### **Critical Success Factors for Robotized Rose Harvesting**

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#### Abstract

To reduce labour costs, the rose industry in the Netherlands is working on methods to robotize the harvest. This is nearly impossible given the complexity of the actual rose crop with its considerable leaf mass and many stems in different developmental stages. Movable benches allow cultivation of plants in an area without paths, and transport of the benches along a central working station, considerably simplifying the development of a harvest robot. Prior to the development of the movable benches for rose cultivation PPO researchers, in close cooperation with Dutch growers and industry, performed a series of research projects on the formulated critical success factors. These critical success factors are more plant-technical factors rather than system-technical factors. A selection of these experiments is presented here. In one experiment the growth of plants moving continuously during 16 months was compared to that of immobile plants, and it proved that movement did not affect rose production or quality. Ebb and flood irrigation was tested as a possible alternative to irrigation by drip lines, a system that hinders movement. A simplified plant shape (the Y-bush) with a limited plant canopy and a good visibility of the harvesting point by camera vision technique, was developed in order to adapt the plant architecture to the system suitable for a robot. A method was developed to synchronize the growth of groups of plants so providing a harvesting robot with sufficient harvestable stems at a given time. This method lead to production flushes harvestable within 5 to 7 days. Finally, the performance of the Y-bush was studied at different plant densities and under different growth conditions. The synchronized Y-bush proved to be a good starting point for a robot harvester, but production was limited (two stems per plant). Higher plant densities increased the number of stems, but reduced quality after a few production flushes.

#### INTRODUCTION

One of the greatest challenges for Dutch horticulture at this moment is to reduce labour costs. Sixty percent of the total labour requirements in rose production concern harvest-related activities (Hendrix, 1996). Therefore, the rose industry in the Netherlands is working on methods to automate the harvesting of roses.

The conventional way of rose cultivation is based on a static complex bush, with a considerable leaf mass and many rose stems in different developmental stages. Building a robot harvester that is able to move in the paths along the crop searching for a stem in the right harvesting stage in such a "forest" and harvesting it on the right spot is a great challenge for robot builders: it involves mobility, manoeuvrability, the capacity to distinguish leaves from stems, ripe from unripe stems and the need for storage. Instead, bringing the plants to a central working station, and modifying the cultivation system and the plant shape to meet the restrictions of a robot appears to be a much easier alternative.

## **Formulation of the Critical Success Factors**

Moving-tables or rolling benches are commonly used in the cultivation of potted plants (e.g. the "walking plant system®"). A gerbera nursery had adapted the "walking plant system®" for the cultivation of gerbera as a cut flower. The plants were moving to a central working station where the workers were harvesting the flowers manually. The

system proved not to be suitable for the cultivation of roses (Beelen, 2002) due to the following problems:

- All the plants need to pass the working station every day (and for fast ripening varieties sometimes twice a day) because every plant can theoretically hold a harvestable stem.
- The harvesters regularly have to wait for a plant with a harvestable stem.
- The complex plant shape makes it difficult to find the correct harvesting point.
- The abundant canopy (bent stems) hinders safe transport of the plants (bent stems are often trapped in the transporting system).
- Irrigation by drippers impedes movement because the drippers connect the plants to each other and to the main water supply; moreover, during movement the water flow must be interrupted.

Taking these considerations into account, PPO researchers formulated a number of "critical success factors" for robotized rose harvesting:

- Internal greenhouse transport and plant movement should not affect the plant growth. In potted plants the movement is known to produce shorter plants, but nothing was known about the effects of movement on rose production.
- Alternatives to drip irrigation should be developed to allow watering independent of movement, and to permit plant singularization in order to allow grading, regrouping and removal of plants.
- Open and simplified plant architecture, with good visibility of the harvesting point.
- Uniformity in development among plant groups, to reduce the number of harvesting days necessary to harvest a group of plants. Bringing only the batch of plants with harvestable stems to the central harvesting station would reduce the number of movements in the greenhouse and increase the performance of the harvesters (manually or with a machine).

From 2001 to 2004 Applied Plant Research has carried out a series of research projects in Aalsmeer (The Netherlands) to investigate and find answers to these critical success factors.

### MATERIALS AND METHODS

### **Experiment 1. Effects of Movement on Crop Production**

The experiment was conducted with young rose plants of the cultivar 'First Red' in a greenhouse of 150 m<sup>2</sup>. The plants had been propagated from cuttings on rock wool blocks (10 x 10 x 7.5 cm) and the blocks with young plants were placed on rock wool slabs (7.5 x 15 x 100 cm). Four rows of these slabs with a total length of 12 m each, were placed on six rolling beds made of wire-netting of 1,2 m wide x 12 m long that were from below heated by means of heating pipes. Net plant density on the bed was 10 plants per m<sup>2</sup>. The cultivation temperature varied, according to commercial practice, between 18°C (night) and 20°C (day). In the summer months higher temperatures were allowed during the daylight period. Additional light with an intensity of 45 µmol/m<sup>2</sup>/s (3750 lux) was supplied by SON-T lamps for a maximum of 16 hours a day (from 2:00 to 20:00 hours), when the natural radiation dropped below 150W/m<sup>2</sup> (675 µmol/m<sup>2</sup>/s). During the light period, additional CO<sub>2</sub> was supplied in order to maintain a concentration of 750 ppm. The plants received water and nutrients (standard nutrient solution for roses on rock wool, De Kreij et al., 1997) by means of drip irrigation. The drain water was collected and the irrigation frequency was adapted according to the drain percentage. The primary shoot was bent and during the entire cultivation period, blind and shoots of inferior quality were regularly bent.

Three of the six beds were connected to each other by clamps. The entire construction was again connected to a rotary engine that forced it to move in a continuous motion 30 cm sideways at a frequency of 25 times per minute. During the first four months of the experiment the beds were moving for 16 hours a day; then movement was increased to 24 hours a day, with the exception of the time needed for crop harvest and

maintenance. The three control beds were not moving and remained in a more or less fixed position.

Assessment of crop response to movement was done by comparing the production of plants on the middle bed of the moving group with its counterpart in the fixed control group: number of stems and the length and weight of each stem were recorded. Vase life of samples of 20 stems was determined three times (twice in wintertime, once in the summer). The dry matter content of the harvested stems (samples of 25 stems per treatment) was also determined three times. Finally, at the end of the experiment after 18 months of cultivation, destructive measurements (root weight, plant weight, and dry matter of different plant parts) were performed.

#### Experiment 2. Ebb and Flow as an Alternative to Drip Irrigation

The experiment was conducted in the same greenhouse as experiment 1. The trial took place from week 20 (2002) until week 10 (2003). Four beds of 1,2 m x 12 m were split into 3 cultivation blocks with a length of 4 m each. Part of these cultivation blocks was equipped for ebb and flood irrigation: a system in which specially-designed gutters could be inundated several times a day for several minutes with the nutrient solution. The rest of the cultivation units were irrigated with drip lines as indicated for experiment 1.

Ebb and flow gutters were filled with a) rock wool blocks (one per plant)  $(7.5 \times 7.5 \times 6.5 \text{ cm})$  on a rock wool slab  $(10 \times 100 \times 5 \text{ cm})$  or b) perlite (course fraction nr. 3) in 11, 5 cm square pots.

Young 'First Red' plants were propagated from cuttings on rockwool blocks for the rockwool treatments and on coco-peat plugs for the perlite treatments. Cultivation conditions were as described above for experiment 1.

Assessment was done by monitoring the production of plants on both watering systems. The number of stems and the length and weight of each stem was recorded. The dry matter content of the harvested stems (samples of 25 stems per treatment) was determined once at the end of the experiment, that lasted in total 20 weeks.

# Experiment 3. Development of the Y-Bush and Performance of the Y-Bush in a Test System

'First Red' plants were propagated from cuttings in coco-peat plugs, and planted in 3.5 litre containers with coco-peat when roots were well-developed and just protruding from the plugs. At this stage, the cuttings had not yet developed a primary shoot. The containers were placed in a greenhouse of 150 m² in a two-row system at a plant density of 6.8 plants per m². In total 14 rows (7 x 2) were planted, of which the centre rows and outer rows (one left, one right) were used as "buffer". These buffer rows were not used for measurements. Cultivation temperature was 20°C (day and night). In the summer months higher temperatures were allowed during the day. If the outside radiation was below 200 W, additional light was supplied by SON-T lamps for a maximum of 16 hours a day (from 2:00 to 20:00 hours). Two different light intensities were used in the greenhouse: in one half of the greenhouse 50 μmol (4250 lux) was used (LL); above the other half 100 μmol (8500 lux) (HL). During the light period, CO<sub>2</sub> was supplied in order to obtain a concentration of 800 ppm. The plants received water and nutrients (standard nutrient solution for roses on rockwool, De Kreij et al., 1997) by means of drip irrigation. The drain water was collected and the irrigation frequency was adapted according to the drain percentage.

The primary shoot of the plants was bent when the bud was ripe. For the entire duration of the experiment, no additional stems were bent except for the ones developing on the primary bent shoot. After bending of the primary shoot, the plants were allowed either to develop to Y-bushes (2 bottom breaks allowed) or to  $\psi$ -bushes (3 bottom breaks allowed). Bottom breaks were harvested at the normal maturity stage just above the lowest first five-leaflet, after which only the axillary bud from this five-leaflet was allowed to develop. Occasional developing shoots below this point were removed at a very early growth stage to maintain the Y or  $\psi$  shape. Figure 2 schematically illustrates the shaping of the Y-bush.

The sprouting of the axillary buds was followed for 10 consecutive harvest cycles. The date at which the sprouted bud was visible, the moment the flower bud became visible, and the harvest date were recorded, thus using the stages defined by Bredmose (1997). The number of days required to harvest 95% of the stems present in a treatment group (high or low light, and Y or  $\psi$ -bushes) was registered as a measure for the level of synchronicity. Length and weight of each harvested stem were measured and the number of leaves per stem was recorded. The occurrence of blind shoots was also recorded. Plants outside the experimental plots were used to test synchronicity-enhancing treatments, such as harvesting height, temporary cooling, and to explore the possibilities of replacing the horizontal canopy, which hinders movement, by a vertical canopy.

# **Experiment 4: Performance of the Y-Bush Compared to a Traditional Bush in a Commercial System**

Cuttings of 'First Red', 'Red Berlin', 'Vendela' and 'Escimo' plants were propagated in coco-peat plugs, and planted in 3.5 litre containers filled with coco-peat. The containers were placed in a greenhouse of 300 m² where in total 14 beds were present in a four-rows per bed system. The outer rows were used as "buffer" and to fill the greenhouse, but were not used for the measurements. Cultivation temperature was, 18°C (night) and 20°C (day). Higher temperatures were allowed during the day in the summer months. If the outside radiation dropped below 150 W, additional light with an intensity of 45 µmol (3750 lux) supplied by SON-T lamps for a maximum of 16 hours a day (from 2:00 to 20:00 hours). During the light period, CO<sub>2</sub> was supplied in order to obtain a concentration of 850 ppm. The plants received water and nutrients (standard nutrient solution for roses on rockwool, De Kreij et al., 1997) by means of drip irrigation. The drain water was collected and the irrigation frequency was adapted to obtain an excess drain of 30%.

Control plants were cultivated traditionally and were planted with a developed primary shoot of variable length at a net density of 12 plants per square metre. Trial plants to be cultivated as Y-bushes, were planted at a density of 24 plants per square meter when the roots were well-developed and protruding from the plugs, but without a sprouted axillary bud. This increased plant density was meant to compensate for the limited production per plant (2 stems, see experiment 3 and Fig. 2). Per variety, one and a half beds (15 square meters in total) were used for both the Y-bush cultivation and the control.

On the day that 50% of the flower buds on the plants designated as Y-bushes were ripe, all the primary shoots of the Y-plants of a given variety were bent. During further plant development and cultivation, no additional stems were bent other than the ones developing on the primary bent shoot. In comparison, the buds from the traditional bushes were removed individually as soon as they became visible, allowing the primary stem to produce lateral shoots. The primary stems were then bent after these laterals showed visible buds. Inferior quality stems or blind shoots were also bent during the cultivation period.

Between July and January five harvest cycles or "flushes" were monitored. The production of both types of plants of each variety was registered: number of stems, stem length and weight and the number of days required to produce a rose from harvest to harvest (cycle duration). The synchronicity of the Y-bushes was also determined, expressed as the percentage of the total production from one cycle that could be harvested within 6 days. The occurrence of blind shoots was recorded. At the end of the experiment also destructive measurements were performed on the 'First Red' plants in order to calculate the harvest index.

#### **RESULTS**

### **Experiment 1. Effects of Movement on Crop Production**

Table 1 shows the number of stems produced in the moving and the non-moving beds, with average stem length and weight ( $\pm$  se) as well as the percentage of dry matter of the bent stems and the bent leaves at the end of the experiment. The observed

differences were not significant (Anova, Genstat). Vase-life after four days transport simulation at 5°C in water was approximately 10 days in the three assessments for both treatments (moving and non-moving beds).

The dry matter content of the harvested flowers varied between 23.6 and 26.3 % depending on the assessment period, but differences between the stems from the moving and the non-moving beds were not significant.

### **Experiment 2. Ebb and Flow as an Alternative to Drip Irrigation**

Figure 1 shows the cumulative production (number of stems) of the blocks irrigated by drip lines (rockwool blocks on slab only) or by ebb-and- flood (rockwool blocks on slab and perlite containers) in numbers of stems per square meter. In the combination of ebb and flood with perlite, both the production numbers (58.8) and also the average stem weights (39.3  $\pm 1.1$  g) were lower than those of stems produced on the combination of rockwool on ebb and flood (67.6 stems per m2 of  $40\pm 0.9$  grams each) and rockwool with drip lines (67.2 stems per m² of  $42.5\pm 1.1$  g each).

# Experiment 3. Development of the Y-Bush and Performance of the Y-Bush in a Test System

From the first harvest onwards, the cumulative mass production of the Y-bushes grown under the high light intensity of 100 µmol was higher than of those growing under the 50 µmol, mainly due to a higher stem weight (Fig. 3). Additionally, in the winter plants under the low light treatment produced a few (about two per treatment) blind shoots that slightly reduced the potential production of 13.6 stems per square meter per cycle. Figure 3 also shows that under the higher light level, the cycles are shorter than under the low light level. Nine harvest cycles were possible within a year under the low light level and almost a complete extra cycle was completed on the plants under the high light level by the time the 9<sup>th</sup> cycle of the low light was harvested. The synchronicity expressed as number of days to harvest was also better for the plants grown under the high light level, as is shown in Table 2. This table also shows that the harvest period was shorter for the summer cycles than for the winter cycles.

 $\psi$ -bushes gave stems of comparable length to those from Y-plants, but the average stem weight was generally  $\pm 5$  gram lower than the stems harvested from Y-bushes (data not shown) The synchronicity level was also lower in  $\Psi$ -plants: the number of days necessary to harvest 95% increased dramatically compared to the Y-plants (Table 2).

All the treatments that were tested to regain synchronicity of plant groups were effective. Low harvesting (knuckle-cut method, (de Hoog, 1998)) followed by cold storage of plants for 16 days at 4°C, restored synchronicity from more than 17 days back to 3 days, but also increased the total duration of one growth cycle with 12 days.

A "vertical canopy" proved not to be feasible. As the apex of the examined vertical canopy was higher than the developing flower stems, the apical dominance of the vertical canopy inhibited the development of the growing laterals. Cutting off this vertical canopy resulted in a high incidence (20 %) of blind shoots in the stems developing in the first cycle after removal of this vertical canopy.

# Experiment 4: Performance of the Y-Bush Compared to a Traditional Bush in a Commercial System

After five harvest cycles, the Y-bushes had produced in total a lower number of stems than the traditional bushes, but because of the higher plant density, the number of stems produced per m² was higher, as is shown in Table 3. The difference varied between 33% (Escimo) and 103% (First Red). The potential number of stems per plant in five harvest cycles (10) was not achieved due to the occurrence of blind shoots (mainly in 'First Red' and 'Red Berlin'). The number of blind shoots increased per harvest, presumably as a consequence of the decreasing light conditions in the Dutch winter. This tendency was also observed in the traditional cultivation system, but in practice these blind shoots are used to refresh the canopy and were not recorded.

Average length and weight of the stems from Y-bushes was significantly lower than from traditional plants for 'First Red' and 'Vendela' (Fig. 4). The synchronicity of the plants decreased from 90 - 95% harvested in 6 days in the second flush (August), to 55-60 % on the fifth flush (December / January). The time from harvest to harvest (duration of the cycle) also increased with the decreasing solar radiation, from 31 to 46 days ('Escimo', shortest cycle) and from 42 to 62 days ('Red Berlin', longest cycle).

At the end of the experiment, the total fresh biomass of the 'First Red' bent canopy was bigger for the traditional plants (1091 gram/ m²) than for the Y-bushes (739 gram/m2). The harvest index (HI) is the ratio between the total harvested mass and the bent canopy, and is an indication of the production efficiency of the bent canopy. With a HI of 6.1, the Y-bushes were twice as efficient during the 5 harvests studied as the traditional ones, which had a HI of 3.1.

### **DISCUSSION AND CONCLUSIONS**

The continuous movement of the 'First Red' plants in experiment 1 did not affect production numbers nor the quality of the production in any way (stem length or weight, dry matter contents, vase life). This result created possibilities for new plant production systems based on plants being transported to a central working station for harvesting and crop maintenance. As a matter of fact, the first prototype of a moving-bench-system for rose was installed at a commercial nursery on a 500 m² surface as soon as the provisional results of this experiment were presented.

The prototype, and all the commercial systems that have followed, are irrigated by drip lines, by means of a retractable connection between the main supply and a drip tube supply on the gutter. Ebb and flood as an irrigation system for rock wool grown roses was shown to have potential (De Dood and Van Weel, 1989), and the results obtained for this substrate in experiment 2 confirmed these results. However, the production losses observed with perlite were rather disappointing, although we can not say whether it is the substrate, the ebb and flood irrigation, or the combination of both as a control treatment of perlite with drippers could not be fitted into the experiment. However, we have obtained some additional information from other experiments. In a previous experiment (week 35 of 2001 to week 18 of 2002, Eveleens et al., 2003), similar results were obtained with a finer perlite fraction. When synchronized Y-bushes were irrigated by ebb and flood, the sudden harvest of all stems in one bed reduced the water requirements dramatically; the water supply needed to be interrupted, and even then, the water retained in the substrates (perlite or rockwool) proved to be too much for the requirements of the plants. These results show that a lot more research is necessary on the possibilities of ebb and flood for different substrate and plant type combinations. The fact that this was not solved and the technical difficulties in moving huge volumes of water around the greenhouse, made growers and the constructers of the mobile systems stick to the irrigation by drippers, even though this means that plant mobility is going to be limited by the irrigation system.

The most ideal plant shape for robotized harvesting would be the single stemmed plant, to be discarded after one flower. Several researchers worked on this principle (De Vries et al., 1977, 1978; Bredmose, 1997), but the low quality of the primary shoot and the high costs of propagation make this approach unfeasible.

A simplified plant shape like a  $\hat{Y}$  or a  $\psi$ -bush could be a good alternative to the single-stemmed plant because of the limited canopy, becoming the starting point for a mobile system. Robotized harvesting should be also easier with such plants because the harvesting point is clearly visible and easily accessible (Van Tuijl and Van Henten, 2005).

The performance of the Y-bush was better than that of the  $\psi$ -bushes in terms of stem quality and synchronicity, which suggests that the potential production weight that can be achieved with a single bent stem is limited: sufficient for two good quality stems but insufficient for three good stems. Light played a key role in the duration of the cycle and in maintaining synchronicity among the plants. At low plant density and with sufficient light, the Y-bush proved to be a good production system. Nine flushes were possible in a year, and the potential production of 2 stems per plant was almost achieved.

An economic evaluation of a mobile system using the Y-bush as a starting point (Van Woerden, 2001) showed that such a system would only be feasible if a 20% production increase could be realised as compared to traditional cultivation.

Increasing the plant density from 6,5 Y-plants to 24 Y-plants per m² made the system feasible for the first five harvest cycles for the four tested varieties. However, the quality of the harvested stems and the synchronicity decreased with each flush. This might be due to the fact that as plants grow bigger, they start to influence each other, thus interfering with the light interception. (Kool (1996) found that light interception can explain 86% of the production.) This does not mean that the system would not be interesting for commercial rose production: firstly, the light interception can be improved by crop management techniques; secondly, higher levels of assimilation light than the 3750 lux (45 µmol) used in the experiment can considerably increase the quality of the stems and improve synchronicity, as it was seen in experiment 3 where Y-bushes were grown under two light intensities. Currently, levels of 10.000 lux (118 µmol) and more are becoming standard practice in Dutch rose growing. The need to maintain a crop for four or more years could also be reviewed: a Y-bush system could be maintained for 4 to 6 flushes a year and then be replaced by a new young plant, thus giving rose growers a more versatile production system to meet quickly changing market demands.

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## **Tables**

Table 1. Number of stems produced in moving and fixed beds, average stem length and weight (se) and dry matter percentage of bent stems and leaves at the end of experiment 1. Differences no significant.

	Fixed beds	Moving beds
Number of stems / m <sup>2</sup>	182	188
Average stem length	81.9 (0.73)	81.4 (1.03)
Average stem weight	40.9 (0.29)	40.3 (0.32)
Dry matter bent stems	39.8 %	40.0 %
Dry matter bent leaves	28.5 %	28.2 %

Table 2. Number of days needed to harvest 95% of the stems of a group of plants in experiment 3. HL = 8500 lux (100 µmol); LL= 4250 lux (50 µmol).

	Harvest cycle (number and date)			
Planttype/light level	2 (18 June)	3 (22 July)	4 (22 August)	5 (1 October)
Y-bushes, HL	13	5	8	12
Y-bushes, LL	12	5	10	15
ψ-bushes, HL	12	10	14	17
ψ-bushes, LL	12	15	17	>25

Table 3. Number of stems per m<sup>2</sup> after 5 cycles in Y- bushes and the traditional bushes, and the difference in percentage (experiment 4).

Number of stems produced per m <sup>2</sup>						
Cultivar	Y-bush (Y)	Traditional bush (T)	Difference Y – T (%)			
First Red	192,0	94,5	103			
Red Berlin	199,8	144,8	38			
Vendela	198,2	128,5	54			
Escimo	209,8	157,8	33			

## **Figures**

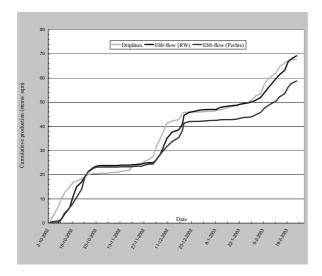


Fig. 1. Cumulative production of the blocks irrigated by drip lines (rockwool blocks on slab only) or by ebb and flood (rockwool blocks on slab and perlite containers) in experiment 2.



Fig. 2. Schematic illustration of the plant build-up for the shaping of the Y-bush.

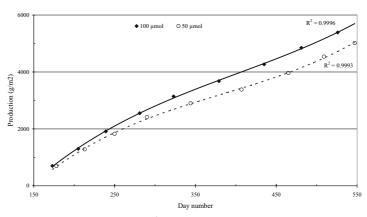
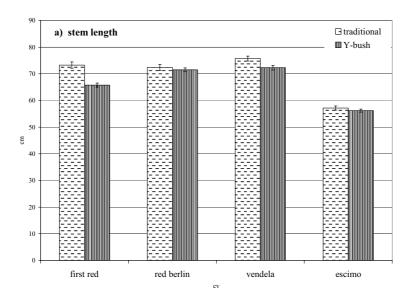


Fig. 3. Cumulative production (in  $g/m^2$ ) after 9 harvest cycles of the Y-bushes grown under 50  $\mu$ mol or 100  $\mu$ mol supplementary light in experiment 3.



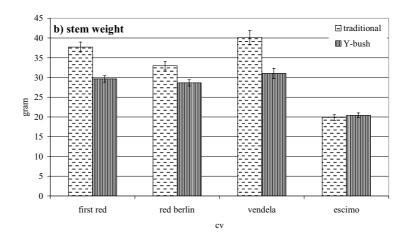


Fig. 4. Average stem length (a) and average stem weight (b) produced by the Y-bush compared to the traditional bush.