Development of a Phase Dependent Growth Strategy for Mobile Rose Cultivation Systems

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Abstract

Nowadays, movable benches are a reality in rose cultivation in The Netherlands. They allow a better use of the greenhouse surface and they reduce labour by bringing all the plants to a central working area in which the crop maintenance and harvest are carried out. The existing systems are all based on traditional plant cultivation systems. Since in this system, each plant potentially can have a harvestable stem, this means that every day all the plants must be brought to the central working station. Mobility also offers many new opportunities to break with the traditional cultivation systems. It can be envisaged that the greenhouse is organized in such a way that plants are synchronized and grouped according to the developmental stage of the stems, thus avoiding the presence of different developmental stages in one plant. In such a system, only those plants that actually hold a harvestable stem would need to be transported to the working station, whereas all other plants can stay in a steady place for the remaining part of the growth cycle. This would reduce the number of movements in the greenhouse already by two thirds. Moreover, a spatial separation of the groups in a similar developmental stage would allow specific climatic conditions for each group and provide tools to direct production towards specific harvest dates. To study the effects of light, temperature, CO_2, EC and VPD on each of three distinguished development stages of a rose stem, tests were performed with synchronized Y-bushes of the rose cv. 'First Red'. The hypothesis that the different phases are sensitive to different climatic conditions was confirmed. The duration of the bud break phase and early shoot growth turned out to be fully dependent on temperature and was completed after ±200 degree-days for this cultivar. The high correlation between the shoot length at the end of this phase and the time required to reach the visible bud stage, makes the shoot length a good parameter for sorting of plants to obtain more uniform groups. The light intensity turned out to play a limited role in this phase. The phase of exponential growth until visible bud is also very much directed by temperature. Under non-limiting light conditions it is completed after ±480 degree-days; more degree-days are necessary to complete this phase below a critical day light sum of 11 mol/m²/day. When this level was not reached (in the period November to February), some bud abortion was observed in this phase. The ripening phase was found to be strongly dependent of light: a higher intensity of supplementary light in this phase significantly shortened the number of degree-days required to complete this phase, and increased the stem weight.

INTRODUCTION

The growth of a rose stem can be divided into three developmental stages that are easy to distinguish and to handle (Van den Berg, 1987; Berninger, 1994; Bredmose, 1997). These developmental stages or growth phases are shown in Figure 1 and were defined as follows: phase 1- bud break phase: the period from harvesting a stem until the shoot subsequently developing from the axillary bud has reached a height of 2-4 cm. Phase 2 - exponential growth phase: the period from 2-4 cm shoot until a flower bud is clearly visible; phase 3 - ripening phase: from visible bud to commercial harvesting stage.

It is known that the contribution of each of the most important cultivation factors (light and temperature) to the different development stages differs. Berninger (1994) affirms that the bud break only depends on temperature, and so does Marcelis-van Acker, who saw a great contribution of temperature and no contribution of assimilate supply on the rate of bud break. Van den Berg (1987) and Bredmose (1997), on the contrary, saw an important contribution of light in this phase in preventing bud abortion. This discrepancy could indicate either that light becomes an important factor at limiting levels, or that the transition from this phase to the exponential growth phase must be carefully chosen. It is not clear whether the shoot length or the number of developing days should mark this transition. According to Zieslin (1992), bud development starts when the shoot measures 3-4 cm, between 5 and 21 days from harvest, depending on the variety. Experiments by Bredmose (1997, 1998) and Maas (1995) showed no abortion when a critical size (length–width ratio) had been reached; for 'Mercedes' this corresponded (Maas, 1995) to a shoot length above 8 cm. A sharp transition parameter was necessary, and a lot of effort was put on defining it.

For individual plants these phases are easy to define; for a group of plants, the transitional stages are hard to determine, as there are always differences among plants. To reduce the plant differences, the trials were conducted with synchronized Y-bushes (Eveleens et al., 2002; Van Telgen et al., 2003). These plants consist of single node cuttings of which during cultivation only the primary shoot is bent and the number of developing bottom breaks is limited to two. The difference in development between groups of Y-plants was normally not more than 8 days. This remaining variation was accepted and the time at which 50% of the plants showed the parameter that indicated transition from one phase to the other was considered as the moment to change the settings.

Energy saving in the phases that high light or high temperatures are not necessary, could be one of the practical implications of the different needs of the crop in the different developmental phases. Also, shortening of the growth cycle without quality losses would theoretically be possible. Finally, the organization of a greenhouse with movable benches in phase growth compartments would reduce the number of movements in the greenhouse by approximately 65%.

With these three defined phases and Y-bushes as a starting point, a research project was conducted at the Aalsmeer location of Applied Plant Research to develop a phase dependent growth strategy for rose cultivation. A total of 23 growth cycles or flushes in which conditions were varied per phase, were monitored during two and a half years.

MATERIALS AND METHODS

Three series of experiments were conducted in four air-conditioned greenhouses of 33 m^2 each. The greenhouse temperature was regulated by a climate control system underneath the greenhouse. Air humidity was also regulated by the air conditioning system. In each greenhouse two levels of supplementary light could be supplied. Either 4.000 Lux (47 $\mu mol/m^2/s$) or 10.000 Lux (118 $\mu mol/m^2/s$) was supplied for 20 hours a day (from 2:00 till 20:00 hours) by SON-T lamps, depending on the experimental setup. During the light period, additional CO_2 was supplied. Rooted and non-sprouted cuttings of 'First Red' were planted and shaped into Y-bushes (1 bent stem and 2 bottom breaks); each "flush" or growth cycle was considered as a separate experiment. Plants were renewed three times during the course of the experiments. The first three crops were propagated and cultivated on coconut peat in 14 cm containers at an initial density of 14 plants per m^2; in one of the experiments after several months of cultivation the plant density was lowered to a density of 9 plants per m^2. In the fourth crop cuttings were propagated on rock wool blocks and the blocks were planted on rock wool slabs at a density of 14 plants per m^2. The plants received water and standard nutrient solution for roses on substrates (De Kreij et al., 1997) by means of drip lines. The drainage water was collected and the irrigation frequency was adapted according to the drain percentage. For each flush, combinations of different temperature and light intensity were supplied in

each greenhouse during the developmental phase that was studied; for the two phases that were not under study, conditions were kept identical in the four greenhouses.

For the first series of experiments the conditions in the greenhouses varied only during Phase 1 (bud break phase); in the other two phases the temperature was kept at 20ºC and the supplementary light level was 10.000 Lux (119 μmol/m^2/s). To compare the results from all the experiments where, between greenhouses and experiments, conditions in terms of time and temperature were different, we recurred to the 'temperature sum', defined as the number of days multiplied by the average daily temperature, with 'degree days (°Days or °D)' as the unit.

In the second series of experiments, the conditions of the bud break phase were identical for all the greenhouses (200 degree-days and 10.000 Lux) and variations were applied in one of the other two phases.

In the third series of experiments, light and temperature conditions were no factor. Although light and temperature varied per phase, they were identical for the four greenhouses. Instead, the effects of a phase-dependent CO_2 concentration, EC or RV were studied in these experiments.

Assessment of effects was done by intensive measurements of 72 Y-bush plants in the central area of the greenhouse. The date of bud break, visible bud and harvest were noted in all trials. The number of days required to harvest 95% of the stems present in a treatment group was an indication for the level of synchrony in development. Stem length was measured three times a week during the entire growth cycle, and the length and weight and number of leaves at harvest were measured. The occurrence of blind shoots was recorded and in two flushes the bud length and diameter at the harvest date were measured.

Data were analyzed with the Genstat statistical program and the contribution of the different factors to each developmental phase was determined using ANOVA and different regression models.

RESULTS AND DISCUSSION

Phase 1: Bud Break Phase

In seven consecutive experiments the length of the developing shoot was measured after different temperatures and light conditions. These conditions had been maintained for a period varying between 6 and 10 days.

1. Effects of Temperature. A good correlation was found between the shoot length and the temperature sum (or the number of degree-days) as is shown in Figure 2. In this phase, shoot length correlated with the total temperature sum received since the moment of cutting. It is tempting to use a high temperature (=more degree-days) to speed up shoot growth. However, the variation in shoot lengths within a plant group increased with the increasing temperature sum (Fig. 3). Since one of the objectives of a phase-dependent growth strategy is to maintain synchrony in the crop, the total temperature sum should therefore not exceed 210-220 degree days.

The shoot length at the end of the bud break phase showed a strong correlation (Fig. 4) with the moment at which the flower bud became clearly visible (the end of the exponential growth phase). Thus, the shoot length will be a good parameter to sort plants in order to group them and steer the growth conditions towards a well predictable harvest date.

2. Effects of Light. No relation was found between the light level during the bud break phase and the length of the shoot at the end of this phase. This is in contrast with the results of Berninger (1984) and Bredmose (1997, 1998), who found the bud break phase to be sensitive for the light intensity. The low light levels during this phase did neither affect the number of developing second order laterals, nor did it increase bud abortion or the incidence of blind shoots, unless the light was limiting in the following developmental phase.

3. Effects of Plant Density. Plant density, on the contrary, seemed to affect the average length of the shoot. On two occasions, in the last cycle before crop replacement, plants

were placed more spaciously (9 instead of 14 plants per m^2). This was done twice: the first time in the autumn, the second time in spring time. The average length of the shoots after a bud break phase of 200 degree days was 2 cm at the density of 14 plants/m^2, but 4 cm for the density of 9 plants/m^2. It is not clear whether this is caused by an improvement of light interception (Kool, 1996), and therefore an increased assimilate supply which has been found to improve elongation (Marcelis-Van Acker, 1994) or by other reasons.

Phase 2: Exponential Growth Phase

After harvest had been completed, plants in all the greenhouses received a bud break phase of 200 degree-days, achieved by maintaining an average temperature of 25°C for 8 days. After this bud break treatment, the shoots were an average 3 cm long. At his moment, different climate conditions were applied to each greenhouse and maintained until the moment at which 50% of the shoots showed a visible flower bud (VFB). At that moment, the exponential growth phase was considered to be terminated, and the conditions were modified again for the ripening phase (20ºC and 10.000 Lux in all four greenhouses).

1. Effects of Temperature. During this phase, the average growth rate (in cm/day) was higher at higher temperature, as shown in Figure 5. The bud develops faster and thus appears earlier. After the bud has become visible, the growth rate decreases independent from the temperature that had been applied, and independently of the temperature that is applied in the following (ripening) phase. At the moment of visible flower bud, the stems had reached an average length of 35-42 cm, which is approximately half of their final length. The final stem length was a few centimetres shorter on the plants that had been grown at higher temperatures during the exponential growth phase. This could be due to the fact that the growth rate declined earlier than at lower temperatures. The high temperature might have speeded up the transition from vegetative to generative stage, thus accelerating the bud formation. In these experiments it was often observed that stems grown under higher temperature during this phase, counted one five-leaflet less than those grown under lower temperatures, according to the observations of Marcelis-Van Acker (1994).

As in the previous phase, again a very good correlation was found between the shoot length and the temperature sum (or the number of degree-days) received from the end of the bud break phase until the flower bud was visible. This is shown in Figure 6.

2. Effects of Light on Bud Abortion. Under the 4000 Lux light intensity during this phase, 25% of the stems did not produce a flower bud in the period December to February (average PAR in this period was 4 mol/m^2/day). Before and after this period an assimilation light level of 4000 Lux during the exponential growth phase proved sufficient to obtain a 98% flowering. Apparently, the average PAR level then reaches above the critical threshold level. The high percentage of bud abortion observed under low PAR levels, was not affected by the light intensity received by the shoots during the bud break phase 1. This suggests that the critical shoot length for bud abortion for this cultivar lies above 3 cm: bud break (till 2-3 cm) under low assimilation light in the winter did not lead to bud abortion if in the subsequent exponential growth phase the high light level of 10,000 Lux was supplied.

3. Effects of Light in Relation to the Temperature Sum. Considering all the experiments, the total temperature sum required from harvest to visible bud averaged 489.1 ± 22.7 degree days at an average light sum of 13 mol/m^2/day. As the shoot length during the exponential growth phase correlates with the received temperature sum until that moment, the shoot length at the moment of visible flower bud averaged 37.5 cm. However, when the received temperature is plotted against the received PAR (Fig. 7), a clear interaction can be seen between light and temperature in this phase 2. At PAR sums below 12 mol/m^2/day, an increased temperature sum is required till visible flower bud is observed, from the average 480 degree days to approximately 525 degree days. This could be explained by a lower elongation rate at limiting light conditions.

4. Effects of Plant Density. As in the previous phase, plant density was found to affect

the temperature sum required till visible flower bud. In the growth cycles directly after the plants had been spaced from 14 to 9 plants/m^2, flower buds were visible after 400 to 450 degree days. Compared to the previous cycle, this meant a reduction of 30 to 80 degree days. This reduction can be attributed to an improved light interception (Kool, 1996), and confirmed for this plant type the results previously obtained in experiments with single-stemmed plants by Bredmose (1997) and Van Telgen (2003).

Phase 3: Ripening Phase

In eight experiments in which the conditions between greenhouses were only varied during the ripening phase 3 (from visible flower bud till harvest) the growth rate after visible bud, the duration of the ripening phase and the quality at harvest were measured.

1. Effects of Light and Temperature. The duration of the ripening phase was affected by both light and temperature, but light contribution seemed stronger than the contribution of the temperatures tried, although there was still a clear relation between light and temperature. At 10.000 Lux supplementary light during this phase, the growth cycle was completed 10 days earlier than at 4.000 Lux. This same trend was observed with the natural radiation: at higher PAR levels, flowers ripened faster (Fig. 8). The strong influence of light on the ripening phase contradicts the results obtained by Berninger (1984) and Bredmose (1996, 1997), who found a smaller influence of light in the ripening phase as in the bud break phase. A possible explanation could be the differences in the plant densities and the light levels supplied in the different experiments (both were much lower in ours).

A lower temperature (18°C instead of 22°C) during this phase prolonged the cycle by 6 to 12 days, depending on the light intensity. Although the stems were a few centimetres longer at harvest, no correlation was found between the length at harvest and the temperature sum received during the ripening phase.

The number of days needed to harvest the whole greenhouse also decreased with increased light intensity during this phase, in other words: high light levels during this phase enhanced the synchronicity (Fig. 9).

Effects of a Phased EC, CO$_2$ and VPD Strategy on the Stem Development

In the third series of experiments, four cycles were followed in which per cycle, one (cycles 20 and 23) or two (cycles 21 and 22) of the factors mentioned above were studied. In two greenhouses the levels were maintained constant during the whole cycle; in the other two, the levels were varied depending on the developmental phase.

1. Effects of Phased EC (0.7 at bud break, 1.2 at exponential growth and 1.6 at ripening). Although the average length and weight of the stems from the greenhouses with phased EC were higher (1 cm and 2 grams, respectively) than those from stems grown at a constant EC (1.6), these differences were statistically not significant. According to Dutch grower's own observations, low EC can improve bud break (number and quality). But in this trial, neither in literature, nor in other specific trials (Baas and García, 2004), have we found any evidence of that.

2. Effects of Phased CO$_2$ Concentration (700 ppm at bud break, 1000 ppm at exponential growth and 1400 ppm at ripening). Again, the phased strategy gave stems with higher average weight and length than those from stems grown at a constant CO$_2$ concentration (1000 ppm), but these differences of approx. 1 cm and 2 grams were statistically not significant.

3. Effects of Vapour Pressure Deficit during Bud Break. The effects of two different VPDs (7 and 2, respectively) on the bud break phase were studied in one growth cycle. The trial plants in two of the four greenhouses were allowed to grow under "reference conditions" (a temperature of 21°C regardless of the developmental stage); the plants in the other two greenhouses were grown according to a phased cultivation strategy (bud break at 25°C). The results are shown in Table 1. After 200 degree days, the plants at VPD 7 gave less shoots per plant and the weight of the shoots was also lower than from

the plants at VPD 2. Moreover, the greatest positive effect on the number and weight of the shoots was achieved if the low VPD was combined with a high temperature (25°C). However, these additional shoots appeared mainly below the primary harvesting points, thus inhibiting the growth and development of the higher-positioned shoots, which with this plant type (the Y-bush), will be harvested. Although the extra shoots were removed, this inhibition could still be seen at harvest, with on average 3 to 8 cm shorter stems than those of the other treatments.

CONCLUSIONS

In conclusion, for the rose cv. 'First Red', it was confirmed that the different developmental stages have a different sensitivity to the main factors light and temperature. The bud break phase and exponential growth phase are mainly temperature dependent, provided the light level is not limiting; the ripening phase is mainly light dependent. Adapting the concentrations of the factors EC, CO_2 and VPD in the studied range to the developmental stages, did not result in significant differences compared to fixed values of these factors, so it can be concluded that they have a modest contribution to quality or cycle duration. A phase-dependent growth strategy for mobile rose cultivation systems with this cultivar was suggested, and it could be as indicated in the following table:

Phase - developmental time (expressed in 'degree-days' (°D)	Conditions – duration (temperature – supplementary light – time)
1. Bud break - 200 °D	25°, 4 kLux - 8 days
2. Exponential growth - 260 °D	21°, 4-10 kLux - 12 days
3. Ripening - 400 °D	20°, 10 kLux - 15 days
Total 850 - 900 °D	35 days

A phased growth strategy for mobile rose cultivation systems as proposed, allows growers to produce in the shortest possible production period with minimal energy input. In addition, the knowledge about the interactions between factors allows producing a flower quality adjusted to the needs of a particular market. Moreover, the harvest period is limited which saves labour and reduces transport frequency of the plants in the green-house.

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Tables

Table 1. Number of shoots sprouting at 2 different VPD values. Data collected after 200 degree days.

	'Phased' growth		Reference growth	
	VPD 2	VPD 7	VPD 2	VPD 7
Number of shoots / 18 plants	82	63.5	62	58
Total shoot weight (g)	106.3	38.1	66.1	52.35
Average weight / shoot (g)	1.3	0.6	1.07	0.9

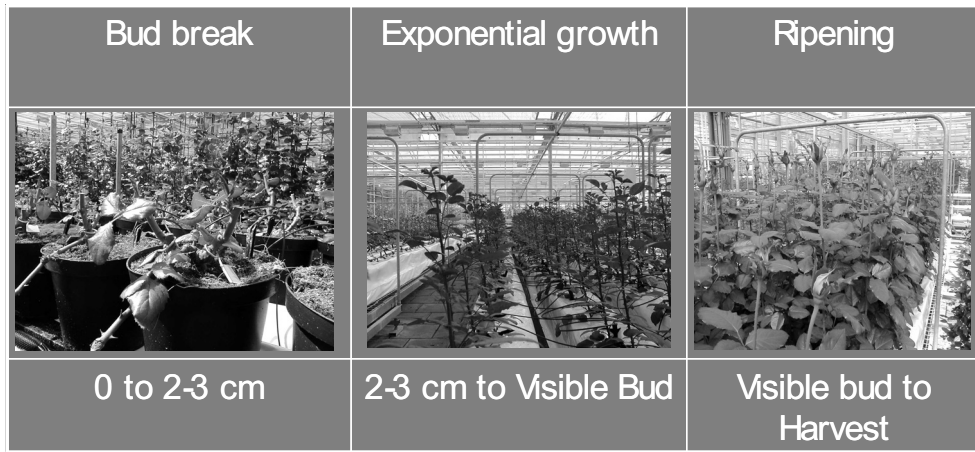| Bud break	Exponential growth	Ripening
0 to 2-3 cm	2-3 cm to Visible Bud	Visible bud to Harvest

Fig. 1. The pictures illustrate the definition of the three development stages: bud break phase, exponential growth phase, ripening phase.
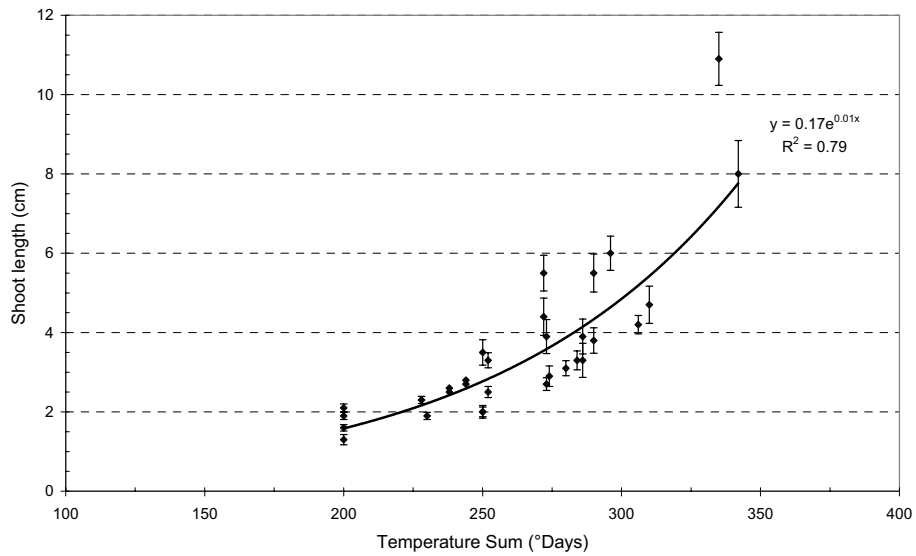

Fig. 2. Relation between shoot length and received temperature sum in the bud break phase. The length at the end of this phase increases with the temperature sum.
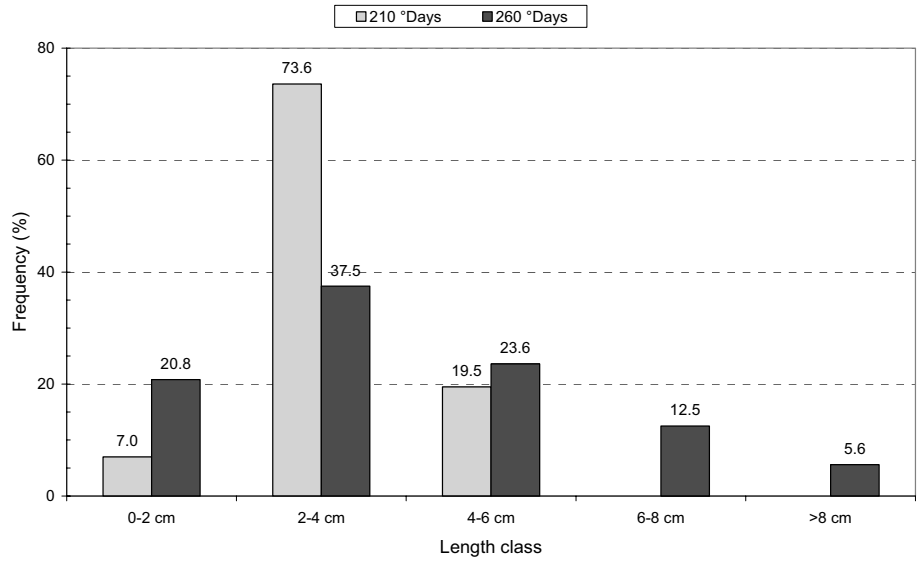
Fig. 3. Distribution of shoots into different length classes. Shoots were measured and counted at the end of the bud break phase, having received a total temperature sum of 210 or 260 degree days, respectively. After 210 degree days, 73% of the shoots are comprehended in the classes 2-4 cm; after 260 degree days, only 37% fall in this class and the variation is larger.

$$y = 34.10e^{-0.23x}$$
$$R^2 = 0.92$$
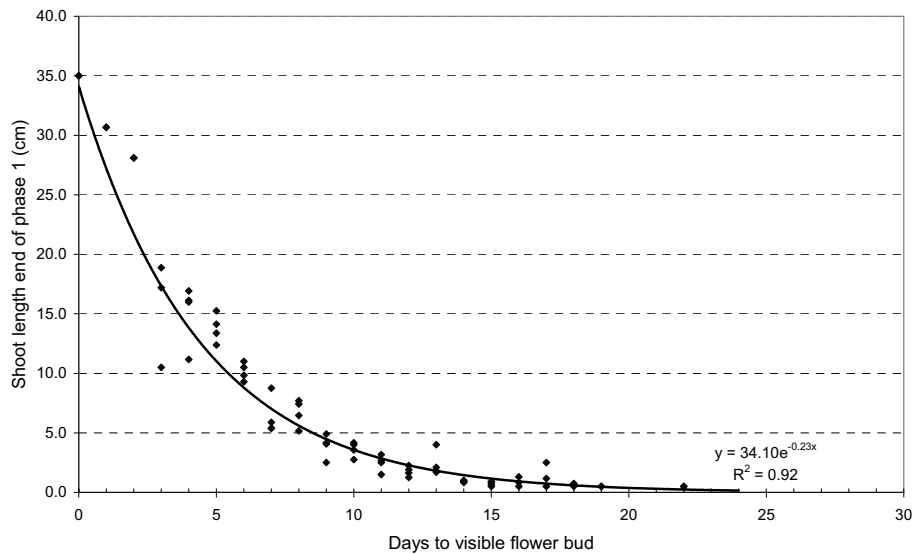
Fig. 4. Correlation between the length at the end of the bud break phase and the number of days needed till visible flower bud.
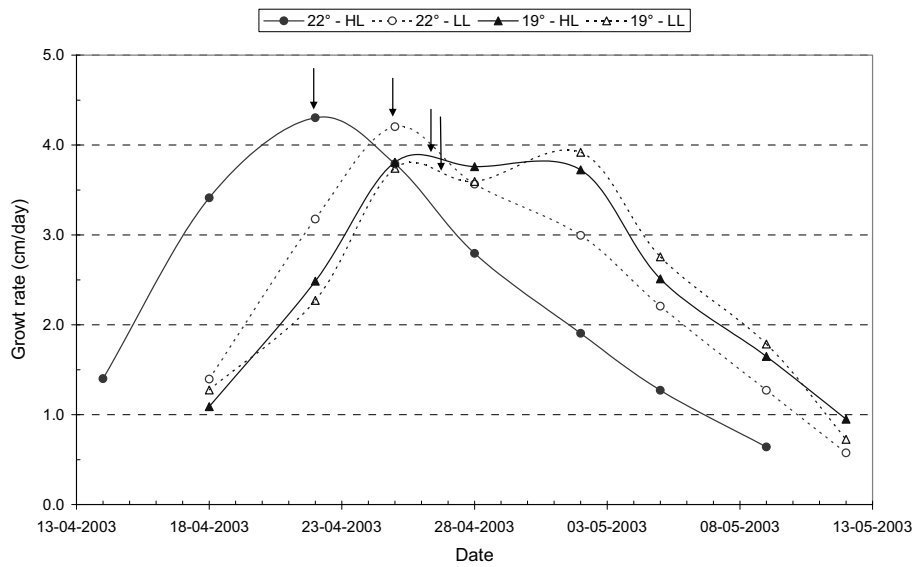
Fig. 5. Average growth rate (cm/day). Growth rate of the stems depended upon the conditions during the exponential growth phase and the ripening phase. The arrows indicate the transition point (visible flower bud) between both phases.
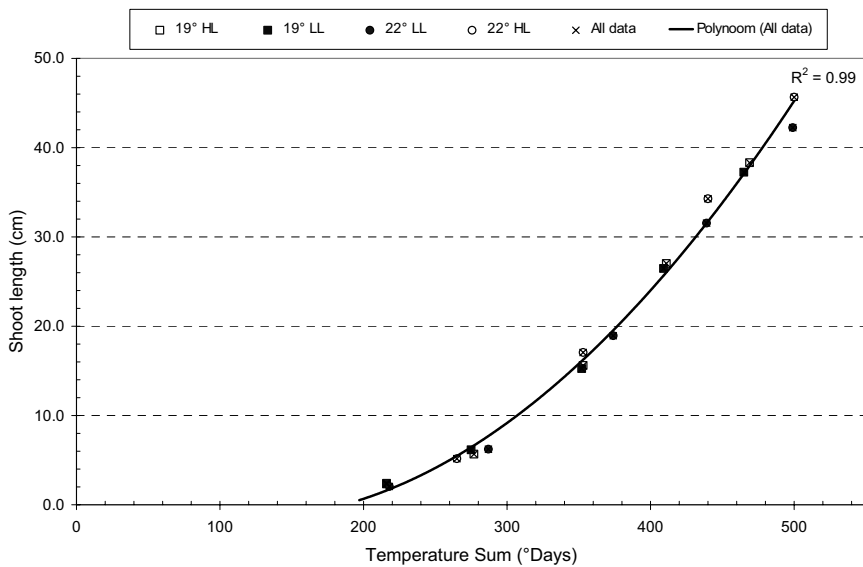

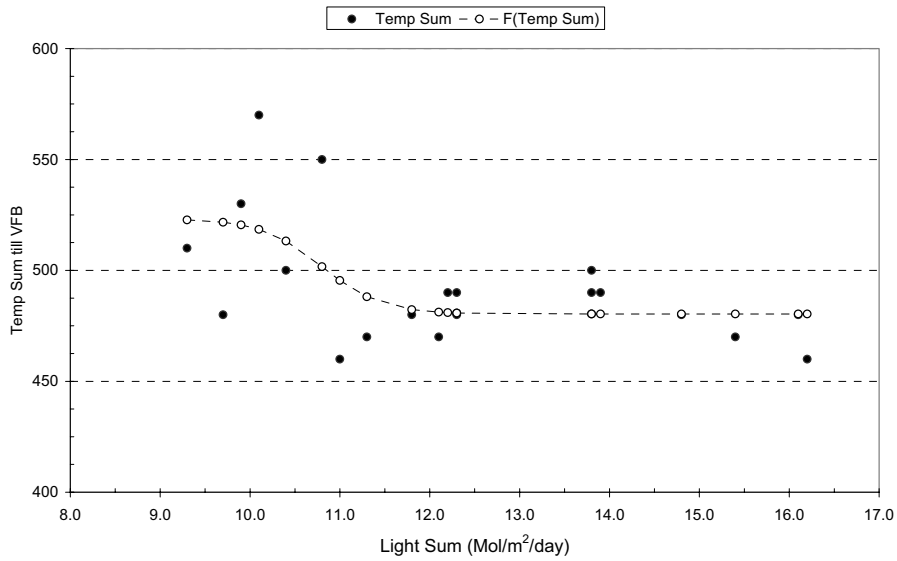Fig. 6. Shoot length as a function of the temperature sum received during the exponential growth phase.

Fig. 7. The necessary temperature sum in the exponential growth phase as related to the average light sum received. Open symbols (discontinuous line) show the best possible fit.
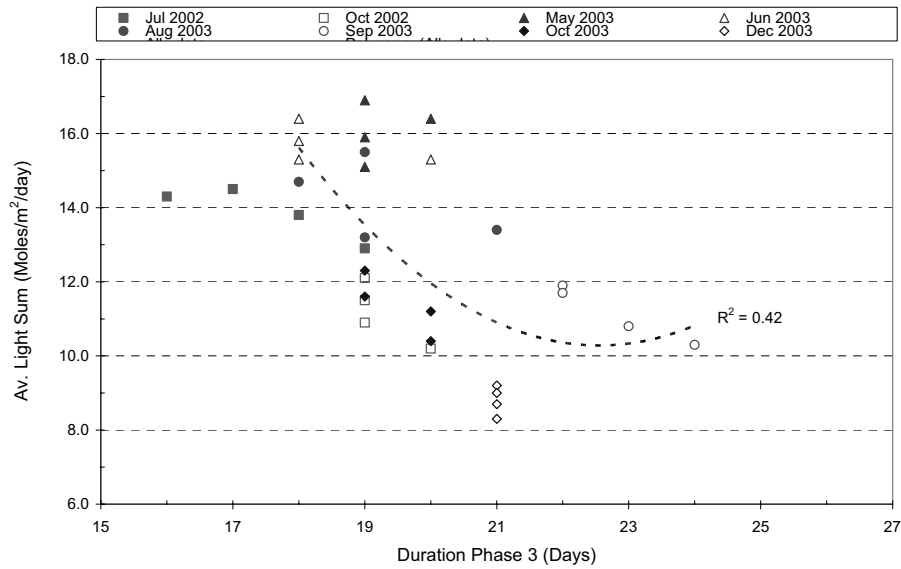

Fig. 8. Duration of the ripening phase in days in relation to the average received day light sum. The discontinuous line shows the trend through all the experiments.
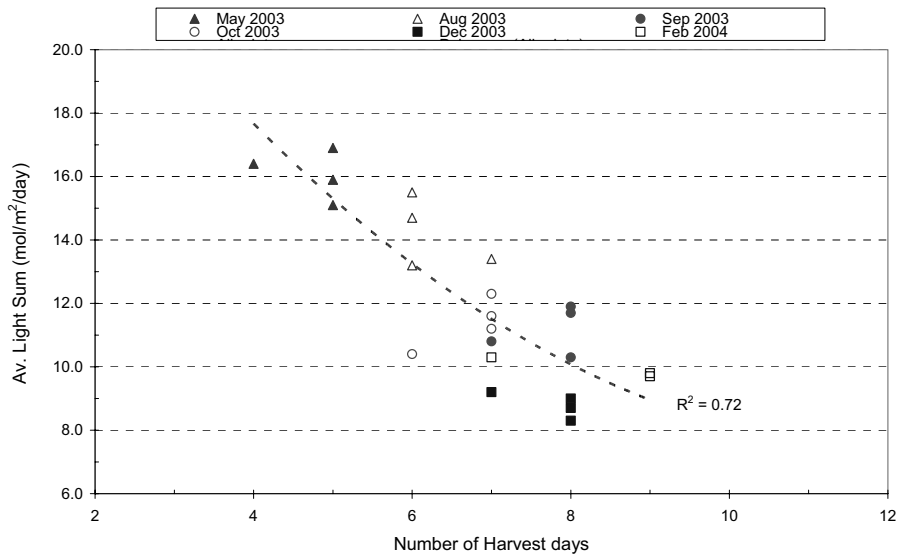
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Fig. 9. Harvest period as influenced by the average light sum received during the ripening phase. The discontinuous line shows the trend through all the experiments.