Irrigation and Horticultural Practices in Ornamental Greenhouse Production

Implementation of Scientific Knowledge into Irrigation Practices and Methods

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Abstract

Irrigation in greenhouse pot plant production is traditionally managed using a tactile perceptual method. This method, in this thesis called 'the golden grip', is based on the grower's experiential knowledge where water requirement is determined by combining the estimated weight of the pot (both growing medium and plant) with factors such as plant age, developmental stage and size in combination with prevailing and future climate conditions. A large proportion of this knowledge is tacit making communication about this subject difficult. Implementation of scientific results into the experientially based knowledge demands specific attention.

This thesis takes a new approach to improving irrigation - a triangular approach consisting of observations, experiments and implementation that bridges the gap between science and experientially based knowledge. The importance of irrigation for plant performance is, demonstrated regarding irrigation frequency and drought levels, confirming the role played by this growth-controlling parameter. To improve irrigation management skills, the degree of reflection on reflection-in-action by commercial growers has to be increased. Suitable tools such as high precision weighing scales and dialogue-inspired methods, discussed in this thesis, have potential in achieving progress.

Keywords: experiential knowledge, irrigation frequency, irrigation strategy, reflection, tacit knowledge

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Populärvetenskaplig sammanfattning

Bevattning av krukväxter i växthusproduktion utförs idag med en metod som i detta sammanhang kallas det ”gyllene greppet”. Odlaren håller plantan i handen och bedömer vikten av krukan (bestående av såväl odlingssubstratet som växten) och sätter detta i samband med en bedömning av plantans vattenstatus (växtens ålder, utvecklingsstadium och storlek) i kombination med rådande och framtida klimatförhållanden. Detta är med andra ord en taktil perceptuell metod och baseras på odlarens erfarenhetsmässiga kunskap av plantans bevattningsbehov. En stor del av erfarenhetsbaserad kunskapen är tyst vilket försvårar kommunikation mellan odlare och mellan odlare, rådgivare och forskare. Kunskapsöverföring från forskning till erfarenhetsbaserade sammanhang kräver särskilt fokus och anpassade metoder.

Denna avhandling om bevattningsstrategier i krukväxtkulturer i växthus utgår ifrån en triangulär ansats bestående av observationer, experiment och genomförande som en bro mellan forskning och yrkespraxis. Bevattningens betydelse för krukväxters utveckling och tillväxt vad gäller bevattningsfrekvens och torkstress har konfirmerats.

En viktig del för att kunna förbättrad bevattningsstyrningen i krukväxtodling är att öka reflektionsnivån i arbetet. Lämpliga verktyg, såsom vågar och dialoginspirerade metoder diskuteras i denna avhandling och har potential att utveckla området.

Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Alsanius B.W., Löfkvist K., Kritz G. and Ratkic A. (2009). Reflection on reflection in Action: a case study of growers conception of irrigation strategies in pot plant production. AI & Soc 23, 545-558.

II Löfkvist K., Englund J.-E., Larsen R.U. and Alsanius B.W. (2009). Light integral as an indicator of water use in commercial greenhouse nurseries. Acta Agriculturae Scandinavia section B Plant and Soil 59 (4), 326-334.

III Löfkvist K., Michel J.-C. and Alsanius B. W. (2010). Respons of *Kalanchoë blossfeldiana, Euphorbia pulcherrima, Impatiens hawkeri* and *Argyranthemum frutescens* to changes in irrigation frequency. (Submitted).

IV Löfkvist K., Lindqvist H. Alsanius B.W. and Larsen R.U. (2010). Effects on drought treatment and *Kalanchoë blossfeldiana* in greenhouse production. (Manuscript).

V Alsanius B.W., Ratkic A., Persson E. and Löfkvist K. (2009). Prospects of dialogue-inspired methods as tools for knowledge transfer: Technology for sustainable horticulture meets experiential knowledge communities. Acta Hort. 832, 27-31.

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Abbreviations

ABA	Abscisic acid
ATP	Adenosine triphosphate
CAM	Crassulacean acid metabolism
DIF	Differences between night and day temperature
EC	Electrical conductivity
FDR	Frequency domain reflectometer
GA	Gibberellic acid
gs	Stomatal conductance
PAR	Photosynthetically active radiation
PSI	Photosynthesis system I
PSII	Photosynthesis system II
RH	Relive humidity
rs	Stomatal resistance
SOLO	Structure of observed learning outcomes
TAW	Total available water
TDR	Time domain reflectometer
TP	Turgor pressure

1 Objective and hypotheses

The main objective of this thesis was to find a way to improve the present irrigation method for production of ornamental pot plants. In order to do so horticultural science and practice had to be combined to create the conditions for a sustainable development in terms of water consumption and irrigation.

The questions examined were:

- What are the fundamental characteristics of the present irrigation control method? (Paper I)
- What variables affect the irrigation of the plants? (Paper II)
- Irrigation strategies differ widely between growers, so what does this mean for the plant quality? (Paper III)
- In what way might the irrigation strategy affect the properties of the growing medium? (Paper III)
- Is it possible to detect when a restricted irrigation regime is inducing negative stress symptoms in the plant? (Paper IV)
- How can improvements to the present irrigation method be implemented? (Paper V)

The starting hypothesis for the thesis were:

- Horticultural practice is driven by tacit knowledge.
- Frequent irrigation events affect plant performance.
- Light is the most decisive variable affecting evapotranspiration.
- Diverging perceptions of knowledge obstructs the transfer of scientific results into horticultural practice.
- Dialogue-inspired methods improve the level of reflection-in-action and thus the level of awareness in implementation of knowledge within horticultural practice.
- Reduction of plant elongation by irrigation is restricted by negative plant responses to drought.

2 Introduction

2.1 Background

In commercial Swedish greenhouses market gardens, climate, crop protection methods and irrigation are controlled by a perceptual, handcrafted method based on the growers' personal expertise and assumptions of crops' requirements. This causes profound variations between and within production sites. Several pot plant producers describe the same production goal but few similarities are found when the growth variables are compared (Löfkvist & Schüssler, 2000; Bulle, 2002). As communication tools for action are missing, fundamental differences in growers' approaches to controlling water supply are difficult to explain.

Irrigation strategies and skills are the basis for all growth control methods in ornamental pot plant production according to the growers themselves (Löfkvist & Schüssler, 2000). They are the first step to a deeper understanding of ornamental plant production and process improvement.

2.2 Pot plant production

The total greenhouse production area in Sweden is 2 657412 m^2 (Jordbruksverket, 2008). Of this area, 1 458453 m^2 of this area are used for the production of pot plants and bulb cut flowers and the remaining area for vegetables and other cut flowers. A total amount 41 892 000 pot plants were produced in 2008 with the following main crops; Pelargonium (10 573000), Kalanchoë (6 387000), Poinsettia (5 669000), Chrysanthemum (3 749000), Marguerite (2 730000), Begonia (2 471000), Petunia (1 452000), Cyclamen (1 017000), Primula (1 008000) and Impatiens (907 000).

2.2.1 Plant material

The plant varieties chosen for the studies in this thesis were major products in Sweden representing different irrigation needs and capacity to cope with drought.

Kalanchoë (*Kalanchoë blossfeldiana*) (Paper I-IV) is produced during the whole year. Kalanchoë is a short day, succulent and is grouped as a CAM (Crassulacean acid metabolism) plant (Kluge at al., 1991). It belongs to the *Crassulacea* family and originates from Madagascar. The extent of the CAM mechanism can be induced or enhanced in *Kalanchoë blossfeldiana* by limiting water availability (Cushman & Borland 2002). In commercial production of *Kalanchoë blossfeldiana* with high relative humidity and water availability the plants are most likely to show the same response patterns as C-3 plants.

Impatiens (*Impatiens hawkeri*) (Paper III) is produced during winter and early spring for distribution in spring. It belongs to the *Balsaminaceae* family and originates from New Guinea Commercially produced varieties are hybrids. The production season of *Impatiens* starts in late December and ends in June a period causing high water demand.

Poinsettia (*Euphorbia pulcherrima*) (Paper III) is grown in Sweden during autumn to be sold from November until Christmas, a time of year when light conditions are suboptimal for growth. The plant belongs to the *Euphorbiaceae* family and originates from Mexico and central Africa. It grows naturally as a bush and needs growth regulation to fit as a pot plant. The production in Sweden starts with rooted or non-rooted cuttings, in July or August for branched products. For production of single stemmed plants the production starts in late August or early September.

Marguerite (Cobbit daisy, Marguerite daisy) (Paper III) (*Argyranthemum frutescens*) is a spring and early summer crop. It belongs to the *Compositae* family and originates from the Canary Islands and Madeira. This crop grows naturally as a bush and has a considerable need of growth regulation to fit as a pot plant. The production period of the crop is short.

2.2.2 Plant quality

In contrast to vegetables and nursery crops, there are no quality standards for pot and bedding plants in Sweden. High quality in pot plant production might be defined as high number of flowers, a well-branched and compact plant with short internodes and high vitality for canopy and root. However, the desired quality differs within the value network of pot plants, creating an ambiguity regarding overall quality aspects.

In greenhouse production of pot plants, an important economic factor is the compactness of plants, in order to maximise the number of units produced per unit area and the efficiency in logistics. To maintain a high turnover of plants per unit greenhouse area, growers strive for a high development rate while maintained final quality properties. Wholesalers want compact plants with long durability and good appearance, while consumer want easily handled, compact plants with a lot of flower buds, vigorous growth and a long shelf-life.

2.2.3 Cultivation methods

Before chemical growth control was introduced into ornamental pot plant production in the 1970s, growth control was exclusively managed by cultural means based on growers' experimental skills. Chemical growth control led to a higher demand for compact plants and subsequently altered production goals. Today, growers depend on chemical growth control agents to produce the quality demanded by the market. However, increasing environmental awareness is leading to demands for restricted use of chemicals, raising a need for alternative non-chemical growth control methods.

Compact plants are obtained by an appropriate combination of the management methods and choices below:

- Compact cultivars and varieties. Plant breeders have focused on compact plants in the recent years.
- Spacing and pinching (Gibson et al., 2003). Wider spaces between the plants give more light to the plants, suppressing elongation. Pinching of the main shoot disrupts the apical dominance and allows the development of secondary branches, resulting in a more compact appearance. Not all crops are suitable for pinching.
- Nutrient supply. Nutrient supply may be altered in several ways: (i) Adjusting of the electrical conductivity and thereby a higher total concentration of nutrients leading to increased water potential and thus decreasing plant water uptake (Bernstein, 1975). (ii) Altering the relationship between nutrients such as potassium (K) and nitrogen (N), since providing a higher relative amount of K for the plants results in more compact growth whereas a higher relative amount of N leads to a more vigorous growth (Marschner, 2003). (iii) Altering in the level of a specific nutrient, e.g. a decreased level of phosphorus (P) is known to affect growth (Asher & Loneragan, 1967).
- Climate factors. Ornamental plant growth can be affected by the following climate management methods: (i) Altering the temperature

regimes, e.g. a lower average temperature decreases the growth rate but increases the production time, while maintenance of the same average temperature with manipulation of night and day temperature will have an effect on plant growth. Negative DIF treatment (with a higher night than day temperature) or a temperature drop in the early morning hours before sunrise leads to reduced elongation as a result of reduced endogenous content of GA (Myster & Moe, 1995). Plant species sensitivity to these treatments varies. Irradiance, light quality and photoperiod interact with negative DIF in that long-day treatment counteracts the effect of DIF while water stress and negative DIF are additive (Myster & Moe, 1995). (ii) Altering the light intensity, choice of wavelength, red to far red ratio and photoperiod are other crucial factors.

- Mechanical growth control. The shoot tips are sensitive to physical contact and therefore mechanical contact such as brushing or air movements leads to compact plants (Beyl & Mitchel, 1977; Schnelle et al., 1994; Garner & Langton, 1997)
- Water supply and irrigation. Shortage of water reduces shoot elongation. The effects of irrigation volume on shoot elongation in different plant species are not well defined and consequently this method is imprecise. However, growth control by irrigation has great potential as it can be combined with other methods, is environmentally sound, applicable during all seasons of the year, and adjustable to the conditions prevailing in the business.
- Chemical growth control can be based on substances such as; chlormequat chloride, daminozide, flurpirimidol and 2-chlorethylphosphoric acid (compounds permitted in Sweden). Most of these agents inhibit the production of gibberellic acid in the plant. Another group of substances are the 'pinching agents', e.g. Off-shoot-O and Sodium-Dikegulac (not permitted in Sweden since 1987) which affect the apical dominance by killing or inhibiting the apical meristem (Luckwill, 1981). The use of chemical compounds in protected cultivation is not considered environmentally sound and most be avoided in all possible ways. Approximately 70-80% of the total amounts of chemical active compounds used in Swedish pot plant production consist of growth control agents (Miljödatabasen 2005).

2.3 Water as a tool to growth control

2.3.1 Function of water and plant-water relationships

Water is the main constituent of plants and acts as (i) structural support to the plant, (ii) the basis for the plant cooling system, (iii) the transport system for nutrients and photosynthates and (iv) a participant in photosynthesis.

Turgor pressure

The turgor pressure (TP) in the plant cell is caused by the protoplast having a lower water potential than the surroundings, and the turgor is counteracted by the pressure of the cell wall. This gives rigidity to the cell and provides the plant with physical support (Meyer & Boyer, 1972; Bacon, 1999; Raviv & Blom, 2001; Wei & Lintilhac, 2003). Cell elongation is proportional to the amount by which TP exceeds a critical value (Cleland, 1967). Cell wall elasticity is related to cell size. Small cells can withstand negative turgor pressure better than large (Chartzoulakis et al., 2002). For a given cell size, the pressure value is dependent on the thickness and elasticity of the walls (Wei & Lintilhac, 2003).

Water and photosynthesis

In photosynthesis, proteolysis of water results in an electron excitation state that drives photosynthesis forward (Larcher, 2001; Prince, 1985). Stomatal conductance is dependent on soil water availability and the photosynthesis rate is directly influenced by variations in stomatal opening (Scocias et al., 1997; Raviv & Blom, 2001). To minimise water losses, stomata open in the early morning hours. In a situation of water shortage oxidative processes such, as those in photorespiration and mitochondrial respiration are not affected by the lack of water as early as photosynthesis (Larcher, 2001). In situations with longer periods of water stress, photosynthesis is further affected by metabolic inhibition (Cechin et al., 2006).

There are two alternative carbon dioxide (CO_2) pathways to the normal C3 pathway; (i) The pathway in C4 plants, where the carboxylation process is through malate or aspartate allowing CO_2 uptake during periods with water scarcity (Larcher, 2001) and (ii) CAM (Crassulacean acid metabolism), where CO_2 can be stored in the vacuoles enabling plants to collect CO_2 during the night (Larcher, 2001).

Fluorescence is an indicator of photosynthetic balance in the plant. When the incident light hits the leaf, one part is reflected, another part is transmitted through the leaf and a third part is absorbed by the leaf. The absorbed part takes one of three competing ways; (i) It is used in photochemistry; (ii) dissipated as heat; or (iii) re-emitted as light as chlorophyll fluorescence (Lichtenthaler, 1992; Schreiber, 1997; Govindjee, 1995; Maxwell & Johnson, 2000). Chlorophyll fluorescence can be measured and acts as an indicator of PSII chemistry efficiency and is thus a general indicator of damage to the photosynthesis apparatus following stress (Lawlor, 1993; Maxwell & Johnson, 2000).

2.3.2 Water balance of plants

Difference in the water potential, is the driving force of all water flow. Water always flows from a high to a low water potential and the rate of the flow is affected by the difference and the resistance. This can be described by the equation:

$$J_v = \Delta\Psi / R \qquad (1)$$

where J_v is the water flow, $\Delta\Psi$ is the difference in water potential and R is the resistance. In the plant a gradient of decreasing water potential is responsible for the flow of water from the soil through the roots into the xylem, along the xylem of the stem into the leaves, and via the leaf intercellular layer through the stomata into the surrounding air. There are two ways by which the water potential gradient can be generated in the plant, transpiration and root pressure. During daytime, when the stomata of most common plants are open, the evapotranspiration process will generates a negative water potential in the leaves that spreads as a gradient through the plant. The driving force for the evaporation is the water vapour deficit. When the stomata are closed, or when the plant is exposed to air saturated with water vapour, the active uptake of mineral nutrients by the roots causes water to be taken up by the roots and pressed into the xylem and up the stem of the plant, creating root pressure. In contrast to root pressure, the flow of water caused by evaporation is the result of a negative pressure in the xylem.

According to equation 1, the flow rate (J_v) is negatively correlated to the resistance in the system. All parts of the plant involved in the transport of water have created resistances of individual sizes that vary with respect to circumstances around and within the plant (Larcher, 2001). The stomata and cuticular resistances have a substantial influence on the ability of plants to control the loss of water to the ambient air. In a similar way they have a controlling effect on the influx and efflux of CO_2.

Water is the transport medium for nutrients from the growing medium to the roots and from the roots to the rest of the plant in the xylem. With high salt concentration near the roots, give a high water potential which may lead to restricted water uptake. Water is also the transport agent for assimilates from the leaves to other parts of the plant through the phloem. The source-sink relationship and predominantly the strength of different sinks defines the direction of assimilate transport within the phloem (Larcher, 2001). Transpiration declines when the fraction of transportable water in the growing medium decreases irrespective of the vapour pressure deficit in the air (Ray et al., 2002; Davies et al., 2005).

The term *evapotranspiration* describes the total water loss from the crop system. This involves both transpiration from the leaves and the evaporation from the growing medium surface or other surfaces in the crop production system. In a pot plant production system, the distribution between transpiration and evaporation is affected by: (i) the canopy width and the area of the growing medium covered by the canopy, (ii) the water content of the growing medium, (iii) the dryness of the growing medium surface and (iv) the plant density (Allen et al., 2004).

Several climate factors and microclimatic parameters of the plant are important for evapotranspiration (Allen et al., 2004). Solar radiation or light intensity is considered by the growers to be the variable that is best linked to the evapotranspiration (Paper I). The reason why light integral is a good inducting variable is that it is directly correlated to the integrated heat load on the crop (Paper II). The transformation from liquid water to water vapour needs heat energy. This energy is taken from the solar radiation and the ambient air (Allen et al., 2004). The energy balance between the plant and its surroundings is the driving force of transpiration (Stanghellini, 1987; Stanghellini, 1988). However, the water vapour deficit and the transpiration resistance are also affected by several other factors such as temperature, humidity and air movement (Stanghellini & van Meurs, 1989).

The Penman-Monteith equation is commonly used to describe evapotranspiration in field crop production (Monteith, 1965). This equation estimates evapotranspiration from an evaporating reference surface and compensates with a crop factor or crop coefficient (Allen et al., 2004). However conditions in the greenhouse are different and the transpiration model by Stanghellini (1987) is more suited when estimating the transpiration in greenhouse vegetable production. The equation has to be altered to suit the canopy structure of pot plants (C. Stanghellini pers. Comm. 2010).

The resistance of air flow from the plants has a substantial effect on the evapotranspiration rate. The main fraction of transpiration passes through the stomata, allowing transpiration in relation to the water balance. The stomatal movement is species-specific and is affected by the surroundings, age and leaf position, as well as light intensity, humidity, temperature, CO_2, air pollutants, internal factors such as abscisic acid, phaseic acid, cytokinins, gibberellins, and the water availability at the roots (Larcher, 2001). The stomatal aperture is the significant factor for stomatal resistance (Larcher, 2001). The stomatal conductance (gs) expresses the rate of pore opening and is reciprocal to stomatal resistance rs (1/rs). The higher the gs value, the more open the stomata. In plants there seems to be a long-distance chemical signalling system based on ABA (abscisic acid) that can close the stomata to sustain root water status (Bacon, 1999; Davies et al., 2005). The boundary layer surrounding the leaves and canopy also restricts the transpiration.

The importance of the boundary layer resistance is dependent on the size of the total leaf surface of the crop, the canopy structure and movement of the ambient air. In greenhouse production with a high density of plants per square meter, compact leaf canopies and a limited rate of air movement, the boundary layer resistance will has a decisive effect on both the rate of evapotranspiration and the CO_2 uptake by the crop. Consequently, the transpiration rate might often be more accurately related to the outer canopy surface area of the plants than to the total leaf area of the plants. To calculate the total canopy area for different plant canopies, equations 2 and equation 3 (section 3.7.1) were used in the present work (Paper II).

A simple and effective way of estimating evapotranspiration in greenhouse production is to weigh the plants using high precision scales (van Meurs & Stanghellini, 1992). Short-term weight loss is related to the transpiration process, while weight gain is related to growth. The fresh weight gain of the crop can be estimated from the long-term trends in total weight after drainage (van Meurs & Stanghellini, 1992). Transpiration is affected by the leaf area, a number of crop parameters and aspects of the prevailing climate such as light, temperature and humidity, which have to be taken into consideration when using the weight data (Stanghellini et al., 1990).

By controlling the micro climate around the plants, the transpiration rate can be deliberately altered (van Meurs & Stanghellini, 1989). Humidity is usually not controlled in pot plant production as control is expensive and humidity is not considered a problem. 'Clever' control of the microclimate in the greenhouse is a more efficient way to control transpiration than humidity management in the traditional way (Stanghellini, 1988).

2.3.3 Water shortage and excess

Stress can be described as one or several simultaneously occurring external factors exerting a disadvantageous influence on the plant occurring under natural or horticultural conditions to different extent and duration (Taiz & Zeiger, 2006). Changes and responses to stress can be either reversible or permanent. Certain stress situations can induce cross-tolerance (drought versus salt stress, strong radiation versus heat) (Larcher, 2001).

Water shortage

Water shortage is defined as a situation where water loss (transpiration) from the canopy exceeds water uptake from the roots (Williams et al., 1999; Raviv & Blom, 2001). It can be caused by restricted water supply to the roots due to osmotic binding of water in saline or frozen soils or inadequate water uptake by roots, or by over-extensive transpiration from the leaves due to climate conditions in the surroundings of the plant and may occur on several different occasions during pot plant production. As the different plant responses occur gradually, it is difficult to distinguish between mild and severe water deficit. Plant species, age of the plant and age of the leaves also affect the reaction to the water shortage (Ottoman et al., 2001; Earl and Davis, 2003; Cechin at al., 2006).

Plant reaction and adaptation to a lower water potential in the soil or growing medium is often seen at an early stage (Davies et al., 2005). The first sign of drought is osmotic adjustment in the cells counteracting the loss of turgor pressure in the plant (Nayyar, 2003). This response is mediated by increased amounts of intracellular solutes (sugars, proline, quaternary ammonium compounds) in the cytosol and vacuole (Nayyar, 2003; Cechin et al., 2006) or increased elasticity in the cells (Chartzoulakis et al., 2002). If the osmotic pressure cannot be adjusted, a decrease is induced. Even a small decline in the turgor pressure results in reduced wall stretching and subsequently reduced cell expansive growth (Raviv & Blom, 2001). Another early sign of water stress is stomatal closure (Raviv & Blom, 2001; Cechin et al., 2006). Both photosynthesis and respiration are affected by low water availability (Flexas et al., 2006). After a period of water stress an increased respiration rate occurs (Miyashita et al., 2005; Flexas et al., 2006). During the initial stress phase the photochemical activity is not affected (Souza et al., 2004) but metabolic inhibition of photosynthesis can take place even at mild stress (Cechin et al., 2006). Complete recovery of all gas exchange and fluorescence parameters can be seen after irrigating the plants that have been exposed to water stress for a shorter period (Mielke et al. 2003; Souza et al., 2004). With severe water deficit the biomass production and development of the plants are influenced (Wakim et al., 2005) mainly due to decreased light absorption and changes in the sink-source relationships (Earl & Davis, 2003).

Drought also affects the hormone balance within the plant. Auxin, ABA, and ethylene are those most affected resulting in alterations in stomatal behaviour, and growth of the plants (Farooq et al., 2009; Wilkinson & Davies, 2010).

At constant exposure to water shortage plants adjust their physiognomy e.g. by altering their leaf area, especially in younger leaves, and reducing the mesophyll thickness (Chartzoulakis et al., 2002; Pinherio et al., 2004; Flexas et al., 2006). Moderate water stress reduces leaf area but maintains the total number of leaves (Williams et al., 1999). Plant exposure to drought affects the leaf area index and not the physiological parameters in the first stage (Hoff & Rambal, 2003).

Flooding

Flooding causes lower oxygen supply to the plants due to slower diffusion rates of gases in water compared with air and the relatively low solubility of O_2 in water (Voesenek et al., 2006). Under oxygen deficiency, root respiration is altered to anaerobic dissimilation resulting in accumulation of phytotoxic metabolites (Larcher, 2001; Visser & Voesenek, 2004), impaired H+ efflux pumps and acidification. Abscisic acid and ethylene are produced leading to stomatal closure, epinasty and abscission (Larcher, 2001). The oxygen shortage also results in a lowered nutrient uptake. The severity of the effects depends on plant species, developmental stage, and growing medium properties such as pH and temperature.

2.3.4 Water in growing medium

Growing media used in pot plant production in Sweden are mainly based on a mixture of light and dark peat with different humification levels, harvested as block, harrowed or milled peat (Alsanius et al., 2010). The physical advantages of peat are characterised by a good allocation of water and air due to a favourable mixture of pore sizes (Puustjärvi, 1974; Michels et al., 1993). Peat properties depend on the peat moss characteristics and biological composition of the peat moss (Cativello, 1991; Grosvernier et al., 1997), the degree of humification (H1-H10, according to L. von Post), harvesting methods and manufacturing processes (Alsanius et al. 2010). Peat-based growing media are often supplemented with lime and clay to improve pH conditions and counteract desiccation (Bævre & Gislerød, 1999).

The water-holding capacity of growing media can be described by:

(i) Container capacity, i.e. the total amount of water that can be retained by the growing medium (Raviv & Lieth, 2008)

(ii) Wilting point, i.e. the stage where no water is available to the plant (Raviv & Lieth, 2008)

(iii) The total available water amount (TAW). i.e. the difference between container capacity and wilting point (Allen et al., 2004).

The transition between container capacity and wilting point is marked by a gradual decrease in water potential and an increase in water pressure head.

The most critically decisive physical properties describing the water buffering capacity of the growing medium are (i) porosity, (ii) hydraulic conductivity, (iii) the water retention curve (iv) hysteresis, (v) wettability, (vi) cation exchange capacity, and (vii) bulk density (Schwärzel et al., 2002; Naasz et al., 2008).

Hysteresis is a change in the physical properties after exposure to external distress. In organic growing media, the hysteresis effect can result in water repellence and decreased wettability during the growing period and thus a change in the hydraulic properties (Naasz et al., 2008). Hysteresis in peat is normally explained by: (i) non-geometrical pore uniformity where drainage is governed by the smaller pore and wetting is dependent of the larger pores, (ii) the presence of trapped water in the gas phase in the small pore space and its gradual dissolution depending on how fast the growing medium is rewetted, (iii) volume changes due to shrinkage leading to changes in pore space and (iv) variations in water repellency as the liquid-solid contact angle varies according to the direction in which water moves (Naasz et al., 2008). The effects of hysteresis can be inclusion of air, formation of water-repelling films and changes in pore geometry and in the spatial structure of pores due to shrinkage (Schwärzel et al., 2002; Naasz et al., 2008).

2.3.5 Irrigation management

Irrigation system in pot plant production

Commercial pot plant irrigation systems comprise: (i) sub-irrigation using tables with gutters that provide a favourable microclimate around the plants, irrigation benches where the water is injected at one end and moves along a 0.5-1% slope to the other end of the table forming a shallow water film during the irrigation event, or ebb and flood tables where the water is both provided and drained through a scuttle at one end of the table or, (ii) irrigation given from above, using drip irrigation systems supplying water through a system of tubes to each pot or canopy irrigation by a central water hose These are constructed from a practical and cost-effective perspective, limiting optimal irrigation strategies.

Monitoring irrigation control

Irrigation regime and the climate conditions affect water availability for the plant. In pot plant production the water buffer is restricted to the amount of water kept in the pot, on the tables and, if present, in the capillary mats. A situation of water deficit can thus occur rapidly, especially when plants are grown in small pots, with high evaporation rate (Williams et al., 1999). The irrigation system and control are therefore considerably important.

The moisture content of the growing medium can be estimated indirectly by physical methods using e.g. electrical conductivity time domain reflectometers (TDR) (Caron et al., 2002; Kritz & Khaled, 2004; Paper I), frequency domain reflectometry (FDR) capacitance sensors (Dean et al., 1987; Whalley et al., 1992), water pressure head tensiometers (Cummings & Chandler 1941), gypsum block, electric resistance, neutron probes, granular matrix, heat dissipation or changes in the water volume in the plants and plant environment by digital balances (Meijer at al., 1985), or by using a perceptual, tactile approach in this thesis referred to as 'the golden grip' (Papers I and II) based on the grower's experiential knowledge where water requirement is determined by holding the pot like a pendulum at the upper edge between thumb and index finger and gently twisting it (Paper I). Digital balances display the total water system within and around the plant. All methods have to be used for a large number of plants to compensate for variations (Williams et al., 1999).

Irrigation strategies

Irrigation strategies employed in greenhouse pot plant production are based on occasional irrigation events. The duration of the irrigation event is based on the technical preconditions in the growing system. Irrigation frequency is adjusted with respect to the season (Papers I and II). Normally irrigation is combined with nutrient supply (fertigation).

Irrigation frequency and water volume at each irrigation event affect the plants in several ways. High irrigation frequency increases yieald in several plant species. This is most apparent at low nutrient levels, most likely due to enhanced uptake of nutrients (Xu et al., 2004) especially of phosphorus (Silber et al., 2003; Xu et al., 2004) preventing phosphorous deficiency (Xu et al., 2004). High irrigation frequency (comparing 2, 10 and 18 times a day) continuously replenishes nutrients in the depletion zone in the vicinity of the roots and promotes transport of dissolved nutrients by mass flow (Silber et al., 2003).

2.4 Horticultural knowledge

The different views of knowledge and the difficulties in communicating experientially-based knowledge make knowledge transfer and the search for scientifically-based solutions for commercial growers difficult issues.

2.4.1 The view of knowledge

Knowledge is knowing something or being able to create something (Gustavsson, 2004). It can be described as the relationship between knowing something within an area of expertise that has been acquired from education and studies or through personally experienced events (Molander, 2004). The view of knowledge has altered through history and the present attitude to knowledge has similarities to the ancient view. Aristoteles divided knowledge into three parts; (i) *episteme*, the theoretic-scientific knowledge, (ii) *techne*, practical productive knowledge or craftmanship with the correct understanding of the principles involved and (iii) *phronesis*, practical wisdom (Gustavsson, 2004; Göranzon et al., 2006). The classical understanding of episteme knowledge is the basic strict science that deals with necessary conditions that are said to be eternal or unalterable (Göranzon, 2006) unaffected by personal, political or ethical values (Gustavsson, 2004).

Episteme and techne are often closely related to each other in practical situations regardless of the theoretical view of the forms of knowledge. Phronesis is a practical form of knowledge where validations are made of the knowledge and of the ability of the person to see the effects of the actions and how the surroundings will be affected by them -this might also be called practical wisdom (Gustavsson, 2004).

Due to these multiple characteristics, the view of knowledge varies in different areas of expertise. There is no actual reason to distinguish between theoretical and practical knowledge. However, separate views on knowledge are consolidated by the attitude of theoretically or practically trained individuals or groups of individuals (Molander, 2004).

2.4.2 Knowledge in natural science

Knowledge from a scientific point of view is theoretical and is based on the fundamental laws of nature. Research within natural science aims to study parts of reality that are not previously known (Gustavsson, 2004). Three specific criteria prevail: (i) experience, watching or observation of the target, (ii) a research method and (iii) a theory base as an approach to answer questions (Gustavsson, 2004).

The classical understanding of knowledge in natural sciences builds on a dualistic relationship between subject and object, body and soul, thinking and action. All knowledge can be verbalised in either mathematical terms or words that are value neutral and repeatable (Molander, 2004). The traditional scientific experiment is based on the hypothesis testing method (Schön 1983), comprising verification and confirmation (Gustavsson, 2004).

2.4.3 Experiential and practical knowledge

Experiential knowledge is defined as knowledge that can only be gained personally by observations of situations or events and cannot be learnt any other way, whereas practical knowledge is defined as something that can be produced with awareness and skill. Experientially-based knowledge is predominantly knowledge that cannot be verbalised so-called tacit knowledge (Polyani, 1966; Polyani, 1978; Schön, 1985; Schön, 1987; Rolf, 1995; Molander, 2004; Johannesen, 1999). In experientially-based knowledge the learning process is intimately associated with the action. The keystones for experiential knowledge can be explained using the guild system (Nielsen & Kavle, 2000).

Practical knowledge, learning by doing, differentiates between 'knowing how' which is the skill to perform certain actions and to be able to give an account of what has been done, and 'knowing that' which is the knowledge of the relationship between things, the ability to do something but also to understand what is being done (Gustavsson, 2004). Producing something by routine or, by a lucky coincidence is not knowledge, whereas producing something that is then improved or modified by reflection or new information and skill is knowledge-based (Gustavsson, 2004). Practical knowledge does not support the dualistic view adopted in natural science and has a tacit base (Molander, 2004). 'Practical intellect', which refers to the qualified thinking behind practising and 'the inner picture' are terms used in this context (Göranzon, 1990; Göranzon et al., 2006).

Situated knowledge

Situated knowledge is specific to a situation and is affected by culture social influences and traditions embedded into the situation (Chaiklin & Lave, 1996; Gustavsson, 2004,). Situated learning is a joint product of processing cognitive, social, emotional and environmental goals (Chaiklin & Lave, 1993). It is based on participation in events and dialogues driven by engagements and dilemmas within a fellowship of practitioners (Nielsen & Kavle, 2000).

Tacit knowledge

Tacit knowledge first described by Michael Polyani (1966) is found in both theoretical and experientially-based knowledge (Gustavsson, 2004). Tacit knowledge is knowledge that may not be fully expressed through language or script (Göranzon et al., 2006), and which is integrated into our subconscious (Gustavsson, 2004). It can only be transmitted by training and observation or through personal experience and skills (Molander, 2004). Tacit knowledge can be expressed through body language or by other forms of expression (Gustavsson, 2004). It can be both experientially and situated-based knowledge. The fact that a part of our knowledge is tacit does not mean that it permanently impossible to verbalise (Gustavsson, 2004).

Reflection-in-action

Reflection-in-action is to consider what we are experiencing and can be described as the ability to analyse the practical situation by adopting previous knowledge to the present situation. Reflection-in-action can be momentarily done for shorter time intervals during a certain performance or it might evolve over time as the process of practice continues (Schön, 1983). The structure of reflection-in-action is a combination of a knowledge base acquired in similar situations, and a recognition of the alterations that have to be made for the prevailing situation (Schön, 1983).

Reflection on reflection-in-action

Schön's work has been widely recognised for bringing reflection into the centre of our understanding of what professionals do. 'Reflection on reflection-in-action', 'reflection-in action' and 'reflection-on-action', are concepts that Schön introduces in his book *The Reflective Practitioner* (1983). The concept of reflection still remains open to different interpretations when it comes to the question of its usefulness in practice (Smith, 2001). In *Educating the Reflective Practitioner,* Schön (1987) characterises reflection on reflection-in-action as an activity aimed at producing a good verbal description of reflection-in-action, which can be shared with other people. A skilled professional who is able to reflect on his reflection in action is in a much better position to mediate insights on the source of his professional performance than a professional who is just able to demonstrate his performance without any verbal description. Reflection on reflection-in-action might be a useful tool to develop the irrigation technique (Papers I and V).

Reflection on reflection-in-action is an activity aimed at producing a good verbal description of reflection-in-action which can be shared with other people. To reflect on an event is a process tied to dialogue thinking about the decisions on action. However, a part of reflection might be tacit knowledge and reflection should not be restricted only to expressions in word.

2.4.4 Present and future knowledge within horticultural practice

The present methods 'golden grip' to control pot plants, is almost exclusively experientially-based tacit knowledge. Despite an often high degree of technical equipment and possibilities, individual perceptually based methods of growers are used in the first place. Several other professions have the same approach and have tacit knowledge as a fundamental base, e.g. farmers, handcraft tutors and nurses (Molander, 2004). For several of these professions, a change to more computerised systems is usually difficult to adapt to due to the extent of tacit knowledge. Some professions are science-based professions but act in practical terms, such as agronomists (Schön, 1983). The same applies for horticulturalists.

The challenge for research on irrigation strategies is its implementation into practical use. Growers are currently trapped in the practical silence limiting themselves from seeing beyond the present technique.

To alter the present irrigation method, scientific insights have to be presented in a way that can be integrated into experientially-based knowledge. Similar cases have been studied in job settings when tasks are computerized (Göranzon, 1993).

Knowledge transfer and exchange is an issue of communication. Extension officers can assist in problem structuring and formulation and by channeling scientific insights. Promotion of awareness of one's action, i.e. reflection on reflection-in-action is also a matter of communication. This can be achieved by dialogue-inspired methods (Paper V).

2.4.5 Methods to extract knowledge in horticultural practice

When learning new things, individuals always start off from their foundation of knowledge (Gustavsson, 2004), making knowledge personal and unique.

Reflection-in-action could be implemented by; (i) dialogue seminars, (ii) future workshops or vision workshops first described by Jungk and Mullert (1987) where the participants gather to address a common problem or question. Through brainstorming and communication with the other participants in different constellations, the problems are dealt with through the criticism phase, the vision face and the concretisation phase (Broms, 2010), (iii) open space seminars, a method where the participants have a theme within which they discuss issues, questions and problems and ideas. The participants' own experience, knowledge, ideas and creativity make up the driving force of the process (Broms, 2010) or (iv) writing groups offering a chance to reflect about the experience (Hammarén, 2006). The method here considered to be the most advantageous in the framework of this thesis was the use of dialogue seminars, which is described in detail below. Participatory research can also be mentioned in this context as a good example to a practical process where scientists, advisors and practitioner are united to develop knowledge (Farrington, 1989; Cornwall & Jewkes, 1995; Eksvärd 2003).

A dialogue seminar is based on the Socratic dialogue method (Persson, 2005) where participants are encouraged to think in wider terms, based on their everyday experiences. Dialogue seminars combine reading, writing and communication all to stimulate the reflection process of the participants (Ratkic 2006). A form of this is 'study circles' (Ratkic 2006), which are commonly used by extension officers to communicate with and between growers. They invite talk about tacit knowledge as long as it is made indirectly and expressed through examples that provide a context and by the use of metaphors and analogies (Ratkic 2006). To help to communicate practical knowledge, certain tools, such as familiarity, are needed (Göranzon 2006).

3 Materials and methods

3.1 Plant material

Model plants were chosen with respect to drought tolerance and their known water requirements in commercial production (Table 1).

Table 1. *Model plants used in this thesis, their water requirements and their sensitivity to water shortage*

Model plant	Water need	Sensitivity to water shortage	Paper
Kalanchoë blossfeldiana (Kalanchoë)	High	Low	I, II, III, IV
Impatiens hawkeri (Impatiens)	High	High	III
Euphorbia pulcherrima (Poinsettia)	Medium	Medium to high	III
Argyranthemum frutescens (Marguerite)	Medium to low	Medium to low	III

The experiments were conducted during the period when the plants were fully rooted and established corresponding to the short-day treatment for *Kalanchoë blossfeldiana* and *Euphorbia pulcherrima*. Apart from the experimental study of irrigation frequency (Paper III) plants that had been moved to their final distance were irrigated by sub-irrigation. The long-day treatment corresponding to the period of establishment of the roots, when irrigation was made from above with a water hose, was not included in the studies. *Kalanchoë blossfeldiana* was grown at a plant density of 30 plants m^{-2} (Company 1) and 45 plants m^{-2} (Company 2) *Argyranthemum frutescens* was grown at a density of 45 plants m^{-2} (Company 1). *Impatiens hawkeri* at a density of 28 plants m^{-2} (Company 3) and *Euphorbia pulcherrima* at a density of 32 plants m^{-2} (Company 3) The plants in the experimental studies had a density of 18 plants m^{-2}.

3.2 Growing systems

The studies were performed in both experimental and commercial greenhouse settings, all situated in southern Sweden (Scania).

The experimental studies were performed at Alnarp. Due to the small area with few plants per square meter and concrete floor, the relative humidity was lower (50% RH) than that commonly found at most commercial pot plant production sites.

The empirical studies were conducted at commercial production sites and the growers were chosen on the basis of their high reputation within regional horticulture. The greenhouse specifications are presented in Table 2.

Table 2. *Data for the greenhouse trials*

Site	Total greenhouse area (m^2)	Covering material	Paper
Experimental greenhouses in Alnarp, Scania (55°65'83''N, 13°08,33''E)	1000 (90[1])	4 m high single spanned greenhouses with two layers of acrylic, solar reflection and blackout curtains and trough irrigation benches	I, III
Company 1 Vä nursery Kristianstad (55°59'45''N, 14°5'35''E)	8500 (2400)	4.5 m high Venlo greenhouses with two layers of polycarbonate in the sides and glass in the roof and energy saving, solar reflection and blackout curtains, artificial lightning and trough irrigation benches	I, II, III, IV
Company 2 Tågerup, Saxtorp, Sweden (55°51'22''N, 12°5 '72''E),	23000 (1000)	4.5 m high Venlo greenhouses with two layers of polycarbonate and energy saving, solar reflection and blackout curtains artificial lightning and trough irrigation benches	I, II,
Company 3 AB Poppelgårdens Driverier Ängelholm, Sweden (56°19'63''N, 12°85'59''E)	6500 (1100)	4,5 m high Venlo greenhouses with glass covering material. . Energy saving and solar reflection curtains, artificial lightning and trough irrigation benches	III

[1] Figures in brackets show the area (section) used for the trials.

3.3 Growing medium

The growing medium for *Kalanchoë blossfeldiana* and *Argyranthemum frutescens* used in Company 1 and in the experimental studies consisted of a mix of

25% low humified peat and 60% sphagnum peat supplemented with clay (0.04:1; w/v) (Hasselfors Garden; Örebro, Sweden) whereas Company 2 used a mix of 100% sphagnum peat supplemented with clay (0.08:1w/v) and limestone (0.006:1; w/v) (Unik Prov, Scanpeat, Strömsnäsbruk, Sweden) for *Kalanchoë blossfeldiana*. The growing medium for *Euphorbia pulcherrima* in the experimental studies consisted of a mix of 70% low humified peat H2-3, 0-35mm and 30% moderately humified sphagnum peat H 5-6, sieved 0-35 mm, supplemented with clay (0.08:1; w/v), limestone (0.004:1; w/v) and dolomite (0.002:1; w/v) (Kronmull, Weibulls Horto, Sösdala, Sweden). In Company 3 the growing medium for *Euphorbia pulcherrima* consisted of a mix of 60% harrowed peat H2-5, 0-20mm and 40% peat in block H 2-4, sieved 0-20 mm, supplemented with clay (0.06:1; w/v), limestone (0.0036:1; w/v) and dolomite (0.001:1; w/v) (S:a Århults Torv AB, Markaryd, Sweden) and for *Impatien hawkeri* of a mix of 50% harrowed peat H2-5, 0-20mm and 50% peat in block H 2-4, sieved 0-20 mm, supplemented with clay (0.08:1; w/v), limestone (0.0036:1; w/v) and dolomite (0.001:1; w/v) (S:a Århults Torv AB, Markaryd, Sweden).

3.4 Fertilisers and fertilisation regime

Experimental studies

The plants in the experimental trials were supplied with a complete nutrient solution (Superba Brown, Yara, Sweden, containing (weight-%); N: 14, P: 3.9, K: 21.5, S: 3.1, Mg: 2.0: and B: 0.025 weight %; EC 1.5 mS cm^{-1}, pH 5.8). All the plants were given the same total amount of nutrition, irrespective of plant species (Papers I and III).

Empirical studies

The plants in the empirical studies were fertigated with complete nutrient solutions (N: 150-200, P: 30-45, K: 150-200, S: 60-100, Mg: 100-150: Ca: 800-1200, Mn: 1-2, Bo 0.8-1.2 and Mo 0.1) in each irrigation event during the trials. Normal fertigation levels and amounts adjusted to the crop and irrigation system were used. The EC levels were kept between 2 and 2.5.

3.5 Climate control

The climate set-points in the plant species studied are listed in Table 3.

Table 3. *Climate set-points in studies of irrigation practice*

Set-point	*Kalanchoë blossfeldiana*	*Argyranthemum frutescens*	*Euphorbia pulcherrima*	*Impatiens hawkeri*
Growth period (weeks)	10-12	7.5	9.5	5
Light period	0700 – 1700 H	0600 – 2400 H	0700 – 1700 H	0700 – 1700 H
Supplementary light (Wm^{-2})	40 when natural light decreased to 50	40 when natural light decreased to 50	None	40 when natural light decreased to 100
Shade curtains (Wm^{-2}) (closed partly/fully)		700/900	400/800	400/800
Temperature set-points (°C) (day/night)	19/20	18 /20	13*/17	15*/17
Ventilation set-points (°C) (day/night)	21/22	19/22	23/18	24/18

*with a positive light-dependent addition of 7°C.

3.6 Experimental set-up

The focus of this thesis was to analyse irrigation from a practical perspective and to implement science-based research into the experientially-based irrigation regimes at commercial pot plant production sites. This was done by a triangular approach comprising a questionnaire and in-depth interviews, observations and experiments. A combination of experimental and empirical trials was used to fulfil the need for a comprehensive dynamic approach when science is implemented into a practical domain.

Table 4. *Experimental set-up and the sites for experiments*

Survey area	Experimental greenhouse	Company 1	Company 2	Company 3	Paper
Description of prevailing irrigation pattern	X	X	X		I, II
Climate variables		X	X		II
Irrigation frequencies	X	X		X	II, III
Indication of water shortage		X			IV
Implementation					V

3.6.1 Irrigation patterns

Experimental studies

In order to scrutinise and compare the irrigation procedures, a greenhouse study on the 'golden grip' was conducted in an experimental greenhouse at SLU, Alnarp.

Table 5. *Experimental set-up for validation studies of 'golden grip'*

Pot capacity (kPa)	TDR value ($m\ s^{-1}$)
0	60
-10	40
-50	24
-100	16
Perceptual	'Golden grip'

Four stable water levels (0, -10, -50, -100 kPa) and one variable level corresponding to the 'golden grip' perceptual method were tested (Table 5). As a model plant, *Kalanchoë blossfeldiana* cv. Simone was grown in three blocks at a density of five plants per treatments resulting in 15 plants per treatment. The trials lasted for the short-day treatment of the plants, corresponding to 11 weeks.

Growing media moisture levels were maintained by continuously monitoring the pot by TDR and manually adjusting of the individual containers, keeping them as close to the set point level as possible. Two plants per treatment were continuously connected to the TDR equipment. The amount of water supplied was measured individually with a volumetric cylinder. Fertilizer (Superba Brown) was added simultaneously to all treatments and adapted to treatment 1.

Empirical studies

In order to monitor the evapotranspiration and irrigation patterns, high accuracy weighting scales were installed under a table at two commercial pot plant producers. A part of a table corresponding to 2.1 m^2 ,was separated from the rest of the table while still remaining in place and placed on two load cells. The weight of plants, pots and water supply was recorded continuously. The plant density was 30 plants m^{-2} at Company 1, resulting in 58 plants on the scale and 45 plants m^{-2} at Company 2 resulting in 90 plants on the scale. The weight changes in the system during night and day were then compared against climate factors. This gave a total screening of the variations in the irrigation frequency and volume at the pot plant production sites. Technical specifications of the scales used are given in Paper II.

Questionnaire

A questionnaire was sent to 324 pot plant growers who were registered members of GRO (Swedish growers association) and who were responsible for corresponding to 900.000 m^2 (50%) of the total production area of pot plants in Sweden (Jordbruksverket 2005).

The survey involved questions about the responsibility for irrigation, the factors behind the decision of when and how much to irrigate and influencing variables and factors in the decision to irrigate according to the growers.

In-depth interviews

To get a deeper insight into the decisions behind the irrigation strategies in-depth interviews were performed using open questions based on the answers given in the questionnaire focusing on deeper inquiries were made. These questions covered areas of irrigation decisions, how the irrigation was managed and what irrigation management affected in the production unit. A total of five *Kalanchoë blossfeldiana* growers were chosen for the interviews. The interviews were held at the growers' premises and were all recorded on tape complemented with written notes. The interviews lasted approximately one hour.

3.6.2 Climate influence

Empirical studies

The weight curves obtained from the high precision digital weight recordings of the pot plants were compared with the recordings of the prevailing climate at the production site (Paper II). The weight recordings were made every 5 min and 10 min at Company 1 and 2, and continued for three years covering a number of climate situations and seasons as well as varieties of *Kalanchoë blossfeldiana*. No adjustments were made to growers' normal regimes and the growers did not use the scales to perform or validate their own regimes.

3.6.3 Irrigation frequency

Experimental greenhouse studies

The set-up for the trials carried out in the experimental greenhouse in Alnarp is described in Table 6. The experiment was conducted during two seasons (Sept–Nov). As no differences were observed between the treatments when using a water volume of 90 mL (season 1), the volume was adjusted to 45 mL during the second trial (season 2). The experimental design was three blocks, with 18 plants per block. Plants were used in destructive measurements every other week and three plants per block (9 per treatment) were analysed. The initial total number of plants per treatment was 54 plants.

Table 6. *Experimental set-up for the trials on irrigation frequency*

	Season	Frequency		
Irrigation frequency and time/s		Once every 3 days, at 0800 hours	Once a day, at 0800 hours	Three times a day, at 0800, 1200 and 1600 hours
Irrigation volume per occasion (ml)	1	90	30	10
	2	45	15	5

Empirical studies

At two of the greenhouse production sites (Company 1 and 3), empirical trials on irrigation frequency were conducted. The normal irrigation regime was compared with more frequent irrigation in which *Euphorbia pulcherrima,* (Company 3) was irrigated once every day (frequent) and once every third day (normal regime), *Impatiens hawkeri* (Company 3) was irrigated once every day (frequent) and once every other day (normal regime) and *Argyranthemum frutescens*, (Company 1), was irrigated three times a day (frequent) and every other day (normal regime) (Paper III). In both companies the studies were made on a whole table resulting in 585 plants for *Argyranthemum frutescens,* 720 for *Euphorbia pulcherrima* and 630 *Impatiens hawkeri*. Ten of these and 10 reference plants from the same crop irrigated as usual were monitored regarding plant development.

3.6.4 Indications of water shortage

Empirical studies

In order to find the point at which a restricted irrigation regime resulted in damages to pot plants, shorter drought intervals were studied in empirical settings. *Kalanchoë blossfeldiana* cv. 'Simone' was used as it is a CAM plant and the onset of the CAM mechanism was used as an indicator of when the plants experienced a water scarcity. The plants were grown in 12 cm pots. The experiment consisted of four treatments in two blocks and 12 plants per treatment and block, resulting in 24 plants per treatment. Photosynthesis and fluorescence measurements were made on three plants per treatment during the drought periods (Table 7).

Table 7 *Experimental setup for the two-factorial study (volume and drought) on indications of water stress*

Treatment	Water volume (ml pot^{-1})	Regime	Drought period
1	50	Normal irrigation regime	2
2	50	Normal irrigation regime	0
3	66.7	33% additional water supply as compensation	2
4	66.7	33% additional water supply as compensation	0

The experiment was set up as a two-factorial trial with water volume (50, 66.7 mL) as factor 1 and exposure to drought as factor 2. The 50 mL dose of nutrient solution per irrigation event corresponds to the standard dose in the commercial setting.

The plants were then exposed to drought during two short periods (period 1: 6 days, period 2: 8 days). These periods were separated by a 5 week period of normal irrigation. The first drought treatment was given week 2, when the grower considered the plants to have the most intensive growth.

3.6.5 Implementation

A range of methods described in the literature for increasing grower reflection were evaluated in relation to horticultural production.

3.7 Analyses and assessments

3.7.1 Plant analyses

In all trials plant development and growth were measured once a week as regards (i) the height of the main shoot or stem length: (ii) canopy width (iii) the stage of development (defined according to Paper II) and the (iv) total canopy surface area (calculated from the width and height data, Paper II). For critical developmental stages 10 plants were analyzed for (v) total leaf area, (vi) dry and (vii) fresh weight of the canopy and stem of the plants (Papers II, III and IV).

The total leaf area for each plant was measured by separating the leaves from the main stem and using a Licor Li 3100 Area meter (Li-Cor Instruments Inc, USA) (Papers II and III).

The total canopy surface area was chosen as the area of transpiration (Paper II, III).

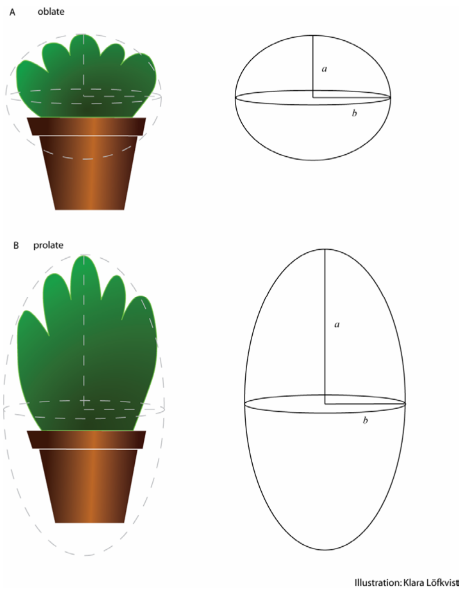

Figure 1. The total canopy surface area estimated as a half-ellipsoid.

Estimation of the total canopy surface area (Paper II) was based on canopy shape separation between oblate (A) and prolate (B) ellipsoid surface areas (equations 2 and 3). We estimated the shape of the leaf canopy to resemble that of a half-ellipsoid. Oblate ellipsoid shapes (Figure 1A) display an ellipsoid rotated around its minor axis with equatorial radius b being larger than polar radius a. Prolate ellipsoid shapes (Figure 1B) were defined as ellipses rotated around their major axis with the equatorial radius *b* being smaller than the polar radius *a* (Michon 2005). The oblate surface area, S_o, can be estimated using equation 2:

$$S_o = 2\pi b^2 \left(1 + (a/b)^2 \operatorname{atanh}(k)/k\right) \quad (2)$$

with $k = \sqrt{1 - a^2/b^2}$ and $\operatorname{atanh}(k) = \tfrac{1}{2}\ln((1+k)/(1-k))$

The prolate surface area, S_p can be estimated by equation 3:

$$S_p = 2\pi b^2 \left(1 + (a/b)\arcsin(\sqrt{1 - b^2/a^2})/\sqrt{1 - b^2/a^2}\right) \quad (3)$$

The length of the plants main shoot was measured from the top of the pot edge to the apical growth point of the plant (± 0.25 cm).

For weight measurements, the plants were cut of at the growing medium base and canopy fresh weight was recorded. The plants material was then dried at 80°C for at least five days in order to estimate the dry weight.

Photosynthesis and stomata conductance

During the drought treatments (Paper IV), photosynthesis and stomata conductance were recorded using an LCpro+ analyser (ACD BioScientific Ltd, UK). The leaf CO_2 assimilation rate was recorded on eight plants per treatment at an irradiation level of 1500 μmol $m^{-2}s^{-1}$ PAR as preliminary studies had shown that the assimilation rate reached an optimum at this irradiation level. Recordings of the photosynthesis and stomatal conductance were all made on one of the leaves of the third fully developed leaf pair counted from the shoot apex.

Chlorophyll fluorescence

During the drought treatments (Paper IV) fluorescence was recorded using a PAM-2000 fluorescence meter (Waltz Mess und Reglertechnik, Effeltrich, Germany).

The fluorescence was measured by first estimating the basic fluorescence from plants placed in total darkness for 20 min. The maximum fluorescence was then determined by exposing the plants to a high light level. The ratio between the two excitation rates (Fv/Fm ratio) was calculated. After 90 s when the fluorescence had relaxed to a value close to F0 again the plants were given actinic (photosynthetically active) light at a strength of 300 μmol $m^{-2}s^{-1}$. The actinic light gave a high fluorescence rise that decreased first quickly and then slowly to a steady state after 10 min. A final light flush was then given to achieve the maximum (Fm') and minimum (Ft) fluorescence under the light conditions and the PSII quantum yield was calculated. Recordings of fluorescence were made on one of the leaves of the third fully developed leaf pair counted from the shoot apex (See section 2.3.1).

3.7.2 Physical properties of the growing medium related to moisture

Moisture level in the growing medium

To evaluate the 'golden grip', level the moisture content of the growing medium was estimated using TDR. Standard levels of water corresponding to a suction of 0, 10, 50 and 100 cm water column (0, 1, 5 and 10 kPa) (Gabriëls and Verdonk 1991) were produced. The standard levels were then compared with data obtained using time domain reflectometry (TDR; Kritz and Khaled 2004). Four distinct levels were selected (i: 60 m s^{-1}, ii: 40 m s^{-1}, iii: 24 m s^{-1}, iv: 16 m s^{-1} corresponding to pot capacity 0, 10, 50 and 100 cm of water pressure head, respectively). The TDR equipment was inserted into the pot diagonally to estimate the water level (Paper I)

The other way to measure the water content was by using the high accuracy digital scales.

Physical analyses of growing medium

The growing media used in all studies were, similar to those used by the growers in commercial production and were adjusted to the crop and the irrigation system at the production site. Characteristics of the growing media used regarding hydraulic characteristics such as rewetting ability and other physical properties were studied to define the hysteresis in the wetting and drying process.

The growing media were prepared following the European standardised procedure NF EN 13041 (2000). Water retention properties were determined using classical hydrostatic methods on four replicates for each growing medium. In brief, small cylinders were first placed on a tension table to drain the materials from -1 kPa to -10 kPa, after which higher suction levels (-31.6 kPa and -100 kPa) were obtained using a high-pressure chamber.

The contact angles related to the medium water content or water potential were measured by the capillary rise method comprehensively described by Michel et al. (2001) (Paper III).

3.7.3 Level of knowledge reflection

Growers' answers were analysed through transformation in to binary numbers and the responses to questions were compared to get a total perspective on irrigation control.

The questionnaire and in-depth interviews were analyzed phenomenologically (Alsanius 2001 and Paper I) using the Biggs and Collis structure of observed learning outcomes (SOLO) scale grouping the level of understanding into five different categories (Biggs and Collis 1982):

1. The pre-structural level where the person is only using small bits of unconnected information that are not organised or understood.
2. The uni-structural level where the person understands simple and obvious connections and can identify simple parts.
3. The multi-structural level where the person can make connections but the relationships between the connections are missing.
4. The relational level where the person can see the relationships between connections and the whole. The person can arrange the facts and theory, action and purpose. There is an understanding of several components which are integrated conceptually. The person can make comparisons, explain causes and integrate, relate and apply the knowledge.
5. The extended abstract level where the person can make connections not only within the given subject but also beyond it. Generalisations and transfer of the principles from the specific area to other areas can be made. A reflection on the knowledge can be made.

3.8 Calculations and statistics

For pair-wise analysis the data were analysed using a one and two-way ANOVA and Tukey's test with $P<0.05$ (Minitab version 14 and 15).

Linear relationships were calculated using regression and fitted line plot (Minitab 14 and 15). (Papers I, III and IV)

In analyzing the questionnaire, alternative responses were transformed into binary numbers and frequencies were calculated (Minitab version 14; U.K.). Alternatives including free answers as well as the in-depth interviews were analysed using the SOLO-scale (Paper I).

The slopes of the weight curves obtained from the scales were calculated for each hour using linear regression (MATLAB version 7, Mathworks Inc., 2005) and a model based on the best fit description was made. The slopes for adjacent hours were modelled as an AR(1)-process unsing SAS (PROC MIXED) (SAS Institute Inc., 1999).

4 Results and discussion

The goal of this study was to create a comprehensive picture of the factors influencing irrigation strategies in pot plant production and to determine how to develop this area of expertise. A triangular approach consisting of a combination of observations, experiments and implementation was used.

Irrigation management covers a large area of expertise. There are a large number of scientific studies on irrigation frequency (Morvant et al., 1998; Composeo & Rubino, 2003; Silber et al., 2003; Silber, 2005; Silber et al., 2005; Beeson, 2006; Katsoulas et al., 2006; Eiasu et al., 2008; Tsirogiannis et al., 2010), drought management (Petersen & Hansen, 2003; Hansen & Petersen, 2004; van Iersel & Nemali, 2004; Emekli et al., 2007; Eiasu et al., 2008), and plant responses to drought (Ota, 1988; Bohnert et al., 1995; Bacon, 1999; Chartzoulakis et al., 2002; Earl & Davis, 2003; Chaves at al., 2009; Farooq et al., 2009; Flexas et al., 2009). There have also been numerious studies of growing media (Puustjärvi, 1974; Michels at al., 1993; Grosvernier, 1997; Raviv & Blom, 2001; Caron et al., 2005) and their properties (Whalley et al., 1992; Michel et al., 2001; Li et al., 2002; Schwärzel et al., 2002; Lebeau et al., 2003; Naasz et al., 2005; Naasz et al., 2008; Wallach & Raviv, 2008) as well as evapotranspiration (Monteith, 1965; Stanghellini, 1987; Barker, 1998; Hsieh et al., 1998; Kage et al., 2000; Rana & Katerji, 2000; Nagler et al., 2003; Beeson, 2006; Farahani et al., 2007; Karam et al., 2007). However a holistic dynamic approach focusing on the practical applications has not yet been presented. This thesis presents a novel approach for irrigation in Swedish greenhouse horticulture as it focuses on the link between horticultural practice and science.

Scientific experiments on irrigation mostly conducted under phytotron and experimental greenhouse conditions commonly focus on one or a limited number of factors. Few experiments are made in commercial greenhouses due to the fact that standardisations are difficult to achieve.

Implementation of the scientific results produced is seldom addressed, resulting in few developments within horticultural production. The importance in the application of the scientific results is the dynamic interaction of all variables involved. This is often handled by creating models but these are mostly not used in Swedish horticultural production. The present studies were built on the unique interest of the growers involved, providing an opportunity to connect science with the practical control of irrigation. Few previous studies have elected to adopt a similar approach.

4.1 Irrigation management

One of the main issues examined in this thesis is the challenge of implementing theoretically-based knowledge into experientially-based knowledge.

The prevailing method for irrigation management used in commercial pot plant production sites is the 'golden grip', a perceptual and tactile method where the grower combines the estimated weight of the pot (both growing medium and plant) with factors such as plant age, developmental stage and size in combination with prevailing and future climate conditions (Paper I). This approach uses, experientially-based, context-bound and situated knowledge (Molander, 2004; Johannesen, 1999) which according to several growers takes at least three years to acquire and is one of the most advanced tasks in pot plant production demanding a lot of the performer (Paper I). At present much of the knowledge base of the 'golden grip' is tacit knowledge, as there is no uniform understanding of the fundamental factors behind the 'golden grip' expressed in words. All growers have the same intention namely to keep the moisture in the growing medium low to limit unwanted elongation growth. Despite this uniform intention regarding irrigation goals, large variations exist both between and within production sites (Papers I and II) (Figures 2 and 3). This tacit dimension makes discussion and communication with scientists, advisors and colleagues difficult.

The technical standards and irrigation equipment are often advanced within pot plant production but might impose limitations on a flexible irrigation regime for the following reasons; (i) irrigation sections are often large, counteracting individual alterations, (ii) the irrigation capacity that cannot supply all plants at the same time (only a problem in summer time), (iii) the irrigation volume supplied in each irrigation event is based on the time it takes to provide all the plants with water. The conventional irrigation method used today is poorly adjusted to the actual water consumption by the plants (Paper II). Comparisons of the growers' own 'golden grip' with alternative irrigation regimes showed that improvements in plant quality were possible (Paper IV). This, in combination with a lack of guidelines, leads to suboptimal irrigation in several situations and a considerable potential for improvement.

4.2 Impact of climate

The need for irrigation is a result of evapotranspiration, which is driven by the vapour pressure deficit between the plant and its surroundings and is affected by a number of climate variables (Allen et al., 2004). Light is the variable singled out by the growers as being the most important for irrigation requirements (Paper I). Increasing light intensity raises, the total heat load in the greenhouse, which affects the vapour pressure deficit and subsequently evapotranspiration (Stanghellini, 1987; Stanghellini, 1988). Studies on tomatoes and Impatiens New Guinea have highlighted the importance of temperature (Mankin et al., 1998 & Riga et al., 2008), which emphasises the close interaction between light intensity and heat load. Previous studies have shown a significant interaction between light intensity and dry weight emphasising the importance of light on plant performance (Gislerød et al. 1989).

When comparing the evapotranspiration recorded by the high precision weighting scales was compared with the prevailing climate, both as a single factor and in combination with others, the light integral was the most influential variable (Paper II). The higher the light integral outside the greenhouse, the more rapid the water loss (r=0.68). The time of day affected the evapotranspiration, indicating that the light intensity was important (Paper II and Figure 3) which is supported by other studies (Nielsen, 2001 & Mortensen, 2004). It was also confirmed by the fact that this phenomenon was expressed more in the winter than in summer, when the overall irradiance is higher. Despite the dominant role of light integral, few direct alterations to the irrigation regime were made by the growers (Figure 2 and 3).

Step-wise correlation of the evapotranspiration with the prevailing climate produced equation 4 (Company 1) and equation 5 (Company 2).

$$y = 0.273 + 0.000171 \cdot light - 0.0004 \cdot temp \cdot RH - 0.0556 \cdot t + 0.00712 \cdot t^2 - 0.00026 \cdot t^3 \quad (4)$$

$$y = 0.539 + 0.000468 \cdot light - 0.02155 \cdot temp - 0.03440 \cdot t + 0.01137 \cdot t^2 - 0.00053 \cdot t^3 \quad (5)$$

where temp (°C) is the average temperature during one hour, light (Wm^{-2}) is the light integral over one hour, RH (%) is the relative humidity and t is the time of day. Surprisingly, the number of days since the last irrigation event was not significantly important for the evapotranspiration rate. This indicates that the plants' transpiration is not normally restricted by the water content in the growing medium.

A plant-related factor affecting the evapotranspiration rate is the resistance to airflow from the plants (Katsoulas et al., 2007). The boundary layer restricts transpiration. In a dense crop in a greenhouse, the surface of the canopy is the area in contact with the surrounding air making the total canopy surface area a better estimation of the transpiration area than the total leaf area. A model for estimation of the total canopy area resembling a half-ellipsoid sphere is presented in Paper II.

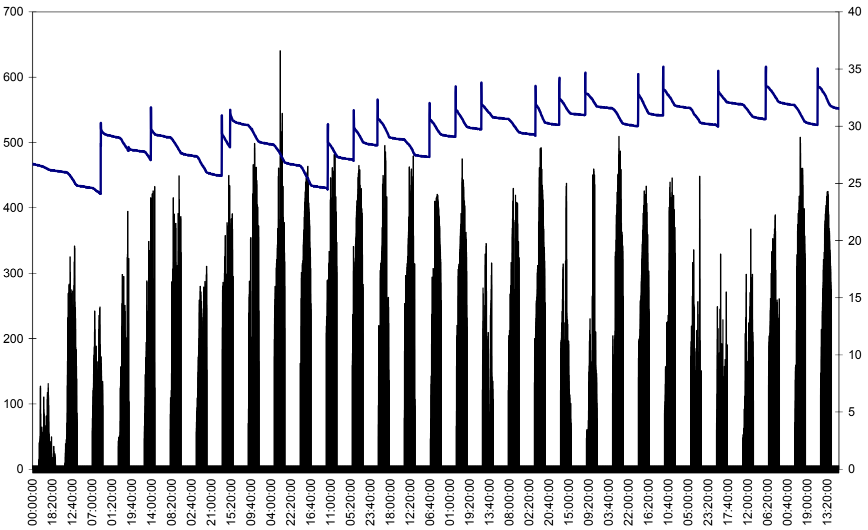

Figure 2. Irradiance (Wm^{-2})(staples) and weight of a pot plant cropping system consisting of 45 plants (*Kalanchoë blossfeldiana*) including pots and growing medium and gutters. Weight was recorded 12 times/hour (every 5 minutes) using a high accuracy digital scale. (Priva Growscale (PRIVA)) The irradiation shown is an accumulated value comprising outside light intensity complemented with supplementary light and adjusted with reductions caused by greenhouse structures. Variations represent measurements made during one month (June 2003) at Company 1.

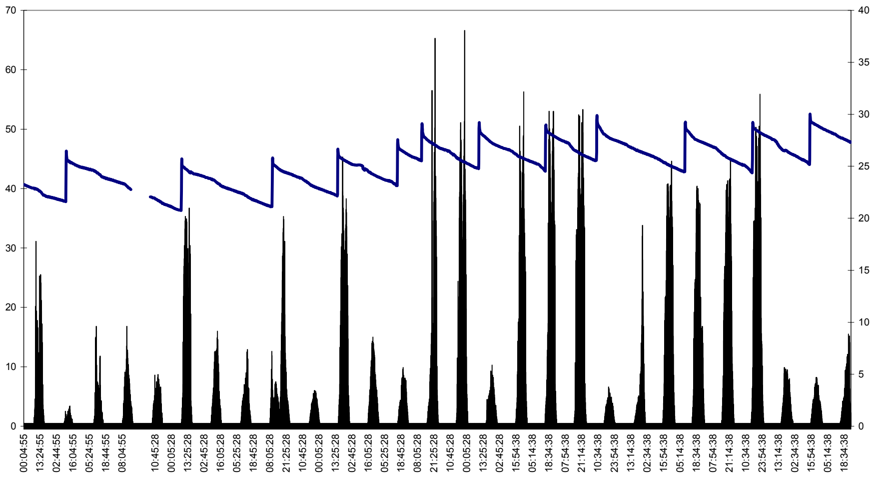

Figure 3. Irradiance (kluxm^{-2})(staples) and weight of a pot plant cropping system consisting of 91 plants (*Kalanchoë blossfeldiana*) including pots and growing medium and gutters. Weight was recorded 6 times /hour (every 10 minutes) using a high accuracy digital scale. (Priva Growscale (PRIVA)). The irradiation shown is an accumulated value comprising outside light intensity complemented with supplementary light and adjusted with reductions caused by greenhouse structures. Values represent measurements made during one month (Febuary 2003) at Company 2.

4.3 Growing medium

In commercial settings the growing medium is chosen with respect to the grower's irrigation system and preferences as regards irrigation strategy, and little or no alterations are made once a suitable medium has been chosen. The physical properties of growing media used today are well covered within the scientific literature and in this thesis, they were only studied regarding their response to irrigation regime. The plant responses to the altered irrigation frequency (Paper III) might be explained by differences in growing medium properties. The rewettability of the growing medium used in the experimental studies for *Kalanchoë blossfeldiana* was higher and had a longer penetration time for water than that used for *Euphorbia pulcherrima*.

When altering the irrigation regime, the influence of the growing medium has to be taken into consideration to give the plants the best opportunity for growth (Naasz et al., 2009). The hysteresis effect of the growing medium used for *Euphorbia pulcherrima* indicated a resistance to rewetting after being severely desiccated (Paper III). Induction of hysteresis through exposure to drought and the concomitant change in physical properties have been reported in previous studies by Schwärzel et al. (2002); Naasz et al. (2008) and Michel (2009).

4.4 Irrigation frequency

Irrigation frequency is one parameter that can be altered under commercial settings. With more frequent but smaller irrigation volume per irrigation event, the total water volume could be decreased. This is unlikely to be adopted by growers, who fear that a more frequent irrigation regime would result in elongated plants (Löfkvist & Schüssler, 2000). To investigate this, a more frequent irrigation regime with the same amount of water given was studied for four plant species (Paper III). Plant responses to altered irrigation frequency became visible when the water was not given in abundance defined as drainage from the pot. No significant differences could be seen with respect to the time of flowering or the amount of flowers between the different irrigation frequencies (Table 8).

The results from the two-factorial trials with two peat species and three irrigation frequencies did not support growers' perception. However, leaf surface increased with more frequent irrigation. Validations under empirical settings indicated increased shoot length for *Euphorbia pulcherrima* and *Argyranthemum frutescens,* as well as higher fresh and dry weight for *Argyranthemum frutescens* and *Impatiens hawkeri* respectively. Hence, increased irrigation frequency enhanced biomass variables and increased nutrient uptake especially of phosphorus as previously demonstrated in other plant species (Silber et al., 2003; Xu et al., 2004; Silber 2005). Generative variables were not affected by altered irrigation frequency (Paper III).

Other studies on *Euphorbia pulcherrima* (Morvant et al., 1998) showed that a higher irrigation frequency produced taller plants with larger canopy diameter and greater flower, bract leaf, root and total dry masses, which partly supports growers' fears and the findings from the validations in the commercial greenhouses. However, the more frequently irrigated plants in the study by Morvant et al. (1998) obtained lower quality ratings. These results might be explained by the fact that plant water consumption measured by weighting scales determined the irrigation amount and the frequently irrigated plants required more water than the intermittently irrigated. The total water volume given affected the amount of flowers (Paper IV), which might be the reason for the results reported by Morvant et al. (1998). The explanation for the growers' perception of more abundant growth due to higher irrigation frequency might be a larger total volume of water administered. Studies with *Gerbera jamesonii* showed no effects on leaf area, fresh weight, harvested cut flowers and quality of gerbera flowers (Tsirogianni et al., 2010). In that study the irrigation frequency was based on the solar radiation amount controlling the irrigation to different irradiation sums, resulting in more or less frequent irrigation. However this approach neglects other parameters important for evapotranspiration and thus the need for irrigation (Paper II).

Table 8. *Plant responses to a more frequent irrigation regime than commercial pot plant production*

Plant species	Shoot length	Total leaf area	Canopy width	Fresh weight	Dry weight
Kalanchoë blossfeldiana (experimental)	ns[1]	Larger at higher i.f.[2]	ns	ns	ns
Euphorbia pulcherrima (experimental)	ns	Larger at higher i.f.	ns	ns	ns
Euphorbia pulcherrima (empirical)	Longer for at higher i.f.	ns	ns	ns	ns
Argyranthemum frutescens (empirical)	Longer at higher i.f.	ns	ns	Larger at higher i.f.	ns
Impatiens hawkeri (empirical)	ns	ns	ns	Larger at higher i.f.	Larger at higher i.f.

[1]ns: no significant differences between the irrigation frequencies.

[2]i.f.: Irrigation frequency

4.5 Indications of water shortage

A restricted irrigation regime is usually mentioned by growers as being used to decrease vigour elongation growth of the main shoot and of flower stems (Paper I). To transform restricted irrigation managements to an operative tool, the cardinal points for drought levels (growth limitation, plant damage) have to be defined. In the present thesis, this was simulated by short periods of drought in *Kalanchoë blossfeldiana* (under commercial conditions) (Paper IV).

The reactions of plants to water shortage were measured by photosynthesis, stomatal conductance and fluorescence, i.e. non-destructive measures reflecting photosynthetic activity.

Both the CO_2 assimilation rate and the stomatal conductance were decreased during the drought treatment, which was expected. Under prevailing conditions the measurements of the photosynthetic fluorescence showed only minor variations during a short drought treatment, indicating that there were no signs of oxidative stress. A small decline in photosynthetic potential of the reaction centres of PSII could first be seen during more severe drought treatment (period 2).

The recordings of shoot height only indicated minor differences between the plants exposed to the drought periods and the plants that were irrigated as normal. This is supported by studies made on marigolds, where smaller, but not compact, plants were achieved by drought (van Iersel and Nemali 2004). However, the number of flowers on the drought-treated plants, recorded at the end of the trial, was lower than on the untreated plants, which has also been reported from drought treatments on Campanula (Petersen & Hansen, 2003). Visual inspection of the plants from the different treatments indicated that the plants subjected to short-term drought treatment had a greyish and dull appearance and had impaired commercial value.

The study clearly indicates that the method of controlling plant growth by manipulating the irrigation is difficult for growers to manage (Paper IV). Using drought as a tool to control plant growth is a hazardous method that demands high awareness of the variables affecting the plant growth. It also demands a high quality growing medium that is resistant to hysteresis (Paper III).

4.6 Implementation of science in practical horticulture

Scientific data on the effects of irrigation on plants and the impact on horticultural practices are available but new approaches have to evolve for successful knowledge transfer. This requires an understanding of different perceptions of knowledge. Due to the tacit dimension of the practical knowledge, communication between growers and scientists is restricted.

A central issue is the fact that the grower's action is not always linked to awareness of the actual decision to irrigate and this level of reflection has to be increased (Paper I). In order to do so, tools for reflection have to be presented to the growers channelling scientific results (Paper V). A conscious awareness in the moment (reflection-in-action) and tools to reflect on the reflection-in-action have to be used within horticulture. In this context, the time gap between action and result (plants ready for sale), delays feedback to the grower and creates a challenge to learning from experiential knowledge. This restricts the opportunity to learn from each irrigation event. Awareness of, and reflection on, the decisions to irrigate could provide insights into the factors affecting evapotranspiration and the associated irrigation requirements and thereby broaden the cognitive level within the group of participants.

Reflection on reflection-in-action is an activity that aims to produce a good verbal description, which combined with visualisation of the "golden grip" through high accuracy digital scales (Figures 2 and 3) may release the tacit dimension in irrigation. Dialogue-inspired methods allow scientific research on knowledge interchange and breakthroughs in introduction of sustainable technology in communities relying on experiential knowledge. Examples of dialogue-inspired methods are study circles and dialogue-seminars (Paper V).

It is tempting to speculate whether lack of distinctiveness on the part of researchers and lack of incentive on the part of growers are possible reasons for the reluctance to implement innovations. This thesis provides no clear answer to that question. The high rate of avoidance or 'not knowing' of gaps in knowledge or need for information on irrigation (Paper I) might shed some light on 'irrigation management' in the practical world where the study was conducted. As practitioners' knowledge is embedded in social and cultural context (Chaiklin & Lave, 1996) and knowledge acquisition is dialogue-based, irrigation management was most likely not a topic within practitioners' general discussions. This is also supported by the low level of complexity found in the survey and in-depth interviews. However, two of the interviewees (Paper I) discussed irrigation on a metacognitive level. In the light of the model for innovation-decision suggested by Rogers (2003), this indicates that the topic at the time of the investigation had been taken up by 'innovators', but not diffused to the group of 'early adaptors'. To enhance this diffusion, dialogue-based seminars on reflection on reflection-in-action would be appropriate (Paper V).

5 Concluding remarks and further perspectives

Improvements to the 'golden grip' should be possible to achieve with the right approach. However any alterations to the conventional method are difficult to accomplish without understanding the different views of knowledge and how to improve experientially-based knowledge. The general understanding of the power of reflection has to be improved and used in communication and improvement of the present methods. High precision weighing scales can give growers a tool to reflect on their irrigation performance and can also facilitate the ability to communicate the knowledge with other growers, further increasing the conditions to reflect on reflection-in-action. Dialogue-inspired study circles with growers should be created and evaluated in order to build a tool for implementation of new scientific results into the experientially-based world of horticulture.

Due to the dominant role of water in plant growth, controlling the water supply could decrease the need for chemical growth control agents. However more research regarding how drought can be used as a method to restrict elongation growth without damaging the plants developmental rate has to be done. According to the growers involved in the in-depth interviews, it is not possible to compensate for a poor irrigation regime with chemical growth regulators. In other words, an appropriate irrigation regime is the key to success in growth control. With the appropriate irrigation and climate regimes in combination with the correct varieties and culture control, compact pot plants can be successfully produced without chemical growth regulators. Finally, more attention to the effects of irrigation frequency and water levels on the growing media properties would improve water supply to pot plants.

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