on crop yield

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Abstract

To control and optimize light entering the greenhouse, different types of glass, screens, and coatings are available. Diffuse cover materials can change the geometrical distribution of incoming sunlight, improving the horizontal and vertical light distribution in the crop. Recently, the unit hortiscatter has been defined to quantify light scattering by cover materials, and it provides information on the geometrical distribution of photons. Diffuse covering materials have proven to increase crop yield in many crops, but in these past studies different glass materials were used, resulting in different levels of diffusivity and light transmission, thereby potentially affecting crop yields. The goal of this research was to establish a quantitative relation between hortiscatter, as a measure for diffusivity, and crop yield of different crops, and thus to establish a rule of thumb for the amount of crop yield increase per unit hortiscatter. A literature review was conducted of earlier studies that compared growth under diffusive with growth under clear glass covers. Also, the cover materials used in these studies were measured to determine hortiscatter and hemispherical light transmission. To account for differences in hemispherical light transmission that accompany different hortiscatter levels, yield was divided by hemispherical light transmission. The difference of this ratio between diffuse and reference material was used to compare data sets for 11 crops. On average, yield increased by 1.8% for every 10% increase in hortiscatter. For tomato and cucumber this was 2.1 and 2.2%, respectively. We conclude that a quantitative relationship between hortiscatter and crop yield can be established.

Keywords: diffuse light, direct light, hortiscatter, hemispherical light transmission

INTRODUCTION

Greenhouses provide a controlled climate environment for efficiently growing crops, by increasing production per unit ground area and year-round consistency (Xin et al., 2019). An important resource for plant growth is (solar) light. Solar light provides free energy to a greenhouse and is the driving force for photosynthesis. Under conditions of near-optimal temperate, [CO_2] and irrigation, plant growth is mainly determined by the amount of light, the light spectrum, the timing, duration, and the geometrical (horizontal and vertical) light distribution (Hemming et al., 2007a). To control and optimize solar light entering the greenhouse, different types of glass, screens, and coatings are available (Hemming et al., 2016). Diffuse greenhouse covering materials can transform direct sunlight into (partly) diffuse sunlight. Greenhouse glass contains micro-structured surfaces which, depending on their geometry, can change the geometrical distribution of the incoming sunlight into another geometrical distribution of the outgoing sunlight towards the crop. Before the year 2018, light scattering by a greenhouse covering material was measured as unit haze, which is the percentage of the radiant flux (in this context, incoming solar energy per unit time) that is transmitted through a material at any direction with an angle larger than 2.5° from the outgoing perpendicular (ISO 14782:2021, 2021). This means that all radiant flux outside the

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cone of 2.5° was equally counted as 'haze', regardless of the scattering angle (Figure 1). Since this measure does not provide information on the geometrical distribution of light towards the crop, and microstructure glasses substantially differ in their geometrical distribution of light, the unit hortiscatter (HS) was introduced. HS is based on a measurement of all radiant fluxes transmitted through the glass under all outgoing angles, the bidirectional transmittance distribution function (BTDF) (Figure 1). The exact measurement protocol and formulas are described in the NEN2675+C1 protocol (NEN, 2018). The NEN (Stichting Koninklijk Nederlands Normalisatie Instituut) is an organization that develops and publishes national and international standards to facilitate consistency and quality in various industries and sectors. A 0% HS means that all transmitted light rays keep their original direction, while a 100% HS means that the scattering distribution of the light rays follows a perfect Lambertian distribution. Besides hortiscatter, hemispherical light transmittance (τ_h) should be considered in determining the effect of a material on crop yield. τ_h describes the transmittance of a cover material, taking into account the angles of incidence the sun makes on a specific location (NEN, 2018). Since 1% more light, or τ_h, means ca. 1% more growth for most crops (Marcelis et al., 2006), HT is an important parameter in comparing different cover materials. Diffuse covering materials have proven to increase production in many crops (Hemming et al., 2007a). In cucumber, it was previously seen that the use of diffuse glass increased total fresh yield by 4.3-9.7% compared to clear glass with the same hemispherical light transmission, which resulted in an increase in the number of fruits by 4-7.8% and fruit weight by 2.0-3.9% (Dueck et al., 2009; Hemming et al., 2007b; Janse et al., 2012). Diffuse glass also had a positive impact on crop yield in tomato, as it increased by 2.8% at low and 11.0% at high light scattering percentages (Dueck et al., 2012; Holsteens et al., 2020). By scattering the light, the light distribution, is improved (Li and Yang, 2015). Light is more homogenously distributed across leaves in all layers (Li et al., 2014a; Li and Yang, 2015), which is advantageous for crop photosynthesis (Kaiser et al., 2018). This increase in crop photosynthesis due to diffuse light can be attributed to multiple factors, as quantified by Li et al. (2014a): i) light is better distributed along the horizontal layer, ii) leaf photosynthetic capacity is increased, iii) light is better distributed along the vertical gradient, iv) leaf area index (LAI) is increased, and v) interactions between these four factors can additionally have a positive effect.

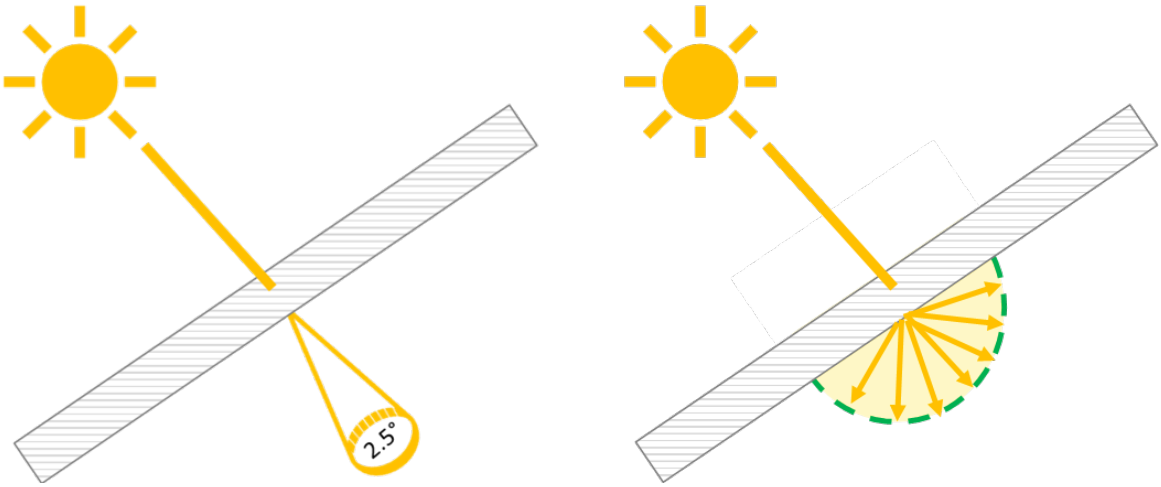

Figure 1. Schematical representation of haze (left), the percentage of the radiant flux that is transmitted through the glass at any direction with an angle larger than 2.5° from the outgoing perpendicular, and hortiscatter (right) a measurement of all radiant fluxes transmitted through the glass under all outgoing angles, the bidirectional transmittance distribution function (BTDF).

Photosynthesis tends to react with a delay to rapid fluctuation in light intensity, which reduces time-integrated photosynthesis rates under fluctuating light (Kaiser et al., 2015,

2018). By improving the horizontal light distribution, light intensity variations due to clouds or moving shadow spots, caused by the greenhouse construction are minimized, preventing limitation in photosynthesis (Li et al., 2016). Light intensity fluctuations during the day also impact light absorption, mainly in leaves in the top layer of the canopy, when high irradiance peaks occur. During light intensity peaks, an imbalance can occur between absorption and utilization of light energy. This excess in energy can potentially lead to an increase of reactive oxygen species in the chloroplast, which can damage photosystem II (Li et al., 2002), resulting in photoinhibition: the photosynthetic potential of a leaf will decrease when the rate of damage exceeds the rate of repair of the D1 protein in the reaction centre of photosystem II (Davis and Hangarter, 2012). In ornamental crops, strong photoinhibition can result in chlorosis and necrosis, reducing their value and resulting in large losses (Van Noort et al., 2013, 2014). Diffuse light has a lower extinction coefficient than direct light, resulting in an improved vertical light distribution, which may result in acclimation of lower leaves to increased light intensity Li and Yang (2015). Increased light intensity at the lower leaves induces the biosynthesis of chlorophyll, therefore facilitating light capture, and increases the photosynthetic capacity in intermediate leaf layers, potentially resulting in a higher canopy photosynthesis (Li et al., 2014a; Stenbaek and Jensen, 2010). These advantages are mainly apparent for crops with a high leaf area index (LAI), e.g., tomato, cucumber and bell peppers grown in high-wire systems, as for crops with a low LAI, more light would not be absorbed by the plant but reach the ground (Li et al., 2014a).

Many studies in which diffuse light was applied show an increase in growth and production as described above. However, in these studies, different glass materials were used, resulting in different levels of diffusivity and light transmission (τ_h), thereby potentially affecting crop yields. Also, most studies quantified light scattering as haze percentage, which does not quantify geometrical distribution of light towards the crop, making it difficult to compare results and draw conclusions on the general effects of diffusivity on crop growth. In this paper, we measured all glass materials used in earlier studies concerning hemispherical light transmissivity and hortiscatter. We reviewed earlier published results on crop growth and development. We then analysed and summarized the effects of diffuse light on crop yield of different crops, based on previous published research. Earlier, a rule of thumb to quantify the amount of yield increase per amount of light increase (Marcelis et al., 2006), thus per increase of the hemispherical light transmissivity of the greenhouse cover, was established. The goal of this paper was to establish a rule of thumb to quantify the amount of crop yield increase per unit hortiscatter (HS).

MATERIALS AND METHODS

Literature review

A literature review was conducted in which a diffusive glass cover was compared to a clear glass cover. For a data set from a paper to be included, the following requirements applied: i) the diffuse light treatment should be applied through the covering material of the greenhouse, and ii) the cultivation technology used during the research must be representative of modern cultivation practice; for vegetables, this means soilless cultivation in stonewool, for ornamentals depending on the crop with representative climate control and crop management strategies. These restrictions resulted in literature where the research was conducted in high-tech glass greenhouses. Included crops were: anthurium (*Anthurium andreanum*) and bromelia (*Guzmania lingulaa, Vriezea splendens*) (Van Noort et al., 2013); bell pepper (*Capsicum annuum*) (Holsteens et al., 2020; Eveleens-Clark et al., 2010); tomato (*Solanum lycopersicum*) (Kempkes et al., 2021; Dueck et al., 2012, 2014; Holsteens et al., 2020); cucumber (*Cucumis sativus*) (Kempkes et al., 2021; Dueck et al., 2009; Hemming et al., 2007b; Janse et al., 2012); *Ficus* (*Ficus benjamini*), *Kalanchoe* (*Kalanchoe blossfeldiana*), potted chrysanthemum (*Dendranthema* × *grandiflorum*) and schefflera (*Schefflera arboricola*) (Hemming et al., 2007c); and rose (*Rosa* × *hybrida* (García Victoria et al., 2012).

From the literature, data on crop yield of both the reference and diffuse greenhouse and the haze value of the glass covers was collected. To determine the hortiscatter value and the

hemispherical light transmission values, all glass covers used in these previous experiments were collected and measured at 'WUR LightLab' belonging to Wageningen University and Research, the Netherlands, following NEN2675:2018+C1. An overview was made of the optical properties of the cover and the reported yield for data analysis.

Data analysis

To correct for differences in hemispherical light transmission (τ_h) and compare the data of both the reference and diffuse treatment within a literature study, the light use efficiency was calculated based on τ_h. Yield (Y) of both treatments was divided by the, to the treatment corresponding, τ_h (Y/τ_h). Y/τ_h gives the light use efficiency per percentage τ_h. Then the relative change between the Y/τ_h of the reference and diffuse treatment was calculated resulting in the Δ(Y/τ_h), giving the relative change in yield per percent τ_h. The crop yield (Y) was reported for all vegetable crops in kg of fresh product m^{-2} and in g dry weight for all ornamental crops, except rose where Y was reported as stems m^{-2}.

In Kempkes et al. (2021), the light use efficiency (LUE) was reported for the reference and diffuse treatment as g mol^{-1} incoming photons, instead of crop yield. Therefore, the difference in LUE between the diffuse and reference data was determined (ΔLUE).

RESULTS AND DISCUSSION

Generally, diffuse light had a positive impact on the yield of both vegetable and ornamental crops, when assuming a linear relationship we observed an increase of +0.18% per percent HS (Figure 2) with an R^2 of 0.71.

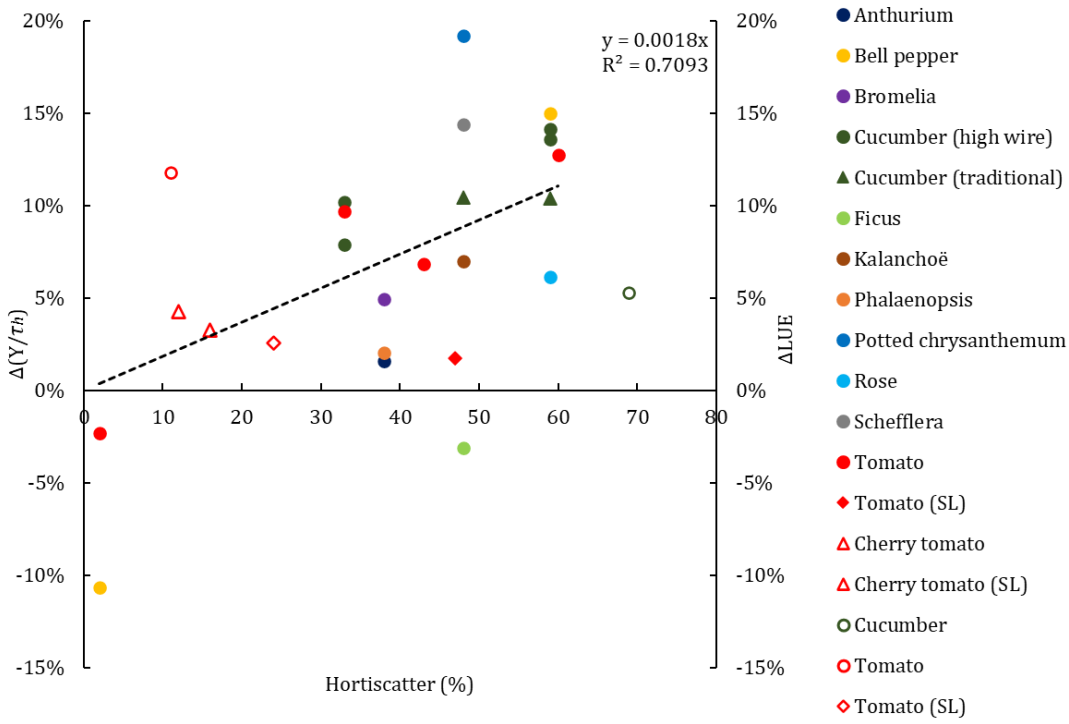

Figure 2. The effect of cover materials with different amounts of hortiscatter (%) on yield per hemispherical light transmittance Δ(Y/τ_h) (closed symbols) or the difference in light use efficiency (ΔLUE) (open symbols) of various crops. The plotted trendline and shown equation is only through the closed symbols and forced through zero.

In bell pepper, cucumber and tomato, the effect of hortiscatter ranged from -11% till 15% yield gain. Light interception in tomato and cucumber increased when light was diffuse, as

observed by Dueck et al. (2009, 2012) and Li et al. (2014a). An increased light interception, especially in the lower leaves, increases the photosynthesis rate and capacity (Dueck et al., 2009, 2012; Li et al., 2014a). Besides an increase in photosynthesis, in the top leaves a higher maximum PSII efficiency (F_V/F_M) was observed in the 33 and 60% HS treatment compared to the reference (Li et al., 2014a).

In crops with multiple crop cycles per year such as cucumber, the effects of a diffuse cover on yield could differ per crop cycle. The ratio between direct and diffuse light differs per season, as more clouds in autumn and winter scatter the incoming sunlight (Durand et al., 2021). Theoretically, therefore, a diffuse greenhouse cover should have the strongest positive effects on crop growth in summer. Cucumber grown in spring at 33% HS resulted in a yield increase of 8%, while in autumn the treatment with the same HS resulted an increase of 10% (Figure 2). At a higher HS of 59%, cucumber grown in spring and autumn resulted in a yield increase of both approximately 14%. In a traditional cucumber in spring and winter, no difference results in yield increase, respectively 11 and 10%. Comparing this data, no effect of season could be observed, meaning that diffuse covers were beneficial even in winter. We speculate that during non-cloudy days in any season, light is still used more efficiently, increasing crop yield under a diffuse cover compared to clear glass. However, this conclusion is based on inherently different experiments, which may affect our results.

In ornamental crops, the effect of diffuse light on yield is shown as the difference between dry weight (g m^{-2}), except for rose, where it is reflected as the amount of stems m^{-2} (Figure 2). Similar as for greenhouse vegetables, diffuse light had a positive impact on dry matter production and number of stems for ornamental crops. Only in *Ficus*, diffuse light reduced dry matter. An increase in growth rate was mainly observed in potted chrysanthemum and schefflera, which could mean that diffuse light shortens the growth cycle of these crops (Hemming et al., 2007c). Most shade tolerant pot plants are sensitive to high light levels during the summer period. When the capacity of photochemical and non-photochemical energy dissipation is exceeded by too high light absorption, photoinhibition might occur, leading to possible discolouring of leaves (Li and Yang, 2015; Long et al., 1994). To avoid these phenomena, growers often use climate screens or chalk to reduce light intensity inside the greenhouse. However a consequence is a potential decrease in crop growth (Li and Yang, 2015), due to reduced light integrals in the greenhouse. When a diffuse cover is applied, it leads to a more uniform distribution of light over the leaves, resulting in fewer light peaks. As a result, leaf temperature decreases and photoinhibition is minimized (Li and Yang, 2015). This then allows for an increase in the amount of light received by plants throughout the day (DLI), which not only improves quality, but also enhances plant growth (Marcelis et al., 2014; Li and Yang, 2015). For multiple ornamentals, it was observed that DLI could be increased when light was applied as diffuse rather than direct light. In bromelia and anthurium, this led to a decrease in growth duration of respectively 4 and 6 weeks, while in phalaenopsis this increased product quality (Li et al., 2014b; Van Noort et al., 2013, 2014).

For most crops only one or two data points were available making it difficult to establish a rule of thumb between horitscatter and crop yield increase. However for cucumber and tomato multiple points at different HS levels were available, therefore an attempt has been done to relate HS to yield for these crops (Figure 3). In case of a linear relationship, the following rule of thumb for cucumber and tomato yield is suggested: for every 10.0% HS yield increases by 2.2 and 2.1% for cucumber and tomato, respectively. This is lower compared to earlier suggested rule of thumb of 3.0% yield increase per 10.0% HS (Kempkes et al., 2021). This suggestion was based on the same literature but hortiscatter was estimated based on haze instead of measured which could explain the difference. The linear trend is, however, expected to flatten off, since there is a trade-off between HS and τ_h, higher HS decreases the τ_h (Figure 4). It is assumed that eventually the higher HS cannot compensate for the light loss, also taking into account the rule of thumb 1% more light is 0.5-1% more yield (Marcelis et al., 2006). Besides the trad-off, it is unsure what the optimal HS is and if higher levels of HS can increase crop yield even further.

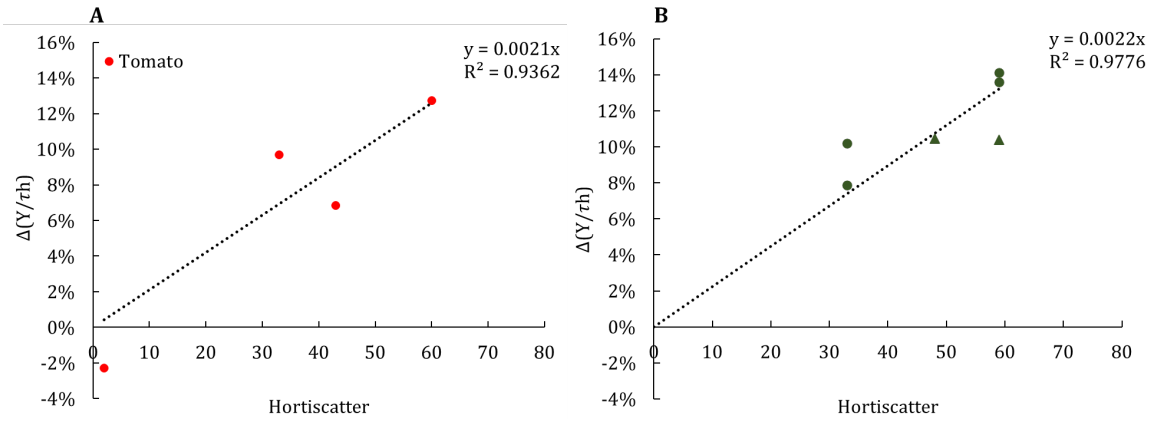

Figure 3. The effect of different HS levels on $\Delta Y/\tau_h$ of cucumber (A) and tomato (B) (Dueck et al., 2009, 2012; Hemming et al., 2007a, b, c; Holsteens et al., 2020; Janse et al., 2012). The plotted trendline and shown equation is through all points and is forced through zero.

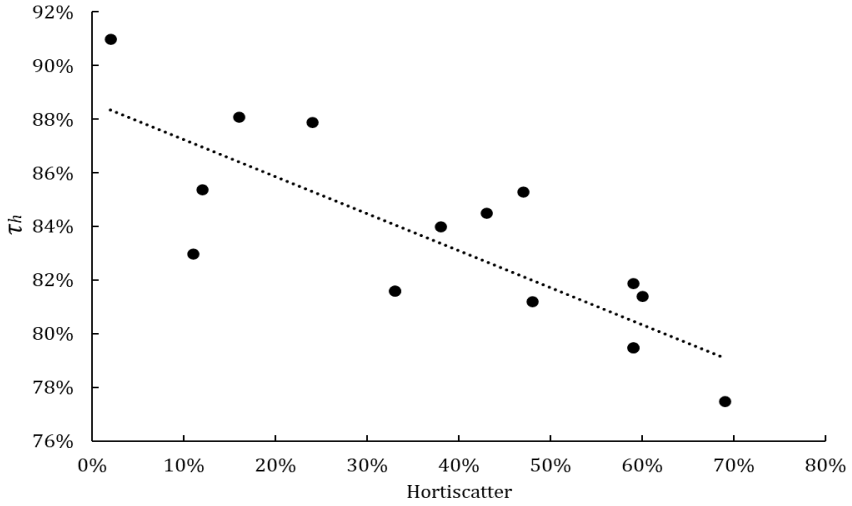

Figure 4. The relationship between hortiscatter and hemispherical light transmission (τ_h) of the diffuse covers from the literature included in the analysis.

CONCLUSIONS

Generally, a positive effect of diffuse glass – as expressed per unit hortiscatter (HS) – was observed on growth of all crops. In cucumber, bell pepper and tomato, yield increased between 6.9 and 15.0% at 30-60% HS. As rule of thumb for cucumber and tomato, a respectively 2.2 and 2.1% yield increase per 10% HS could be estimated. However, more studies are needed, as very few data were available to accurately quantify the relationship between hortiscatter and yield increase. Points of attention here are to include a wider range of HS values, both in the low as high range, and equal hemispherical transmission between cover materials used for a better comparison.

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Literature cited

Davis, P.A., and Hangarter, R.P. (2012). Chloroplast movement provides photoprotection to plants by redistributing PSII damage within leaves. Photosynth Res *112* (*3*), 153–161 https://doi.org/10.1007/s11120-012-9755-4. PubMed

Dueck, T.A., Poudel, D., Janse, J., and Hemming, S. (2009). Diffuus licht - wat is de optimale lichtverstrooiing? (Wageningen University & Research, Business Unit Glastuinbouw).

Dueck, T., Janse, J., Li, T., Kempkes, F., and Eveleens, B. (2012). Influence of diffuse glass on the growth and production of tomato. Acta Hortic. *956*, 75–82 https://doi.org/10.17660/ActaHortic.2012.956.6.

Dueck, T.A., de Gelder, A., Janse, J., Kempkes, F., Baar, P.H., and Valstar, W. (2014). Het nieuwe belichten onder diffuus glas. Rapport (Wageningen UR Glastuinbouw).

Durand, M., Murchie, E.H., Lindfors, A.V., Urban, O., Aphalo, P.J., and Robson, T.M. (2021). Diffuse solar radiation and canopy photosynthesis in a changing environment. Agric. For. Meteorol. *311*, 108684 https://doi.org/10.1016/j.agrformet.2021.108684.

Eveleens-Clark, B., Lagas, P., Driever, S., Zwinkels, J., de Vaate, J.B., and Kaarsemaker, R. (2010). 40 kg Paprika. Een project gefinancierd door het Productschap Tuinbouw.

García Victoria, N., Kempkes, F.L.K., Van Weel, P., Stanghellini, C., Dueck, T.A., and Bruins, M. (2012). Effect of a diffuse glass greenhouse cover on rose production and quality. Acta Hortic. *952*, 241–248 https://doi.org/10.17660/ActaHortic.2012.952.29.

Hemming, S., Dueck, T., Janse, J., and van Noort, F. (2007a). The effect of diffuse light on crops. Acta Hortic. 2008.

Hemming, S., Jongschaap, R., Janse, J., and Dueck, T. (2007b). Effecten van diffuus licht op komkommer. Resultaten van een teelt experiment. Nota *446*, 38.

Hemming, S., van Noort, F., Hemming, J., and Dueck, T. (2007c). Effecten van Diffuus Licht bij Potplanten: Resultaten van een Teeltexperiment (Wageningen UR).

Hemming, S., Swinkels, G.L.A.M., van Breugel, A.J., and Mohammadkhani, V. (2016). Evaluation of diffusing properties of greenhouse covering materials. Acta Hortic. *1134*, 309–316 https://doi.org/10.17660/ActaHortic.2016.1134.41.

Holsteens, K., Moerkens, R., Van de Poel, B., and Vanlommel, W. (2020). The effect of low-haze diffuse glass on greenhouse tomato and bell pepper production and light distribution properties. Plants (Basel) *9* (*7*), 806 https://doi.org/10.3390/plants9070806. PubMed

ISO 14782:2021. (2021). https://www.iso.org/standard/81840.html.

Janse, J., Moerenhout, S., Kempkes, F., and Dueck, T. (2012). Vroege komkommerteelt onder diffuus glas. Rapporten GTB No. 1183 (Wageningen UR Glastuinbouw).

Kaiser, E., Morales, A., Harbinson, J., Kromdijk, J., Heuvelink, E., and Marcelis, L.F.M. (2015). Dynamic photosynthesis in different environmental conditions. J Exp Bot *66* (*9*), 2415–2426 https://doi.org/10.1093/jxb/eru406. PubMed

Kaiser, E., Morales, A., and Harbinson, J. (2018). Fluctuating light takes crop photosynthesis on a rollercoaster ride. Plant Physiol *176* (*2*), 977–989 https://doi.org/10.1104/pp.17.01250. PubMed

Kempkes, F., Brunsting, M., Franken, G., Hemming, S., Tsafaras, I., and Stanghellini, C. (2021). Diffuus Kasdek – Maak Het Eens Helder (Wageningen UR).

Li, T., and Yang, Q. (2015). Advantages of diffuse light for horticultural production and perspectives for further research. Front Plant Sci *6*, 704 https://doi.org/10.3389/fpls.2015.00704. PubMed

Li, X.-P., Müller-Moulé, P., Gilmore, A.M., and Niyogi, K.K. (2002). PsbS-dependent enhancement of feedback de-excitation protects photosystem II from photoinhibition. Proc Natl Acad Sci USA *99* (*23*), 15222–15227 https://doi.org/10.1073/pnas.232447699. PubMed

Li, T., Heuvelink, E., Dueck, T.A., Janse, J., Gort, G., and Marcelis, L.F. (2014a). Enhancement of crop photosynthesis by diffuse light: quantifying the contributing factors. Ann Bot *114* (*1*), 145–156 https://doi.org/10.1093/aob/mcu071. PubMed

Li, T., Heuvelink, E., Van Noort, F., Kromdijk, J., and Marcelis, L. (2014b). Responses of two *Anthurium* cultivars to high daily integrals of diffuse light. Sci. Hortic. (Amsterdam) *179*, 306–313 https://doi.org/10.1016/j.scienta.2014.09.039.

Li, T., Kromdijk, J., Heuvelink, E., van Noort, F.R., Kaiser, E., and Marcelis, L.F. (2016). Effects of diffuse light on radiation use efficiency of two *Anthurium* cultivars depend on the response of stomatal conductance to dynamic light intensity. Front Plant Sci *7*, 56 https://doi.org/10.3389/fpls.2016.00056. PubMed

Long, S.P., Humphries, S., and Falkowski, P.G. (1994). Photoinhibition of photosynthesis in nature. Annu. Rev. Plant Biol. *45* (*1*), 633–662 https://doi.org/10.1146/annurev.pp.45.060194.003221.

Marcelis, L.F.M., Broekhuijsen, A.G.M., Meinen, E., Nijs, E.M.F.M., and Raaphorst, M.G.M. (2006). Quantification of the growth response to light quantity of greenhouse grown crops. Acta Hortic. *711*, 97–104 https://doi.org/10.17660/ActaHortic.2006.711.9.

Marcelis, L.F.M., Buwalda, F., Dieleman, J.A., Dueck, T.A., Elings, A., de Gelder, A., Hemming, S., Kempkes, F.L.K., Li, T., van Noort, F., and de Visser, P.H.B. (2014). Innovations in crop production: a matter of physiology and technology. Acta Hortic. *1037*, 39–45 https://doi.org/10.17660/ActaHortic.2014.1037.1.

NEN. (2018). Greenhouse glass - Determination of optical properties of greenhouse covering materials and screens (The Netherlands: Netherlands Standards) https://www.nen.nl/en/nen-2675-c1-2018-nl-251295.

Stenbaek, A., and Jensen, P.E. (2010). Redox regulation of chlorophyll biosynthesis. Phytochemistry *71* (*8-9*), 853–859 https://doi.org/10.1016/j.phytochem.2010.03.022. PubMed

Van Noort, F., Kromwijk, J., Snel, J., Warmenhoven, M., Meinen, E., Li, T., Kempkes, F., and Marcelis, L. (2013). 'Grip op Licht' bij *Potanthurium* en *Bromelia*: Meer Energie Besparing bij Het Nieuwe Telen Potplanten met Diffuus Licht en Verbeterde Monitoring (Wageningen UR).

Van Noort, F., Snel, J., Warmenhoven, M., Meinen, E., Steenhuizen, J., Kempkes, F., and Marcelis, L. (2014). 'Grip op Licht' bij *Phalaenopsis*: Meer Energie Besparing bij Het Nieuwe Telen Potplanten met Meer Natuurlijk, Diffuus Licht en Verbeterde Monitoring (Wageningen UR).

Xin, P., Li, B., Zhang, H., and Hu, J. (2019). Optimization and control of the light environment for greenhouse crop production. Sci Rep *9* (*1*), 8650 https://doi.org/10.1038/s41598-019-44980-z. PubMed