Supplementary Light and Higher Fertigation EC in the Cultivation of Bromelia Improve Quality and Accelerate Growth

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Abstract

In order to provide Bromelia growers with lacking information about optimal levels of supplementary light and nutrient EC, two consecutive greenhouse experiments were conducted by Wageningen UR Glasshouse Horticulture in Bleiswijk (The Netherlands). In the first experiment a light intensity gradient (17-155 µmol m^{-2} s^{-1} PAR) was installed in the length direction of two 144 m^2 greenhouses. In the width direction four mineral nutrition levels were supplied (EC of 0.6, 1.0, 1.5 and 2.0 dS m^{-1}) to three plant species: *Guzmania*, *Vriesea* and *Neoregelia* (a CAM Bromelia). Each greenhouse had a different (supplementary) photoperiod: 12 or 16 hours. It was concluded that the optimum intensity of supplementary light was 43 µmol m^{-2} s^{-1} PAR for *Vriesea*, and 80 µmol·m^{-2}·s^{-1} PAR for *Guzmania* and *Neoregelia* applied during 12 hours. The corresponding optimum EC of the nutrient solution was 1.5. At higher light levels, longer photoperiod, or the same light levels but nutrition with a lower EC, signs of light damage appeared (chlorotic leaves, reduced plant diameter, red spots on leaves). *Neoregelia* was tolerant to the 16 hour photoperiod. These optima were validated and compared to a non-lighted control by means of a second experiment with 10 cultivars of 4 different genera grown at a EC of 1.5 dS m^{-1} under three light levels: 43 µmol m^{-2} s^{-1} PAR (applied to all *Vriesea* and *Guzmania* 'Hilda'), 80 µmol m^{-2} s^{-1} PAR (applied to *Aechmea*, *Tillandsia*, *Guzmania* 'Rana' and *Guzmania* 'Tempo') and no supplementary light (as reference for all varieties). Compared to the reference, the use of supplementary light enhanced plant growth and ornamental quality and it shortened the time to commercial development stage for most studied cultivars, with the exception of *Vriesea* 'Miranda' and *Vriesea* 'Stream'.

INTRODUCTION

Though in their natural habitat Bromeliads grow in a wide range of light climates, in commercial cultivation often genera with different light preferences are grown in the same greenhouse. Due to light shortage in the winter, the flowering and the time to commercial ripeness of many species is delayed with respect to the summer condition (Zimmer, 1986). The ethylene production by the plants increases with the light intensity (Van Dijk et al., 1987; Bessler et al., 1998), and this is necessary for flower induction. Light shortage during flower induction in January reduced the flowering success rate of *Guzmania* 'Tempo' (García Victoria and Warmenhoven, 2005) as compared to induction in lighter months. The light levels after flower induction (generative plants) greatly determine the quality of the developing inflorescence (Zimmer, 1986) in terms of color, size and degree of branching. Too high light levels, however, usually need to be avoided by shading, as light overexposure is known to cause chlorotic leaves, increase of succulency (Maxwell et al., 1992), purple leaf spots by anthocyan accumulation (Benzing, 2000), and other commercially unwanted effects. The use of supplementary light to overcome the effects of light shortage in winter was not common practice yet because orientative trials conducted by Bromelia growers did not seem conclusive, as results depended on the cultivated species and the light levels installed. In some of these trials growth had been enhanced by lighting, but plant color and shape were negatively

affected. These observations suggested that a higher mineral supply could be necessary when growing plants with supplementary light. Literature further supported this last suggestion: (I) Fernandes et al. (2002) found that nitrogen supply to CAM plants stimulated a protective effect against photo-inhibitive reactions to high light levels; (II) Fetene et al. (1990) measured (also in CAM plants) increased photosynthesis and Nitrogen Use Efficiency when high light was combined with high nitrogen supply.

Dutch growers needed more information about the light intensities to be installed for the cultivated species and the recommended duration of the light period, as well as about the interactions with nutrition. The potential benefits due to light supply needed to be evaluated as compared to a not lighted control for important species. In order to find answers to these questions, the two experiments described in this paper were conducted with commercially relevant varieties.

MATERIALS AND METHODS

The experiments were carried out in two 144 m^2 compartments of a Venlo-type glasshouse in Bleiswijk, The Netherlands, at 52°N.

The first experiment lasted from September till April. The plants (*Vriesea poelmanii* 'Barbara', *Guzmania* 'Tempo' and *Neoregelia carolinae*) were supplied by commercial growers in the last stage of the cultivation in their usual potting soil mixtures and were grown on 24 raised tables with a net cultivation surface of 2,2 m^2 each. Below each table, a 1000-L water tank contained a nutrient solution prepared automatically by the fertilization unit, based on a commercially used variant of the standard solution for *Guzmania* (Straver et al., 1999), as shown in Table 1. The plants were irrigated manually with a hose (once to twice a week). Each table row (6 tables per row) in the north-south direction of the greenhouse received a different concentration of the solution, in four increasing EC steps: 0.6; 1.0; 1.5 and 2.0 dS m^{-1}. Differences in EC were reached by changing the macro elements concentration maintaining the proportion between these elements.

Artificial lights (600W SON-T lamps) were installed at increasing distance from each other to obtain a continuous light gradient in the east-west length of the greenhouse varying from 17 to 155 $\mu mol \cdot m^{-2}\ s^{-1}$ PAR. The lamps were switched on whenever the outside radiation dropped below 90 W/m^2, and off when it exceeded 140 W/m^2. The maximum lighting time was 12 hours in one greenhouse and 16 hours in the other. This led to different daily light sum along the whole greenhouse (due to the gradient) and in both greenhouses (due to the applied photoperiod) for the same intensity of the artificial light. Table 2 shows the calculated contribution by the lamps to the daily light sum for a number of spots and per greenhouse. Shade screens (LS 10) were closed as in commercial practice when outside radiation exceeded 275 W/m^2.

Heating temperature setpoint was 21°C day/night, and ventilation 26°C. Targeted relative humidity was in the first 2 months 85-90%; 75% after that. CO_2 was supplied up to 700 ppm during daytime and if the artificial lighting was switched on. Climate data were recorded at 5-min intervals by the greenhouse control computer system.

Flowering was induced by means of an ethylene treatment (Slootweg and García Victoria, 2007) except for *Tillandsia* in the second experiment, where Etephon (2-Chloroethylphosphonic acid) was used (Van Dijk et al., 1987).

Plant growth was determined at the end of the experiment, when the majority of the plants had reached their commercial maturity stage. Three plants were measured per variety and per EC, at 22 pre-selected spots in the greenhouse length. The spots were situated at 40 cm distance intervals. The light intensity at each spot had been previously measured in absence of natural light. In total 264 plants were used for measurements of plant height, plant diameter, fresh and dry weight and number of leaves, as well as of the weight, length, width and branching of the inflorescence. Results were analysed with ANOVA.

The second experiment consisted of two cultivation cycles in two different seasons: November to May (emphasis of the supplementary light in the vegetative phase)

and May to December (emphasis of the supplementary light in the generative phase). Ten different cultivars of four genera were grown: *Vriesea* 'Miranda', *Vriesea* 'Charlotte', *Vriesea* 'Stream'; *Guzmania* 'Hilda', *Guzmania* 'Rana', *Guzmania* 'Tempo'; *Tillandsia cyanea* 'Anita'; *Aechmea* 'Primera', *Aechmea* 'Felicia' and *Aechmea* 'Blue Rain'(the last two only one season each). The 144-m^2 greenhouse compartment used was equipped with 14 tables of 6,4 m^2 each. White light-tight plastic curtains divided the greenhouse in the east-west direction in three sub compartments, each with a different intensity of supplemental light: 43 $\mu mol \cdot m^{-2} \cdot s^{-1}$PAR (applied to *Vriesea*, *Tillandsia* and *Guzmania* 'Hilda'), 80 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PAR (applied to *Aechmea*, *Tillandsia*, *Guzmania* 'Rana', *Guzmania* 'Tempo' and *Guzmania* 'Hilda') and no supplementary light (as reference for all cultivars). PAR light sensors were installed in each sub compartment connected to a data logger that recorded at 5-min intervals. The decision which light level to apply to each genus/cultivar was supported by comparing the light-response curves (determined by means of Li-Cor 6400 photosynthesis meter on half age specimens) to those of the cultivars whose optimum supplementary light level was determined in the first experiment (Warmenhoven and García, 2008). The same nutrient solution was used as in the first experiment with 1.5 EC (Table 1), with the exception of *Aechmea*, where 1.6 to 2.0 EC was used (as in practice). Climate management was as in the first experiment. Plant growth was determined at commercial plant ripeness by means of measurements to 20 plants per cultivar and light level. The development time from flower induction till commercial stage was determined in the second cultivation cycle only.

RESULTS AND DISCUSSION

First Experiment: Optimum Light Intensity in Combination with EC

Guzmania plants reacted positively to the increased light intensity: the number of leaves per plant increased, as did the fresh weight of the leaves (Fig. 1). The dry weight of the inflorescence and the leaves was highest at a light intensity of 90 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PAR (Table 3). This indicates that the fresh weight increase in the leaves above 90 $\mu mol \cdot m^{-2} s^{-1}$ PAR is caused by a higher water accumulation (increased succulence) rather than by biomass production, as reported by Maxwell el al. (1992) for *Guzmania monostachia*. Leaf width was highest at 80 $\mu mol \cdot m^{-2} s^{-1}$, another indication of succulency above this level (succulent leaves tend to be narrower and thicker (thickness was not measured)). A clear interaction between supplied light intensity and nutrition EC was observed in the color of the foliage (greener at higher EC for equal light levels). Plant diameter increased with increased EC and light, up to EC 1.5 and supplementary light to 5 mol per day (Fig. 2). Above this light level or at the same level achieved with the longer photoperiod, plant diameter decreased. A light protection mechanism might be responsible for this diameter reduction: the efficiency by which light is intercepted is reduced by reducing the orientation angle of the leaves; the plant protects itself from excess radiation (Skillman et al., 2005) by the different orientation and consequently decreases in diameter. At the lower nutrient EC (0.6 and 1.0 dS m^{-1}), these inhibitory effects on diameter appeared at lower light intensities. At the lowest ECs in combination with a longer photoperiod of 16 hours, red-purple spots appeared on the leaves at day light sums that did not induce them in the shorter photoperiod of 12 hours. The pigment spots were attributed to anthocyan accumulation (Benzing, 2000) to provide some light screening in the lower tissue layers and to protect the photosynthetic systems from excess light. At the higher EC levels, spots appeared only at the highest light intensities combined with the longer (16 hour) photoperiod.

Vriesea 'Barbara' showed similar reactions to light intensity, photoperiod and nutrient concentration (EC). Maximum dry weight was achieved at EC 1.5 and light intensity of 90 $\mu mol\ m^{-2}\ s^{-1}$ PAR during a maximum of 12 hour. The leaf orientation was more vertical than in *Guzmania*, achieving the maximum plant diameter at daily supplementary light sums of 2.6 to 4 mol $m^{-2}\ s^{-1}$ (corresponding with 45 to 92 $\mu mol\ m^{-2}\ s^{-1}$ PAR during 12 hours or 36-70 $\mu mol\ m^{-2}\ s^{-1}$ PAR during16 hour). The change in leaf

orientation permitted more light to reach buds at the plant basis, leading to a commercially undesirable increase in side-shoots. At lower light levels than those leading to a decrease in plant diameter, *Vriesea* leaves became chlorotic and leaf tips necrotic. This happened above 45 µmol m^{-2} s^{-1} PAR when 1.5 or 2.0 EC were supplied, and above 30 µmol m^{-2} s^{-1} when nutrition EC was 0.6 or 1.0.

Neoregelia, a CAM Bromelia, showed a linear increase in both fresh (Fig. 1, right) and dry weight (Table 3) with increasing light intensity, even in the longer photoperiod. The diameter of the inflorescence increased up to an intensity of the supplementary light of 150 µmol m^{-2} s^{-1} PAR. The higher the EC supplied, the stronger also the diametral growth (Fig. 3). High nitrogen in the leaves could protect *Neoregelia* against photo-inhibitive reactions induced by high light levels (Fernandes et al., 2002), explaining the continued increase in growth. The plant diameters only started decreasing when the intensity of the assimilation lights exceeded the 83 µmol m^{-2} s^{-1} PAR at the 16 hour photoperiod, and were accompanied by a downward leaf orientation (unlike the upward orientation observed in *Guzmania* and *Vriesea*). The leaf orientation light-defence mechanism does not seem to play a role in the decrease in plant diameter in *Neoregelia*. Firstly, the mechanism has only been described for C3 plants, secondly, no other signs of light induced damage where observed in the plants. moreover, the fresh weight increase was accompanied by dry weight increase. Therefore it is not clear whether the observed plant diameter decrease at the high light levels is due to the earlier mentioned morphologic leaf adaptations (thicker and more succulent leaves), reported by Maxwel et al. (1992) for C3 Bromelia, and by Medina et al. (1993) for CAM-Bromelia. An explanation could be found in the plant density, which was the same for all light levels. At the highest levels plant grew bigger, but the physical lack of space could have hampered the diametral plant expansion. At higher light intensities, the number of red leaves increased at the expense of the green leaves (Fig. 1, left), and the surface of the leaves in the rosette showing a red colour increased. This is a positive effect as it enhances the ornamental value of the plants.

It was concluded that at an EC of 1.5, the optimum growth and plant quality of *Guzmania* 'Tempo' was obtained at supplementary light intensities between 80 and 90 µmol m^{-2} s^{-1} PAR during a photoperiod of 12 hour, and that *Vriesea* 'Barbara' should not be grown at levels exceeding 45 µmol m^{-2} s^{-1} PAR during a photoperiod of 12 hour to ensure a good leaf colour. The optimum light values for *Neoregelia* at ECs of 1.5 and 2.0 could possibly lie at higher levels. However, an intensity of around 80 to 100 µmol m^{-2} s^{-1} PAR during a maximum of 16 hours should be recommended. At least, until it has been clarified if the observed decrease in plant diameter obeys to a photoprotective mechanism or it is the consequence of too high plant densities.

Second Experiment: Optima Validation for 10 Cultivars

Most species showed a reduced time to commercial ripeness (Fig. 4) due to the supplementary light as compared to the non-lighted control. None of the signs of light overexposure as described in the first experiment were observed in the second experiment. This confirms that the light-response curves measured with the Li-Cor were a useful tool to estimate the light preferences of the genera and cultivars.

For the three studied *Guzmania* cultivars, the use of 80 µmol m^{-2} s^{-1} PAR supplementary light increased leaf width, plant fresh and dry weight and the fresh weight and length of the inflorescence with respect to the non-lighted control plants (Fig. 4). The strongest effect was obtained with *Guzmania* 'Hilda' with inflorescences 42% heavier than the control plants. Also the three studied *Aechmea* cultivars became heavier with more leaves per plant and significantly bigger flowers (as much as 52% heavier) when they were grown with the 80 µmol m^{-2} s^{-1} PAR supplementary light.

The supplied 45 µmol m^{-2} s^{-1} PAR light to *Vriesea* 'Charlotte' led to straighter and better filled inflorescences with on average, 3 branches more. The increase in branches has a positive effect on the market value of this variety.

Vriesea 'Stream' showed a smaller increase in inflorescence weight (6%) when

lighted in the vegetative phase than in the generative phase (22% increase). *Vriesea* 'Miranda' plants, to which 45 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PAR was supplied, did not differ in plant weight and development speed from the control plants. Uncertain is whether the lack of reaction obeys to saturation of the photosynthesis at relatively low light intensities. Indeed light saturation was observed (in photosynthesis measurement, data not shown) already at 100 $\mu mol\ m^{-2}\ s^{-1}$ PAR, but at 200 $\mu mol\ m^{-2}\ s^{-1}$ PAR, the net photosynthesis of *Vriesea* 'Miranda' was more than twice as high as that of *Vriesea* 'Stream'; this could indicate that the cultivar has the capacity to use light in a very efficient way and is suitable for cultivation at low light intensities.

CONCLUSIONS

A clear interaction between supplied light intensity and nutrition EC was observed for *Guzmania* 'Tempo', *Vriesea* 'Barbara' and *Neoregelia carolinae*. At the lowest nutrient EC (0.6 and 1.0 mS/cm), *Guzmania* and *Vriesea* plants turned chlorotic at lower light intensity levels than at the higher nutrient EC (1.5 and 2.0 dS m^{-1}). Plant diameter proved to be a good indicator of the optimum combination of light intensity and EC specially for *Guzmania* and *Vriesea*. At an EC of 1.5 dS m^{-1}, the optimum intensity of the assimilation light with *Guzmania* lied in our conditions between 80 and 90 $\mu mol\ m^{-2}\ s^{-1}$ PAR supplied during 12 hours, corresponding with an average day sum on top of the natural day light of 3.5 mol/day. The maximum acceptable light intensity for *Vriesea* was 45 $\mu mol\ m^{-2} \cdot s^{-1}$ PAR (2 mol/day). *Neoregelia* grew best with the highest supplied EC (2.0 dS m^{-1}) and was rather tolerant to high light levels and 16 hour photoperiod.

Compared to a not lighted control, the use of supplementary light and fertigation EC according to these levels, improved the quality and accelerated the growth of eight out of ten evaluated Bromelia species: *'Vriesea* 'Charlotte'; *Guzmania* 'Hilda', *Guzmania* 'Rana', *Guzmania* 'Tempo'; *Aechmea* 'Primera', *Aechmea* 'Felicia', *Aechmea* 'Blue Rain'; and *Tillandsia cyanea* 'Anita' The weight of the inflorescence increased by 6% to 52% and the cultivation period was 8 to 20% shorter.

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Tables

Table 1. Composition of the standard nutritive solutions used.

		Main elements (mmol/L)							Trace elements (µmol/L)					
EC	pH	NO_3	SO_4	P	NH_4	K	Ca	Mg	Fe	B	Mn	Zn	Cu	Mo
0.6	6.5	4.1	0.5	0.3	0.4	3.4	0.2	0.6	15	4.0	4.0	1.5	1.5	1.0
1.0	6.5	6.9	0.8	0.5	0.6	5.6	0.4	1.0	15	4.0	4.0	1.5	1.5	1.0
1.5	6.5	10.3	1.2	0.9	0.9	8.4	0.6	1.5	15	4.0	4.0	1.5	1.5	1.0
2.0	6.5	13.8	1.6	1.0	1.3	11.3	0.8	2.0	15	4.0	4.0	1.5	1.5	1.0

Table 2. Average contribution (mol day^{-1} m^{-2}) over the experimental period of the supplementary light (in µmol m^{-2}) to the daily light sum for the two photoperiod (h).

Supl. light	18	25	45	60	70	82	94	104	112	121	129	137	150
12 hour	0.8	1.1	2.0	2.6	3.0	3.5	4.0	4.4	4.8	5.2	5.5	5.9	6.4
16 hour	1.0	1.4	2.6	3.4	4.1	4.8	5.5	6.0	6.5	7.0	7.5	8.0	8.7

Table 3. Average dry weight (g) of Bromelia plants exposed during growth to three different intensity levels of the supplementary light. Values are means of 12 plants per level (3 per nutrient EC). Different letters indicate significant differences.

Supl. light (µmol m^{-2} s^{-1})	*Guzmania* leaves	*Guzmania* inflorescence	*Neoregelia* leaves	*Vriesea* leaves	*Vriesea* inflorescence
20	5.56 a	2.91 a	7.11 a	19.28 a	18.03 a
90	9.35 b	4.56 c	9.82 b	31.99 b	19.19 b
150	9.25 b	3.70 b	12.65 c	33.38 b	18.11 a

Figures

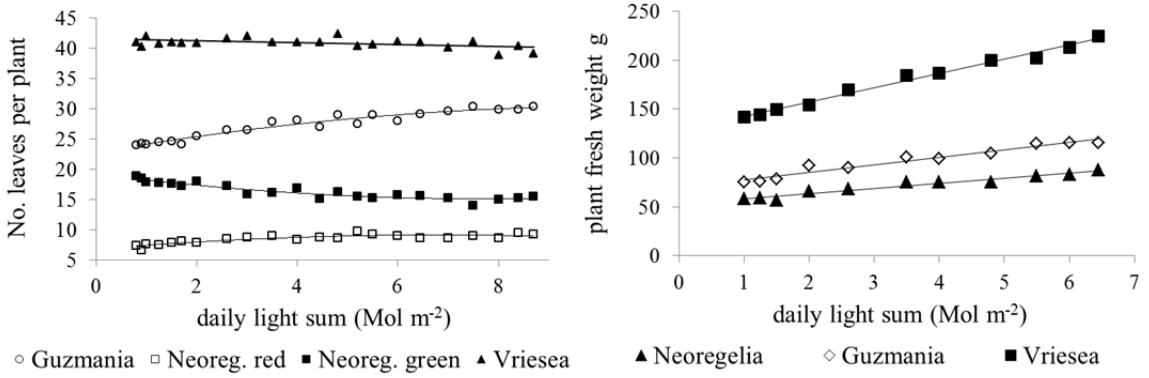

Fig. 1. Left, number of leaves and right, plant fresh weight in relation to the average supplemental daily light sum (in addition to natural day light). Dots are means of 12 plants (3 plants per light level and EC level). *Neoregelia* red and green leaves are counted separately.

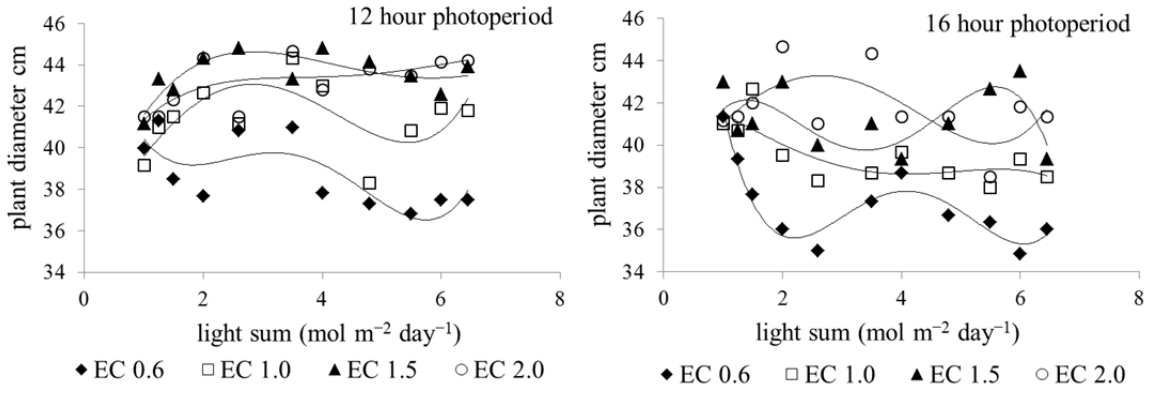

Fig. 2. Plant diameter (*Guzmania*) as affected by the EC and the daily light sum supplied by the lamps (in addition to natural day light) and the applied photoperiod, left 12 h, right 16 h).

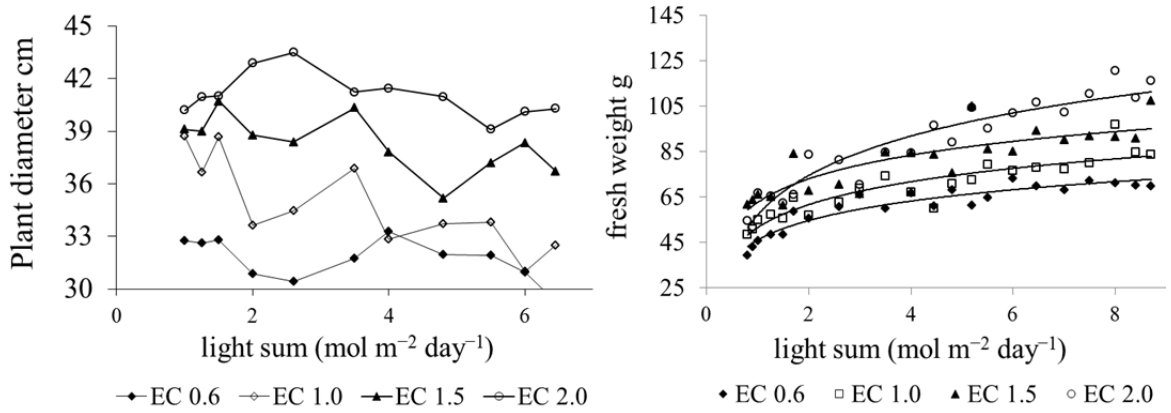

Fig. 3. *Neoregelia*, left, plant diameter; right, fresh weight as affected by EC and the daily light sum supplied (additional to natural day light) averaged for both photoperiod.

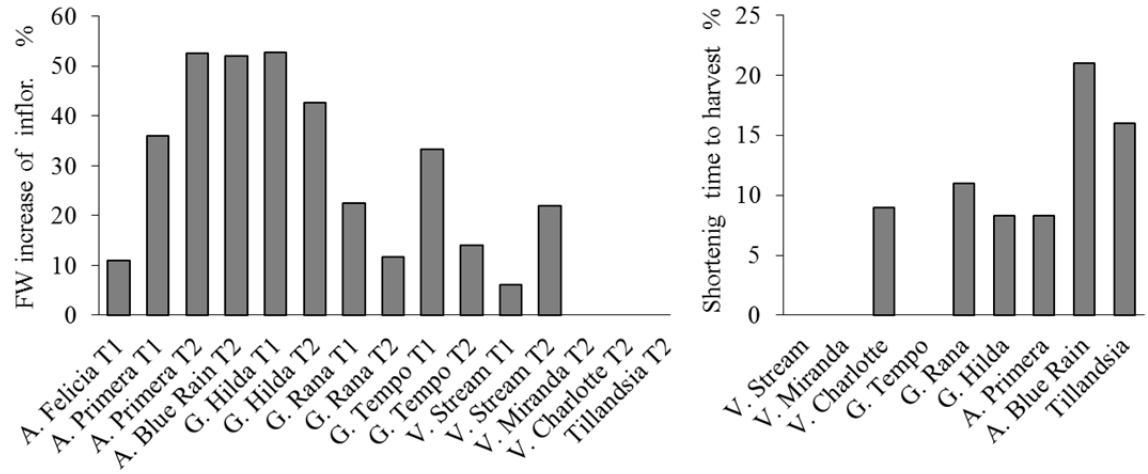

Fig. 4. Increase in inflorescence fresh weight (left) and shortening of time to harvest (right) of lighted plants (45 or 80 µmol $m^{-2} \cdot s^{-1}$ PAR) compared to control (0 µmol $m^{-2} \cdot s^{-1}$ PAR). T1=the November to May cultivation; T2=the May to December cultivation. Time to harvest measured in T2. G.=*Guzmania*; A.=*Aechmea*; V=*Vriesea*.