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High output LED in hybrid lighting for *Alstroemeria*

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Abstract

***Alstroemeria* cultivation in the Netherlands requires artificial light in order to overcome the low levels of natural light in winter. Typical supplementary light levels are low (60-100 µmol m^{-2} s^{-1}). In order to increase the supplementary light intensity with the lowest possible electricity costs, *Alstroemeria* producers are placing LED lights as an addition to the existing High Pressure Sodium lamps. This paper describes an experiment at a commercial nursery with a Hybrid lighting installation. The Hybrid lighting was created by complementing the existing 61 µmol m^{-2} s^{-1} HPS lamps with 21 µmol m^{-2} s^{-1} Philips High Output (HO) LED lamps to a total intensity of 81 µmol m^{-2} s^{-1}. The performance of the crop under this hybrid lighting was compared with that under the existing HPS installation (62 µmol m^{-2} s^{-1}) and with that under Regular Output (RO) full LED at an intensity of 79 µmol m^{-2} s^{-1} . The experiment lasted 16 months. The total light sum over de duration of the experiment in the Hybrid lighting was 4% higher than in the HPS reference due to the higher intensity installed and the fact that the grower switched on the HO LED lamps for more hours than the HPS lamps. The light sum in the LED treatment was 3% higher than the reference, due to the higher intensity, as it was used as many hours as the HPS lamps. Both the Hybrid and the LED lighting systems increased production. Of the three systems, the LED option was the most energy-efficient.**

Keywords: energy saving, energy use efficiency, high pressure sodium lamps, HPS, light interception, light spectrum, light use efficiency, PAR, 'Virginia', yield

INTRODUCTION

To overcome the low levels of natural radiation in the Dutch winters, the cultivation of most cut flowers takes place with supplementary light. Traditionally light was supplied with High Pressure Sodium lamps. *Alstroemeria* growers used to work with relatively low light intensities (60-100 µmol m^{-2} s^{-1}). The possibilities to replace or complement these lamps by the more efficient LED lamps have received quite some attention by growers in different ornamental crops. Orientative research at a commercial *Alstroemeria* company (García Victoria et al., 2015) showed that LED cultivation was possible with this crop without any adverse consequences for the ornamental value. The results were encouraging with regard to LED lighting for this crop, but the used lamps (Valoya, Finland) despite a tailored spectrum and light intensity did not result in either production gains or energy savings compared to the HPS lamps at the same intensity. An improved lamp made to complement the spectrum of the HPS lamps in a hybrid lighting system (Valoya, Finland) resulted in a 9% higher light use efficiency in a rose crop compared to HPS lamps alone (García Victoria and Pot, 2015). It is still under discussion whether this improved light use efficiency is due to the hybrid spectrum with a high proportion of far red and blue. In gerbera, hybrid lighting (HPS as top lighting and red and blue (95/5%) and LED as interlighting (García Victoria et al., 2016)) did not lead to a production increase, nor did the light use efficiency compared to the same intensity of HPS light only as top lighting. This illustrates how the results depend not only on the light spectrum, but also largely on the crop.

Alstroemeria growers are currently increasing the supplementary light intensity by adding LED lights to the existing HPS installation resulting in hybrid systems. This is done

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because an exploratory, in-company test with hybrid lighting compared with HPS lighting showed that in the company sections with hybrid lighting the flowers produced had a higher quality than in the sections with HPS only. For a good assessment of the effects and the opportunities for LED or hybrid lighting, a robust experimental setup and reliable measurements are required.

With the objective to support such an assessment, the program by the Dutch Ministery of Agriculture and the Growers Association "Greenhouse as Energy Source " supported this research project for two winter seasons. The goal was to monitor the first application of High Output LED lamps in a hybrid system in a commercial cultivation of *Alstroemeria*. The hybrid lighting system was created by supplementing the existing HPS lamps (61 µmol m^{-2} s^{-1} PAR) with 21 µmol m^{-2} s^{-1} PAR light from the latest generation of LED lamps (Signify, The Netherlands). With an output of 2.7 µmol/$W_{electric}$, these lamps are 40% more efficient than the HPS lamps. The hybrid light system (2640 m^2) was compared with the HPS lamps present in the largest part of the greenhouse compartment, and with a smaller surface (100 m^2) equipped with full LED.

MATERIALS AND METHODS

Location, greenhouse equipment and crop

The experiment was conducted in a commercial *Alstroemeria* company. The greenhouse was a Venlo-type covered with float glass and was located in the Westland region of The Netherlands. Two screen installations were used for shade and insulation purposes: the upper screen was a dark screen (PH 98 mat special Flame Protect) with 98% light screening and 70% energy saving capacity to avoid light emission to the environment (according to Dutch regulations) during the night hours. This screen was therefore mostly closed at night. The lower screen (PH Super B1) was a shading screen (13% light screening and 45% energy saving capacity) that is sometimes used as energy screen at night. During sunny days, it was used for shading whenever the outside radiation exceeds 600 Watt (700 Watt in summer); gaps between screen segments were allowed until 30%.

In the compartment where the trial took place, *Alstroemeria* × *hybrida* 'Virginia' (Royal van Zanten, Rijsenhout, The Netherlands) planted in 2009, was grown in the soil at a density of 3.6 plants m^{-2}. According to common cultivation practice, the root layer of the soil was cooled to a temperature of 15-15.5°C by means of four water pipes per bed (120 cm width). The path had a width of 40 cm.

The plants were fertigated with water and fertilizers trough a drip line, according to the normal strategy for the entire company.

Treatments and light installations

Three treatments consisting on tree different lighting systems were present in the same compartment: 1 – HPS (Control treatment, the normal light system of the company); 2 – Hybrid system (HPS complemented with high output LED on a surface of 2640 m^2; and 3 – Full LED system (regular output LED), 100 m^2.

The efficiency of the three lamps in the trial was expressed as the output in µmol PAR light per Watt electric, being 1.85 for the HPS lamps, 2.7 for the HO LED and 2.3 for the RO LED.

The hybrid lighting configuration alternates lamps lengthwise (one LED lamp followed by an HPS lamp), and in line in width (all HPS lamps in a row and all LEDs lamps in the next row). The installations could be switched on and off separately: the full LED system switches on and off simultaneously with the HPS of the entire company (and thus the control treatment); the HPS installation in the Hybrid section consisted of two phases in checkerboard arrangement that could be switched on and off separately from each other. These two lamp strands and the LED installation from the Hybrid section both switched on and off separately and were controlled independently. The grower controlled the installations differently. Moreover, the different installations yielded a slightly lower light output than calculated prior to installation. All these differences resulted in different light levels for all three treatments.

The implication was that the flower yield results should not be assessed per surface area (m^2 greenhouse) as is usual in experiments where all the treatments receive the same light, but in relation to the light(sum) received by the plants from each treatment, and in relation to the electricity used.

Measurements

To be able to calculate accurately the total light received by the plants in each treatment, the transmission of the greenhouse cover and the screens were measured twice during the duration of the experiment. The intensity and the spectrum of the light in the test sections were measured in the absence of daylight, with all three light installations switched on individually and jointly. To calculate the light sum received by the plants in the different treatments, 5 min data of the climate computer from the grower were supplied of outside radiation, the moments in which the screens were closed or open, and the moments in which the different light installation were switched on.

For measuring yield and quality, harvest sections were delimited in each light treatment. The harvest sections cover a total area of 32 m^2 for the Hybrid and HPS treatments, and of 25.6 m^2 for the LED treatment, which covers a smaller area than the other treatments. The harvest took place at the usual commercial maturity stage and with the normal frequency of the company: that is 3 times a week in spring and summer and only twice a week in autumn and winter. The number and the weight of the harvested flowers was recorded at each harvest, at full length and after recut all stems to the commercial length of 90 cm. Once every two weeks, 15 flowering stems per treatment were measured in detail: length, fresh weight, dry matter content (after drying at 80°C) number of leaves and flowers, total leaf area and chlorophyll content (non-destructive by absorbance with a SPAD-502 Chlorophyll meter, Konica Minolta, Inc., Eu).

Light interception by the crop was measured three times: January (the period of highest exposure to artificial light), March and September (the transition periods with more natural light and less artificial light). In March and September the sunlight interception was measured with the SunScan, an integrating light meter of 1 m length (SS1 SunScan, Delta-T, Cambridge, UK); the January measurement was done with artificial light only and therefore a spectrometer was used instead (Specbos 1211N, Jeti Technische Instrumenten GmbH, Jena, Germany). The sunlight was measured twice per height per treatment and repeated five times spread over the harvest sections. Five more repetitions were taken per height with the sun scan partly in the bed and partly in the path. The measurement with the spectrometer is replicated in different position of the width of the bed: in the middle, at 1/4 of the bed width and at the edge of the bed. In all cases, light was measured at five different heights in the crop: just above the crop at 140 cm from the ground, at a height of 105, 70, 35 and 0 cm (at ground level).

RESULTS AND DISCUSSION

Light spectra

The intensity and spectrum of the different light systems was measured in absence of natural light. The Hybrid lighting had an intensity of 81 µmol m^{-2} s^{-1}, the LED 79 µmol m^{-2} s^{-1} and the existing HPS installation 62 µmol m^{-2} s^{-1}. The spectra are shown in Figure 1. The LED light consists of a little blue light and mainly red light. This causes a considerable increase in the red in the hybrid lighting compared to the SON-T spectrum. Figure 1 shows that in the much smaller area of the LED treatment there is some influence from the surrounding SON-T lighting. The influence of the surrounding SON-T lighting in the LED is also visible at the bottom of the crop: as the top crop layers absorb most of the red and blue light, “yellow light” (which is not included in the LED lamps used but is present in the HPS lamps) remains (see also light interception results).

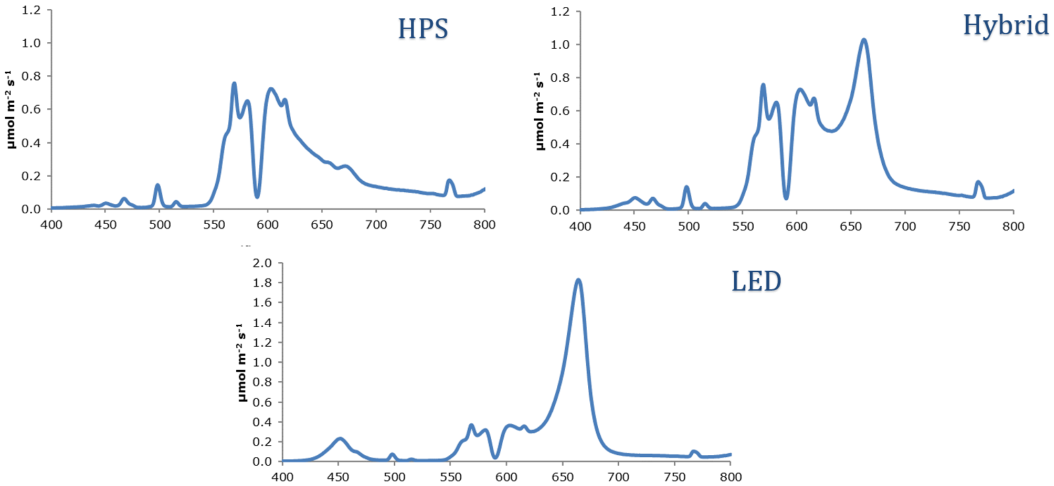

Figure 1. Spectra of the light in the three treatments. On the *x*-axis the wavelength in nm.

Light interception by the crop

1. Interception of artificial light.

The results for the three light treatments are shown in Figure 2. The crop intercepted more light under the HPS treatment, in particular the middle layers of the crop (Figure 2, left). In the middle of the bed, the crop intercepts more of the lamp light in the HPS sections than in the hybrid lighting sections. On a quarter of the bed and in the edge, there are no differences in interception between the crops in these two treatments. On average throughout the entire crop (Figure 2, right); the interception of light from the HPS lamps is highest, followed by the hybrid lighting. The crop intercepts the least light from the LED treatment, maybe because of the smaller leaves (see “Production and Quality”). This could be a consequence of the predominant red light in the spectrum of the lamps, which is absorbed at the higher crop levels (Paradiso et al., 2011). In the HPS treatment, still 10% of the incident light reaches the ground, while the amount of light measured at ground level under the LED section is 15%. This value would contradict the absorption of the red light by the upper layers; however, most of the light measured at ground level is stray light from the surrounding HPS, which is a consequence of the small trial size positioned in the middle of the HPS, the main lighting system of the company.

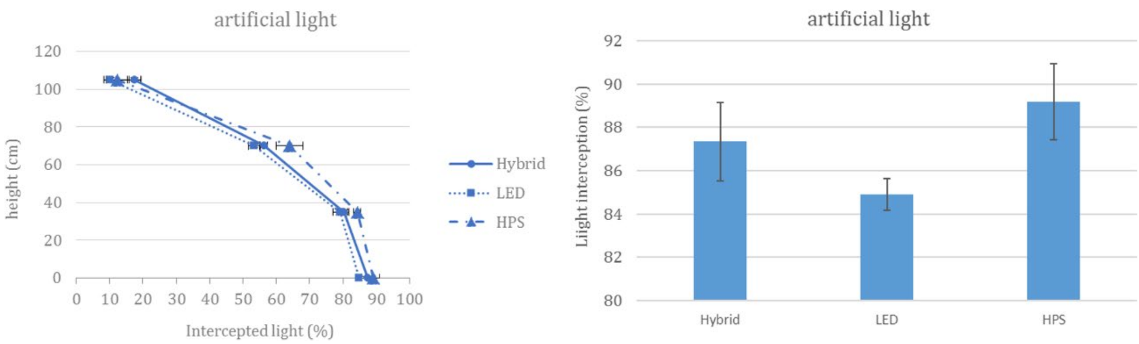

Figure 2. Left, light interception per treatment in the different layers in percentage of the total incident light at a height of 140 cm. Right, the average artificial light intercepted by the crop per treatment.

In the treatment with LED light, a relatively large amount of light falls in the path, with large variation between measuring points. This is a consequence of the positioning of the LED lamps in strands above the crop, parallel to the paths and with more strands next to each other than in the HPS and hybrid treatment.

2. Interception of natural light.

The natural light interception results were different in September and March (Figure 3). In the September measurement, most of the incident light (more than 50%) was intercepted by the crop layer of 75-105 cm height from the ground. Only a small amount of light (5%) lands on the ground. Significant differences are found between treatments in the upper crop layer (crop height 140-105 cm) where the crop under HPS intercepts 30% of the light while the Hybrid and LED intercept 15 and 19% respectively. This means that the crop was fuller there. The March results show more light intercepted by the crop in the hybrid treatment; however, only in the lower layer is the interception of sunlight reliably higher than in the LED and HPS treatment meaning a denser crop in the hybrid treatment. It is not clear whether this indicates a seasonal pattern or a coincidental difference in the productive flush. If a seasonal pattern, it could be partially explained by the use of the artificial light: in September, the crop has grown for three months with only natural light and hence no differences in intensity or spectrum, while the crop in March is coming from the winter, having had for three months mostly artificial light.

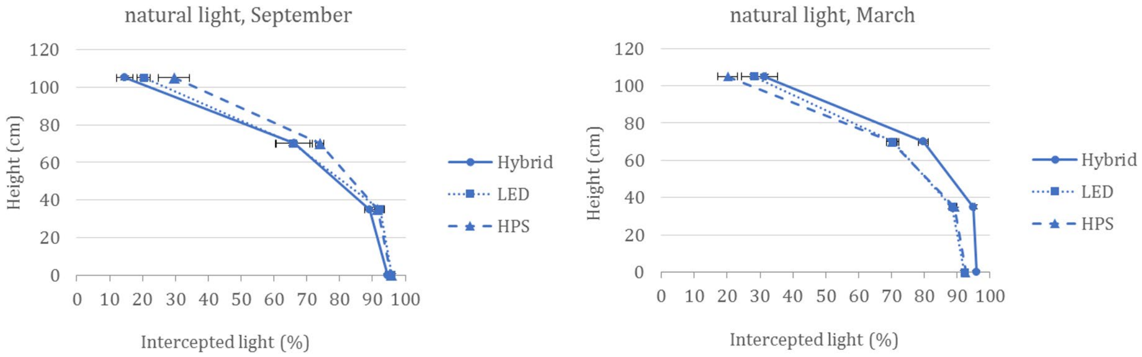

Figure 3. Interception of natural light in the three treatments (in percentage of the total incident light at 140 cm height). Left: September, right: March.

Production and quality

The cumulative production as recorded by the grower is shown in Table 1 and expressed in total number of stems per m^2 harvested from each measurement field (25.6 or 32 m^2). The production is also expressed as total fresh weight (kg product m^{-2}) at a stem length of 90 cm. The quality of the flowers harvested is expressed as average stem weight at the commercial length of 90 cm. The cumulative production until the end of the supplementary lighting season (May 7th) was 736 flowers m^{-2} at the HPS reference, 732 in the Hybrid treatment and 781 in the LED treatment. The production difference between the HPS and Hybrid treatment is marginal, but the LED treatment resulted in a yield increase of 6%. The cumulative fresh weight production from the Hybrid treatment was 42.5 kg m^{-2} (30 January 2017 to 7 May 2018), which is an increase of 9.8% compared to the HPS treatment (38.7 kg m^{-2}). With 41.3 kg m^{-2}, the LED treatment resulted in a 6.9% higher fresh weight production compared to the HPS treatment. Once cut to the marketable length of 90 cm, the differences in biomass became +8 and +6% for the Hybrid and LED treatments respectively. A small fraction of fresh weight production increase is being discarded once cut to the marketable length.

The Hybrid treatment produced 9.8% more fresh weight than the HPS control for a similar number of stems, meaning a higher average weight per flower stem (50.6 g) than in the HPS treatment (46 g). The LED treatment produced 6.9% more fresh weight than the control but in this treatment the increased fresh weight production was due to an increase in number of stems of similar average stem weight.

Table 1. Production and quality per treatment.

Production and quality as:	HPS	Hybrid	LED
Number of flower stems m^{-2}	736	732 (-0.5%)	781 (+6%)
Total fresh weight (kg m^{-2})	38.7	42.5 (+9.8%)	41.3 (+6.9%)
Total fresh weight at 90 cm (kg m^{-2})	33.7	36.5 (+8%)	35.7 (+6%)
Average stem weight at 90 cm (g)	46.0	50.8 (+4.8)	46.1
Average stem weight uncut (g)	52.8	59.2 (+6.4)	53.4
Average residual stem weight (g)	6.8	8.4	7.3

Besides the differences in production, the detailed quality measurements (data not shown) resulted in small but significant differences in some of the quality aspects of the stems produced under the three light treatments: in the hybrid treatment the stems were 4 cm longer, had 0.7 flowers more per stem and these were slightly heavier. In the LED treatment, the stems had a bit smaller leaf surface and a higher chlorophyll (SPAD) content. The dry matter percentage of the flowering stems was 8.25% and was similar for all treatments. The number of leaves per stem was 33 and did not differ either among treatments.

However, the treatments had different light intensities and were not used for exactly the same duration; hence, the plants in the three treatments received a different light sum during the test period. To enable comparison between the light treatments, we corrected the yield for the light sum of each treatment and for the electricity input that was needed to achieve it.

Light and electricity use efficiency

The Light Use Efficiency (LUE) is defined as the yield in fresh weight (kg m^{-2}) divided by the light sum (mol PAR m^{-2} of the lamps plus the natural light) over the total experimental period. The Electricity use efficiency (EUE) as the yield in fresh weight (kg m^{-2}) divided by the total used Electricity (kWh m^{-2}). The light sum (sun and lamp light separately) and the electricity used per treatment are shown in Table 2. The calculated LUE and EUE are shown in Table 3.

In both tables the results are presented separately for three different periods in the experiment: Period 1 (1-02 to 20-05), period 2 (21-05 to 9-08) and period 3 (10-08 to 7-05). In period 2 (summer) the lamps were permanently switched off, so the light sum was very similar for all treatments (small differences (0.14% lower in the LED treatment) caused by differences in transmission of the glass cover and incidental differences in the use of the screens).

Table 2. Light sum (mol PAR m^{-2}) and electricity use (kWh m^{-2}) per treatment and period.

Treatment	Sun light			Lamp light			Total light			Electricity use		
	P1	P2	P3	P1	P2	P 3	P1	P2	P3	P1	P2	P3
Hybrid	1638	2062	2779	241	0	828	1879	2062	3607	33	0	113
LED	1614	2032	2739	227	0	769	1841	2032	3508	27	0	93
HPS	1638	2062	2779	178	0	603	1816	2062	3382	27	0	91

The differences in PAR light sum between the lamps are substantial (6-7% lower PAR in the LED than the Hybrid; 35-37% less PAR sum in the reference). These differences are caused not only because of the differences in light intensities, but there were also different in the number of hours that the lamps were switched on: the HO LED in the hybrid treatment were used 442 h more (13% more hours) than the HPS and than the RO LED lamps. In total, the light sum in the Hybrid Treatment was 288 mol PAR m^{-2} (4%) higher than in the HPS reference; that of the LED treatment was 121 mol PAR m^{-2} (1.6%) higher that the HPS reference.

The LUE or the efficiency with which the crop converts the light into flowers over the duration of the experiment differed little between treatments, but was slightly higher (4%) in the Hybrid and LED treatments than in the HPS reference. Meaning that the increased light intensity (from 61 to 80 µmol m^{-2} s^{-1}) is well used by the crop.

The results show also that the LUE of the crop is lower in summer (P3, the period when the lamps were permanently switched off, and no electricity is used). Lee et al. (2003) also found a decrease of the LUE in Chrysanthemum in summer: the low levels of light in winter are used more efficiently than the high summer levels, probably because they often exceed saturating light levels in combination with limiting CO_2 levels.

Table 3. Yield in kg m^{-2}, LUE (g mol^{-1} PAR) and EUE (g kWh^{-1}) per treatment and period.

Treatment	Yield			LUE			EUE		
	P1	P2	P3	P1	P2	P 3	P1	P2	P3
Hybrid	7.9	8.0	20.6	4.2	3.9	5.7	238	-	182
LED	8.2	7.6	19.9	4.5	3.7	5.7	300	-	215
HPS	7.5	7.9	18.3	4.1	3.8	5.4	281	-	202

Looking at the EUE or how many grams of flowers can be obtained from one kWh, we can conclude that the Hybrid system was the least efficient in terms of energy. The HPS system is more efficient than the Hybrid. The most efficient of the three systems is the LED, even though it was used in the Regular Output lamp type and relatively less efficient.

CONCLUSIONS

The high output LED in a hybrid light system for *Alstroemeria* in this commercial company gave an 8% higher production brought about in the form of longer, heavier branches compared to HPS reference. The production gain was due to an increased light level (approx. 33%) and 13% more lamp hours than in the HPS reference, leading to a 4% higher light sum than the HPS reference. The regular output LED, also with an approximately 33% higher intensity but used for as many hours as the reference, also resulted in more production (6% more flowering stems, 7% more total weight). The Light Use Efficiency of the crop (expressed as grams of product per Mol light) was approximately the same for both LED systems (hybrid and full LED), and in both LED systems, the LUE was higher than in the HPS reference with a lower light level. This could mean that there is still room for increasing the light level in this crop.

From an energy point of view, the EUE (in grams of crop per kWh electricity), the hybrid lighting was the least efficient of the three systems. The most energy-efficient of the three systems is the LED option, even in this case where the lamps have a regular output (and are therefore relatively less efficient). However, before implementation of LED, research is needed to determine the right spectrum for this crop, and care must be taken of a good positioning of the lamps in relation to the crop to ensure maximum light interception by the crop and minimum light "waist" above the paths.

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Literature cited

Garcia Victoria, N., and Pot, S. (2015). Lichtspectrum als middel voor energiezuinige rozenteelt: praktijkproef bij Van der Arend Roses. Wageningen UR Glastuinbouw Rapport GTB- 1368.

García Victoria, N., van der Helm, F.P.M., and Warmenhoven, M.G. (2015). Praktijkproef LED Alstroemeria: invloed licht spectrum op bladkwaliteit, bouwstenen voor energiebesparing. Wageningen UR Glastuinbouw Rapport GTB-1337.

García Victoria, N., Weerheim, K., Van der Helm, F.P.M., Kempkes, F., Visser, P., and De Groot, M. (2016).

Energiebesparing met LED belichting in gerbera. Resultaten van 1e jaar LED onderzoek. Wageningen UR Glastuinbouw Rapport GTB-1389.

Lee, J.H., Goudriaan, J., and Challa, H. (2003). Using the expolinear growth equation for modelling crop growth in year-round cut chrysanthemum. Ann. Bot. *92* (*5*), 697–708 https://doi.org/10.1093/aob/mcg195. PubMed

Paradiso, R., Meinen, E., Snel, J.F.H., De Visser, P., Van Ieperen, W., Hogewoning, S.W., and Marcelis, L.F.M. (2011). Spectral dependence of photosynthesis and light absorptance in single leaves and canopy in rose. Sci. Hortic. (Amsterdam) *127* (*4*), 548–554 https://doi.org/10.1016/j.scienta.2010.11.017.