CROP QUALITY CONTROL SYSTEM:
a tool to control the visual quality of pot plants

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Proefschrift
ter verkrijging van de graad van doctor
op gezag van de rector magnificus
van Wageningen Universiteit,
prof. dr. ir. L. Speelman,
in het openbaar te verdedigen
op vrijdag 20 september 2002
des namiddags te vier uur in de Aula.

Abstract

Dijkshoorn-Dekker, M.W.C., 2002. Crop Quality Control System: a tool to control the visual quality of pot plants. Dissertation, Wageningen University, Wageningen, The Netherlands, 117 pp. English and Dutch summaries.

The market is increasingly dictating the specifications for products. A well-defined marketable product must be delivered at a defined moment in time. A system was developed for growers to control development and growth of pot plants to achieve a defined quality on a specified delivery date.

A theoretical framework of quality modelling used in the food industry was successfully implemented within the domain of pot plants. The visual quality of *Ficus benjamina* 'Exotica' was explained for 88.7% by four variables (in addition to the fixed plant height of 1.20 m.): the density of the leaf mass in front-view, 40-60 cm above pot rim; the width in side view, 40-60 cm above pot rim; the width in front-view, 0-20 and 20-40 cm above pot rim. Effect of temperature, plant density (control factors) and season (not controlled) on the growth and development of *Ficus* in relation to these quality features was quantified. Development of *Ficus benjamina* 'Exotica' showed a regular pattern. Plant height increased with temperature up to 29.5°C. The effect of plant density on this variable was small. Leaf unfolding rate was influenced by light and temperature, plant density was of minor influence. Its response to temperature showed an optimum at 30°C. The final internode length was mainly affected by light intensity, temperature had no effect. The width of the plant and the density of leaf mass increased at lower plant densities. The effect of temperature on visual quality of *Ficus* was small. A simple model based on only two major quality features, plant height and plant width, was developed and could successfully control visual quality of *Ficus*. Plant height as a function of plastochron age and internode length in relation to temperature and light was adequately predicted. Plant width was successfully controlled by spacing operations, using image processing to monitor this crop feature.

By integration of four functional modules, a model for visual quality, a crop growth control model, image processing to monitor crop development and a neural network to grade plants, a crop quality control system (CQCS) was obtained and successfully implemented. This system was compared to other systems and its limitations and transferability to other crops was discussed. Furthermore, the system was evaluated for commercial practice.

Key words: quality, growth, model, leaf unfolding rate, internode, plant height, plant width, leaf area, temperature, plant spacing, season, light, development, image processing, grading, neural network, pot plant, *Ficus benjamina* 'Exotica'.

Voorwoord

Aan de totstandkoming van dit proefschrift hebben veel mensen een bijdrage geleverd en daarvoor wil ik iedereen hartelijk bedanken. Een aantal mensen wil ik in het bijzonder noemen.

Allereerst wil ik Hugo Challa hartelijk bedanken voor zijn bereidheid als promotor op te treden. Ik dank hem voor zijn stimulerende en kritische begeleiding zowel tijdens de uitvoering van het onderzoek als bij het schrijven van dit proefschrift. Zijn enthousiasme voor mijn werk is voor mij een enorme stimulans geweest om te komen tot een goede afronding. De directie van het Praktijkonderzoek Plant en Omgeving bedank ik voor de mogelijkheid die zij mij geboden hebben om het onderzoek op het gebied van ketengerichte teeltsturing van bladplanten af te ronden met een proefschrift.

Mijn dank geldt ook voor de vele collega's van het Praktijkonderzoek Plant en Omgeving, en ook een aantal personen daarbuiten, die een bijdrage hebben geleverd aan de uitvoering van het onderzoek. In het bijzonder wil ik Barbara Eveleens noemen. Zonder haar inspanningen waren er nooit zoveel metingen verricht en datafiles verwerkt. Haar enthousiasme, inzet en grote interesse voor dit onderzoek alsmede de vele discussies die we samen op onze kamer hebben gevoerd, heb ik zeer gewaardeerd. Ik bedank haar ook voor de correcties die zij heeft aangebracht in de Engelse tekst. Dank ben ik ook verschuldigd aan Peter van Weel. Zijn steun in dit onderzoek op het gebied van onder andere beeldverwerking en systeemontwikkeling, zijn suggesties en opmerkingen tijdens de uitvoering van het onderzoek en het schrijven van het proefschrift waren een waardevolle bijdrage. Ik bedank hem ook voor het ontwerp van de uiteindelijke kaft van dit proefschrift. Jan Meuleman (IMAG-DLO) en Jan-Willem Hofstee (WU) wil ik bedanken voor hun inbreng in dit onderzoek op het gebied van neurale netwerken en beeldverwerking. Dankzij de fijne samenwerking was het mogelijk de plant op de juiste wijze technisch te benaderen.

Voor het objectiveren van de kwaliteit, het telen van een Ficus evenals het testen van dit onderzoek in de praktijk werd er vaak een beroep gedaan op Ficus-telers. Hartelijk dank hiervoor. Mijn dank geldt ook voor de Landelijke Ficus Commissie (LTO). Door deel te nemen aan overleggen van deze commissie bleef ik goed op de hoogte van de ontwikkelingen in de sector.

Diverse begeleidingscommissies zijn tijdens het onderzoek betrokken geweest. Met name noem ik José Vogelezang, Erik Persoon en Heino van Rijnberk, zij hebben mede richting gegeven aan het onderzoek.

De medewerkers van de Technische Dienst wil ik bedanken voor de technische ondersteuning tijdens het onderzoek, in de vorm van meetnetten, lichtmeters en dataloggers. De Teelttechnische Dienst, met name de gewasverzorgers Jacques van Zoest en Hans Schüttler, wil ik bedanken voor de goede verzorging van de proeven.

Ook een dankwoord aan de statisticus Jaco Klap. Door het geven van ondersteuning bij het statistisch verwerken van de gegevens heeft hij een essentiële bijdrage geleverd voor het slagen van dit proefschrift.

Mijn collega's wil ik bedanken voor de fijne samenwerking.

Mijn ouders wil ik bedanken voor de gelegenheid die zij mij gaven om te studeren. Zij hebben mij altijd gestimuleerd en gesteund.

Tenslotte wil ik Nico bedanken voor het vertrouwen in een goede afloop van de periode waarin dit proefschrift werd geschreven. Jouw steun en liefde evenals de leuke dingen samen met onze kinderen, Susan, Linda en Rick, waren in deze periode onmisbaar.

Contents

Chapter 1

General introduction

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1. General introduction

Greenhouse horticulture is an important industry in The Netherlands valuing about 5 billion euro in 2000 (LEI-DLO, 2001), an increase of 11% compared to1999. The total area under glass has increased from less than 8000 hectare in 1976 to more than 10.600 hectare in 2000. The share of ornamental horticulture in the total greenhouse area has continually increased and is now nearly 60%; of which two thirds cut flowers and one third pot plants. In contrast to the increase in area the number of enterprises has decreased; for pot plants (including bedding plants) from 3400 (1980) to 2900 nurseries (1999) (Van Woerden and Bakker, 2000). The Netherlands is one of the worlds leading pot plant producers. In 2000 the export value of pot- and bedding plants increased with more than 9% (LEI-DLO, 2001).

Pot plants can be divided into two categories: flowering pot plants and foliage pot plants. They are cultivated in plastic pots or clay pots and are produced for ornamental use in homes and offices. Either the leaves, the flowers, or both, determine the ornamental value of pot plants. Pot plant nurseries are variable in size and in degree of automation and the thousand or more registered products virtually all require a different and specialised production process. Bots (1991) listed the many differences in production process between various pot plants, the number and length of cultivation stage, the climatic and nutritional requirements and the logistics of the production process. New products are frequently being introduced and because of this it is difficult to obtain exact data on pot plant production, cultivation, and grading strategies.

There are different production systems for pot plants. Plants can be grown on the ground, on concrete floors, on fixed or rolling benches, or benches that can be automatically transported. In some advanced production systems, the plants can be transported to a central location for each treatment. In most greenhouses climate control is highly automated. This is, however, generally not true for processes such as picking of cuttings and planting of cuttings, spacing plants and preparing the final products for transportation. These processes are only automated on large, specialised high-tech nurseries.

A large share of greenhouse production is marketed via the Dutch co-operative auction system. In the past the auctions have been based on a push-market, the product was produced at the lowest possible (cost-)price and the auction took care of marketing. Consumer preferences played a minor role in this system. At present large supermarket chains dominate the market and their experience with consumer preferences allows them to dictate what the producer should supply; thus creating a pull-market. Retailers have their own specific requirements; quality specifications to facilitate shop planning and to satisfy critical consumers are the factors behind this transition in marketing methods.

At the moment marketing of pot plants is still producer oriented. During the last years increasing mechanisation and process-automation have strongly reduced the costs of Dutch production. Despite this fact, the increasing year-round competition from other European countries and a production surplus have put the price under pressure. The introduction of quality standards in The Netherlands could help distinguish certain products from those from competing countries. Therefore it is important that a year-round production of products with high quality is possible. In agreement with Anonymous (2000) and references therein a transition of a producer oriented to a consumer oriented market is necessary: a well defined product has to be delivered at a defined moment in time.

The situation to this day is that current production methods tend to result in marketable products with a large variation in quality. Delivery of uniform batches of marketable products on a specified delivery date is not possible. As a result growers can not meet the demand of large orders and only in a few cases are growers capable of continually producing enough products to meet demand. Joint ventures or co-operating growers have more potential to provide the required quantity, however they are not always able to meet the preferred quality because of the lack of measurable quality standards.

It is clear that to strengthen the position of ornamental horticulture it is necessary to define quality specifications and to provide instruments to growers to meet these specifications on the specified delivery date.

1.1   Crop control system

Present production processes are solely based on the judgement of the grower leading to products according to subjective quality standards. These processes are coupled to the cultivation schedule (based on blue print) adopted by the grower. A cultivation schedule describes the cultivation process, in terms of actions, timing and crop status over time, including the crop attributes at harvest in terms of quantity and quality (Challa, 1999). It defines the start and end of the production process of a given product, including the requirements in terms of materials, space and labour. Cultivation schedules and the underlying cultivation blue prints are grower specific and dependent on circumstances, for example the judgement of the grower of the conflicting requirements or the market segment the grower is aiming for (Challa, 1999). However, blue prints are not always available and the control processes are in reality only partly effective, because of technical and logistic shortcomings. Probably the most noticeable problem is that the control processes are not primarily based on an optimum combination of quality, quantity and costs but rather on the prevention of damage. Additionally the reaction of a plant to climatic or other changes in the environment is dependent on the developmental stage. All these points illustrate that the

present control processes in greenhouse environment are not geared to optimise quality, quantity and costs. This could be improved by providing the grower with information during cultivation to improve decisions.

Decision-support systems (DSSs) can provide information for the grower to help improve management or control decisions. They may be aimed at tactical or strategic planning decisions or at operational control and may include complex process models of crops/greenhouses, simple models derived from complex ones or from data, expert systems, decision trees, etc. (Jones and Ruijs, 1998). There are all kinds of DSS types, with different purposes and approaches. Besides DSSs on climate control in greenhouses (Challa and Van Straten, 1993; Challa, 1997), logistics (Koerhuis, 1998; Annevelink, 1999) and planning (Hofstede, 1992) there are also DSSs for quality control (Adams et al., 1996; Fischer and Heins, 1996). The DSS (named CARE) of Fisher and Heins (1996) helps growers to achieve height and flowering date targets for flowering pot plants, Easter lily and chrysanthemum. The system is based on graphical tracking, which is a technique in which measured and extrapolated plant height is compared over time with a target height curve (Fischer and Heins, 1995). In The Greenhouse CARE System graphical tracking is combined with simulation models and knowledge-based systems to predict development rate and stem elongation five days ahead and to recommend optimum temperatures and growth retardant applications. The DSS of Adams et al. (1996; 1997) is based on a model that predicts effects of environment on plant quality of pansy cv. Universal Violet, as well as on time to flowering. The system also provides growers information for planning sowing schedules. Besides DSSs there are models dealing with aspects of external quality of greenhouse crops (Meeteren, 1998). Examples are models describing the effects of environmental conditions on the development and shape of plants such as height, branching and flower size (Moe et al., 1992; Larsen and Gertsson, 1992; Pearson et al., 1995, Larsen and Hidén, 1995) or on plant architecture (De Reffye et al., 1998).

1.2   Basis for the present research

In this study we want to develop a system for growers to control development and growth of the crop to achieve a defined quality on a specified delivery date. Controllable factors temperature and plant density affect growth and development of pot plants together with available natural light which cannot be controlled. A DSS can be a helpful tool to cope with this complexity and enables the grower to improve management and to control decisions. In practice DSSs must be simple to operate, easy to interpret, and provide relevant information to the grower. Jones and Ruijs (1998) stated that DSSs may fail due to the complexity of the models used and the numerous inputs required for their operation. Generally, models in DSSs

should be simple, although the scope of the problem to be addressed may require complex models, particularly if the decisions are not structured (Jones and Ruijs, 1998).

The system for quality control in this study needs to meet some important requirements:

- The total visual quality of the marketable product must be objectively defined.
- Data collection of quality features must be accurate to make control of these features possible.
- Data acquisition must not be laborious.
- The marketable product has to be uniform with a defined quality at the specified delivery date.

The total visual quality of the marketable product has to be defined. Different models of aspects of external quality in relation to the cultivation of greenhouse crops are available, however, they are lacking a link to the objectively defined external quality of the plant. Most models deal with one or two quality attributes (section 1.1). Only De Reffye et al. (1998) dealt with a complete description of plant architecture, but a weak point of these models is the poor performance with respect to the controllable factors in a greenhouse, because their models lack physiological basis. The model-based DSS CARE also considers only few quality attributes. It deals only with two quality attributes for flowering pot plants, plant height and flowering date, and with only one for foliage plants, namely plant height. Another restriction of the system is that it can not give insight on strategies on temperature or light to achieve the target height on a specific delivery date. CARE tracks a target height curve based on an average strategy for the pot plant concerned. With CARE it is only possible to predict five days ahead and recommend optimum temperatures and growth retardant applications.

Data collection of plant features must be quite accurate to make control of these features possible and the data acquisition must be simple. In the CARE-system plant height is measured by hand, which is quite laborious. The importance of this aspect increases as more quality attributes are taken into account. Image processing is an accurate and quick measuring technique to determine plant features. Cardenas-Weber et al. (1988) described its application for the feature measurement of cuttings. Visual plant features such as shape, stage of development and health were determined. Simonton et al. (1990) described a system to measure features of *Geranium* cuttings such as main stem internodes and petioles. Feasibility of image processing in grading container-grown ornamental plants was analysed by Hines et al. (1986, 1987). Plant features such as height, width, shape, foliage density and symmetry were chosen for grading. Bennedsen et al. (1991) used image processing for inspection of pot plants. By taking a top- and a side-view, features of *Cyclamen* were measured; area of flowers, area of leaves and centre of gravity for flowers and leaves. Promising results of

feature measurement and grading were also obtained with crops such as *Begonia* (Straat, 1991; Dijkstra et al., 1997), Chrysanthemum (Van Vliet, 1990), *Saintpaulia* (Dijkstra and Theeuwen, 1990; Dijkstra, 1994) and *Dieffenbachia* (Dijkstra and Meuleman, 1995). In this study image processing is used for monitoring plant development.

The marketable batch had to be uniform at the specified delivery date. To deliver uniform batches with the CARE system one has to use uniform starting material. Neural networks were successfully used to grade pot plants (Meuleman and Dijkstra, 1995; Meuleman et al., 1998; Meuleman, 1998). Also in this study plant features extracted from images were used as an input for a neural network to grade the plants in uniform batches.

1.3   Objectives and approach of this thesis

Considering the points put forward above, the objective of this thesis is to develop a tool to control the visual quality of pot plants. The following approach has therefore been adopted:

1) To control the development and growth of pot plants to a preferred visual quality the first prerequisite is to specify quality.

For this purpose a mathematical model to describe and quantify quality as a complex feature is required. In the food industry a theory has been developed in which complex features such as quality were described and quantified using a model (Steenkamp et al., 1986). This additive model structure will be considered and if necessary revised for pot plants (chapter 2). Then the most important quality attributes can be defined and quantified (chapter 3). In this chapter panel assessments are used to analyse the quality subjectively, image processing is used to quantify the quality attributes objectively. The chapter also includes a description of the parameterisation and quantification of the weight of the most important quality features. Finally the selected quality attributes should be directly or indirectly suitable for control purposes.

2) The effect of temperature, plant density (control factors) and season (not under control) on growth and development of pot plants has to be quantified (chapter 4).

These are considered the most important factors regarding growth and development of pot plants. Crop responses and relevant plant processes in relation to the important quality features are discussed. Finally a crop growth control model can be developed that describes plant processes that determine the quality of the pot plant (chapter 5).

3) By integration of these four functional modules, a model for visual quality, a crop growth control model, image processing for monitoring crop development and a neural network to grade plants, a system is obtained to control development of pot plants to uniform batches with a predetermined quality on a specified delivery date (figure 1.1).

This system is presented in chapter 6. In the general discussion (chapter 7) the system is compared to other systems and its limitations and the transferability to other crops is discussed. Furthermore, the system is evaluated for commercial practice.

Figure 1.1: A system to control crop development of pot plants to uniform batches with a predetermined quality on a specified delivery date.

For this study *Ficus benjamina* 'Exotica' was chosen as a pilot foliage plant. *Ficus* is the most popular foliage plant and has a turnover of 10% of the total pot plant production in The Netherlands. It is a year-round crop where uniform batches and mechanisation are already of importance. Also the crop does not have the added complication of flowering.

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Chapter 2

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A mathematical model for visual quality of pot plants

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Abstract

The market is increasingly dictating the requirements on production. To deliver a well-defined marketable product the desired quality must first be mathematically defined. A model to describe and quantify quality as a complex feature, used within the food industry was considered and revised to obtain a mathematical description of visual quality in ornamental horticulture.

The model obtained was tested with a pot plant, *Ficus benjamina* 'Exotica'. The most important quality attributes were defined and used to compile a questionnaire. A set of plants was evaluated by a panel based on this questionnaire and their images were also quantified using image processing. Mapping of the evaluations from subjective measurement, i.e. panel assessment, on the data from the objective measurements, i.e. image processing, resulted in a mathematical model for quality of *Ficus.*

The theoretical framework of quality modelling used in the food industry was successfully implemented within the domain of pot plants. The relevance of the approach for other crops and the perspective of this methodology for the future is discussed.

2.1   Introduction

Changing market strategies influence production, distribution and sales of ornamentals. At present there is a clear transition from a producers market towards a consumers market; the requirements of the consumers are more and more governing production. This change is a slow process and can currently be seen in many fields within society. A well-defined marketable product must be delivered at a defined moment in time. This changing strategy will force producers to introduce additional methods to optimise production. In only few cases are individual growers capable of continually producing enough products to demand. Joint ventures of co-operating growers have more potential to provide the required quantity. However, current production methods tend to result in batches of marketable products containing a large variation in external plant features. This problem is partly caused by the lack of an objective method for the measurement of visual quality, and partly by the lack of a method to control crop development to a defined marketable product. A mathematical model of visual quality is the first prerequisite to specify quality attributes and to make contractual delivery of specified products between grower and marketing-organisation (e.g. supermarket chain) possible.

In research within the food industry a theory has been developed (Steenkamp et al., 1986) in which complex features such as quality were described and quantified using a model. Steenkamp et al. (1986) defined quality of a product as: it's suitability for use as experienced

by the consumer. Quality is based on certain attributes and different consumers will perceive these attributes differently. A best quality exists for each consumer and this best quality is not necessarily the same for all consumers.

The objective of this research was to investigate how the theory that was developed in food industry could be used in ornamental horticulture. *Ficus benjamina* 'Exotica' was used as a pilot crop because it is one of the most popular foliage plants and because it is a year-round crop.

The following strategy was adopted:

1. The additive model structure used in the food industry (Steenkamp et al., 1986) was considered and revised (this paper)
2. The most important plant quality attributes were defined and a questionnaire for panel assessment was compiled (chapter 3)
3. A panel assessment by experts was carried out to obtain numerical values of subjective quality (chapter 3)
4. The plant quality attributes were quantified using image processing (chapter 3).
5. By linking numerical values of subjective quality to numerical values obtained by analysing the images (objective quality features) the model could be parameterised and the weight of the various features could be quantified (this paper; chapter 3).

2.2 Description of the model

2.2.1 Model used for quality

The definitions of quality that are used in literature are diverse. In some studies the subjective quality is emphasised while other studies focus on objective quality. Steenkamp et al. (1986) studied the relation between subjective and objective quality. The subjective quality concept emphasises the purpose of products and gives a (possible) description of how suitable a product is. The objective quality concept emphasises the production and gives a (possible) description of the objective 'conform specifications' approach of quality.

Steenkamp et al. (1986) used an additive model to analyse the subjective and objective features of quality. They described the subjective quality, a relation between quality and the scores on underlying quality attributes for a consumer, as follows:

$$K_{ij} = c - [\sum_{t=1}^{m} w_{it} \cdot (x_{ijt} - y_{it})^2]^{\frac{1}{2}} \quad (1)$$

where: K_{ij} = quality of product j according to individual i; m = number of attributes that are rated as important quality features; w_{it} = weight which individual i scores for quality attribute

t; x_{ijt} = score of product j on quality attribute t according to individual i; y_{it} = ideal score of a product. The constant c designated the maximum score. For each deviation, both below or above the optimal score for each feature, a correlation value, depending on the weight w, was subtracted from the maximum score.

The objective quality was described by the following equation:

$$K_j = c - [\sum_{t=1}^{m'} w_t \cdot (x_{jt} - y_t)^2]^{\frac{1}{2}} \tag{2}$$

where: K_j = quality of product j; c = constant; m' = number of attributes which are determined objectively; w_t = weight of attribute t; x_{jt} = score of product j on attribute t; y_t = ideal score.

Equations (1) and (2) differed in a few points. The scores allotted by the producers to the quality attributes were calculated 'objectively' with a standardised method, independent of the individual (x_{jt} replaces x_{ijt}). Only the attributes that could be technically measured were included in the quality assessment (m' replaces m). The weight allotted to these dimensions was assumed to be the same for all the individuals and this in turn was the main problem of the objective approach (w_t replaces w_{it}). In vertical product differentiation (Lancaster, 1979) the weight allotted to the attributes was of minor importance in contrast to the horizontal product differentiation. In the latter differentiation the weight allotted to the attributes was decisive in determining the quality ranking of the products. This differentiation was the most common situation (Hjorth-Andersen, 1981). A synthesis between the subjective and objective quality is achieved when firstly the product met the quality requirements of the potential buyers, secondly these requirements were accurately translated into technical specifications, and finally the product was produced and sold conforming to these specifications (Steenkamp et al., 1986).

2.2.2 Model for the process of quality perception

Two starting points formed the basis for the research model for the process of quality perception in the food industry (Steenkamp et al., 1986):

1. Products were categorised as a set of attributes. Besides technical and economical attributes, also psychological attributes were of importance.

2. The consumer is an imperfect solver of problems because (a) limited information about the different options, (b) incorrect perception of the alternatives, (c) limited memory and data processing capacity and (d) limited time for each separate decision (Wierenga, 1983).

Establishment of quality perception

```
                    ┌─────────────────────────────┐
                    │  Information about products: │
                    │      - experience            │
                    │      - advertisement         │
                    │      - knowledge             │
                    │  - information by for example│
                    │ government and consumer      │
                    │      organisations           │
                    │  - observation of the product│
                    └─────────────────────────────┘
```

Establishment of preference

Intrinsic indicators $a_1 \ldots a_m$	Extrinsic indicators $a_m \ldots a_n$

Perception of attributes relevant for quality $x_1 \ldots x_d$

Quality weights $w_1 \ldots w_d$

Perceived quality
- $K=K(x,w,y)$
- uncertainty

K

Perception of product attributes $x_1 \ldots x_1$

Preference weights $w_1 \ldots w_i$

Preference $P=P(x,w,y)$

Choice

Strategies

Unpredictable circumstances

Figure 2.1: Model for the process of quality perception (Steenkamp et al., 1986).

Any experience with a product is an important source of information for the consumer (Howard, 1977; Box, 1984; Corsten and Meijer, 1984). This information can positively or negatively influence the concept the consumer has of the product. The establishment of the perception of quality in relation to the products and the establishment of preference is a complicated process and is shown in figure 2.1 (Steenkamp et al., 1986).

2.2.3 Adaptation of the models of Steenkamp for pot plants

The models of Steenkamp et al. (1986) were revised by Oprel (1989). The model for the perception of quality used in the food industry is very comprehensive. For the adaptation of the model for floriculture the producer will give first priority to production which must meet the demand and preferences of the market (the aggregated demand). The visual quality plays an important role. At retail and consumer levels other quality attributes also become important (e.g. price, shop and vase-life). In this research only the aggregated demand was studied; the direct relation between producer and the market. A few points were of importance: the assessment of subjective quality per individual, the assessment of subjective quality in general and the link between subjective and objective quality.

The research model used in the present study was based on an assessment of quality attributes according to a scale from 0 (worst) –10 (best). Contrary to the model of Steenkamp both the bottom limit and the top limit of the range are known, eliminating the need to estimate these values. These modifications lead to the following equation:

Subjective quality per individual plant per individual was calculated as:

$$K_{ij} = c_s^{'} - \sum_{t=1}^{m} w_{it}^{'} \cdot x_{ijt} \tag{3}$$

where: K = quality; j = plant $(1\ldots n_j)$; $c_s^{'}$ = constant of the subjective quality; m = number of attributes that are rated as important quality attributes; w' = weight; x = score of the subjective attributes; i = individual $(1\ldots n_i)$.

Assuming an idealised individual an equation describing the subjective quality independent of the individual can be obtained. Then only the attributes are of importance.

The subjective quality K of plant j, judged by an idealised individual is:

$$K_j = c_s^{'} - \sum_{t=1}^{m} \overline{w}_t \cdot \overline{x}_{jt} \tag{4}$$

The model for objective quality is then:

$$K_j = c_o + \sum_{t=1}^{m'} w_t \cdot X_{jt}$$ (5)

where: c_o = constant of the objective quality; m' = number of attributes which are determined objectively; X= score of the objective attributes.

2.2.4 Collection of quality attributes

Preliminary research showed that according to the producer ten subjective quality attributes were very important: shape and total impression of the plant from different views, width of the plant, density of leaf mass at different levels of plant height and from different views (data not shown). These quality attributes of a set of plants were evaluated by a panel. The same plants that were assessed were also digitally recorded and processed. To this end the plant was vertically divided into five layers, each of 20 centimetres (figure 2.2). Finally the numerical values of the subjective quality and the objective quality were analysed using equation 3, 4 and 5.

Figure 2.2: Segmentation of the plant with central axis through middle of pot.

2.3   Results

A very good mathematical description of the quality of *Ficus* was obtained by linking data from subjective measurement to objective measurement (table 2.1; Dijkshoorn-Dekker, 1995). The quality of the plant, determined by the producer, was explained for 94.3% using two objective quality attributes, namely the density in front-view of the plant of the third and fourth layer, the width in side-view of the plant of the third layer and the width in front-view of the fourth and fifth layer. In this context 'front-view' means that side of the plant showing the most developed side shoots. A correct translation of the subjective quality attributes into technical specifications (objective quality attributes) gave a high contribution towards the percentage of explanation of the total impression. This then allows the producer to produce and deliver products according to these specifications.

Table 2.1: The selected statistical model explaining the objective quality, Kj (Equation 5).

Variable[1]	Coefficient[2]	Standard deviation	t-value	% contribution to R^2
Front-view				
Density of layer 3	5.15	1.93	2.67	
Density of layer 4	4.19	1.90	2.20	
Width of layer 4	0.01439	0.00670	2.15	
Width of layer 5	0.01805	0.00740	2.44	
Side-view				
Width of layer 3	0.0694	0.0135	5.14	
Constant	-7.404	0.934	-7.93	
Total R^2 (%)				94.3
R^2adjusted				92.7

[1] X_{jt} in Equation 5.

[2] w_t in Equation 5.

2.4   Discussion

The models of quality used in the food industry Steenkamp et al. (1986) are also very useful to describe quality in floriculture. The application of the revised models, as described in paragraph 2.3, was a success for the pilot crop *Ficus benjamina* 'Exotica'. From literature it was known that quality requirements of the producer could be defined (Dijkshoorn-Dekker, 1995; Oprel, 1986, 1988) and could be translated into objective quality attributes. Synthesis

between the subjective and objective quality resulted in a mathematical model of visual quality for *Ficus*.

The implementation of models to describe quality of plants seems to be rather limited to the plant investigated. The number and preferred quality attributes are crop and probably variety and also market dependent. Large-leafed and small-leafed varieties can be distinguished within the crop *Ficus*. For example the roundness of a plant of large-leafed variety could play a different role to a small-leafed variety in a quality assessment. Roundness is also important for *Dieffenbachia* (Oprel, 1986). Density of leaf mass is invariably a very important quality attribute for foliage and flowering pot plants. Examples of these are *Begonia* and *Saintpaulia* (Oprel, 1986,1988).

Application of the model was successful using small-scale exploratory panel assessments of *Saintpaulia*, *Dieffenbachia* (Oprel, 1986) and *Begonia* (Oprel, 1988). This supports the idea of a more universal implementation of the method for foliage and flowering pot plants. A disadvantage of the method is that it is fairly time-consuming. Many research steps had to be taken to parameterise the models and to give a value to the different quality attributes.

The understanding of quality of pot plants in general can be enlarged by defining objective quality. Objective quality assessment, moreover, has many advantages in relation to marketing, because of the specific requirements of the market, to meet the grading and product specifications of auctions and, in general, to deliver a specified product on a contract-base. Models of visual quality can assist the producer in grading plants at all stages during the crop and together with a crop development model they can be implemented in crop management systems (Dijkshoorn-Dekker and Eveleens-Clark, 1999; Dijkshoorn-Dekker and Meuleman, 2000).

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Chapter 3

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Automatic assessment of quality of pot plants using image processing

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Abstract

To quantify the visual quality of a marketable pot plant, the desired quality must first be mathematically defined. Image processing techniques offer opportunities in determining visual quality features of pot plants. By linking data from subjective measurement, i.e. panel judgement by growers, to objective measurement, i.e. image processing, a mathematical description of quality can be obtained.

A preliminary experiment was conducted to obtain and to interpret the most important plant quality features. Using a questionnaire, growers assessed the importance of plant features in explaining the total quality of the plant. The images of the same plants were also recorded in three positions and processed. To this end the plant was projected on a window of 100 cm high, the lower border coinciding with the rim of the pot. The window was divided into five horizontally joined split-windows, each of 20 centimetres, numbered from above from 1 to 5. *Ficus benjamina* 'Exotica' was used as a pilot crop.

The visual quality of *Ficus benjamina* 'Exotica' was explained for 88.7% by a mathematical model. The quality of *Ficus benjamina* 'Exotica' could mainly be characterised by four variables; the density of the leaf mass in the third layer in front-view; the width in the third layer in side-view; the width in front-view of the fourth and fifth layer.
The mathematical model of visual quality could be coupled with a model of crop development to control quality during the production process.

3.1   Introduction

In addition to price and an adequate supply, quality is one of the most important factors in strengthening the position of a product in the market. Product quality is affected by decisions that are made during the course of events from crop to consumer but this relation is not well established. There are many different definitions of the concept of quality. According to Artley (1975) it seems that there are as many definitions of quality as there are researchers. Feigenbaum (1961) defines quality as 'the composite characteristics of engineering and manufacture that determine the degree to which the product in use will meet the expectations of the consumer'. Quality could also be defined as 'the total in characteristics that define the ability to satisfy a certain need' or in other words 'suitability for use' (Fremery and Van Lier, 1975). Juran (1974), Vorstman (1981) and Box (1984) used this definition in virtually the same form. Considering plants, quality could for example mean more flowers per plant or heavier plants (Vogelezang et al., 1988). Quality of plants encompasses many plant features, including external (visual quality) as well as internal (physiological condition) features. An

objective system of classification of quality could help to define it in a way that is suitable for scientific investigation.

Steenkamp et al. (1986) distinguished objective and subjective quality. The objective quality of a product can be described as 'conform specifications'. This refers to the quality resulting from the production process. The emphasis is mainly on the technical characteristics of the product. To what extent the product meets the technical specifications is the most important standard for quality. The consumer experiences the production process and the (specified) quality as a given fact. The consumer judges the product from his own (subjective) point of view as he assesses the suitability of the product for his own use. Steenkamp et al. (1986) defined this last type of quality assessment as subjective quality.

This study focuses on pot plants because in ornamental horticulture there is a need to define plant quality of the finished product. The first introduction to an objective classification system for pot plants was by Oprel (1986, 1988). The visual quality of some pot plants was established using a small-scale exploratory panel assessment. In this experiment the height and shape when viewed from above (roundness) and the shape when viewed from the side (density of the leaf mass) were decisive for the visual quality. The number and position of the flowers on flowering pot plants were also of importance (Straat, 1991). The conclusions were generally similar to results from an investigation among consumers as to their motives for buying, i.e. the shape of the plant, size and general appearance (Genugten, 1986; Anonymous, 1987). The studies of Oprel (1986, 1988) were promising, but still of preliminary nature and required laborious hand recording.

Digital image processing appears to be a suitable method for recording objective plant features (Guyer et al., 1986; Hines et al., 1986, 1987; Straat, 1991; Vegter, 1992). Subjective judgement inherent to man can be eliminated when linked to objectively measured plant features of the finished product. Plant quality can then be defined based on these features. The quality features that are important for the buyer or user (height, diameter) can be influenced by the grower. At a later stage it is even possible to link quality features to measured plant features at the half-product stage, or of cuttings and seedlings. If sufficient correlation exists, grading early in the crop could create more uniform batches of plants. Encouraging results have been reached in the grading of *Saintpaulia* cuttings (Dijkstra and Theeuwen, 1990; Vegter, 1992). Chrysanthemum cuttings have also been graded using image processing (Van Vliet, 1990).

This study was undertaken to develop and evaluate a method to automatically assess subjective quality of ornamentals using image processing. This main task can be divided into a number of subtasks:

1. How do experts assess visual plant quality?
2. How consistent is this assessment?

3. What is the contribution of different plant quality features to the total impression of the subjective quality?
4. How can these descriptive plant quality features be quantified subjectively?
5. To what extent can these subjective plant features be quantified by image processing ?
6. How accurately can the subjective quality be matched to the objective quality?

To tackle the first three subtasks the quality features which are important in the eyes of growers and their motives for choosing them were recorded (preliminary experiment). For this purpose, ideally a representative panel of representatives of the target group is required. A thorough investigation for such a panel would have been needed. However it is the methodology, which is generic, that is the basis for determining quality features. In this case the target group is growers of *Ficus*, because the model of visual quality obtained is used for crop growth control. *Ficus benjamina* 'Exotica' was used as a pilot crop; a year-round crop where mechanisation and hence uniform batches are already of importance. Moreover, the crop does not have the added complication of flowering. To perform tasks 4, 5 and 6 in which a synthesis between subjective and objective quality is accomplished, the quality features that appeared to be important in the preliminary experiment, were used (main experiment). A panel assessment of these features by experts was set up to obtain a quantitative evaluation of subjective quality. Using the mathematical model for visual quality of pot plants, described in chapter 2, subjective data could be linked to objective data, obtained by image processing, to parameterise the model and to quantify the weight of the various features. The validation of the model obtained is not within the scope of this study.

3.2 Material and methods

Preliminary experiment (subtasks 1, 2, 3)

A number of factors are important when using a panel to assess the qualitative and quantitative plant quality. The variation within the group of plants to be assessed must be as large as possible. Only then can the plant features that govern quality be found. To determine the most important plant features of the subjective quality of *Ficus benjamina* 'Exotica', eight 1.20 m. plants with two cuttings per pot were used. Plants from different growers were used to obtain a large variation in visual quality. All plants were exhibited in the same way, a uniform pot was used (21 cm ES) and all the necrotic and damaged leaves were removed. Seven growers visually ranked the plants according to quality. During the seven separate ranking sessions each of the growers was questioned as to the plant features he considered the most important when assessing and ranking the plants. Questions concerning the reasoning behind

the ranking were also posed in response to the action of the grower e.g. 'What are the most important plant features of a plant when assessing quality?', 'How would you describe these features?', 'Why is a plant ranked higher than the next?' Finally the contribution of different plant features to the total impression of the subjective quality was quantified.

The consistency of the assessment was tested using the Kendall's Coefficient of Concordance (Siegel, 1956), which gives the level of correlation between multiple series of rankings, similar to the Spearman rank correlation for one pair of rankings.

Main experiment

Subjective quality (subtask 4)

From the preliminary experiment the most important plant features and their contribution to the total impression are known. Based on this information a questionnaire was designed. In order to quantify the weight of the various plant features, plants as described in the preliminary experiment were used. The plants were placed in a row with the front side of the plant facing the panel. In this context the front side is the side of the plant showing the most developed side shoots (chapter 2: figure 2.2). Using the questionnaire each plant was then judged by growers. The panel members had to differentiate between the different plant features. Marks were given for each feature on a scale from zero to ten. In this way floating averages during an assessment were avoided. A floating average arises when each plant is judged on all the plant features at the same time, thus making it easy to compare plants. The main experiment was repeated once. The first experiment was carried out in April 1991 with 13 plants and 11 growers, the second experiment in October 1991 with 12 plants and 8 growers.

Objective quality (subtask 5)

The plant features of each plant used for panel assessment in the main experiment were recorded in three positions using image processing; front-view, side-view (i.e. view perpendicular to the front-view) and view from above. After considering the reasoning behind the ranking of the plants in the preliminary experiment these three views should encompass the features important for the subjective quality. A special room was designed to provide uniform illumination of the plants. A background lighting system was used so that black and white images could be made and to obtain a better segmentation between the plant and background. By placing plant and camera in an almost closed dark environment disturbance by sunlight and other light sources were eliminated. The distance between camera lens and the

plant was chosen in such a way that the relative error of the recorded images due to distortion was less than or equal to 5%. The images were recorded using a camera (black/white CCD Sanyo VC 1960) in combination with a frame grabber card (Data Translation 2871) in RGB-mode. A specially developed program, based on TCL-image with a resolution of 512 x 512 pixels, was used for segmentation of the images and to extract the plant features. According to the preliminary assessment the base of the plant appeared to be very important. Therefore the original image of the plant was projected on a window of 100 cm high, the lower border coinciding with the rim of the pot. The window was divided into five horizontally joined split-windows, each of 20 centimetres, numbered from above from 1 to 5 (chapter 2: figure 2.2) and into two parts by drawing a vertical line through the middle of the pot up through the top of the plant. In front-view the following features were recorded: the convex hull; the height of the plant and largest width with corresponding height of the convex hull; the optical centre (figure 3.1); the width per layer; the density of leaf mass per layer and the object area per layer (chapter 2: figure 2.2). The last three features from the front-view were also recorded for the side-view. In the view from above, the optical centre (figure 3.1), the ratio between the inscribed largest (R_2) and the outer smallest radius (R_1) from the optical centre (figure 3.1) and the area of the object were recorded.

Figure 3.1: The optical centre in front-view and view from above

       ocfr = optical centre in front-view

       ocab = optical centre in view from above

       R1 = the outer smallest radius from the optical centre

       R2 = the inscribed largest radius from the optical centre

Matching subjective to objective quality (subtask 6)

A mathematical model for visual quality of pot plants was described in chapter 2. The model is based on three equations, two equations (1, 2) show the relationship between the assessment of the total impression per plant per individual and by an idealised individual and the assessment of the subjective (visually defined) features as described in the questionnaire (table 3.2). In this context the term idealised is used to indicate that the individual is representative for the purpose of the judgement. In this case the target group is growers of *Ficus*, because the model is used for crop growth control. The third equation (3) shows the relationship between the assessment of the total impression per plant averaged over the number of panel members and the objective (digitally measured) values. The structure of the model is additive meaning that each important plant feature is weighted. The model is used for the statistical analysis of the values obtained by panel assessment and measurements obtained by image analysis.

Subjective quality per individual plant per individual:

$$K_{ij} = c_s' - \sum_{t=1}^{m} w_{it}' \cdot x_{ijt} \tag{1}$$

where: K = quality; j = plant $(1…n_j)$; c_s' = constant of the subjective quality; m = number of attributes that are rated as important quality attributes; w' = weight; x = score of the subjective attributes; i = individual $(1…n_i)$.

Assuming an idealised individual an equation describing the subjective quality independent of the individual can be obtained. Then only the attributes are of importance.

The subjective quality K of plant j judged by an idealised individual is:

$$K_j = c_s' - \sum_{t=1}^{m} \overline{w}_t \cdot \overline{x}_{jt} \tag{2}$$

The model for objective quality is then:

$$K_j = c_o + \sum_{t=1}^{m'} w_t \cdot X_{jt} \tag{3}$$

where: c_o = constant of the objective quality; m' = number of attributes which are determined objectively; X = score of the objective attributes.

Statistical analysis

The data of April and October have been combined for statistical analysis. The variation among plants used in the assessments of October and April was significant larger than the variation between the seasons. An explorative analysis of all relationships mentioned in subtask 6 was done by the construction of correlation matrices of the included variables, followed by an in-depth analysis based on regression techniques. The model coefficients of the three equations (see subtask 6) can be estimated from the obtained subjective and objective data by linear regression on the original not transformed scale and the Logit scale. Two separate series of statistical analyses have been carried out.

In the first analyses, the total (subjective) impression was explained by the subjective plant features. The link between the rating of the expert for the subjective plant features and total impression was carried out for every expert separately and for all experts together. The latter case offered the possibility to test the dependency of the relationships on the expert's judgement (in terms of interactions), taking into account correlation structures related to observations from the same plant or from the same expert. The general applicability of the obtained relationships, independent of the observer (K_j in equation 2), can only be assured when no significant interaction terms or correlation between expert and predictor variable are found. The replacement of K_{ij} (equation 1) by K_j is not substantiated by the observations when there are significant interaction terms.

The impact of replacing of the values for the total impression on the original non-transformed scale with Logit-transformed data, which is a better method for analysing data on a scale that is limited to both ends (scale 0-10), was investigated. The selection of the `best' model was based on Mallow's Cp criterion (Miller, 1990) for the analysis of all data together, and on the R^2_{adj} for the expert-wise analysis of the data. The latter was necessary due to the limited number of observations in these analyses. A non-negativity constraint was added, in order to avoid unlikely (or impossible) models with meaningless negative regression coefficients (Flack and Chang, 1987).

Correlation structures within these data and possible systematic differences in the scale of scoring by the individual experts, were also analysed. The former by normalising the data per expert to 0 mean and unit variance. The latter by including variance components in a mixed model (REML) (Gillmour et al., 1995).

In the second analyses, the total impression was explained by the objective (digitally measured) values. The link between the measured plant features and the overall impression was preceded by calculating an average value for the total impression for the investigated plants. The same type of statistical analysis was applied as in the analyses of subjective plant features except normalisation and REML. In previous studies (Dijkshoorn-Dekker, 1995;

chapter 2) only the original non-transformed scale was used instead of the more appropriate Logit-scale.

3.3 Results

Preliminary experiment

In the preliminary experiment the reasoning behind the ranking process of the grower was investigated. Density of the leaf mass proved to be the most important ranking criterion for growers. Low density of the leaf mass in the lowest part of the plant was negatively assessed. The shape of the plant was the second criterion for selection. A pyramidal plant shape is important. As long as the back of the plant has a similar leaf mass and shape as the front side of the plant the quality was not impaired The general opinion was that the quality of the plant decreased as density of the leaf mass decreased and shape became more irregular.

Table 3.1 shows the ranking of the quality of the plants per individual expert (grower). The consistency of the rankings by these experts was satisfactory (Kendall's Concordance Coefficient of 0.258; χ^2 =12.6; p=0.082) (Siegel, 1956).

Table 3.1: The ranking of visual quality of different plants of *Ficus benjamina* 'Exotica', numbered 1 to 8, per individual grower.

Ranking number	1st	2nd	3rd	4th	5th	6th	7th	8th
Grower 1	8	6	4	1	7	5	3	2
Grower 2	1	5	4	8	7	6	2	3
Grower 3	1	8	4	5	7	6	3	2
Grower 4	8	4	7	6	2	1	5	3
Grower 5	8	4	1	7	6	5	2	3
Grower 6	8	1	7	4	5	6	3	2
Grower 7	8	1	6	7	4	5	3	2

Main experiment

A questionnaire was compiled based on the results of the preliminary experiment (table 3.2).

Values for the panel assessment for the different plant features covered a full range (table 3.2). The correlation matrices per expert between different subjective plant features showed a high level of correlation between these features. With a few experts correlation coefficients between 70.5 and 85% were observed and with the remainder having correlation coefficients above 90%. The correlation coefficients for the entire database (including all experts) varied between 77% and 90%. Similar values and patterns were found for the correlation coefficients between the different subjective plant features and the total impression. Because of the high correlation between the separate features meaningless negative parameters had to be taken into account relatively frequently in the successive model selection.

Table 3.2: The average value, maximum variation and average per feature for 25 *Ficus benjamina* 'Exotica' assessed in the main experiment.

Variable	Mean	Variation (min/max)	Mean variation (min/max)
Total impression	6.1	0/10	2.7/8.8
Density	6.2	0/10	2.4/8.8
Width	6.2	0/9	2.6/8.8
Front-view			
Shape	6.1	0/9	2.6/8.8
Density in lower part	5.9	0/9	2.5/8.7
Density in upper part	6.1	0/9	2.9/8.6
Total impression	6.1	0/10	2.7/8.8
Side-view			
Shape	6.3	1/10	3.2/8.8
Rear-view			
Total impression	6.0	0/10	2.4/8.8
Density	5.8	0/9	2.5/8.6

In the selection process of the best model for the individual experts plant feature 'Density of leaf mass in rear-view' occurred 10 times and plant feature 'Density of leaf mass in total-view' 8 times in the best model found for each expert (table 3.3). These two features, however, never occurred simultaneously. Both features seem to be important but may be at least partially exchangeable. The plant features 'Width', 'Density of leaf mass in the upper 60 cm of the plant in front-view' and 'Total impression in rear-view' were also relatively frequently selected (4 or 5 times). The selection process for the entire data set has lead to the

Table 3.3: Results of the selection of `best' regression models explaining the subjective quality, presented by the number of selected subjective plant features of the individual experts and by the regression coefficients of the models with all experts (with (w.) and without (w.o.) interaction terms), using different statistical techniques.

	Constant	Total view		Front view				Side view	Rear view		R^2_{adj}
		Density	Width	Shape	Density in lower part	Density in upper part	Total impres- sion	Shape	Density	Total impres- sion	(%)
Selected models from original data											
# selected of 19 experts	(19)	9	3	3	5	6	4	3	10	2	90.7 (avg.)
All experts w.o interact.	0.078	0.241	0.100			0.057	0.213		0.204	0.180	87.6
All experts w. interact. (mn,avg,mx)[1]	0.066	0.359	0.117			-0.120 -0.004 0.129	0.211		0.253		90.3
Selected models from normalised data on logit-logit scale											
# selected of 19 experts	(19)	11	4	4	4	5	5	4	6	4	88.7
All experts w./w.o. interactions[2]	0.033	0.475	0.087	0.222					0.237		85.5
Entire mixed model (REML) on logit-logit scale (no selection applied)											
Effect	0.518	0.143	0.045	0.338	0.035	0.038	0.113	0.007	0.046	0.254	n.a.
SE	0.126	0.067	0.115	0.113	0.061	0.093	0.066	0.051	0.048	0.117	

1) Minimum (mn), average (avg) and maximum (mx) coefficient per expert in case of interaction between term and expert.

2) The model with (w.) and without (w.o.) interactions were the same, since no interaction terms were selected.

same set of relevant features as mentioned for the best models for the individual experts plus the plant feature 'Total impression in front-view' (table 3.3). The inclusion of an interaction term for 'Density of leaf mass in the upper 60 cm of the plant in front-view' indicates that this

judgement is very dependant on the expert's own view.

Logit transformation of the data and successive normalisation and model selection gave slightly different models, especially regarding the features selected from the front view of the plant (table 3.3). In comparison with the best models for all experts obtained from original data plant feature 'Shape in front-view' was selected instead of the two previously selected plant features namely 'Total impression in front-view' and 'Density of leaf mass in the upper 60 cm of the plant in front-view'. In this case there was no need to include interaction terms (i.e. expert-dependent coefficients). Therefore, normalisation appears to be an interesting tool to improve the model outcome. Finally, the mixed effect analyses (on the logit-logit scale) resulted in a model in which all coefficients were positive when they were all included. The level of significance of the effect, however, varied.

Table 3.4: Details of the selected statistical model explaining the objective quality, Kj (n=24).

Variable	Original data (DF=18)				Data on logit-logit scale (DF=19)			
	Coefficient	Standard deviation	t-value	% contribution to R^2	Coefficient	Standard deviation	t-value	% contribution to R^2
Front-view								
Density of layer 3	5.15	1.93	2.67		4.39	1.58	2.77	
Density of layer 4	4.19	1.90	2.20		-	-	-	
Width of layer 4	0.01439	0.00670	2.15		0.01050	0.00518	2.02	
Width of layer 5	0.01805	0.00740	2.44		0.01701	0.00495	3.44	
Side-view								
Width of layer 3	0.0694	0.0135	5.14		0.0399	0.115	3.47	
Constant	-7.404	0.934	-7.93		-7.181	0.687	-10.45	
Total R^2 (%)				94.3				88.7
R^2adjusted				92.7				86.3

When analysing the original data for the objective quality the mean total impression is explained for 94.3% by five variables namely the width in the third layer of the side-view, the

density of the leaf mass in the third and fourth layer of the front-view and the width of the front-view of the fourth and fifth layer (table 3.4). On the more appropriate logit-logit scale the mean total impression is explained for 88.7% by the same variables except density of the leaf mass in the fourth layer. The optimal visual quality was reached by increasing density of leaf mass around the optical centre. The lower the density of the leaf mass, the lower the quality. The shape of a plant influenced the position of the optical centre in the x and y direction. For *Ficus* the optical centre is located in the lowest 40 cm of the plant. More information could be obtained about the lowest part of the plant by measuring the width of the plant. A low density of leaf mass at the base of the plant has a negative effect on the visual quality. The side-shoots in the fourth and fifth layer must be of a certain length. The width of the third layer in side-view gives an impression of the shape of the plant. The view from above has no contribution at all to the visual quality.

3.4   Discussion

The model for visual quality of pot plants as described in chapter 2 was parameterised and the weight of the important quality features were quantified for *Ficus benjamina* 'Exotica'. By linking subjective data to objective data it was concluded that only two objective quality features (in addition to the fixed total plant height of 1.20 m.) were important to explain the total impression of *Ficus benjamina* 'Exotica'; density of the leaf mass and the width explained the total quality for 94.3% on the non-transformed scale and for 88.7% on the Logit scale. The model agrees very well with the results from the preliminary experiment. The same 'best' models were found with or without transformation. The density of leaf mass at the base is important for the total impression. The contribution of the width of the third layer in side-view in the model emphasises the fact that the density of the leaf mass and shape in front-view must correspond with the rear-view of the plant. Optimal visual quality will be reached at increasing density of leaf mass around the optical centre.

It can be concluded that the application of image-processing is a good method for objective registration of visual plant features. Positive results were also found by Guyer et al. (1986), Hines et al. (1986, 1987), Bennedsen et al. (1991), Dijkstra (1994) and Meuleman et al. (1998). The segmentation of the images and the extraction of the plant features were performed accurately thus providing accurate and absolute values for these features. It is difficult for a human being to give an absolute value to a plant feature without having a standard with which to compare. A correct translation of the subjective quality features into objective features and the correct extraction of these features from the images is essential to allow accurate explanation of the total impression of quality of the plant.

The subjective quality per panel member and per plant (total impression K_{ij}) were strongly correlated with all the plant features. The separate plant features were also strongly correlated. This is in contrast to the preliminary experiment where differentiation between the different plant features could be made. This effect is probably related to strong correlations between those variables for small subsets of the participating experts. It is quite likely that there are different groups of experts for which the total impression is determined by one or another plant feature. There is also a difference in 'theory in use' versus 'theory in action'. The grower is unable to explain how he assesses the plants but he is able to assess them. He appears to have 'tacit knowledge' (Van Zanten, 2000). These effects propagate easily to the total model, due to the small number of experts. With a larger panel this problem would probably not occur but in fact it is very difficult in practice to organise 50-100 growers to be present at the same time.

The question arises if growers are the most suitable target group to determine visual quality. Boisset (1997) made an inventory of the plant market in three countries: Denmark, France and The Netherlands. In her study she made an overview of the judgement of different experts with respect to four criteria: 1) knowledge of the plant, 2) experience with grading, 3) overview of the plant market and 4) overview of the consumer market. The wholesaler appeared to be the best choice, the consumer the worst. The grower met criteria 1 and 2, which are of importance for crop growth control. This argument substantiates the choice of growers as a target group in this study. The model for visual quality presented in this paper is valid for this group. Other target groups such as consumers or retailers could result in different models for visual quality. Research by Vogelezang (1988) and Straat (1991) showed that the subjective quality of *Begonia* could be defined accurately using a panel consisting of growers as well as a panel consisting of consumers. The results of the assessment by growers and consumers were similar. Results from consumer research on the motives for buying pot plants (plant shape, plant height and appearance of the plant in general) (Genugten, 1986; Anonymous, 1987; Wolnick, 1983) seem to point in the same direction as results from research of Vogelezang (1988). A remark must be made on the research of Vogelezang (1988). The panel of consumers in her case is not representative for the Dutch population. It can be expected that the consumers, all living in the pot plant production area of Aalsmeer, are more critical.

Mathematical models of visual quality can be used for different purposes such as grading of plants at all stages during cultivation (Dijkstra, 1994; Dijkshoorn-Dekker and Eveleens-Clark, 1999, Dijkshoorn-Dekker and Meuleman, 2000), classifying the final quality for the market, but also for crop management systems to control plant growth to a defined finished product. Selected plant features describing quality should be directly or indirectly suitable for control purposes. Once a mathematical model of visual quality is obtained, a model of crop development could be used to control quality during the production process.

These models must describe plant processes that determine the quality of the plant.

Models to describe quality of plants seem to be rather limited to the plant investigated and their development is fairly time-consuming as also mentioned in chapter 2. For flowering pot plants more generally applicable plant features have been found. The results from panel assessment on *Begonia* (Vogelezang, 1988) correspond to results with *Saintpaulia* (Vogelezang, 1985) and *Dieffenbachia* (not flowering) (Oprel, 1986). The validity of the model is limited to the target group used in this study and it will lose its validity when used in other countries. Preferred quality of a pot plant is often specific to a country. In an European project the panel assessments with wholesalers showed that the experts agree in general about the important features but they do not appreciate all features to the same extent (Meuleman et al., 1998). Since the model has a generic structure, adjustment to other target groups or crops should be possible by adaptation of relevant parameters.

It can be concluded that quality, as experienced by the grower, can be effectively incorporated into a mathematical model. In this way a more accurate definition of the quality of pot plants is available for implementation e.g. in auctions and for process control.

Acknowledgements

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Chapter 4

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Effect of season, temperature and plant density on the growth and development of *Ficus benjamina* 'Exotica'

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Abstract

Total plant height, width of the plant and density of the leaf mass are the most important delivery specifications for *Ficus benjamina* 'Exotica'. The effect of season, temperature and plant density on the dynamic behaviour of *Ficus benjamina* 'Exotica' in relation to these important quality features was studied.

Ficus benjamina 'Exotica' was subjected to 7 different mean day and night temperatures from 17 up to 35°C in temperature controlled daylit chambers. This foliage plant was also grown in greenhouse compartments at different plant densities varying from high, 48 pots per m^2, to low, 3 pots per m^2. The effect of season on development and growth was studied in greenhouse compartments at a temperature of 20°C using a spacing schedule of 23-10-5 pots per m^2. During all experiments plant features were measured to enable identification and evaluation of the plant processes that contribute most to the description of plant quality of *Ficus benjamina* 'Exotica'.

The development of *Ficus benjamina* 'Exotica' showed a regular pattern. Three leaves are unfolded on the main axis before a primary side shoot sprouts on the fourth leaf axil, counting from the top of the plant. Plant height increased with temperature up to 29.5°C. The effect of plant density on this variable was small. Leaf unfolding rate was influenced by light and temperature, plant density was of minor influence. Its response to temperature showed an optimum at 30°C. The final internode length was mainly affected by light intensity, temperature had no effect. The width of the plant and the density of leaf mass increased at lower plant densities. The effect of temperature was small. Except for temperatures ≥ 32°C or extremely low or high plant densities the visual quality of *Ficus* was affected.

The relationships between the important quality criteria of *Ficus benjamina* 'Exotica' and measurements of development under different climatic conditions could be used to build a model for crop development to control plant growth and production.

4.1   Introduction

Current methods in pot plant production tend to result in marketable products with a large variation in external plant features. Production of uniform batches of preferred quality is however, necessary to strengthen the position of ornamental horticulture. Growers are being forced to control growth to obtain a predetermined marketable product. This is difficult because on the one hand there is no objective method for the measurement of visual quality of pot plants, on the other hand there is no method to control crop development to a predefined marketable product on a specific delivery date.

A theoretical framework for modelling quality used in the food industry was successfully implemented within the domain of pot plants (chapter 2). A mathematical description of visual quality of *Ficus benjamina* 'Exotica' of 1.20-meter height was obtained.

Images of plants were recorded in three positions and processed. To this end the plant was projected on a window of 100 high, the lower border coinciding the rim of the pot. The window was divided into five horizontally joined split-windows, each of 20 centimetres, numbered from above from 1 to 5. The visual quality of *Ficus benjamina* 'Exotica' was explained for 88.7% and mainly expressed by four variables; the density of the leaf mass in the third layer in front-view; the width in the third layer in side-view; the width in front-view of the fourth and fifth layer (chapter 3). These important quality criteria of the product under consideration represent a target for crop growth and development to obtain a predetermined marketable product. Total plant height is, together with these features, one of the most important delivery specifications. Internode length and leaf unfolding rate are the basis for plant height. In previous research Dijkshoorn-Dekker found that plant width strongly correlates with the length of the primary side shoots. Density of leaf mass will increase when using more cuttings per pot. Density of leaf mass can be interpreted as the total amount of leaves or the total leaf area.

Factors such as temperature, season and plant density affect growth and development of pot plants. Also the starting material and the number of cuttings per pot influence the appearance of the plant at the marketable stage (Kromwijk and Van Mourik, 1992; Dijkshoorn-Dekker, 1995). Temperature and plant density play an important role in plant processes such as leaf unfolding rate, elongation and dry weight. From literature it is known that many foliage plants grow very well when grown at higher temperatures than normal (Mortensen and Larsen, 1989; Mortensen, 1991). In The Netherlands greenhouse temperatures between 18-20°C are still recommended for *Ficus* species. This is also emphasised in literature (Van Adrichem et al., 1979 and Von Hentig, 1982) which indicates that night temperatures should not exceed these greenhouse temperatures. In this study 20°C was used as a reference for all experiments.

The application of a negative DIF (i.e. temperature difference between day and night) has proved successful to reduce the internode length in many species of pot and bedding plants although not in all (Dijkshoorn-Dekker, 2000; Mortensen and Moe, 1992; Myster and Moe, 1995; Vogelezang et al., 1992). The internode length of *Ficus benjamina* was not significantly shorter at negative DIF (Jensen and Andersen, 1992; De Beer, 1996). At zero DIF in the range 21 to 33°C the internode length of *Ficus benjamina* was only shorter at 29 and 33°C. The quality of *Ficus* was not affected using a negative DIF (Jensen and Andersen, 1992).

Leaf unfolding rate has been studied in a number of plant species. For practical purposes leaf unfolding rate is often described as a linear function. The leaf unfolding rate for

sunflower (Rawson and Hindmarch, 1982), Easter lily (Karlsson et al., 1988*), Hibiscus rosa-sinensis* (Karlsson et al., 1991), *Saintpaulia* (Faust and Heins, 1993) and Chrysanthemum (Larsen and Hidén, 1995) was approximated by linear relationships within a limited temperature interval. The relationship between the rate of leaf formation and temperature can be described by a second degree polynomial, i.e. an optimum temperature exists at which the rate of leaf formation is highest (Dale and Millthorpe, 1983). In this study leaf unfolding rate was investigated over a wide range of temperatures for *Ficus benjamina*.

Limited information is available on the influence of plant density on architecture of foliage plants. In general, higher plant densities lead to an increase in LAI and dry weight production per square meter as has been demonstrated for many crops such as tomato (Papadopoulos and Ormrod, 1991) and rose (Kool, 1996). Papadopoulos and Ormrod(1991) found that the development of plants is limited due to the decreasing exposure of the individual plant to light. High plant densities influence the quality of foliage plants (Christensen, 1976) as light penetration in the canopy is reduced and leaf abscission and poorly branched plants occur (Conover, 1980). Plant density may also largely affect microclimate.

Most research mentioned above describes and in a few cases quantifies the effect of temperature, season and plant density on processes such as leaf unfolding rate or internode length in relation to the quality of the plant. However, the effects of these factors in relation to the quality features of *Ficus* as mentioned above are inadequately supported by quantitative data. The objective of the present study was to quantify the effect of season, temperature and plant density on growth and development of *Ficus benjamina* 'Exotica' in relation to the important quality features. The following strategy was adopted:

1. Identification and evaluation of the plant processes that contribute most to a description of plant quality (chapter 3).
2. Establish the influence of season, temperature and plant density on the plant processes selected in the first task.

To perform task 1 the dynamic behaviour of *Ficus* was registered under constant conditions using the quality features for *Ficus* as mentioned above. *Ficus benjamina* 'Exotica' was used as a pilot crop.

4.2   Material and methods

During the period 1991-1994, three experiments in duplicate were carried out with *Ficus benjamina* 'Exotica'. Experiments were performed in greenhouse compartments (Experiment 1 and 3) or in temperature controlled daylit chambers (Experiment 2). Two cuttings per pot were used as is common in practice. The cuttings originated from stock plants produced *in*

vitro. Rooting of this type of cuttings is faster and more uniform leading to a more homogeneous crop of better quality (Kristiansen, 1989; Kromwijk and Van Mourik, 1992) than cutting obtained *in vivo*. The cuttings were potted in an ebb-and-flood mix consisting of 15% perlite, 10% coarse white peat and 75% white peat, 3.25 kg lime, 0.75 kg 14N-7P-14.9K and trace elements as stock fertilisation m^{-3}. Plants were watered simultaneously as required with nutrient solution (EC 2.0 $mS.cm^{-1}$; pH 5.5) using an ebb- and- flow system (Experiment 1 and 3) or using irrigation matting (Experiment 2). The soil and the nutrient solution were regularly analysed to trace and adjust any deficiencies. CO_2 was not controlled. Plants were spaced at Leaf Area Index 3 which may be considered an appropriate value for maximum light interception (Goudriaan, 1990). LAI was measured with a light interception meter (Delta-t-Devices) and with occasional destructive measurements of leaf area. The cuttings were supported by a stick and a ring was attached every 15 cm. More general details of the three experiments are presented in table 4.1.

Table 4.1: Description of the treatments.

	Experiment 1	Experiment 2	Experiment 3
Experimental period	January'91 - September'91 October'91 - July'92	July'92 - September'92 August'92 - October'92	March'93 - July'93 December'93 - July'94
Growth facilities	2 greenhouse compartments	7 temperature controlled daylit chambers	1 greenhouse compartment
Temperature (°C)	20	17, 20, 23, 26, 29, 32, 35	20
Spacing schedule (plants/m^2)	$25 \rightarrow 10 \rightarrow 5$[1]	$48 \rightarrow 24 \rightarrow 12$[1]	48-48-48; 24-24-24; 12-12-12; $48 \rightarrow 24$-24; $24 \rightarrow 12$-12; $12 \rightarrow 6$- 6; 48-$\rightarrow 4 \rightarrow 12$; $24 \rightarrow 12 \rightarrow 6$; $12 \rightarrow 6 \rightarrow 3$.[1]
Pot size (cm)	24	14	14
Total plant height (incl. pot) (m)	1.20	0.60	0.60
Screening (W/m^2)	700	450	700
RH or vapour pressure deficit	60%	-	7g/kg a.m. and 4g/kg p.m.

[1] $\rightarrow$ = plants were spaced at Leaf Area Index 3; - = plants not spaced.

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Climate registration

The environmental conditions in all experiments were recorded every minute, averaged as ten minutes or hourly values, and logged. Temperature and humidity were measured centrally in the compartments 40 cm above-crop level with screened and aspirated PT-100 sensors (dry and wet bulb). In experiment 2 the microclimate among plants (dry- and wet bulb temperatures) was additionally registered per treatment using ventilated psychrometers containing Pt-100 sensors; to avoid air disturbance psychrometer type 2 was chosen (Stichting Technische Dienst voor de Landbouw, 1979).

Experiment 1: Growth pattern of *Ficus* under constant circumstances.

Every three weeks 30 cuttings (15 pots) per greenhouse were measured non-destructively and the following measurements were made:

a) length of the main shoot (cm)
b) number of leaves on the main shoot
c) total number of leaves up to a plant height of 60 cm (Experiment 1,2)
d) number of primary side shoots
e) number of secondary side shoots
f) length of every primary side shoot (cm)
g) position of every primary side shoot

In the replicate the measurements were accompanied with destructive measurements of 4 cuttings (2 pots) per greenhouse every three weeks:

h) leaf area of the main shoot, primary side shoots and secondary side shoots (cm^2)
i) length of the primary and secondary side shoots (cm)
j) position and length (cm) of each internode of the main shoot
k) position, length (cm), width (cm), leaf area (cm^2) of each leaf of the main shoot
l) of two random side shoots: the position of the primary side shoot and measurements of the internode and leaf as mentioned under j) and k).

The number of unfolded leaves on the main shoot and the primary side shoots were recorded weekly or every three weeks. A leaf was recorded when it had a length of ≥ 2 cm and a width of ≥ 1 cm. The leaf unfolding rate of the main shoot or the primary side shoot is defined as the

number of leaves unfolded per day. The plastochron, the time required to form a new leaf, is, by definition, the reciprocal of the leaf unfolding rate.

Experiment 2: Temperature

Every three weeks, the measurements a) to l) as mentioned above were made on four cuttings (2 pots) per compartment. At the end of the experiment additional measurements on 8 cuttings (4 pots) of features a) to e) and h) were made. Also the angle between primary side shoots and main shoot was determined for four cuttings per compartment (2 pots).

The temperature experiments were followed by a transport simulation of 0, 7 and 14 days in darkness at 17°C and 70% relative humidity. During post-harvest life, plants were watered using an ebb and flood system. The plants were placed in a conditioned room (20°C day and night temperature, 60% relative humidity and a light level of 3.0 W.m^{-2} photosynthetically active radiation). Post-harvest life was evaluated during 5 weeks by counting the number of leaves that had dropped and number of leaves showing necrosis.

Experiment 3: Plant density

Plants were placed at nine plant densities in duplicate in the greenhouse minimising variation in radiation among treatments. For eight plants (2 pots per plot) measurements a) to l) were destructively determined at the moment of spacing. During the last ten weeks of the first and second experiment the development of four plants per plant density of one plot were registered weekly by recording a), b), d), f) and m) the number of leaves on the 8th, 12th and 16th primary side shoot (only for the first experiment).

Statistical analysis

Data obtained from experiments 1 and 2 (the effects of season and temperature) were analysed using regression analysis. Linear and quadratic relationships were tested. The significance of these relationships was expressed as the percentage of variance explained (R^2_{adj}). The quadratic functions for the temperature effect on number of leaves, leaf area, number of secondary side shoots and the length of the primary side shoots also gave estimations for the optimum temperature. The relationship between length and temperature was analysed by applying mixed model analysis (REML) on the differences in length of the individual plants with the mean starting length. Data obtained from experiment 3 (the effect of

plant density) were subjected to an analysis of variance (ANOVA), including tests of pair-wise differences between the treatments. Differences were considered significant at a Student's t-probability <0.05.

4.3 Results

4.3.1 Growth pattern of *Ficus* (experiment 1)

The development of *Ficus benjamina* 'Exotica' shows a regular pattern. At plastochron age (P) of 4 leaves the plant has no primary side shoot (figure 4.1). When the fifth leaf on the main shoot is formed, a side shoot breaks on the first leaf axil (P=5), the fifth internode appears and the second side shoot is formed three positions lower (P=6), and so on. In summer as well as in winter this fixed pattern was found (figure 4.2). All buds on the main shoot sprouted.

P=4   P=5   P=6

Figure 4.1: Growth pattern *Ficus benjamina* 'Exotica'; P = Plastochron age.

The length of the internode depended on the position on the main axis. On the main shoot an increasing length of the internode with increasing internode position was observed (figure 4.3). The length increased until a stationary phase was reached. On the main shoot the stationary phase was eventually reached at about the tenth internode. The length of the internodes on the primary shoots followed the development observed on the main shoot (data not shown). The pattern of leaf length was essentially the same as that of internode length.

Figure 4.2: The number of leaves and primary side shoots of the main shoot of *Ficus benjamina* 'Exotica'.

Figure 4.3: The internode length versus position of *Ficus benjamina* 'Exotica' for 3 different spacing schedules starting with 12 pots per m^2.

4.3.2 Temperature

The keeping quality of the plants was not affected by the temperature treatments. The number of leaves that had dropped and leaves showing necrosis were insignificant. Leaves of plants

grown under higher temperatures were lighter and the stems were less woody than at lower temperatures.

Figure 4.4: The effect of temperature on the plant height (excluding height of pot) of *Ficus benjamina* 'Exotica'.

Total plant height

The effect of temperature on plant height (i.e. without pot) is presented in figure 4.4. Plant height increased as temperature increased to an optimum temperature of 29.5°C. The curve had a R^2_{adj} of 97.9%.

Plastochron –Fitting of the leaf unfolding rate (*LUR* in day^{-1}) to temperature (*T* in °C) at the prevailing light conditions according to equation (1) resulted in a R^2_{adj} of 73.7% (figure 4.5).

$$\log(LUR) = -6.58 + 0.3163 \times T - 0.00532 \times T^2 \qquad (R^2_{adj}\ of\ 73.7\%) \qquad (1)$$

The optimum temperature was about 30°C. *LUR* was more sensitive to temperature below than above the optimum temperature.

Internode length – There was no significant influence of temperature on the final size of internodes of the main stem. In both experiments the final size of the internode (stationary phase) was 3 cm.

Figure 4.5: The leaf unfolding rate in relation to temperature of *Ficus benjamina* 'Exotica'.

Figure 4.6: Effect of temperature on the angle between main stem and primary side shoot of *Ficus benjamina* 'Exotica'.

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Plant width

After the first 6 weeks the effect of temperature on the total length of the primary side shoots was not statistically significant. At the end of both experiments the effect was significant (table 4.1). The total length of the primary side shoots increased with temperature. 39.8°C is the optimum temperature for this variable. The angle between main shoot and primary side shoot decreased with increasing temperature (figure 4.6).

Density of the leaf mass

At the end of both experiments significant effects of temperature were found on the number of leaves, leaf area, number of the secondary side shoots and the total length of the primary side shoots (table 4.1). There was no strong relation between the number of leaves or length of primary side shoots and temperature. The optimum temperature for leaf area was 27.9°C, R^2_{adj} of the regression was 73.8%. Above 32°C the leaf area was visibly reduced.

Table 4.1: Regression analysis on the effect of temperature on different plant variables, expressed as percentage of explained variance (R^2_{adj}) by the selected quadratic regression model and the estimated optimum temperature (°C).

	Optimum temperature	R^2_{adj}
# leaves	27.3	37.9
Leaf area (cm^2)	27.9	73.8
# secondary side shoots	23.1	21.5
Length primary side shoots	39.8	45.0

4.3.3 Plant density

At the lowest plant densities (12-12-12; 12→6-6; 12→6→3) plants developed abnormally. After formation of the twelfth primary side shoot the following side shoots remained shorter. Differences between treatments developed after the first spacing of the plants.

Total plant height

The largest effect of plant density on plant height was observed when plants started to grow at a very high density i.e. combination 48-48-48 or 48→24-24 (table 4.2). At the end of the experiment plants were significantly longer than at lower densities. When the plants grew at a low density from the beginning i.e. combination 48→24→12 or different combinations of 24 or 12 pots per m^2, the effect of low density on plant height was less.

Table 4.2: Effect of plant density in pots per m^2 on length, number of leaves, leaf area of the primary and secondary side shoots and the total length of the primary side shoots. Different letters denote a significant difference at the 5% level.

Plant density (pots/m^2) [1]	Length (cm)	Primary side shoots			Secondary side shoots		
		Leaf area (cm^2)	Number of leaves	Total length side shoots (cm)	Leaf area (cm^2)	Number of leaves	Number of secondary side shoots
48-48-48	60.5 d	5114 a	461.0 a	214 a	138 a	20.5 a	1.5 a
48→24-24	59.1 cd	7153 b	588.5 b	274 b	1082 a	128.0 b	10.3 b
48→24→12	51.5 a	9168 cd	729.5 cd	325.8 c	2098 ab	253.5 c	23.0 c
24-24-24	58.6 cd	8616 c	700.0 c	319.8 c	1829 ab	219.0 c	10.0 ab
24→12-12	56.4 bcd	10036 de	719.0 cd	347.5 cd	3275 bc	336.0 d	27.5 cd
24→12→6	55.1 abc	9502 de	759.0 cde	385.6 d	5173 cd	461.5 e	33.7 de
12-12-12	55.9 abc	9745 de	779.0 def	342.5 c	4914 cd	496.5 e	28.5 cde
12→6-6	54.1 ab	10135 de	803.0 ef	352.4 cd	6593 d	713.5 f	36.2 e
12→6→3	52.4 ab	10410 e	834.5 f	337.0 c	6282 d	657.5 f	33.7 de

[1] → = plants were spaced at Leaf Area Index 3; - = plants not spaced.

Plastochron-In the period December-July the leaf unfolding rate of the main stem was lower (plastochron is higher) compared to conditions in the period March-July (table 4.3). At low plant density plastochron was higher than at high density. The effect in the period December-July was less. The mean value of the plastochron for all treatments in March to July was 7.7 days, in December to August 10.1 days.

Spacing had no significant effect on plastochron of the eighth and twelfth primary side shoot (Dijkshoorn-Dekker, 1995). At very low plant density the plastochron of the sixteenth primary side shoot was higher than at high density.

Table 4.3: The effect of plant density on leaf unfolding rate (leaf/week). Different letters in columns mean a significant difference at the 5% level.

Plant density (pots/m^2)[1]	Leaf unfolding rate (leaf/week)	
	March-July	December-July
48-48-48	0.967 c	0.785 de
48→24-24	0.971 c	0.815 e
48→24→12	0.942 bc	0.723 cde
24-24-24	0.977 c	0.677 bcd
24→12-12	0.977 c	0.679 bcd
24→12→6	0.861 ab	0.692 bcd
12-12-12	0.936 bc	0.668 abc
12→6-6	0.803 a	0.602 ab
12→6→3	0.789 a	0.561 a

[1] → = plants were spaced at Leaf Area Index 3; - = plants not spaced.

Internode length-In the stationary phase internode length on the main stem was 4 cm. The final size of the internodes at low plant density was (not significantly) smaller than at high plant density.

Plant width

The effects of plant density on the development of primary and secondary side shoots are presented in table 4.2. The total length of the primary side shoots as well as the number of secondary side shoots decreased at high plant density. The angle between the main stem and primary side shoot was independent of plant density.

Density of the leaf mass

In general the number of unfolded leaves and leaf area were larger at lower plant density (table 4.3). High plant density (different combinations of 48 pots per m^2) had a large effect on these variables e.g. 20.5 leaves for the 48-48-48 pots per m^2 compared to 253.5 leaves for the 48→24→12 pots per m^2. At low plant density (12 pots per m^2) the differences were smaller and no longer significant. The effect of plant density on the total length of the primary side shoots was comparable.

4.3.4 Season

<u>Total plant height</u>

Development of plants during summer and winter showed a constant pattern as described in the section 'growth pattern of *Ficus*' (experiment 1). In winter, from week 50 until week 4 no visible increase in length of the main stem and the primary side shoots was observed.

Plastochron-The plastochron depended on the outside light level (figure 4.7). Leaf unfolding rate (*LUR* in day^{-1}) was described as a function of daily global radiation (*R* in MJ.m^{-2}.day^{-1}) at 20 °C by equation 2 (R^2_{adj} 75.5%.).

$$LUR = (0.05014 + 0.005102 \times R) \hspace{3cm} (2)$$

As the average outside radiation over the last three weeks dropped below ±2 MJ.m^{-2}.day^{-1}, from week 50 until week 4, the leaf unfolding rate decreases and no visible new leaves were formed.

Figure 4.7: The leaf unfolding rate, air temperature and outside radiation (average of three weeks) in relation to season.

Internode length-Final internode length showed an abnormal pattern in the second experimental period with seasonal influence (Experiment 1) when compared to experiments with temperature and plant density. The final size of the internode located between position ten and fourteen in nearly every individual plant was reduced. From internode position eighteen internode length increased but unfortunately this phenomenon could not be confirmed in other experiments which were stopped at an earlier stage.

Plant width

Length of the primary side shoots was determined by the ambient light conditions, comparable to reaction of the main shoot. When the ambient light conditions were too low the development of the primary side shoot stopped. There were only eleven to thirteen developing primary side shoots at the same time.

4.4   Discussion

The shape of a *Ficus benjamina* 'Exotica' plant and therefore the external quality is mainly determined by the length of the main stem and the primary side shoots. The density of leaf mass is mostly determined by the length of the primary side shoots and the number of the secondary side shoots. In previous research of Dijkshoorn-Dekker it was found that these variables were strongly correlated with the number of unfolded leaves.

In *Ficus*, three leaves were unfolded on the main stem before a primary side shoot sprouted in the fourth leaf axil, counting from the top of the plant. This is also in agreement with architecture of fig tree found by Prosperi (personal communication). Also in apple, the number of growing primary side shoots was considered to be dependent on the number of unfolded leaves that had been formed on the main shoot (Lindhagen, 1996).

Mortensen and Larsen (1989) found that plant height of *Ficus benjamina* increased with day temperature up to 32°C (night temperature fixed at 21°C) or night temperature up to 32°C (day temperature fixed at 21°C). Day temperature had a stronger effect than night temperature on plant height. These results confirm our results. Increasing mean day and night temperature from 17 to 35°C showed that plant height increased to an optimum of 29.5°C which is outside the range covered by Mortensen and Larsen (1989). In the research of Mortensen and Larsen (1989) the realised mean temperature was not higher than 27.4°C. The effect of plant density on plant height is small, negligible for practice. Only at very high plant densities, which are never applied in practice, was the main stem significantly longer when compared to lower densities. This is probably due to the decreasing interception of light by the individual plants. The red light is mostly absorbed by the canopy. This means that the far-red radiation converted the reversible red/far-red receptor system (phytochrome) to the red-light absorbing

form which stimulated the elongation of the internodes. This tendency of increased plant height at higher plant densities was also observed by Poole and Conover (1988).

The relationship between rate of leaf formation and temperature can be described by a second degree polynomial with a clear optimum temperature with regard to leaf unfolding rate (Dale and Milthorpe, 1983). For *Ficus* within the temperature range 17 to 35°C a similar relationship was observed, with an optimum temperature at 30°C and a R^2_{adj} of 73.7%. Temperature had a strong influence on the leaf unfolding rate while light intensity had a minor effect, as also found for apple (Lindhagen, 1996). Leaf unfolding rate was strongly correlated with the outside light level. In winter the light level was the limiting factor for the development of shoot length. At very low plant densities, 12→6 or 12→6→3 pots per m², which are never applied in practice, the leaf unfolding rate dropped. At these densities more exposure of the individual plant to light led to more secondary side shoots and therefore more leaves. When the ambient light conditions were too low the development of the primary side shoot stopped. At densities of 12→6 or 12→6→3 pots per m², where exposure of the individual plant to light remained high, the first eleven to thirteen primary side shoots continued to develop during the whole experiment (data not shown). The high plastochron of the sixteenth primary side shoot found at these densities is probably due to competition between the younger formed side shoots and the first eleven to thirteen primary side shoots.

The final size of the internode followed the same pattern for all experimental conditions. The internode size increased with position number until a full equilibrium was obtained at internode position 10. Pieters (1974, 1999) found that the equilibrium values of the final internode size were related to radiation. At low light intensities the final internode size (stationary state) was smaller than at high radiation. This is in accordance with our results. The low light conditions during the temperature experiments led to a lower final size of the internode when compared to the density experiments where light conditions were higher. Involvement of other than environmental factors could explain the abnormal pattern of the internode length in obtaining the stationary state in experiment 1. Beside the low light conditions outside the greenhouse from start to half-way the experiment and spacing of the plants during the crop, limitations in the root environment could also play a role, according to Pieters (1974). With *Ficus* the final internode length was mainly influenced by light, temperature had no significant effect. Since temperature does have an important effect on plastochron this implies that this effect is fully compensated by the effect on growth rate: at high temperature plastochron is short and growth rate of the internode is high.

The width of the plant and the density of the leaf mass can be influenced by plant density. Growth of primary side shoots can be stopped by maintaining a higher plant density. Total length of the primary side shoots increased with temperature due to the higher leaf unfolding rate. The number of secondary side shoots is strongly influenced by plant density, but temperature had no effect on it. The availability of assimilates seems to be the driving

force for the number of secondary side shoots formed. The lower the plant density, the more exposure of the individual plant to light, resulting in a bigger supply of assimilates and more secondary side shoots. The outgrowth of primary branches in apple is promoted by an increased radiation (Lindhagen, 1996). Leaf area as well as the number of leaves were influenced by temperature and plant density. The stronger effect of plant density on the number of leaves when compared to the effect on temperature was explained by the higher number of secondary side shoots found at a lower plant density. Except for temperatures ≥ 32°C and extremely low (12, 6 or 3 pots per m^2) or high (48 pots per m^2) plant densities it can be concluded that the visual and internal quality of *Ficus* was unaffected. For temperature this is confirmed by the study of Mortensen and Larsen (1989).

In this study a link has successfully been made between the important quality criteria of *Ficus benjamina* 'Exotica' and development under different climatic conditions. The relationships found can be used to provide insight in crop management on pot plant nurseries when controlling plant growth and production of a predetermined marketable product. Different approaches for modelling the development of *Ficus benjamina* 'Exotica' could be chosen. Models could be based on the interactive growth patterns of the phytomeres that describe plant architecture (Challa, 1997). The plant can be considered as being built up of a series of basically identical phytomeres, differing only in size. Once a phytomere is initiated, its final length is not influenced by temperature and radiation (Pieters, 1999). This mechanistic model is based on assumptions made by trying to understand the behaviour of the individual components of the system and their interactions with one another (Thornley 1976, Thornley and Johnsson, 1990). Due to the complexity of this mechanistic model implementation in practice is not that simple. As the production of uniform crops of a preferred quality will improve the position of ornamental horticulture, an alternative simple and directly applicable model is a must. Such a model will be mainly empirical and could be based on increase in length linked with important quality criteria, where plant processes as plastochron and internode length under different tested climate conditions play an important role. Finally the grower could use this tool to control plant development using temperature and plant density in relation to outside light level.

Acknowledgements

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Chapter 5

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A simple model to control visual quality of *Ficus*

Dijkshoorn-Dekker, M.W.C. and Challa, H., 2002. A simple model to control visual quality of Ficus.

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Abstract

Temperature, plant density and season are important factors to affect visual quality of *Ficus benjamina* 'Exotica'. Visual quality is characterised by plant height, plant width and density of leaf mass in the relevant layers of the plant. A conceptual model was presented to simulate development of these quality attributes in relation to temperature, spacing and daily radiation.

Because this model was considered too complex for practical use, it was simplified. External quality could satisfactorily be described by only two attributes, plant height and plant width. Density of leaf mass, also an important quality attribute, strongly correlated with plant width. Plant height is determined by the average internode length and the number of internodes (plastochron age), which was described as a function of temperature and light. Plant height was adequately predicted by the simple model, and plant width could interactively be controlled by spacing operations, using first leaf area index and finally plant width as criteria. These plant features were monitored by image processing. The model worked satisfactorily.

5.1 Introduction

During the last decade, due to increased competition, there has been a clear transition from a producers market towards a consumers market. This changing market situation is forcing growers of horticultural crops to organise their production in line with the production chain, which implies that growers have to deliver a well-defined product at the right moment. For such a chain oriented production organisation there are a number of problems to be solved. The required product should be defined in terms of product attributes, and then a production scheme and control procedure should be obtained to ensure that, under the given conditions and with the specified starting material and the production system of a given grower, the target product is produced at the right time.

Growers usually apply fixed cultivation schedules for a particular situation. These schemes are based on publications and recommendations, and are further influenced by the own experience and tradition of the grower. In practice there are, however, good reasons to deviate from these schedules. Product specifications may differ, the starting material may be different, or consisting of different batches with distinct properties, the weather conditions may have caused delays, or advances in development, or the market may demand for products that were not scheduled at the required harvesting time. All these situations may force a grower to adjust the cultivation schedule to meet the requirements of the market.

Theoretically, to solve this problem there is a need to define quality in an objective, quantitative way, specifying product attributes that determine (external) product quality. Next,

a relation has to be established between growth and development of the crop, more specifically of the quality attributes, and the external factors. Once this relationship has been established and formalised in a crop growth model, it is possible to make predictions, which could be used to control growth and development such that the quality and time requirements are met.

It is, however, not easy to model quality of horticultural products and there are a number of bottlenecks, which create in particular challenges with ornamentals (Van Meeteren, 1998). Different models of aspects of external quality in relation to the cultivation of greenhouse crops have been described. Examples are models predicting plant height and branching (e.g. Adams et al., 1996; Fischer and Heins, 1996), flowering/harvesting time (e.g. Fischer et al., 1996). However, these models do not cover external quality, but only one, or in the best case two quality attributes, ignoring others.

In a previous study it has been shown that, indeed, external quality of ornamentals can be mathematically defined. In that study a model, used in the food industry to describe and quantify quality as a complex feature, was revised to obtain a suitable description of visual quality of ornamental crops, based on the major quality attributes (chapter 2 and 3).

To obtain such a specified product at a specified moment requires detailed models. Challa (1999) discussed the feasibility of using advanced, photosynthesis driven models (Gijzen et al., 1998) for greenhouse management support. Modelling of aspects, such as plant architecture, the flowering process, water relations, ion uptake etc. could benefit from the knowledge that is represented within the photosynthesis model. Such enhanced photosynthesis models, at least in theory, could provide valuable information for the grower, including quality aspects.

Although crop growth models have been developed for horticulture, growers hardly have used them. This is partly due to limitations in current crop growth models (Challa and Heuvelink, 1996), but also to a more general problem of incorporating scientific knowledge into commercial software. In sophisticated mechanistic models a large number of processes are described in considerable detail, whereas the grower is only interested in those parameters that are specific for the problems of the grower e.g. timing of the harvest and amount and quality of the produce (Challa, 1999). In the past most crop models have focused primarily on growth (i.e. accumulation of biomass), generally attempting to predict final yield or to simulate progress of the system towards final yield. In horticulture biomass is frequently only one component of yield whereas crop timing and morphology may be of equal, if not greater, importance, particularly when considering ornamental crops (Lieth and Koning, 1998). The complexity of these mechanistic models makes implementation in practice difficult. An alternative simple and directly applicable model for controlling crop development, based on those factors, which have the largest impact on development of the crop, will stimulate implementation in practice.

This study therefore focuses on the development of a simple model to control growth and development of pot plants by temperature and plant spacing in relation to natural light, thereby focusing on the major external quality features. *Ficus benjamina* 'Exotica' was used as a pilot crop; a year-round crop where uniform batches and mechanisation are already of importance. The crop does not have the added complication of flowering. The main task was structured along the following subtasks:

1. Matching of the main plant quality determinants with possible model output
2. Set-up of a conceptual model relating temperature and plant spacing to the required output
3. Description of a simplified model for the case of *Ficus benjamina* 'Exotica'
4. Test of the model

5.2   Model development

5.2.1   Matching of main plant quality determinants

A mathematical model to define visual quality of *Ficus benjamina* 'Exotica' on the basis of image processing techniques was described in chapters 2 and 3. Images of *Ficus* plants were recorded in four positions and processed (Dijkshoorn-Dekker and Eveleens, 1999). To this end the plant was projected on a window of 100 cm high, the lower border coinciding with the rim of the pot. The window was divided into five horizontally joined split-windows, each 20 centimetres high, numbered from above from 1 to 5. The model was able to explain visual quality of 1.20 m height *Ficus benjamina* 'Exotica' for 88.7%. The most important variables were the density of the leaf mass in the third layer of the front-view; the width in the third layer of the side-view; the width of the front-view of the fourth and fifth layer (chapter 3).

To translate all these complex features into a growth model would require a full account of the three dimensional development of the plant, including a description of the first and second order side shoots. Also the phyllotaxis, the angle of insertion between the main axis and the first order side shoots, and bending of these shoots would have to be considered, to account for the shape and contours of the plant. This type of models have been developed by De Reffye et al. (1998), but the amount of data and work required to develop such a model for a new crop are prohibitive in this context. Therefore we aimed at a much simpler approach, based on the phytomere approach described in chapter 4. The inputs to be considered were the control measures, temperature and plant spacing, and the disturbances (factors we cannot control), seasonal and day-to-day variations in radiation.

5.2.2   A conceptual model

The frame of the solid of revolution making up the contours of the plant can be described on the basis of a phytomere model. A full description of the effects of temperature, radiation and spacing on growth and development of *Ficus benjamina* 'Exotica' has been given elsewhere (chapter 4). Plastochron (reciprocal of the leaf unfolding rate), internode length, branching and termination of growth of shoots are the essential plant characteristics that have to be described to generate the required output.

The model describes the development of *Ficus* as a vertical and lateral accumulation of internodes, where after each plastochron the length of the main stem and of the side shoots is increased by the length of one internode. For the main stem this process continues, but the side shoots stop growing when the local radiation levels drops below a certain threshold value (chapter 4). A relational diagram of growth of *Ficus* is presented in figure 5.1.

Figure 5.1: A relational diagram of growth of the main shoot (ms) of *Ficus benjamina* 'Exotica'. Boxes are state variables and circles are parameters. Solid lines represent carbon flow and dashed lines represent information flow. The same diagramme also applies to the side shoots, the difference is that the plastochron stops increasing, when the local radiation is below a critical level.

Plant height

Plant height (H) is described by

$$H = (PA_t - PA_0) \times \overline{I_{ms}} + H_0 \tag{1}$$

where PA_t is plastochron age expressed by the number of leaves at time t, PA_0 the plastochron age at planting (time $t = 0$), H_0 the height at planting and $\overline{I_{ms}}$ is the average internode length of the main shoot. The increase in plastochron age, by definition, is a function of the (average) leaf unfolding rate $\overline{(LUR)}$ and time t.

$$PA_t = \overline{LUR} \times (t - t_0) + PA_0 \tag{2}$$

LUR is a function of temperature (T) and daily light integral (R) (chapter 4) and can be described as:

$$LUR = f_R \times f_T \tag{3}$$

where LUR is expressed as the number of leaves formed per day and f_T is the relative effect of temperature on leaf unfolding rate compared to the leaf unfolding rate at 20 °C.

f_R, equal to LUR at 20 °C, is a linear function of the daily radiation integral R:

$$f_R = (0.05014 + 0.005102 \times R) \qquad (R^2_{adj} \text{ of } 75.5\%) \tag{4}$$

where R is the daily light integral in MJ.m^{-2}.day^{-1}. The effect of temperature (in °C) on LUR can be described according to Dale and Milthorpe (1983) and Dijkshoorn-Dekker (chapter 4)

$$f_T = \exp(-6.58 + 0.3163 \times T - 0.00532 \times T^2) / f_{20} \qquad (R^2_{adj} \text{ of } 73.7\%) \tag{5}$$

where f_{20} is 0.092.

The final size of internodes at different positions always showed the same pattern (chapter 4). The length of an internode increased with position number until a full equilibrium was reached at internode position 10. Within certain constraints the final length of the internode was not influenced by season, temperature and plant density. Only at very low light levels or very close plant spacing, not applied in practice, internode length was affected. At the start of

the crop cuttings already had 5 to 7 fully formed internodes. The contribution of the next 3 to 5 internodes to total plant height (120 cm, including height of the pot of 19 cm) is therefore negligible. $\overline{I_{ms}}$ (average internode length in equation 1) was 3.47 cm through different seasons (chapter 4, experiment 1).

Plant width

Growth of the side shoots can be described analoguous to the description of the main shoot. A side shoot sprouts from a given phytomere when its plastochron age is 4. Length of a side shoot L_n at phytomere n of the main shoot is then described by

$$L_n = PA_n \times \overline{I_{ss}} \tag{6}$$

where PA_n is the plastochron age of phytomere n and $\overline{I_{ss}}$ is the mean internode length of the side shoot. We assume that the development of a side shoot (PA_{max}) stops when the local daily light integral (R_n) at the top of the side shoot is too low.

$$PA_{\max} = f(R_n) \tag{7}$$

Plant width W_h at height h can then be derived from equation (7) according to a transformation factor F, which takes bending and the angle of insertion in the main shoot into account.

Density of leaf mass

Density of leaf mass is defined as the leaf area per unit of volume of the solid of revolution representing the plant. To obtain this figure the total leaf area of the plant should be predicted. There are several approaches to model leaf area. Here we will follow the phytomere approach, assuming that leaves have the same average area $\overline{A}$. Because the total number of phytomeres on the main and first order side shoots is defined by the previous account, also the total leaf area on the main and first order side shoots is known:

$$LA_p = \sum PA \times \overline{A} \tag{8}$$

where LA_p is the total leaf area on the main and first order side shoots of the plant. Leaf length and corresponding leaf width showed the same pattern as found for the internode length. The

length of the leaf increased with position number of the internode until a full equilibrium is obtained. Maximum leaf length is reached at a very early stage of the crop when compared to the final total amount of leaves. Therefore an average leaf area ($\overline{A}$) is used to calculate the density of leaf mass. It is assumed that the leaf area on the secondary side shoots and therefore the total leaf area is proportional to LA_p and that in this phase there is no loss of leaves.

5.2.3   Simplification of the model for *Ficus*

The model described above, in spite of simplifications and assumptions that were made, is rather complex and requires quite a number of parameters. Especially modelling of plant width and leaf area is not simple. The local daily light integral (R_n) at the level of individual side shoots is difficult to asses (data not shown) and the relation with termination of growth of a side shoot is not well established. Moreover, to predict plant width and leaf mass at a specific height, the orientation of every shoot in the xyz-direction is required. For the density of leaf mass the PA of all the shoots including the secondary shoots is important.

Therefore we tried to find a way around this problem. A solution was found by considering the effect of the two control factors, temperature and plant spacing separately in relation to the plant features to be controlled. In fact, plant height (development of the main shoot) is mainly influenced by temperature, whereas plant width and corresponding density of leaf mass, is mainly determined by plant density. Therefore the model only had to describe growth in plant height, whereas plant width could be controlled interactively during spacing. The following strategy was applied. Plants were spaced when Leaf Area Index (LAI) ≥ 3, which may be considered an appropriate value for optimum light interception (Goudriaan, 1990). Each spacing the number of plants per m^2 was reduced by half, when LAI was above 3, maintaining a minimum number of 3 plants per m^2, and until the target plant width had been reached.

5.2.4   Experimental validation

An independent data set was used to validate the model. Experiments with uniform half-grown material of growers were conducted from week number 42 of 1996 till week 14 of 1997 (Dijkshoorn-Dekker and Meuleman, 2000). The target quality attributes of the marketable product are represented in figure 5.3. The target leaf area was 1.5 m^2 and the target height 1.20 m. Experiments were performed in greenhouse compartments. Plants were watered simultaneously as needed with nutrient solution (EC 2.0 mS.cm^{-1}; pH 5.5) using an

ebb- and flow system. CO_2 was not controlled. Relative Humidity was kept on 60% and sun screens were closed at 700 W.m^{-2} global radiation. Plants were spaced at Leaf Area Index 3. LAI was determined using image processing. Temperature was controlled according to the model.

The environmental conditions were recorded every minute, averaged as ten minutes or hourly values, and filed. Temperature and humidity were measured centrally in the compartments 40 cm above-crop level with screened and aspirated PT-100 sensors (dry and wet bulb). The model was tested using determined plant features of the half-grown material, collected daily average temperature and natural daily light sum from the experiment, both averaged per week. Every three weeks plant features such as object area, width and plant height were obtained from four positions using image processing (Dijkshoorn-Dekker and Eveleens-Clark, 1999; Meuleman et al., 1998). Model predictions were compared with results obtained by image processing.

Figure 5.2: Test of the model, comparing observed and simulated height of the plant.

Agreement between observed and simulated plant height and width was relatively good (figure 5.2 and 5.3). In winter, when light levels were low, temperature had to be < 24°C to avoid steep branches and related quality loss. In summer the control over plant height was limited at high outdoor temperatures; in this case only spacing of plants may reduce increase in height. There was no significant difference between the target and the actual plant width

(p<0.05). In this case cultivation started at a plant density of 5 pots per m^2 and ended with 3 pots per m^2.

Figure 5.3: Development of plant width of *Ficus* interactively controlled during spacing.
The open symbols denote the target width of each 20 cm layer measured from pot rim, the closed symbols the actual plant width.

5.3 Discussion

In this study we have indicated how visual quality of *Ficus benjamina* 'Exotica' pot plants could be modelled, based on studies on developmental processes in this species. Implementation of the model was successful. Two other major visual quality criteria, plant width and leaf density proved to be too complex and hence too laborious to model for the purpose of quality control. We found a way around when we noticed that the two control instruments, temperature and spacing had a distinct effect on visual quality. Temperature affected only the leaf unfolding rate (LUR) of *Ficus benjamina* and not the length of internodes. Of course temperature affects also the growth of side shoots, but the critical factor here is termination of growth, which is essentially controlled by spacing of the plants. Therefore, within this context, we could focus the model on plant height.

In this way the model was kept simple and plant width and the related density of leaf mass were successfully controlled without a model, using image processing. A disadvantage

of this approach is that during cultivation more frequent monitoring and hence transportation of plants is necessary to determine the right moment of spacing.

Due to the simplicity of the model, implementation could be relatively easy, especially as growers are interested in a tool to control the timing of the harvest and the quality of the produce. Extensions of the model with other features, e.g. temperature integration (Buwalda et al., 1999) may be easily accepted in practice, following successful introduction of the basic model in practice. From literature it is known that simple methods, e.g. graphical tracking (CARE-system, Fischer and Heins, 1996) and models (Lieth, 1999) find their way to practice quicker than complex methods and models, e.g. models for operational management in pot plant production (Leutscher, 1995) or greenhouse climate management (Henten, 1994). A comprehensive, mechanistic model would not only describe plant responses, but also give some degree of explanation. Complex mechanistic models, however, have a tendency of becoming inaccurate if they contain a multitude of sub-models (Larsen, 1990) and understanding is not always necessary to adequately control plant development (Larsen, 1990).

The model structure used in this study may be transferred to some other foliage plants, but the concomitant adaptation of the model may still be laborious if data are not available. Parameters have to be estimated for every cultivar and predictions have to be validated, which is fairly time consuming and hence very expensive. Neural nets could possibly be a suitable and powerful additional tool for modelling plant growth and development. From literature it is known that a supervised neural network was able to grade plants in half-grown stage in relation to the quality of the marketable product (Meuleman et al., 1998). The neural network was able to follow and to predict the development of plant features in time. Neural nets (a black-box model) could describe in a more flexible way some of the less well understood parts of the system, while output from explanatory models could enhance this process (J. Meuleman, pers.comm.; Challa, 1999). In further research data collected by the grower could be used to train a neural net. This could provide a faster and less time-consuming method to build systems to control quality of different crops.

Acknowledgements

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Chapter 6

Introduction of a prototype of the Crop Quality Control System

Abstract

Control of plant development is a major challenge in commercial pot plant production. The Crop Quality Control System (CQCS) provides a new tool in the production process to meet the demand of the market to deliver an uniform product with a preferred quality on a specified delivery date. This system integrates a model for visual quality, a crop growth control model, image processing to monitor crop development and a neural net work to grade plants. CQCS has been successfully developed and tested at the Research Station in Aalsmeer (The Netherlands) in 1997 using *Ficus benjamina* 'Exotica' as a pilot crop. Image processing is used as a measuring technique to register plant development. Image features are used as an adequate input for the neural network and the crop growth control model included in the system. Application of this system reduces labour costs and facilitates the complete automation of internal transport, spacing, grading and marketing.

A prototype was used at commercial companies in The Netherlands. Two batches of half-grown *Ficus* plants were formed, a control batch to be controlled by the grower and an experimental batch to be controlled by CQCS. The neural network graded the experimental batch into uniform groups. Each uniform group was subjected to a different spacing schedule and temperature regime as determined by the crop growth control model. At the specified delivery date, visual quality was more uniform in the experimental groups, than in the control batch. However not all experimental groups had reached the marketable stage and therefore they could not be combined into one uniform batch. Although the crop growth control model can accurately predict the visual quality for each group to the specified delivery date, this was not achieved due to the inflexibility of the present logistics and inadequate facilities on the nurseries.

6.1   Introduction

The market is becoming increasingly important in dictating the demands on production. Taking this into account the position of ornamental horticulture can be strengthened by producing uniform batches of pot plants with preferred quality. Current production methods tend to result in marketable products with a large variation in external plant features. Growers are being forced to control growth to a predetermined marketable product, which is very difficult. The Crop Quality Control System (CQCS) provides a new tool for the grower in the production process to meet the demands of the market. The system integrates four functional modules namely the model for visual quality (chapter 2 and 3), the crop growth control model (chapter 5), image processing to monitor crop development and a neural network to grade plants. It enables a grower to deliver an uniform product with a preferred quality on a

specified delivery date. In 1997 CQCS has been successfully developed and tested at the Research Station in Aalsmeer (The Netherlands) (Dijkshoorn-Dekker and Meuleman, 2000). *Ficus benjamina* 'Exotica' was used as a pilot crop.

A model for visual quality is used to specify quality attributes (chapter 2 and 3). Image processing is used as a good measuring technique for monitoring plant development both at the start and during the growth of the crop (Dijkshoorn-Dekker, 1999). A special program has been developed for the segmentation of the images and extraction of plant features. These features are used as an adequate input for the neural network and the crop growth control model (Dijkshoorn-Dekker, 1999; Meuleman et al., 1998). An unsupervised neural network is used to grade the plants, if variation within a batch is too large (Van Kaam, 1997; Meuleman et al., 1998). For crop control, the crop growth control model has been developed for *Ficus benjamina* (Dijkshoorn-Dekker, 1995; chapter 5). The development rate was mainly affected by temperature, while plant density was critical for external plant features such as plant width.

The objective of this study was to test CQCS at the commercial companies using *Ficus benjamina* as a pilot crop. In this paper the results from one company are presented.

6.2   Material and methods

A prototype of CQCS was tested at a commercial company in The Netherlands using *Ficus benjamina* 'Exotica'. A batch of 1200 half-grown plants was allocated to two treatments: one group was controlled using the system, the other group by the grower. At the start of the experiment the delivery date and the marketable quality were determined. At delivery date the final plant height was determined at 1.02 meter excluding height of the pot. The control factors were temperature, plant density and season (not under control). All the other factors such as relative humidity and irrigation were kept optimal during cultivation.

6.2.1   Image processing

At the start of the experiment plant features of each plant were recorded from four positions using image processing. Every three weeks during the cultivation period a sample of 25 plants was taken from each batch to record plant features. A special chamber was designed to provide uniform illumination of the plants. A front lighting system was used such that coloured images could be made. Sunlight and other sources were eliminated by placing plant and camera in an almost closed dark environment. The background of the chamber was blue instead of red, which was used in previous research (Dijkshoorn-Dekker, 1999). Blue

provided a better segmentation between the plant and the background. The distance between the camera lens and the plant was chosen in such a way that the relative error of the recorded images was less than or equal to 5%. The images were grabbed using a camera (Sony 930DXC-P) in combination with a Matrox Comet frame grabber. A specially developed program was used for segmentation of the images and to extract more than 80 plant features such as plant height, object area and convex hull (Meuleman et al., 1998). A selection of these features was used by the neural network and the crop growth control model (Dijkshoorn-Dekker, 1995).

6.2.2 The neural network

Instead of the supervised neural network used in previous research (Dijkshoorn-Dekker and Meuleman, 2000) an unsupervised neural network was realised for grading the plants into growth groups (Dijkshoorn-Dekker, 1999). This in such a way that differences in feature values between the groups are maximised and within the groups are minimised.

6.2.3 Crop control

To control the crop during the cultivation period a crop growth control model was used to determine a relevant strategy for each uniform batch (Dijkshoorn-Dekker, 1995; chapter 5). The model uses greenhouse temperature, radiation and density as input variables. The experiment started in week 4, 1998. The predetermined delivery week was week 24, 1998.

6.3   Results

6.3.1   Uniformity of the batch

The neural network was able to grade the batch to be controlled by CQCS into three uniform CQCS-groups. Several plant features were responsible for the grading such as plant height, convexhull area, convexhull perimeter. Figure 6.1, 6.2 and 6.3 illustrate the uniformity of the batches by presenting these plant features in so-called box plots. 50 Percent of the data is represented by the box. The line above the box indicates the maximum value of the data, the line below the box the minimum. It is clear that the CQCS-groups show more uniformity compared with the batch of the grower. The maximum and minimum values are closer

together and 50% of the data lies within a smaller range. The grower did not decide to grade his batch.

At the end of the cultivation period the CQCS-groups were much more uniform then the grower's batch. The grower's batch had to be marketed over a period of five weeks, whereas for each uniform CQCS-groups only one week was required.

Figure 6.1: Boxplot of the plant feature: plant height.

Figure 6.2: Boxplot of the plant feature: convexhull area.

Figure 6.3: Boxplot of the plant feature: convexhull perimeter.

6.3.2 Control of crop development

A temperature increase was necessary to obtain the marketable product in the week stated. However, in winter the maximum increase in temperature was limited due to the capacity of the heating system and the low light level. At the commercial company it was difficult in winter to realise temperatures above 22 °C. Spacing of the plants could only take place as production area was available. In practice the area required to space some batches was not available at the recommended time.

Figure 6.4 shows the control of plant height of the half-grown plants from one CQCS-group up to the predefined delivery date. The plant height at the beginning of the experiment was 38 cm. The diamond on the right marks the target height and delivery date defined by the grower. Using the crop growth control model, the final date, week 24, was reached. The plant heights recorded by image processing closely follow the curve, except one. In week 13 plants were not adequately secured to the stick which lead to an underestimation of plant height. The control of plant height from the half-grown plants of another CQCS-group up to the marketable product is presented in figure 6.5. Also in this figure the diamond on the right marks the delivery date defined by the grower. By using the crop growth control model, the final date, week 24, was not reached. Following the strategy for this group high temperatures of 24,5 °C were necessary to obtain the marketable product. In winter it was difficult to realise these temperatures. The grower was aware of this at the start of the experiment and another delivery date was chosen.

Figure 6.4: Plant height of CQCS group 3 as controlled by the crop growth control model.

Figure 6.5: Plant height of CQCS group 1 as controlled by the crop growth control model.

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The control of plant width of one of the CQCS-groups is shown in figure 6.6. The plant was projected on a window of 100 cm high, the lower border coinciding with the rim of the pot. The window was divided into five horizontally joined split-windows, each 20 centimetres high, numbered from above from 1 to 5. The preferred width at delivery date is denoted by open symbols. The figure shows that the preferred quality is achieved for all layers.

Figure 6.6: Development of plant width interactively controlled during spacing:
- layer is 20 cm thick; measured from pot edge
- open symbols denote preferred quality of each layer

6.4   Discussion

The unsupervised neural network is able to correctly grade batches into uniform groups. The boxplots of the plant features plant height, convexhull and convexhull perimeter show that grading creates batches (CQCS-groups) that are much more uniform when compared to the ungraded batch of the grower. In previous research CQCS used a supervised neural network (Dijkshoorn-Dekker and Meuleman, 2000). This network was obtained by using known input-output relationships and was based on potential quality of the plants. Such a network was not completely adequate in grading half-grown material; the network needed a reference batch that resembles the new half-grown material to enable it to grade meaningfully. Such a batch is difficult to find. The unsupervised neural network in this present study has the advantage that

for realising such a network no reference is required, no human expert, nor data from previous experiments. The batch of plants itself is used to create this network.

The implementation of CQCS at the commercial companies was successful. The predictive capacity of the crop growth control model is also very good and the frequency of image processing can therefore be reduced. The segmentation of the images and the extraction of the plant features were performed accurately. The plant features formed an adequate input for the neural network and the crop growth control model. Only the plant feature plant height formed an exception if plants were not regularly secured to the stick. Especially at the start of a cultivation period underestimation of plant height will result in a wrong strategy for controlling development to a predetermined marketable product.

At the end of the cultivation period the grower was not able to deliver the predetermined marketable product: uniform with preferred quality at a predefined delivery date. The CQCS-groups could meet this demand. Due to the heterogeneity, the grower's batch needed a marketing period of five weeks instead of the one week needed for the uniform CQCS-groups.

During the practical experiments implementation was limited by several restraints. Implementation of such systems requires insight into climate control. At the commercial company the capacity of the heating system was insufficient for applying required temperature set-points. Other requirements for implementation are careful planning of production area and labour and sufficient capacity of internal transport systems. Implementation requires also more than one suitable temperature controlled compartment. In practice it was clear that one CQCS-group can easily be controlled to the predetermined marketable product, whereas it was more difficult to control three different uniform CQCS-groups to one single uniform marketable product due to the restrictions already mentioned.

In general, during implementation of CQCS the grower will learn from the system and will gain insight into further optimisation. Complete implementation of the system will facilitate automation of internal transport, spacing, grading and marketing due to the uniformity of the batches. It also reduces labour costs due to automation, optimises space utilisation and makes production on demand possible.

Conclusions

It can be concluded that implementation of the Crop Quality Control System enables growers to meet the demand of the market to deliver a product with a preferred quality on a specified delivery date. Implementation of the system at commercial companies was successful. The added value and success of CQCS in the commercial production of pot plants increases as restrictions for example in climate control and logistics are minimised.

Acknowledgements

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Chapter 7

General discussion

7.   General discussion

The system described in this thesis is an integration of four functional modules as mentioned in the introduction namely the model for visual quality, the crop growth control model, image processing for monitoring crop development and a neural net work to grade plants. The theoretical framework of quality modelling used in the food industry was successfully implemented within the domain of pot plants (chapter 2 and 3). The selected quality attributes for *Ficus benjamina* (chapter 3) could be controlled by temperature and plant density taking season into account (chapter 4). Finally this resulted in a good functioning system for quality control (Crop Quality Control System; chapter 5 and 6).

Section 1.2 describes the basic requirements of the system, namely:

- The total visual quality of the marketable product must be objectively defined.
- Data collection of quality features must be accurate to make control of these features possible.
- Data acquisition must not be laborious.
- The marketable product has to be uniform with a defined quality at the specified delivery date.

Considering these requirements, it may be questioned to what extent the objective of this study has been reached within the domain described above and to what extent this system differs from other systems mentioned in the general introduction? To answer these questions the strategy of the Crop Quality Control System (CQCS) is evaluated (section 7.1).

The CQCS in this thesis was developed for foliage plants using *Ficus benjamina* 'Exotica' as a pilot crop. It may be questioned to what extent this system can be generalised for other foliage plants, and whether there are any limitations. Furthermore, one would like to know whether CQCS offers perspectives for use with flowering pot plants (section 7.2).

Introducing CQCS at a nursery has many consequences and therefore limitations for its implementation will be considered (section 7.3). Introduction of CQCS may also affect the relations within the whole chain of events, from producer till consumer, which therefore need to be considered (section 7.4).

7.1   Evaluation of the system to control external quality

A system like CQCS is new and has not yet been described in literature. However, a few decision support systems (DSS)s for quality control have been developed. As mentioned in the introduction, examples of such DSSs are the greenhouse CARE-system (Fischer and

Heins, 1996) and a system developed by Adams et al. (1996). The objectives of the greenhouse CARE-system of Fischer and Heins (1996) are to some extent comparable with the CQCS developed and described in this study. To facilitate discussion the most important differences between both CQCS and the CARE system are presented in an overview (table 7.1).

Table 7.1: Differences between the greenhouse CARE-system and the Crop Quality Control System (CQCS).

Elements of a system for quality control	CQCS of this thesis	The greenhouse CARE-system
1. Definition of quality	- Integrated	- One attribute
2. Monitoring crop development	- Integrated	- One attribute
	- Automatically (Image processing)	- Manual (ruler)
3. Crop growth/development control model		
a. Input variables	a. Temperature, radiation and Density	a. Temperature, growth retardant
b. Approach	b. Model-based control	b. Graphical tracking
c. Target	c. Quality and delivery date	c. Plant height and delivery date
4. Grading	Yes	No

The target quality must first be defined before crop control is feasible. It must be clear what quality attributes are important and whether these quality attributes are suitable for direct or indirect control. Both systems differ in approach. The CQCS assesses integrated external quality and uses a model to describe and quantify it, whereas the greenhouse CARE system only focuses on target height. The visual quality model of CQCS uses five important variables to define quality, namely: total plant height, density of leaf mass in the third layer of the front-view; the width in the third layer of the side-view; the width of the front-view of the fourth and fifth layer (chapter 3). Although quality was defined on the basis of these five features it could finally be described satisfactorily by only two attributes namely total plant height and plant width. Density of leaf mass, also mentioned as an important quality attribute, strongly correlates with plant width (chapter 4). In the case of *Ficus* CQCS appears to be rather similar to CARE (Fischer and Heins, 1996).

Considering the process of monitoring crop development, the input of the greenhouse CARE-system is plant height. It is measured twice a week by hand, which is simple but quite

laborious. In CQCS only image processing is successfully used as a powerful and accurate sensor for monitoring crop development. More attributes which are necessary to support the CQCS in grading or controlling actions can be measured simultaneously. Advantages of image processing are the ease (low cost) of data collection and the availability of more attributes for further processing. This enables integrated quality control. Plant width, for example, was successfully controlled by spacing operations, using image processing to monitor this crop feature.

One of the objectives of this study was to control the two most important quality attributes, total plant height and plant width, using an integrated crop growth control model (chapter 4). Modelling plant width, however, appeared to be quite laborious and its control was therefore not based on a model but on crop monitoring. Height control of the CQCS is comparable to that in the CARE system, but the approach is different. CARE is based on graphical tracking, where deviations from a target curve are locally corrected by temperature and growth retardants. CQCS instead, knowing the initial plant height, the target plant height and the delivery date, calculates the required average temperature which is then used to determine a temperature regime.

An important improvement of CQCS with respect to CARE is its ability to obtain a uniform product, which is a quite relevant quality attribute of a batch (section 7.3). CQCS has successfully been tested in a large-scale experiment with *Ficus benjamina* 'Exotica' (Dijkshoorn-Dekker and Meuleman, 2000). In this experiment half-grown plants were used as starting material. Plants were graded into three groups using a neural network and were grown to 1.20 m with three different temperature and spacing regimes. In this way the final quality and specified delivery date requirements were met.

7.2   The transferability of the CQCS to other pot plants

A large and rapidly expanding and changing assortment characterises the pot plant industry today. The aim of this thesis was to develop a generic approach for visual quality control of pot plants. To control crop development of pot plants to a preferred quality the first prerequisite is specification of the quality attributes of a given pot plant. To obtain this defined visual quality, study of the growth and development of this pot plant within a range of temperatures and at various plant densities is required. The system for quality control in this thesis was developed for *Ficus benjamina* 'Exotica'. It may be questioned whether this system can be used for other foliage plants. This question will be tackled using the four functional modules as a basis.

Each functional module of the system, the model for visual quality, the crop growth control model, image processing for monitoring crop development and a neural net work to

grade plants, consists of crop specific elements. The model for quality control used to specify the quality attributes for a given pot plant has a generic structure, but the plant features selected and the quantification of the weight of the important plant features are crop specific. It is likely that the important quality attributes found for *Ficus benjamina* 'Exotica' are not necessary the same in other foliage plants. With *Dieffenbachia* for example additional plant features were important (Oprel, 1986). The addition of extra plant features should not be too problematic for the model of visual quality. If the model of visual quality for *Ficus* is extended by other important plant features, image processing can easily be adapted for foliage plants. The adaptation of the crop growth control model is more complex. The approach (and structure) of the crop growth control model for *Ficus* may be applicable with other foliage plants, however the processes could be different. For *Ficus* a number of simplifications have been made, resulting in a crop growth control model based on a fixed internode length and plastochron depending on temperature and radiation. The assumption of a fixed internode length will almost certainly not be applicable to all other foliage plants. It is known that temperature does have an effect on internode length of several foliage plants (Mystar and Moe, 1995). For each cultivar parameters of the crop growth control model need to be estimated in relation to temperature, plant density and season and predictions have to be validated. This is fairly time consuming and very expensive. The grading module of the CQCS for *Ficus* can be easily adapted for other foliage plants provided that the target quality of a given foliage plant is objectively defined.

CQCS could also be used with flowering pot plants. Quality attributes such as flowering stage, flower distribution and number of flowers play an important role in defining visual quality (Vogelezang, 1985; Vogelezang et al., 1988; Straat, 1991). The addition of these attributes to the model of visual quality should not be difficult. Monitoring crop development could be more complex when internal processes leading to plant quality attributes, e.g. flower initiation, are involved. In that case the crop growth control model has to include developmental processes related to flowering. For example, modelling flower distribution will be difficult and as least as complex as modelling the 3 –dimensional distribution of axillary shoots of *Ficus* (chapter 5). Adaptation of the unsupervised network for flowering pot plants, however, should not be complicated.

It can be concluded that the approach of the system is generic. To transfer the system to other foliage plants special attention must be paid to the crop growth control model. When considering the other functional modules i.e. the model for visual quality, monitoring crop development and grading of plants no fundamental problems are expected in the transferability of the system. The transferability of the system to flowering pot plants is less simple, unless internal plant processes can be adequately controlled or predicted.

7.3   Implementation of CQCS at a nursery: consequences and limitations

The introduction of a CQCS at a nursery requires three relatively new facilities namely separate, independently controlled glasshouse compartments, a central measuring device and an automated transport system. In existing pot plant production this implies a different use of glasshouse area. Batches of plants will be transported to a central monitoring area, requiring easy movement of plants within the nursery. A mechanised transport system is therefore essential. The status of the plants may require modification in the climatic regime, or plant spacing. With CQCS, in fact, each batch of plants will be allotted a certain strategy to achieve the target quality. This then involves movement of the plants to a larger area or to another compartment within the glasshouses. This has far-reaching consequences for space allocation, scheduling, labour and logistics at the nursery. This means that compartments within the nursery are needed to accomplish this.

Existing pot plant nurseries normally consist of only one large area for culture of the plants. There are generally no separate compartments available. Moreover, space utilisation is better in one large area, than in separate areas with distinct growing conditions and this is even more pronounced in nurseries where more than one type of crop is grown. Depending on the type of nursery there are often several crops at different stages all growing in one compartment.

When considering the set-up of today's nurseries it is likely that the implementation of CQCS will take some time, although there is a clear trend in present-day pot plant cultivation towards spatial separation of cultivation and crop management. On the other hand there is a development nowadays towards concentration of crop management in a central working area, separate from the actual cultivation under optimal growing conditions. At some nurseries this central working area is even provided with techniques to monitor the marketable product and to grade it into uniform batches. This trend allows for more and specialised mechanisation and this will lead to an increase in internal transport. (Annevelink, 1999). This development is of course favourable for a quick implementation of the CQCS within the enterprise.

Control over quality or despatch date is impossible as long as enterprises do not have an automated logistic system nor separate cultivation compartments. Even in that case, however, CQCS can at least provide insight into the complete cultivation process. In the absence of different growing compartments, only one temperature regime can be used within the greenhouse and applied to all plant stages. Using CQCS it is possible to obtain a uniform batch of preferred quality, but specification of the delivery date is no longer an option in that case. Grading of plants will result in more batches, that cannot be combined to large uniform batches.

Without a central measuring device for monitoring crop development, data have to be collected manually. In practice this is only applicable for a limited number of easy to observe

plant characteristic, such as plant height and eventually plant width. This means that the crop growth control model could still be useful, based on the height of a sample plant. Plant width should be controlled by the traditional method. In this respect the CQCS is similar to the greenhouse CARE-system except that CQCS uses a superior crop growth control model. At nurseries with more than one crop species the problems will increase rapidly, because of lack of detailed knowledge and complex organisation.

Integration of CQCS into a pot plant nursery influences decisions at both tactical and operational levels. At tactical level the formulation of a cultivation plan is the most important activity at a pot plant nursery. A cultivation plan consists of sub-plans such as a financial plan (specifying costs, sales and liquidity), a labour plan, a space allocation plan (specifying the allocation each week) and a materials plan (Hofstede, 1992). Factors such as limitations of the nursery, the crop, the delivery date and the market, but also the experience of the grower, are very important when formulating the tactical plan. The traditional tactical plan within a pot plant nursery is based on fixed cultivation schedules (blue prints) for optimal space utilisation. Application of CQCS will result in a complex tactical plan based on variable and less predictable cultivation schedules. Plants are graded into uniform batches and different strategies are used to control the batches to a preferred marketable product on a specified delivery date. The grower has to find a trade-off between the optimal space utilisation and optimal control of batches. To control individual batches there is a need for space that may or may not be available depending on the slack in the tactical plan. From a logistical study on grading systems (Koerhuis, 1998) and preliminary research into the logistical and financial consequences of grading pot plants (Benninga and Van Weel, 1998) it is known that the introduction of computer supported grading systems for pot plant production is, under the conditions tested, theoretically feasible. Total implementation of CQCS will restrict the number of batches because batches with differing starting dates can be combined. Each batch of plants is more homogenous making mechanisation and automation of the internal transport system, spacing and grading an option, thus reducing labour costs. Since the whole batch of plants can be transported and dispatched at the same time, there is no need for paths, thus enhancing better use of the cultivation area. Additionally the cultivation period can be reduced (up to 30%) and delivery of a specified product at a specified date is realised. (Benninga and Van Weel, 1998). The utilisation potential of the greenhouse area is improved by grading during the production cycle. At operational level monitoring and control are very important. In pot plant cultivation the grower never exactly follows strict cultivation schedules, due to weather conditions and market related adjustments in the delivery schedules (section 7.4). Therefore the grower needs a method to monitor and, if needed, control the growth and development of the plant, to reach the target quality of the finished product. CQCS is able to support and assist the grower in this process.

It can be concluded that CQCS is especially suitable for specialised nurseries. The set-up of most enterprises within the pot plant sector does not allow a complete implementation of CQCS as yet. It seems that the adaptations in the logistics are less of a bottle-neck than the introduction of separate compartments. However the production process is already improved by using a partial implementation of CQCS. CQCS is useful for the grower and gives him insight into the complete cultivation process. In the end this added value of the system will motivate the grower to adapt his nursery to enable a complete implementation of the system.

7.4 CQCS in the chain

A chain in the agri-industrial sector is defined as "a chain of actors in which the mutual dependency contributes to the production of food" (Beulens and Visser, 1999). In the pot plant industry the chain may involve the following links: breeding/propagation - production nursery - (auction) - wholesaler - sales outlet.

As mentioned in the introduction the role of the consumer is becoming increasingly more important and indeed there is evidence of chain reversal in the pot plant branch. The sales outlets for horticultural products are now closely linked to the market and growers seek more contact both with suppliers and buyers with the aim to improve service in the marketplace. Interaction between each link in the chain is becoming more important. Information channels both upstream towards the consumer and downstream towards the producer are important. (Splinter et al., 1999; Beulens and Visser, 1999). Essential elements in chain reversal include knowledge of the market, consumer preferences and quality control within the complete production chain (Jongen et al., 1999). Definition of the specified target quality is the first step in this approach and the expectation of the consumer must be translated into product quality features that can be both measured and defined. The following step is the control of the production process to achieve the specified target quality (Jongen et al., 1999). As CQCS embraces these elements, its implementation will improve functioning of the pot plant chain. Quality can be objectively defined and the grower is enabled to deliver uniform batches of specified target quality on the correct delivery date. Agreements between individual growers can provide the basis for even larger orders so anticipating the trend to supply larger and more diverse outlets (e.g. D.I.Y. stores) where large, uniform contracts for special week offers are required. When using CQCS, specifications can also be set for cuttings or seedlings. Propagation nurseries will have to provide uniform young plants which enable control of plant development to meet quality specifications.

In the auctions quality classification of pot plants at present is subjective by an inspector or by the growers themselves. Pot plants can be bought via the auction clock, the trading centre (e.g. Marketing Sales Aalsmeer) or using internet. CQCS provides the auctions

with a method to develop an objective quality classification system which is based on the quality model of CQCS in combination with image analysis. Products no longer have to be moved physically to the front of the auction clock (subjective quality assessment by a person) so enlarging the share of the facilities for trading and bargaining. Good objective criteria will increase confidence in the system and provide a better chance to extend facilities for buying via internet. Large orders can be directly placed with the producers and then classified using an objective classification system on the nurseries. This could mean that the auctions move from their present role of logistic centre to that of an information provider.

Indeed the introduction of CQCS in the pot plant chain is an unique chance to link pot plant production to the expectations of the consumer. The preferred quality (and quantity) can be defined and guarantees can be made to buyers. Moreover, the quality assessment system could play a key role to establish quality standards in the trade of pot plants.

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Summary

The Netherlands is one of the worlds leading pot plant producers. In 2000 the export value of pot- and bedding plants increased with more than 9%. The diversity in pot plant industry is enormous. Pot plant nurseries are variable in size and in degree of automation and the thousand or more registered products virtually all require a different and specialised production process. This makes it difficult to obtain exact data on pot plant production, cultivation, and grading strategies. Additionally new products are frequently being introduced. Production systems also differ: plants can be grown on the ground, on concrete floors, on fixed or rolling benches, or benches that can be automatically transported. In some advanced production systems, the plants can be transported to a central working place. In most greenhouses climate control is highly automated. Processes such as taking and planting cuttings, spacing plants and preparing the final products for transportation are only automated on large, specialised high-tech nurseries.

A large share of greenhouse production is marketed via the Dutch co-operative auction system. In the past sales by the auctions were based on a push-market. At present the role of the consumer is becoming increasingly more important. There is evidence of chain reversal in the pot plant branch. The sales outlets for horticultural products are now market-oriented and growers seek more contact both with suppliers and buyers with the aim to improve service in the marketplace.

However, at the moment marketing of pot plants is still rather producer oriented. To strengthen the position of Dutch horticulture and to survive competition from other European countries, a transition of a producer oriented to a consumer oriented market is necessary: a well defined product has to be delivered at a defined moment in time. Current production methods are based on fixed cultivation schedules (blue prints), which tend to result in marketable products with a large variation in quality and delivery date. Therefore it is necessary to define quality, to set quality specifications and to provide instruments to growers to meet these specifications on the specified delivery date. An objective method for the measurement of visual quality of pot plants is not available and existing methods e.g. decision-support systems (DSSs) to control quality are not able to deliver a uniform marketable product of defined quality on a specified delivery date.

The aim of this study was to develop a system for growers to control development and growth of the crop to achieve a defined quality on a specified delivery date. Controllable factors temperature and plant density affect growth and development of pot plants together with available natural light which cannot be controlled. The following requirements to the system were formulated: a) the total visual quality of the marketable product must be objectively defined, b) data collection of quality features must be accurate to make control of these features possible, c) data acquisition must not be laborious and d) the marketable

product has to be uniform with a defined quality at the specified delivery date. For this study image processing was used for monitoring plant development and in combination with a neural network for grading the plants into uniform batches. *Ficus benjamina* 'Exotica' was chosen as a pilot foliage plant because *Ficus* is one of the most popular foliage plants, and because it is a year-round crop where uniform batches and mechanisation are already of importance.

To control the development and growth of pot plants to a preferred visual quality the first prerequisite was to specify quality (chapter 2). A model used within the food industry to describe and quantify quality as a complex feature, was considered and revised to obtain a mathematical description of visual quality in ornamental horticulture. The application of the revised models was a success for the pilot crop *Ficus benjamina* 'Exotica'.

The most important quality attributes were defined and quantified in chapter 3. Panel assessments by growers were used to subjectively analyse the quality. The quality features which were important according to growers, such as density of leaf mass and shape of the plant, and their motives for choosing them were recorded. Using a questionnaire, growers assessed the importance of plant features in explaining the total quality of the plant. Image processing was used to quantify the quality attributes of the same plants objectively. Images were recorded in three positions and processed. To this end the plant was vertically projected on a window divided into five horizontally joined split-windows, each of 20 centimetres, starting at pot height, counting from the top from 1 to 5. Finally the model for visual quality of pot plants as described in chapter 2 was parameterised and the weights of the important quality features were quantified. By linking subjective data to objective data the visual quality of *Ficus benjamina* 'Exotica' was explained for 88.7% by four variables (in addition to the fixed total plant height of 1.20 m.): the density of the leaf mass in the third layer in front-view; the width in the third layer in side-view; the width in front-view of the fourth and fifth layer.

Total plant height, width of the plant and density of the leaf mass are the most important delivery specifications for *Ficus benjamina* 'Exotica'. These quality attributes should be directly or indirectly suitable for control purposes. The effect of temperature, plant density (control factors) and season (not under control) on the growth and development of *Ficus benjamina* 'Exotica' in relation to these important quality features had to be quantified (chapter 4). These were considered the most important factors regarding growth and development of pot plants. Different plant features were measured to enable identification and evaluation of the plant processes that contribute most to the description of plant quality of *Ficus benjamina* 'Exotica'.

The development of *Ficus benjamina* 'Exotica' showed a regular pattern. Three leaves unfold on the main axis before a primary side shoot sprouts on the fourth leaf axil, counting from the top of the plant. Plant height increased with temperature up to 29.5°C. The effect of plant density on this variable was small. Leaf unfolding rate was influenced by light and temperature, plant density was of minor influence. Its response to temperature showed an optimum at 30°C. The final internode length was mainly affected by light intensity, temperature had no effect. The width of the plant and the density of leaf mass increased at lower plant densities. The effect of temperature on visual quality of *Ficus* was small and only at temperatures $\geq$ 32°C or extremely low or high plant densities there was a significant effect..

A link was successfully been made between the important quality criteria of *Ficus benjamina* 'Exotica' (chapter 3) and development under different climatic conditions (chapter 4).

Chapter 5 describes the development of a simple model to control visual quality of pot plants by temperature and plant spacing in relation to natural light, thereby focusing on the major external quality features. Although quality was defined on the basis of five important quality features it could finally be described satisfactorily by only two attributes namely total plant height and plant width. Density of leaf mass, also an important quality attribute, strongly correlated with plant width. Plant height was described as a function of plastochron age and internode length in relation to temperature and light and was adequately predicted. Plant width was successfully controlled by spacing operations, using image processing to monitor this crop feature.

By integration of four functional modules, a model for visual quality (chapter 3), a crop growth control model (chapter 5), image processing for monitoring crop development and a neural network to grade plants, a crop quality control system (CQCS) was obtained to control development of pot plants to uniform batches with a predetermined quality on a specified delivery date (chapter 6). A prototype was used at commercial companies in The Netherlands. Two batches of half-grown *Ficus* plants were formed, a control batch to be controlled by the grower and an experimental batch to be controlled by CQCS. Image processing was used as a measuring technique to register plant development. The neural network graded the experimental batch into uniform groups. Each uniform group was subjected to a different spacing schedule and temperature regime as determined by the growth control model. At the specified delivery date development and quality of the experimental groups was more uniform than the control batch. However not all experimental groups had reached the marketable stage and therefore they could not be combined into one uniform batch.

In the general discussion (chapter 7) the strategy of the system was evaluated and compared to the well-known greenhouse CARE-system for quality control. The CQCS assesses integrated external quality and uses a model to describe and quantify it, whereas the greenhouse CARE system only focuses on target height. Considering the process of monitoring crop development, the input of the greenhouse CARE-system is plant height. In CQCS image processing allows more attributes to be measured simultaneously. The crop growth control model of CQCS is with respect to height control comparable to that in the CARE system, but the approach is different. CARE is based on graphical tracking, where deviations from a target curve are locally corrected by temperature and growth retardants. CQCS instead, knowing the initial plant height, the target plant height and the delivery date, calculates the required average temperature which is then used to determine a temperature regime. The control of plant width in CQCS is not model based. An other important improvement of CQCS with respect to CARE is its ability to obtain a uniform product using a neural network for grading.

The limitations and the transferability of CQCS to other crops were discussed. The approach of CQCS is generic. To transfer the system to other foliage plants extra attention must be paid to the crop growth control model. When considering the other functional modules i.e. the model for visual quality, monitoring crop development and grading of plants no fundamental problems are expected in the transferability of the system. The transferability of the system to flowering pot plants is less simple, unless internal plant processes can be adequately controlled or predicted.

Considering the limitations and consequences when implementing CQCS at a nursery CQCS is especially suitable for specialised nurseries. The set-up of most enterprises within the pot plant sector does not allow a complete implementation of CQCS yet. It seems that the adaptations in the logistics are less of a bottle-neck than the introduction of separate compartments. However the production process is already improved by using a partial implementation of CQCS. CQCS meets the growers requirements and gives him insight into the complete cultivation process. This added value of the system will motivate the grower to adapt his nursery to enable a complete implementation of the system.

The introduction of CQCS in the pot plant chain provides a unique chance to link pot plant production to the expectations of the consumer. The preferred quality (and quantity) can be defined and guarantees can be made to buyers. Moreover, the quality assessment system could play a key role to establish quality standards in the trade of pot plants.

Samenvatting

De Nederlandse potplantenteelt is internationaal toonaangevend. In 2000 nam de exportwaarde van de pot- en tuinplanten met ruim 9% toe. De diversiteit in de potplantenteelt is groot. Potplantenbedrijven variëren in grootte en in de mate van automatisering. Meer dan duizend geregistreerde producten vereisen ieder een verschillend en gespecialiseerd productieproces. Dit maakt het moeilijk om exacte gegevens omtrent de productie van planten, het opkweekproces en het sorteerproces te verkrijgen. Tevens worden er regelmatig nieuwe producten en productiesystemen geïntroduceerd. Planten kunnen op de grond worden geteeld, op betonnen vloeren, op vaste tafels en roltafels, maar ook op tafels die automatisch getransporteerd kunnen worden. In sommige geavanceerde productiesystemen worden de planten getransporteerd naar een centrale werkplaats. In de meeste glastuinbouwbedrijven is de klimaatbesturing in hoge mate geautomatiseerd. Processen zoals het plukken en steken van stekken, het wijder zetten van planten en het klaarmaken van het eindproduct voor transport zijn slechts geautomatiseerd op grote, gespecialiseerde high-tech glastuinbouwbedrijven.

In de glastuinbouw wordt een groot deel van de productie verhandeld via de coöperatieve veilingen. Historisch gezien werken de veilingen vanuit een push-situatie: de producent produceert tegen zo laag mogelijke kosten en de veiling zorgt ervoor dat het product verkocht wordt. Op het moment wordt de rol van de consument steeds belangrijker. In de potplantenbranche is er sprake van een ketenomkering. Afzetketens van tuinbouwproducten gaan meer en meer marktgericht werken en telers treden steeds meer in contact met hun toeleveranciers en afnemers om uiteindelijk de markt zo goed mogelijk te bedienen.

Echter, het vermarkten van potplanten is nog steeds tamelijk producent georiënteerd. Om de positie van de Nederlandse tuinbouw te versterken en de concurrentie met andere Europese landen aan te kunnen, is een verandering van een product georiënteerde naar een consument georiënteerde markt noodzakelijk: een goed gedefinieerd product moet geleverd kunnen worden op een gedefinieerd moment in de tijd. De huidige productiemethoden zijn gebaseerd op vaste teeltschema's (blauwdrukken), die resulteren in eindproducten met een grote variatie in kwaliteit en aflevertijdstip. Daarom is het noodzakelijk om kwaliteitsspecificaties te ontwikkelen en telers te voorzien van instrumenten om deze specificaties te kunnen realiseren op het gewenste aflevertijdstip. Een objectieve methode voor het meten van de visuele kwaliteit van potplanten is niet beschikbaar en bestaande methoden voor kwaliteitssturing zijn slechts gedeeltelijk in staat om planten naar een uniform eindproduct van een gedefinieerde kwaliteit op een gespecificeerd aflevertijdstip te sturen.

Het doel van deze studie was het ontwerpen van een systeem voor telers dat de groei en ontwikkeling van planten kan sturen naar een gedefinieerde kwaliteit op een gespecificeerd aflevertijdstip. De stuurbare factoren temperatuur en plantdichtheid beïnvloeden de groei en

de ontwikkeling van planten, evenals de niet stuurbare factor globale instraling. De volgende eisen zijn voor het systeem geformuleerd: a) de integrale visuele kwaliteit van het eindproduct moet objectief worden gedefinieerd, b) kwaliteitskenmerken moeten nauwkeurig worden gemeten om sturing van deze kenmerken mogelijk te maken, c) het meten moet weinig tijd vergen and d) het eindproduct moet uniform zijn en de gewenste kwaliteit op het gespecificeerd aflevertijdstip zijn gerealiseerd. Voor deze studie is beeldverwerking gebruikt voor het volgen van de ontwikkeling van planten en voor het sorteren van planten in uniforme partijen (met een neuraal netwerk). *Ficus benjamina* 'Exotica' is gekozen als pilot-gewas voor de bladplanten. *Ficus* is namelijk één van de meest populaire bladplanten, het gewas is jaarrond te telen en uniforme partijen en mechanisatie zijn bij de teelt hiervan al belangrijk.

Een eerste vereiste om de groei en ontwikkeling van potplanten te kunnen sturen naar de gewenste visuele kwaliteit was het specificeren van de kwaliteit (hoofdstuk 2). Een model dat gebruikt wordt in de voedingsindustrie om de kwaliteit als een complex kenmerk te beschrijven en te kwantificeren is voor dat doel onderzocht en aangepast om een wiskundige beschrijving van de visuele kwaliteit in de sierteelt te krijgen. Het aangepaste model werd met succes toegepast bij het pilot-gewas *Ficus benjamina* 'Exotica'.

De belangrijkste kwaliteitsattributen zijn gedefinieerd en gekwantificeerd in hoofdstuk 3. Panelbeoordelingen door telers van de kwaliteit zijn geanalyseerd. Daartoe zijn de kwaliteitskenmerken die volgens de telers belangrijk waren, zoals gevuldheid en vorm van de plant, en hun motieven voor die keuze geregistreerd. Met behulp van een enquête beoordeelden de telers hoe belangrijk bepaalde plantkenmerken waren in het verklaren van de totale kwaliteit van de plant. Beeldverwerking is gebruikt voor het objectief kwantificeren van de kwaliteitsattributen van dezelfde planten. De beelden zijn in drie posities genomen en verwerkt. Hiertoe is de plant verticaal geprojecteerd in een venster, dat verdeeld werd in vijf verticaal aansluitende sub-vensters van elk 20 cm, beginnend op pothoogte. Uiteindelijk is het model voor de visuele kwaliteit van potplanten zoals beschreven in hoofdstuk 2 geparameteriseerd en zijn de gewichten van de belangrijkste kwaliteitskenmerken gekwantificeerd. Het koppelen van subjectieve data aan objectieve data verklaarde de visuele kwaliteit van *Ficus benjamina* 'Exotica' voor 88,7% door vier variabelen (met toevoeging van de vaste planthoogte van 1,20 m): de gevuldheid in vooraanzicht in de laag 40-60 cm boven de pot; de plantbreedte in zijaanzicht in de laag van 40-60 cm boven de pot, de plantbreedte in vooraanzicht in de laag van 0-20 en 20-40 cm boven de pot.

Planthoogte, breedte en gevuldheid zijn de belangrijkste afleverspecificaties voor *Ficus benjamina* 'Exotica'. Deze kwaliteitsattributen dienen direct dan wel indirect bestuurbaar te zijn. Het effect van temperatuur, plantdichtheid (stuurfactoren) en seizoen (niet stuurbaar) op

de groei en ontwikkeling van *Ficus benjamina* 'Exotica' in relatie tot deze belangrijke kwaliteitskenmerken zijn gekwantificeerd (hoofdstuk 4). Deze zijn beschouwd als de belangrijkste factoren ten aanzien van groei en ontwikkeling van potplanten. Verschillende plantkenmerken zijn gemeten om herkenning en evaluatie van plant processen mogelijk te maken die het meest bijdragen aan de beschrijving van de plantkwaliteit van *Ficus benjamina* 'Exotica'.

De ontwikkeling van *Ficus benjamina* 'Exotica' liet een regelmatig patroon zien. Drie bladeren worden afgesplitst op de hoofdscheut voor een zijscheut in het vierde bladoksel uitloopt, geteld vanaf het groeipunt. Planthoogte nam tot 29,5°C toe met de temperatuur. Het effect van plantdichtheid op planthoogte is gering. De bladafsplitsingssnelheid werd beïnvloed door licht en temperatuur, plantdichtheid was van minder belang. De bladafsplitsingssnelheid liet een optimum zien bij 30°C. De uiteindelijke internodiumlengte werd voornamelijk beïnvloed door het licht, de temperatuur had geen effect. De plantbreedte en gevuldheid namen toe bij lage plantdichtheden. Het effect van de temperatuur op de visuele kwaliteit van *Ficus* was gering en slechts bij temperaturen $\geq$ 32°C of bij buitengewone lage of hoge plantdichtheden was er een duidelijk effect.

Met succes is er een koppeling gemaakt tussen de belangrijkste kwaliteitskenmerken van *Ficus benjamina* 'Exotica' (hoofdstuk 3) en de ontwikkeling onder verschillende klimatologische omstandigheden (hoofdstuk 4).

Hoofdstuk 5 beschrijft de ontwikkeling van een simpel model om de groei en ontwikkeling van potplanten te sturen met behulp van temperatuur en plantdichtheid in relatie tot het natuurlijke licht. Daarbij werd gestuurd op de belangrijkste visuele plantkenmerken. Hoewel kwaliteit bij *Ficus* is gebaseerd op vijf belangrijke kwaliteitskenmerken, kon de kwaliteit uiteindelijk goed beschreven worden door slechts twee attributen, namelijk planthoogte en plantbreedte. De gevuldheid, eveneens een belangrijk kwaliteitsattribuut, was sterk gecorreleerd met de plantbreedte. Planthoogte is te beschrijven als het product van gemiddelde internodiumlengte en plastochronleeftijd (een functie van temperatuur en licht) en werd adequaat voorspeld. Gebruik makend van beeldverwerking voor het waarnemen van de plantbreedte, werd dit plantkenmerk goed gestuurd door het wijder zetten.

Door het integreren van vier functionele modulen, een model voor de visuele kwaliteit (hoofdstuk 3), een model voor het sturen van de groei van het gewas (hoofdstuk 5), beeldverwerking voor het volgen van de ontwikkeling van het gewas en een neuraal netwerk voor het sorteren van de planten is een systeem verkregen voor het sturen van de kwaliteit (Crop Quality Control System, CQCS). Hiermee kan de ontwikkeling van planten gestuurd worden naar uniforme partijen met een van tevoren vastgestelde kwaliteit op een gespecificeerd aflevertijdstip (hoofdstuk 6). Een prototype is gebruikt op commerciële

bedrijven in Nederland. Twee partijen van *Ficus* in het halfwas-stadium zijn gevormd, waarvan één controle partij is gestuurd door de teler en één experimentele partij is gestuurd door CQCS. Het neurale netwerk sorteerde de planten van de experimentele partij in uniforme groepen. Voor elke uniforme groep is een verschillend wijderzetschema en temperatuurregime vastgesteld door het groeimodel. Op het gespecificeerde aflevertijdstip waren ontwikkeling en kwaliteit van de experimentele groepen uniformer dan de controle partij. Echter niet alle experimentele groepen haalden het vermarktbare stadium en deze konden daarom niet worden gecombineerd tot één uniforme partij.

In de algemene discussie (hoofdstuk 7) is het systeem geëvalueerd en vergeleken met het wel bekende CARE-systeem voor het sturen van kwaliteit. CQCS neemt de gehele integrale externe kwaliteit in beschouwing en gebruikt een model om deze te beschrijven en te kwantificeren. Het CARE-systeem daarentegen richt zich alleen op de uiteindelijke planthoogte. Voor het volgen van de plantontwikkeling gebruikt het CARE-systeem de planthoogte. In CQCS is het mogelijk om meerdere attributen tegelijk waar te nemen door het gebruik van beeldverwerking. Het groeimodel van CQCS is voor wat betreft het sturen van de hoogte enigszins vergelijkbaar met het sturen van planthoogte in het CARE-systeem, echter de benadering is verschillend. CARE is gebaseerd op 'graphical tracking'. Afwijkingen van de gewenste curve worden lokaal gecorrigeerd door temperatuur en groeiremmers. Uitgaand van de initiële planthoogte, de vastgestelde eindhoogte en het aflevertijdstip, berekent CQCS daarentegen de vereiste gemiddelde temperatuur, welke vervolgens gebruikt wordt om een temperatuurregime voor te schrijven. Het sturen van de breedte van de plant is in CQCS niet op een model gebaseerd. Een andere belangrijke verbetering van CQCS vergeleken met CARE is de mogelijkheid om een uniform product te krijgen door sorteren met behulp van een neuraal netwerk.

De beperkingen en overdraagbaarheid van CQCS naar andere gewassen zijn bekeken. De aanpak van CQCS is generiek. Ten aanzien van de overdraagbaarheid van het systeem naar andere bladplanten moet extra aandacht besteed worden aan het groeimodel. Bij de implementatie van de andere functionele modulen, te weten: het model voor de visuele kwaliteit, het volgen van de plantontwikkeling en het sorteren van de planten, worden er geen onoverkomelijke problemen verwacht. De implementatie bij bloeiende potplanten is minder vanzelfsprekend, tenzij interne plantprocessen adequaat gestuurd of voorspeld kunnen worden.

Gelet op de beperkingen en consequenties van implementatie van CQCS op een bedrijf is CQCS met name geschikt voor gespecialiseerde bedrijven. De opzet van de meeste bedrijven in de potplantenindustrie leent zich nog niet voor een volledige implementatie. Waarschijnlijk is het aanpassen van de logistiek minder problematisch dan de introductie van aparte compartimenten. Een verbetering van het productieproces kan overigens al worden

verkregen door gedeeltelijke implementatie van CQCS. CQCS ondersteunt de teler en geeft hem meer inzicht in het productieproces. De hierdoor verkregen meerwaarde zal de teler op den duur kunnen motiveren om zijn bedrijf steeds meer aan te passen, zodat een volledige implementatie van het systeem een feit wordt. De introductie van CQCS in de potplantenketen creëert de unieke mogelijkheid om de potplantenproductie goed te laten aansluiten bij het koopgedrag van de consument. De gewenste kwaliteit (en kwantiteit) kan gedefinieerd worden en gegarandeerd worden naar afnemers. Bovendien kan het kwaliteitsbeoordelingssysteem een sleutelrol gaan spelen bij het opzetten van kwaliteitsstandaards in de handel van potplanten.

Curriculum vitae

Maria Wilhelmina Catharina Dekker werd geboren op 9 augustus 1966 in Delft en groeide op in een tuindersgezin met drie kinderen. In 1984 behaalde zij het Gymnasium-β diploma aan het Stanislascollege te Delft en begon zij aan de studie Tuinbouw aan de Landbouwuniversiteit te Wageningen. In het kader van deze studie liep zij zes maanden stage bij het toenmalige Sprenger Instituut te Wageningen. Tijdens de doctoraalfase werden de afstudeervakken tuinbouwplantenteelt, *in vitro* cultuur en fytopathologie uitgevoerd met als extra vak agrarische onderwijskunde. Hiervoor liep zij stage bij de RMTuS te Nijmegen. In 1990 behaalde zij haar doctoraal examen en breidde zij haar achternaam uit tot Dijkshoorn-Dekker. Aansluitend aan haar studie werd zij op tijdelijke basis aangesteld als wetenschappelijk onderzoeker op het toenmalige Proefstation voor de Bloemisterij in Nederland (PBN) op het project 'Ontwikkeling en kwaliteit van potplanten'. Hierna volgden meerdere projecten op het gebied van ketengerichte teeltsturing van bladplanten waarna zij in 1998 in vaste dienst trad. Naast het ontwikkelen van een ketengericht teeltsturingssysteem voor bladplanten, waarvan de resultaten in dit proefschrift zijn beschreven, waren het ontwikkelen van een dergelijk systeem voor bloeiende potplanten en het objectiveren van kwaliteit bij andere gewassen belangrijke onderwerpen van onderzoek. Ook het vermarkten van ketengerichte teeltsturingssystemen vormde een onderdeel van haar werk. Sinds 15 juli 2002 is zij werkzaam binnen een leer- en ontwikkelingstraject op managementgebied bij het Praktijkonderzoek Plant en Omgeving cluster Bollen en Bomen te Lisse.