Chapter 14
Fertigation Management of Potted Plants

14.1 Introduction

The horticultural crops considered in this chapter are characterised by the fact that the plants are grown in a restricted volume, like pots, containers, plastic trays or compressed peat blocks. In the market these crops are recognized as potted plants, bedding plants and container grown nursery stock, mostly for ornamental purposes. Another group is the raising of young vegetable and cut flower plants, due to production holdings. Although extremely diverse, all these plants are grown as single units and this makes the water supply of the plants complicated. Trickle irrigation is generally unsuitable because it is laborious, due to rapid changing crops and plant densities and besides expensive because of the large number of units per area. Exceptions are the plants grown in large containers, like balcony and patio plants, some nursery stock and subtropical trees with a long growing period and a low plant density. Overhead sprinklers induce excessive losses of irrigation water and nutrients, since a considerable amount of the irrigated water falls alongside the pots or drips from the leaf canopy mostly also alongside the pots. Moreover, the water supplied is absorbed per individual plant or plant batch, which strongly enhances the variation in the water and nutrient status of such units. To avoid these problems, potted plants already have been grown for many years on concrete floors or on container benches with sub-irrigation. Nowadays, in all modern greenhouses this is the common growing system. In contrast with vegetable and cut flower nurseries, potted plant nurseries are not always specialised in one crop, but in different plant species. Even if they are specialised in one plant type, different plant stages are present at the same time, like with *Kalanchoë and Chrysanthemum*. A variety of crops creates diversity in nutrient demands and other parameters for the root environment. This complicates a crop-specific nutrient management in greenhouses grown with potted plants, which can also be aggravated by the relative short growing period of some of these crops. Moreover, unlike vegetables and cut-flowers, the research on nutrient demands for many potted plants is limited and the number of species and cultivars grown change rapidly with the constant introduction of novelties. Therefore, the nutrient management is partly based on experience and the complexity of the management induces the need for a general and robust approach.

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Picture 14.1 Potted plant production in a modern greenhouse

In virtually all crops peat or peat based mixes are used as growing medium. The chemical characteristics of potting media and the analytical methods used are extensively discussed in the Chapters 11 and 4 respectively. In this chapter the 1:1½ by volume extract is meant in all cases of nutrient analysis in the potting medium, unless stated otherwise. The rooting volume is very restricted for this category of plants, especially in plant propagation at which it varies from only less then 50 ml per plant for pressed peat blocks to 250 ml for fruit vegetable plants in rock wool blocks. Also for bedding plants the root volume is restricted to less than 100 ml per plant.

Hydroculture plants form a specific group and are mostly grown in expanded clay granules. For the nutrient management these plants are treated as hydroponics. A nutrient solution as generally used for this type of cultivation is added to Appendix C.

Potted plants are typically marketed in the growing medium. Therefore, the nutrient management must not only be focussed on the growing process in the greenhouse but also on the post-harvest phase. The plant must be prepared for the transport, the shopping phase, as well as the stay at the consumer.

The conditions for the propagation of vegetable and cut flower plants are for a great part equal to those of potted- and bedding plants. These nurseries nowadays are often very large and specialised in crop type and virtually all of them grow the plants on concrete floors with ebb and flood irrigation.

Picture 14.2 *Beaucarnea* grown on a concrete floor with ebb and flood irrigation

14.2 Classification

As mentioned, the number of different potted plant species grown is huge and as a consequence the requirements for the nutrient supply are divers and will be met with a classification to groups with reasonable agreement. The species originate from different climatic zones and from places with very different soil or growing medium, which makes a classification on basis of such parameters more or less impossible. Classification by family or genus is also inadequate, since differences between species can be larger within one genus than between genera. For the Dutch situation a simple system is chosen which is applicable in practice and based on a classification in groups with more or less equal demands for the root environment. The system is characterized by three parameters, viz. the nutrient status, the EC level and pH requirements (Straver et al., 1999).

The first parameter concerns the nutrient concentrations and the different nutrient ratios in the root environment. The differences of last item mainly exist in the K:Ca and the K:N ratios. In total 11 classes are defined, each with its typical nutrient solution and accompanying target values for the nutrients in the root environment, as determined in the 1:1½ extract. The micro element concentrations are kept equal for all groups. All known potting- and bedding plants are assigned to one of these 11 nutrient classes.

The second parameter of the system is aiming at the salt sensitivity of the crops. Three levels are defined by the total EC in the root environment (Table 14.1).

Table 14.1 Parameters for salinity and pH used for the classification of potted and bedding plants. The values for salinity represent the maximum acceptable values per class determined in the 1:1½ extract. The values for the pH indicate the range for each class, the boundary value indicates when additional NH_4 should be supplied

Class	Salt sensitivity of the crop	EC dS m^{-1}	Na mmol l^{-1}	Cl mmol l^{-1}
1	susceptible	1	1.7	1.7
2	moderate susceptible	1.4	2.5	2.5
3	not susceptible	1.8	3.5	3.5
Class	**pH classes[1]**	**boundary**		
1	< 4.6	5.1		
2	4.6 – 5.4	5.9		
3	4.9 – 5.7	6.2		
4	5.2 – 6.0	6.5		
5	5.5 – 6.3	6.8		

[1] In mixtures with clay, the values should be increased with 0.5 unit.
Data after Straver et al. (1999).

The determination of the EC includes residual salts as well nutrients, thus the total osmotic potential. The concentrations of Na and Cl in the potting soil are defined also, since some crops are specific sensitive for Na or Cl (Sonneveld, 2000). A complication is that some crops show a distinct difference in response tot salinity dependent on the climatic conditions (Sonneveld, 2000). If this is the case, the crops are classified following the lowest acceptable level.

The third parameter concerns the pH requirements, in which five levels are distinguished. This is aimed at the pH conditions in the natural habitat of the plants and described more in detail in Section 14.5.

The combination of 11 nutrient, 3 salt sensitivity and 5 pH classes results to 165 categories in theory. However, many combinations are not required. The most important categories with the most representative species are listed in Appendix D.

The plant propagation is not categorised in this system. Usually the standard nutrient solution for the adult crop is used, with some incidental adjustments towards extra Ca and Fe. The management will be presented in section 14.10.

14.3 Potting Media

The growing media used for potted plants are mainly peat-based and consist of a mixture of different fractions white peat, black peat and a variety of constituents like perlite, clay, coir, fibrous materials and even artificial foams. The recipes for any mixture of these components have been developed by experiences of growers, substrate producers and research on the physical properties of the growing media (Klapwijk and Mostert, 1992; Kipp et al., 2002). For potted plants the use of different white peat fractions from sod turfs is essential, since this material together with other constituents offers opportunities for the production of substrates with specific characteristics due to the requirements of the crop and the growing system. For instance specific mixtures were developed for ebb and flood systems since they require both rapid water suction in the irrigation phase and rapid drainage in the drain-off phase and in the long run sufficient stability to maintain sufficient air space in the substrate, despite the intensive water movement. Last characteristic is brought by sufficient course fractions in the substrate, like from sod turf. For pressed pots, used for propagation of some soil grown crops and for bedding plants, special mixtures are required to give the blocks sufficient compaction, as merely black peat can be used for this purpose. Mixtures due to sowing, or rooting of cuttings, require a rather finer structure than mixtures used for plants which are transplanted with a well developed root system. The container size plays a role too, for lower pots often more course material is needed than for higher pot sizes. In practice many different recipes for substrates due to potted plants exists. The majority are developed in close cooperation between grower and substrate producer during many years and in some cases only based on experience, but widely used. For example clay addition in substrates is practised as it is claimed to prevent lush growth and improvement of plant quality for example for *Cyclamen* (Klapwijk and Mostert, 1992). The majority of potted plants are grown in mixtures with 40–60% peat moss, 40–60% coarse white peat fractions, like derived from sod turf. For bedding plants in trays, it is mainly 60–70% black peat and 40–30% peat moss. Orchids like *Phalaenopsis* require a very coarse mixture, for this crop only specific bark fractions are used, sometimes mixed with perlite or other coarse materials.

Nowadays, in some countries there is pressure on the use of peat and therefore, peat free substrates are developed. In many cases mixtures with compost or other renewable sources of organic material are used (Wever, 2002). In substrates mostly no more than 20% by volume of the peat could be replaced by compost without growth reduction or quality decline (Surrage and Carlile, 2008). The effects of the composition of the substrate mixtures on fertilization aspects are discussed in Chapter 11.

14.4 EC Control

The EC is an important parameter in view of fertilization and salinity aspects. This has been elaborated on in previous chapters. However, for potting and bedding plants the control of the EC and the effect of the EC show some typical characteristics. For short term crops, the EC is mainly determined by the base dressing of the substrate mixture and less by top dressings by the grower during the cropping period. For long term crops, accumulation of salts and nutrients can be a serious problem and is affected by both the nutrient management, the water quality as well as by the irrigation method. The small rooting volumes often practiced with potted plant strongly aggravate the accumulation of residual salts from the irrigation water as well from the nutrients, like shown in Fig. 8.1. Therefore a close control on the development of the EC in the root environment during the cultivation period is important.

14.4.1 EC Base Dressing

In Chapter 11, general aspects of the addition of the base dressing to peat mixtures are explained. For potted plants often compound fertilizers, like Pg-mix, are used in many European countries. Usually the base dressing is between 0.5 and 1.0 kg Pg-mix m^{-3} potting soil. Only when big plants are grown higher base dressings up to 1.5 kg m^{-3} are used. In case of cuttings directly planted into pots, only a limited base dressing of 0.25 kg m^{-3} is recommended, as otherwise formation of callus and initial root formation slowed down, because of too high salt concentrations. The low base dressing suffices, since young plant material requires only limited nutrients at the start. Another reason for a low base dressing is the often relative high proportion of NH_4 in the compound fertilizer, which can be toxic to plants and can rapidly decrease the pH value of the substrate, either by uptake or by nitrification. Generally, the EC in the potting mixture varies between 0.5 and 1.0 dS m^{-1} after the base dressing, which of course depends on the quantity of base dressing added and the constituents of the mixture, as discussed in Chapter 11.

14.4.2 EC Top Dressing

The majority of research of nutritional aspects in potted and bedding plants deals with the EC in the root environment during the cultivation period. The general aspects of EC on plant growth and quality have been explained and there is no reason to suppose that potted plants behave very differently. However, some effects of the EC are typical for potted plant species and a good example is the effect on plant quality. Potted plants are traded as a whole plant due to decoration and thus, any damage or deformation of any plant part is unacceptable. With some species leaf damage will occur if the EC in the substrate becomes too high. One of the effects often attributed to the EC is the phenomenon of necrotic margins or leaf tips, although this could not always be confirmed in experiments. This has been described for *Codiaeum* (Straver, 1991a) and *Dracaena* (Mulderij, 1999). Sometimes the climatic conditions also have an effect as was clearly demonstrated in trials with palm trees by Mulderij (1999a). The combined effect of the relative humidity and the EC of the nutrient solution were studied with *Chamaedorea* and *Chrysalidocarpus* (*Areca*). The effects on the plant weights were small and not significant, but a high EC clearly aggravated the development of necrotic leaf tips and also the necrotic spots were larger, especially in *Areca* (Table 14.2). Under lower humidity the EC effect was increased, mainly because of larger necrotic areas, shown by a higher necrosis index. The plants were followed throughout the post-harvest phase and the necrosis increased, however, in this case the increase was only affected by the EC treatments and not longer by the humidity treatment during the cultivation. The cause of the necrosis, however, could not be clarified as no indication was found in the analytical data of the tissue analysis. However, the leaf tips were not sampled separately which for example can specifically accumulate B or Mn as has been shown in Table 5.2.

Table 14.2 Plant weight and number of necrotic leaf tips per plant and the index for the disorder as affected by the EC of the nutrient solution supplied and the relative humidity with *Chamaedorea* and *Areca* as test crops. Index for the necrosis, 0-no and 10-serious symptoms

Factors studied		*Chamaedora*			*Areca*		
			Necrotic leaf tips			Necrotic leaf tips	
EC[1] dS m^{-1}	Humidity	Total weight g/plant	Number	Index	Total weight g/plant	Number	Index
1.2	High	29.5	0.45	0.01	94.7	6.4	2.7
2.5	High	26.8	0.81	0.04	83.9	7.8	6.4
1.2	Low	30.9	0.46	0.01	91.8	7.3	3.2
2.5	Low	25.8	2.17	0.19	84.5	8.6	7.7

[1] In the 1:1½ extract
After Mulderij (1999a).

Leaf colours are also important quality characteristics of many potted plants but are not well defined and rather different among the variety of plants grown and therefore comprise a complex phenomenon. In some cases the EC level affects the leaf colours, like in the experiment of Mulderij (2000) in which different EC levels in combination with the light level on the leaf colour of *Chamaedorea* was studied. An increased EC resulted in darker leaves. A complication in these trials was that with increasing EC the pH in the substrate was decreased too, which likely is caused by the increased NH_4 supply due to the extra nutrient addition with the higher EC treatments. So it is not yet clear whether the better leaf colour is either an EC or a pH effect. A lower pH induces a better condition for the uptake of most micro nutrients, which also can improve the leaf colour. Comparable results have been found with pelargonium (Van Leeuwen, 1992). Leaf and flower colour were improved with increasing EC level, but also in this experiment a decreasing pH was found in the substrate with increasing EC level, likely also induced by increasing NH_4 supply with the increased fertilizer addition.

Azalea is known to be sensitive for leaf scorch, which often is related to the salt sensitivity of this crop (Arnold Bik, 1965). This was confirmed in combined EC and NaCl trials by Van Leeuwen and Bulle (1992). *Azalea* was grown in an ebb and flood system with reuse of the drainage water. The addition of NaCl and the concentration of nutrients in the irrigation water were studied in six treatments as shown in the first column of Table 14.3. The weights of the aboveground plant parts were measured at the end of the vegetative and at the end of the generative period. In the vegetative period the plant growth was negatively affected merely by the high fertilization level and in the generative period mainly by the NaCl addition. This is understandable, because the NaCl in the root environment was highest in the second period. The plants grown at the low nutrient concentration showed a pale colour and leaf drop during the vegetative period, caused by nutrient deficiency. Plant quality and flowering at the end of the vegetative period was negatively affected by an increased EC value, caused as well by the higher nutrition as by the NaCl concentration in the

Table 14.3 Growth of *Azalea* as affected by fertilization levels and by NaCl concentrations in the irrigation water. The fertilization levels were complete nutrient solutions added to the irrigation water at concentration of 0.4 and 0.8 dS m^{-1}

Water supplied EC/NaCl-fertilizer	Vegetative period		Generative period	
	EC/NaCl[1]	Relative weight	EC/NaCl[1]	Relative weight
0.7/0.7-0.4	0.33/1.4	98	0.55/3.1	100
0.9/2.7-0.4	0.40/2.0	100	0.95/6.0	86
1.1/4.7-0.4	0.53/2.7	99	1.70/10.4	88
1.1/0.7-0.8	0.50/1.6	92	0.95/4.1	98
1.3/2.7-0.8	0.73/2.3	89	1.75/7.8	82
1.5/4.7-0.8	0.90/2.9	86	2.10/9.0	83

[1] In the 1:1½ extract of the substrate
Data from Van Leeuwen and Bulle (1992).

irrigation water. The results do not give the possibility to conclude about the character of the salinity effect, being an osmotic or specific NaCl effect. Result of Arnold Bik (1965) and of Brumm and Schenk (1991) give rise to the conclusion that specific effects play an important part, in view of the strong leaf scorch following the addition of NaCl. Many woody crop plants are specific sensitive to NaCl additions (Bernstein, 1976).

Another aspect is the use of the EC in the root environment to control growth. Bulle et al. (1996) compared the effect of different concentrations of a nutrient solution at EC values of 1.0, 2.2 and 3.4 with chrysanthemum. The total plant weight and the shoot weight were reduced, both at the lowest and the highest EC, while the flower weight was only slightly affected. The plant length and shoot length were reduced more strongly with the increasing EC. This resulted in an increasing compactness, expressed as the total fresh weight per cm length and this effect was stronger for shoots than for the total plant (Table 14.4).

Fertilization determines quality in many ways, which is demonstrated with an experiment of Boertje (1980). Bedding plants were grown in multiple pot trays in a well fertilized peat mixture. During cultivation the plants were supplied with 10 top

Table 14.4 Plant and shoot length in cm, plant and shoot weight and total flower weight in g/plant and the compactness expressed as g/cm of the shoots of pot chrysanthemum, as affected by different EC values of the nutrient solution

	Plant growth parameters					Compactness	
EC supplied dS m^{-1}	Plant height cm	Shoot length cm	Plant weight g	Shoot weight g	Flower weight g	Total plant g/cm	Shoot g/cm
1	14.2	7.9	91.6	35.3	39.0	6.5	4.5
2.2	15.2	8.3	113.8	53.9	41.4	7.5	6.5
3.4	14.0	7.3	108.2	52.0	37.3	7.7	7.2

Data after Van Leeuwen (1992a).

Table 14.5 Leaf scorch as affected by overhead fertilization of bedding plants with the mixed fertilizer 17-6-18. The leaf scorch was judged as following: 0-no, X-some, XX-substantial and XXX-severe

	Fertilizer concentration g l^{-1}					
Crop	0	0.5	1	1.5	3	4.5
Petunia	0	0	0	0	0	0
Impatiens	0	0	0	0	0	X
Dahlia	0	0	0	0	X	XX
Salvia	0	0	0	0	X	XX
Tagetes	0	0	X	X	XX	XXX
Ageratum	0	0	0	0	XX	XXX

Boertje (1980). *Reprinted by permission of the International Society Horticultural Science*

dressings of a fertilizer solution. After addition of the top dressing the plants were not rinsed with clean water. In the treatments where high fertilizer concentrations were used most plants showed serious leaf scorch (Table 14.5). However, there was a great difference among the sensitivity of the crops. *Tagetes* was most sensitive, while *Petunia* did not show any effect. In experiments with tomato leaf scorch especially was promoted by high NH_4 concentrations (Section 15.4). The N content in the fertilizer used for the top dressing in the experiment was 8% as NO_3 and 9% as NH_4. Leaf scorch started in the treatment of 1 g l^{-1} of the fertilizer which mean a NH_4 concentration of 6.4 mmol l^{-1}, and in the treatment with half of this concentration no any leaf scorch was found. This result is in good agreement with the data found for tomato as presented in Fig. 15.3.

Generally, the plant weight was linear increased with the concentration of the top dressing solution, like shown in Fig. 14.1. This especially was the case for the fast growing plant types, like *Petunia* and *Impatiens*. Such a relationship will be expected as long as the optimal nutrient levels not are crossed and osmotic stress occurs. Plant weight does not always reflect linearly plant quality. This is shown by the data in Fig. 14.2, where the relationship between plant weight and plant quality is shown. The relationships strongly differ for the plant type. With *Salvia* a sharp optimum for the quality is shown, while *Petunia* shows a broad range in optimum values. Negative optimum quality ratings in the low range often are connected with plant colour and in the high range a too wealthy vegetative development as well leaf damage by too high EC values in the root environment can play a part.

Sometimes the potential of growth regulation with EC gives conflicting results. Verberkt and De Jongh (1995) found with *Cyclamen* that an EC level of 1.7 resulted in larger plants of better quality than those grown at an EC of 1.1, but the flowering time was delayed. Moreover, the bulbs were bigger at the lowest EC.

As already mentioned, the EC is not only important for the results during the growing period in the greenhouse, but it also affects the consumer phase. This was demonstrated in experiments with bedding plants (Mulderij, 1998). Eight different EC treatments were compared with *Impatiens* and *Petunia* as test crops.

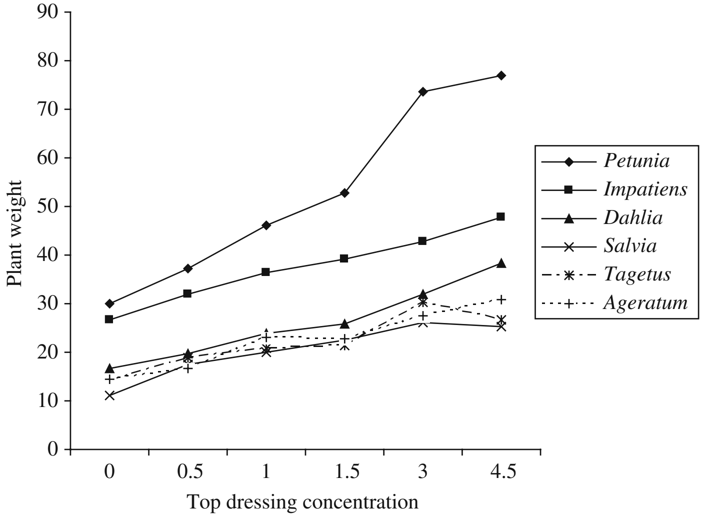

Fig. 14.1 Relationship between the concentration of the top dressing solution in g l^{-1} 17-6-18 and the plant weight of a series of bedding plants. Data after Boertje (1980). *Modified by permission of the International Society Horticultural Science*

In some treatments the EC was kept constant whereas in others the EC was changed between values from 0.3 to 2.2, like shown in Table 14.6 . *Petunia* showed improved growth when continuously supplied up till the highest EC value of 2.2. In all the treatments with a variable EC the growth was reduced in comparison with the treatment of the EC value of 2.2. It seems rather feasible that the plants react to an average EC. The *Impatiens* treatments showed less effect, and the highest plant weight

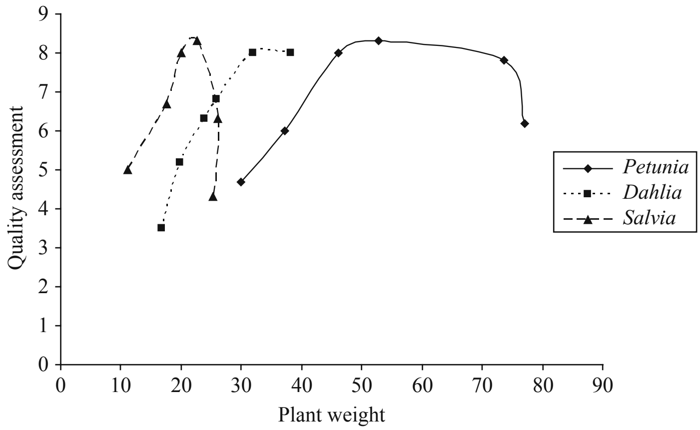

Fig. 14.2 The relationship between plant weight in g per plant and quality index of some bedding plants. The quality index rated from 0 – bad to 10 – excellent. Data after Boertje (1980)

Table 14.6 Plant fresh weights of *Petunia* and *Impatiens* at marketable stage and after 7 weeks of post harvest treatments in fertilized and non-fertilized balcony containers, as affected by 8 different EC regimes during the production phase

Treatments production phase[1]			*Petunia*			*Impatiens*		
			Marketable	After 7 weeks		Marketable	After 7 weeks	
1	2	3		Non fertilized	Fertilized		Non fertilized	Fertilized
0.6			2.6	5.0	24.1	3.6	6.7	31.8
1.1			3.8	8.0	26.4	4.4	11.1	31.1
2.2			4.6	13.1	36.4	4.1	16.8	39.3
0.6	2.2		3.6	13.1	22.8	3.8	12.7	33.5
2.2	0.6		3.8	8.3	32.6	4.0	12.9	31.3
0.3	2.2		3.2	7.7	25.4	3.9	10.8	31.3
2.2	0.3		3.5	7.1	24.9	4.2	10.3	35.5
0.6	2.2	0.6	3.4	7.1	29.9	3.6	9.9	36.2

[1] Phase 1, 2, and 3, weeks 1–2, 2–4 and 4–6 of the growing period, respectively.
After Mulderij (1998).

was obtained at an EC value of 1.1. The plants were monitored during a post-harvest period as well, when planted in balcony containers. Half of the plants were not fertilized in the container, while the other half received a base fertilizer in the containers. After 7 weeks the final weights of the plants were measured. It was remarkable that the effects of the production period were still apparent in the post-harvest period. This especially was the case in the non-fertilized treatment where large differences were shown in growth between the lowest and the highest EC treatment. These differences were also present in the fertilized containers but less distinct than in the non-fertilized containers. The *Impatiens* showed comparable results in the consumer phase, but less pronounced than with *Petunia*. Remarkably, the treatments with the highest EC in the production phase performed best in the consumer phase.

A specific problem with EC is the accumulation of salts at the top layer in the pot as has been shown in Fig. 8.1 (De Kreij and Straver, 1988). This problem arose with the introduction of the flooded bench systems, with water supply by ebb and flood instead of overhead irrigation. As long as the plants are flooded frequently, the plant development is less affected by a partially high EC value in the root environment, since plants escape from high salinity as discussed in Chapter 8. Effects of partial high EC values in the post-harvest phase will be discussed in Section 14.6.

14.5 pH Management

The pH of the substrate solution in the root environment is mainly determined by the substrate components in it. This is mainly peat of which the pH can be affected by liming as has been described in Section 11.4. The requirements for the target pH value in potted plants vary widely. For the majority of these plants no experimental data are available suitable for a classification into target pH ranges. The general effects of the pH value in the root environment as described in the Sections 11.3, 12.2 and 13.4 are also operative for potted plants. If no specific requirements are known for crops, the general recommendations for potted plants can be used as listed in Table 14.1. Nevertheless, some plant species have specific requirements for an acidic environment, like *Ericaceae* (Heathers) and *Rhododendrae*. The target value for the pH for these crops should be not higher than 4.6 and therefore often no liming at all is required (Arnold Bik, 1972). Even water without carbonate is recommended (Röber, 1987). Also *Hydrangea* spp. for blue flower production requires a low pH as will be discussed further in Section 14.7. Other species that positively react on low pH values are *Epipremnum aureum* and *Anthurium scherzerianum*. For these species the target pH values recommended varies between 4.6 and 5.4. Mulderij and Hüner (1997) found that with increasing pH in a range between 4.8 and 6.4 the number of misshapen leaves increased from 5 to almost 50%. Not only the number of affected leaves but also the extent of the damage increased dramatically. In other species of the *Araceae* this phenomenon is also known (Poole et al., 1984; Mulderij and De Jongh, 1995). So far the cause of the phenomenon is not yet clear, although some authors suggest that Mn is involved, as has been concluded from the decreased Mn content in the plant tissue (Mulderij, 1999a). However, this is not likely, since it is quite common that Mn contents decrease strongly with increasing pH value. A moderate low pH range, between 4.9 and 5.7 is required by a number of crops like palm trees *Chamaedorea* and *Dyctiosperma,* members of the *Orhidacea,* the *Gesnerceae* and the *Euphorbiaceae*. In this case the recommendation of the pH is mainly based on the conditions of the soils in the natural habitat of the plants rather than on experimental data. This is also true for a large group of species which require a high pH, with a target range between 5.5 and 6.3. All succulents like *Crassula, Euonymus, Echeveria, Sedum* and the *Cactaceae* belong to this group which also includes *Yucca, Pelargonium* and *Kalanchoë*. These plants all share a natural habitat in calcareous soils in arid and semi-arid zones, with naturally high pH conditions. Also *Hydrangea* for pink flower production requires a sufficient high pH level.

Trials with *Saintpaulia* illustrate that the pH can cause serious problems. Straver (1988) examined the effect of three lime application rates: 2.5, 4.5 and 6.5 kg limestone per m^3 of potting soil in combination with three NH_4:NO_3 ratios of 0:100, 25:75 and 50:50 in the nutrient solutions, with two different cultivars. With cultivar “Nr 83” severe incidence of malformed flowers appeared. The symptoms increased with decreasing lime applications and with increasing NH_4:NO_3 ratio, like shown in Table 14.7. This phenomenon is called “black-flower” and is characterized by small flowers, with glassiness margins of the petals, turning purple or black. With cultivar “Heidrun” no symptoms were found. The total fresh weight of the plants showed inconsistent effects. With “Nr 83” the growth was better with increasing lime application, however with “Heidrun” the best results were found at the lowest lime treatment. Both cultivars performed best at the lowest NH_4:NO_3 ratio. Tissue analysis showed that Mn and Fe contents were very high in some plant parts at the

Table 14.7 Total fresh weight and the % of black flowers with two cultivars of *Saintpaulia* as affected by liming levels in the base dressing (kg m^{-3}) and the NH_4/NO_3 ratio in the fertilizer application during top dressing

Lime addition	NH_4/N	Fresh weight		% "black flowers"	
		Nr 83	Heidrun	Nr 83	Heidrun
2.5	0	50.3	84.6	57.0	0
	0.25	49.5	80.5	78.8	0
	0.50	47.9	77.6	49.2	0
4.5	0	57.2	84.6	12.8	0
	0.25	52.0	80.5	39.3	0
	0.50	49.4	77.6	46.8	0
6.5	0	55.6	79.2	0.8	0
	0.25	55.3	74.0	1.6	0
	0.50	49.9	69.3	1.5	0

After Straver (1988).

lowest pH, in the damaged flowers however the contents were not extremely high. It shows that pH effects on plants not always could be related to nutrient uptake and also that there are extreme differences in susceptibility between genotypes.

With *Schefflera* often leaf yellowing and leaf senescence occur which often is associated with too low pH values in the substrate and with indications that Mn is involved. Straver (1997) examined the effects of lime application rates in combination with Mn levels and cultivars. The results showed that both a too low and too high liming reduced plant weight, with optimum results at a lime dosage of 4 kg m^{-3}, resulting in pH values on average of 5. However, leaf yellowing was not found, despite extreme Mn contents in the tissue. He demonstrated also that the Mn uptake can be rather extreme as a result of the Mn supply, more or less independent of the lime application. With increasing lime application, the Mn concentrations in the substrate analysis were reduced considerably, but the Mn uptake was scarcely reduced as shown in Fig. 14.3. The explanation is that the uptake merely is affected by the frequently supplied fresh nutrient solution which had standard pH conditions. Roots tend to concentrate at the bottom of the pots where with ebb and flood frequently fresh nutrient solution penetrates, while the samples mainly are gathered from the higher layers in the pots, whereas the Mn is oxidized especially at the high lime addition.

Basically, the pH in the potting soil as created by the lime addition can drop during crop cultivation if insufficient lime is added (Straver, 1997). This is also illustrated in Fig. 14.4, showing the pH developments with a *Schefflera* crop grown at three liming regimes. The pH development usually has a decreasing tendency, caused at one hand by processes due to the plant uptake, the nitrification of NH_4, decomposition of the organic matter and on the other hand by processes in the substrate by the dissolution and leaching of the lime buffer. It is complex to predict the pH development in a potting soil and this problem is enhanced when the particle size of lime varies (Fisher, 2006).

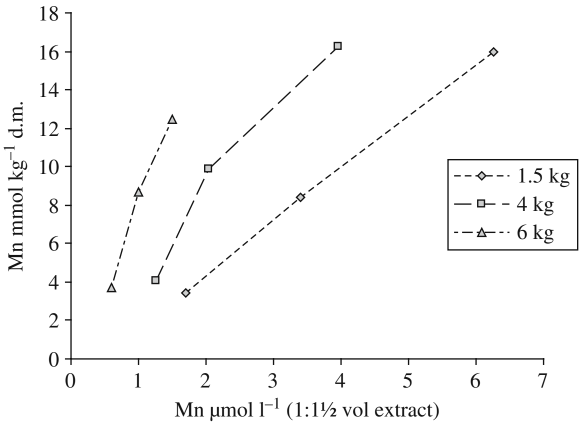

Fig. 14.3 Relationship between the Mn content in the potting soil (1:1½ extract) and the Mn content in *Schefflera* leaves, in an experiment with three lime application rates in the substrate of 1.5, 4 and 6.5 kg m^{-3} and three Mn concentrations in the nutrient solution supplied (After Straver, 1997)

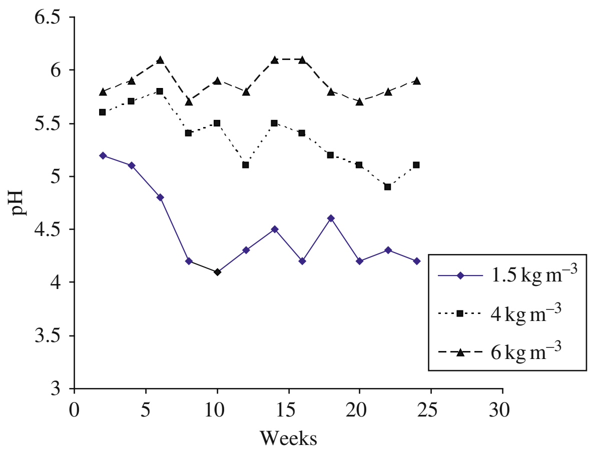

Fig. 14.4 pH values in the drainage water of *Saintpaulia* during the growing period at three levels of liming in the base dressing. After Straver (1997)

14.6 Nutrients

Although the uptake of nutrients can differ greatly between plant species, most plant types are not very sensitive for somewhat low or high concentrations of specific nutrients. This for example is shown with the results of an experiment of Straver (1991c). Two palm species *Howeia* and *Chrysalidocarpus* (*Areca*) were grown in substrate with a wide range of K:Ca ratios in the nutrient solution supplied. In the potting soil also equal K:Ca ratios were detected, while the plant weight and plant quality was unaffected, although the K:Ca in the plant changed seriously. The plant adjust the uptake more or less by increasing the K:Ca ratio in the plant above the external solution at low ratios and decrease this ratio in the plant below the K:Ca ratios in the external concentration at high K:Ca ratios as shown in Fig. 14.5. The same effect was found with *Spathyphyllum* (Straver, 1990). This merely will be true with an ample supply of nutrients and when not too extreme concentrations occur in the root environment. Obviously, with extreme low nutrient supply the growth as determined by shoot length, number of shoots and total fresh weight will be negatively affected, like is shown by Arnold Bik (1976). Thus, effects of marginal nutrient supply have perspectives for growth regulation. With the change over from overhead irrigation to ebb and flood irrigation of bedding plants it appeared that the traditional growth regulation by drought stress was less effective (Vogelezang et al., 1992). Baas et al. (1995) showed that with suboptimal P applications the growth in terms of plant fresh weight, plant height and leaf area could be reduced with advantages for the quality of a number of crops. However with *Poinsettia* and *Salvia* in some cases also the number of side shoots or the number of flowers were reduced, which downgraded the ornamental value. For *Impatiens* no negative side effects were determined. They also concluded that P stress could only be obtained and controlled in the top dressing if no P was supplied in the base dressing. This was confirmed in an extensive study by Warmenhoven and Van Noort (2005) who investigated 12 different bedding plants in a range of different P concentrations in the top dressing solution, including treatments with and without P in the base dressing. In these experiments the base dressing was carried out with either 0 P or 4% P in the compound fertilizer, in combination with P concentrations of 0.02, 0.1, 0.2 and 0.5 mmol l^{-1} in the nutrient solution supplied. P stress could hardly be obtained if the fertilizer used for base dressing of the substrate contained 4% P. In the treatments without P in the base dressing, the growth was strongly affected if the P supply was lower than 0.2 mmol l^{-1} in the nutrient solution supplied as is

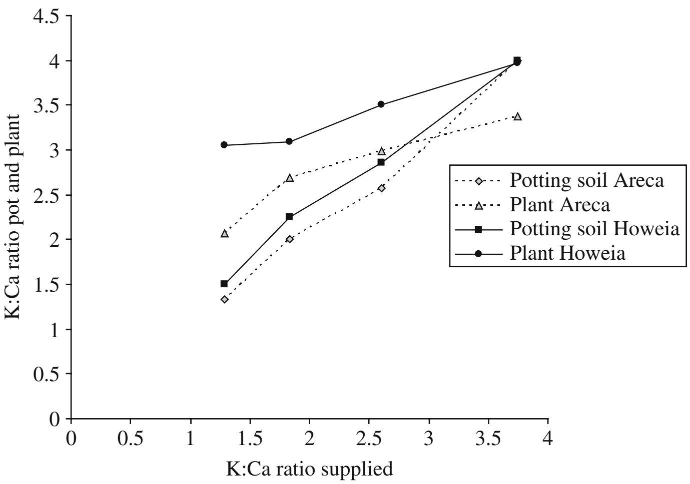

Fig. 14.5 K:Ca ratios in the 1:1½ extract of the substrate and in plant tissue as affected by the K:Ca ratio in the nutrient solution supplied in an ebb and flood system with *Howeia* and *Areca* (Straver, 1991c)

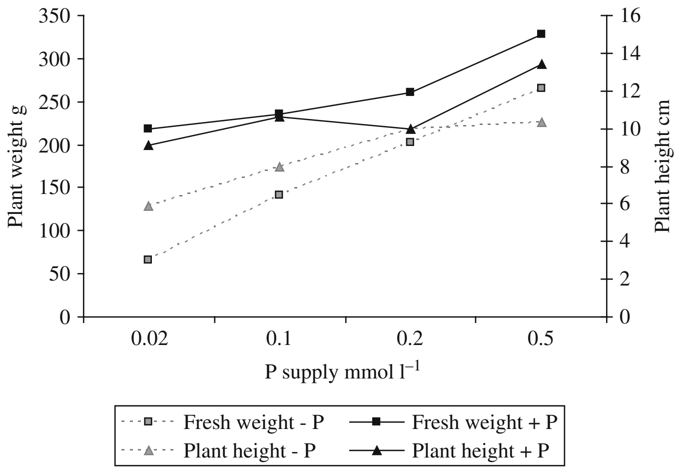

Fig. 14.6 Plant weight and plant height as affected by the P supply in the nutrient solution supplied with *Pelargonium* with and without P in the base dressing in the substrate. After Warmenhoven and van Noort (2005)

illustrated in Fig. 14.6 with *Pelargonium*. However, with some species even below 0.5 mmol^{-1} growth reduction was found (*Begonia, Petunia*). The overall conclusion was that growth regulation with reduced P addition is possible but the bandwidth for the P supply to obtain at one hand a sufficiently reduced growth and an acceptable ornamental quality on the other hand is rather small. Quite easily thresholds are exceeded to either a too lush or a too retarded growth with a strongly visual P deficiency. However, from these results it also became clear that in case of bedding plants, the P-level in the base dressing often can be lowered, when P is added as base dressing. With potted chrysanthemum it appeared to be impossible to use P for growth regulation, indeed P reduction led to shorter plants and a reduced plant weight, however, the plant quality was also reduced (Van Leeuwen, 1992).

Specific research to the addition of micro nutrient elements in potted plant cultivation have been given less attention and the addition for top dressing is merely based on results gained with vegetables and cut flowers, as has been elaborated in Chapters 12 and 13. In the years a general recommendation for micro nutrient levels in potting soils has been developed. This is based on the general experience of micro nutrient requirements of crops and the effect of peat and the other constituents on fixation and complex formation of for instance Cu and Zn, as is presented in Chapter 11. The general recommendations for micro nutrients in potted and bedding plants grown in peat based substrates consist of fixed concentrations in the mixed fertilizers added with the base dressing and those in the nutrient solution and general target values for many crops and plant stages in the 1:1½ extract. In a series of experiments with *Spathiphyllum* (Verberkt et al., 1998), *Kalanchoë* (Verberkt et al., 1996) and *Epipremnum* (Mulderij, 1998) this generalization for micro nutrients was evaluated and it proved to work out quite well. Nevertheless, they drew attention to pH deviations, which can induce serious problems. Fe deficiency easily occurs in susceptible crops if the pH becomes too high and could hardly be cured by extra addition of Fe chelate (Mulderij and Hüner, 1997). Mulderij and De Jongh (1995) also concluded from trials with *Chamaedorea* and *Chrysalidocarpus* that the pH of the substrate much more affect the occurrence of Fe chlorosis than either the Fe concentration in the substrate or the type of Fe chelates used. With too low pH, Mn toxicity occurs in susceptible crops and at a high pH the uptake of Mn is strongly reduced. Mn supply to cure the symptoms is less effective at high pH values (Straver, 1997). Problems with Fe and Mn addition both are discussed more in detail in the Chapters 12 and 13.

Basically, the addition and recommendation for micro elements follow general rules for all categories of potted plants. One reason is that a major part of the micronutrients will be added by the base dressing of the substrate as has been discussed in Section 11.4 and the concentrations in the top dressing will have only limited effect. The other reason is the lack of information about specific micro nutrient requirements for the plant species grown. In Appendix D the general application and recommendation for micro element is listed.

14.7 Nutrient Management

The nutrient management of potted and bedding plants is complicated, since no direct information can be derived from the actual status of the EC, pH and nutrient concentrations in the root environment. In contradiction to rock wool cultivation with which the substrate solution easily can be sampled, it is difficult to gather such a solution from the substrate of potted and bedding plants. The circulating nutrient solution from ebb and flood systems is not suitable, since this solution is scarcely affected by the concentrations in the root environment. Suction of the substrate solution by means of porous cups has been tried but showed to be too laborious, as discussed in Section 4.8. For routine testing, sampling of the substrate of sufficient pots and analysis with the aid of 1:1½ extraction method as described in Section 4.5 is the best suitable and the commonly used method to get information about the nutrient status in the root environment during cultivation.

Apart from the lack of information on the nutrient status of the crop, the tools for nutrient management in growers practice are also limited. Compound fertilizers are mainly used for the fertigation of the crops as this is the most straightforward solution for growers and prevent the complexity of the calculation of nutrient solutions (De Jong, 1987). However, the fixed nutrient ratios in these fertilisers are a hindrance to meet the specific requirements of the great variation in the potted and the bedding plants. Nowadays, modern substrate producers can deliver substrates for specific requirement by using a mixture of different fertilizers and thus, it is also logical that growers prepare nutrient solutions closely focussed to the specific needs of crops. Base dressing of substrate is necessary, since the adsorption and fixation of some nutrients is substantial. Without a base dressing plants can suffer at the start by too low nutrient concentrations, despite a direct start of the top dressing. There will be interaction between the level of the base dressing and the top dressing, which can be illustrated by an experiment with *Saintpaulia*. In this experiment four levels of base dressing in the substrate viz. 0, 300, 600 and 1200 mg l^{-1} of a fertilizer mixture was added. In the 0 treatment only micro nutrients were supplied. The EC values in the 1:1½ extract of the substrate after fertilization were 0.3, 0.4, 0.6 and 0.8 respectively. The plants grown in 9 cm plastic pots filled with the different fertilized substrate were placed in benches with and ebb and flood irrigation in which two concentrations of the nutrient solution were compared with EC values of 1.1 and 1.7 dS m^{-1}. Two cultivars were included "Emi" and "Ramona" and two cropping periods were compared autumn and spring (Van Leeuwen, 1993). The total plant weights are listed in Table 14.8. Lowest weights often were found with combinations of low base dressing and low concentration in the nutrient solution used during cultivation as well in the combinations high base dressing and high concentration in the nutrient solution. With a high base dressing (0.6–0.8) mostly the EC value 1.1 is best and with a low base dressing (0.3–0.4) mostly the EC value of 1.7 is best. "Ramona" in autumn growing is an exception on this rule. A low base dressing requires a higher nutrient concentration in the irrigation water and upside down, being effects that could be expected. No consistent different effects of the fertilization regimes were noticed between the reaction of the cultivars and of the growing seasons.

The composition of the nutrient solution supplied is still important and will be tuned to the need of the crop, especially for crops with a long growing period to avoid accumulations or depletions during the growing period. However it is impossible to develop strict guide lines for the nutrient management for all different crops, so a general approach is chosen in the fertilization recommendation system as presented in Section 14.2. Especially for crops with a long growing period sampling and analysis of the substrate is recommended to trace unbalanced accumulations and depletions. Results can be compared with the guide values listed in Appendix D and the nutrient solution supplied can be adjusted following the algorithm presented in Chapter 12. As already mentioned, the fixed ratios of nutrients

Table 14.8 Plant weights (g per plant) of two cultivars of *Saintpaulia* as affected by different fertilization regimes in autumn and spring growing

Base dressing	Nutrient solution EC 1.1				Nutrient solution 1.7			
	Autumn growing		Spring growing		Autumn growing		Spring growing	
EC 1:1½	"Emi"	"Ramona"	"Emi"	"Ramona"	"Emi"	"Ramona"	"Emi"	"Ramona"
0.3	54.6	66.5	40.5	40.9	57.9	68.3	44.7	49.7
0.4	54.1	65.0	44.6	46.9	62.4	67.3	45.7	49.9
0.6	56.3	60.9	46.6	50.9	56.8	63.3	45.4	46.7
0.8	59.7	45.7	45.9	51.7	55.1	56.7	43.2	46.0

Data after Van Leeuwen (1993).

in compound fertilizers is a hindrance to a good tuning to the crop demand in relation to the analytical data of substrate analysis. Moreover, many of these fertilizers contain high levels of NH_4 or urea, which can cause an undesirable pH drop in the substrate with growth or quality problems as has been discussed.

In view of the aspects mentioned previously, the EC and the composition of the nutrient solution supplied at one hand and the uptake by the plant at the other hand, obviously will result to certain nutrient concentrations in the substrate. For any recommendation system based on substrate analysis it is important to know these interactions for an adequate crop specific nutrient management. It is unfeasible to achieve extensive studies for all potted plant species and these, generalisation is unavoidable. The suitability of the developed recommendation system as presented in Section 14.2 was studied in a series of experiments. (Straver, 1991; 1991a, b; Mulderij, 1993; 1994; Verberkt and De Jongh, 1995). The experiments were carried out with crops representative for different classes of the recommendation system, viz. *Saintpaulia, Codiaeum, Adiantum, Asplenium, Begonia, Nephrolepis, Poinsettia, and Cyclamen* in ebb and flood system. In the experiments nutrient solutions were compared in at least three concentrations, usually applied at EC values of 50%, 100% and 150% of the standard recommendations. Plant weight and plant quality were monitored as well as the development of the nutrients in the potting soil and in the plant. The results were evaluated for the different crops and compared with the established target values for the composition of the nutrient solution supplied as well for the composition of the 1:1½ extract of the substrate. The main conclusion was that in nearly all cases the established nutrient solution offered a satisfactory plant production, plant quality and mineral contents in the plant tissues. With *Asplenium* and *Nephrolepis* the EC level initially declared lead to strong accumulation of nutrients in the substrate and osmotic stress of the plants. Successive experiments with a reduced EC range gave better results for these crops. In all other crops no significant effect on plant weights were found within the range of EC values tested. A more or less linear relationship was found between the supplied concentration and the concentration in the substrate as determined in the 1:1½ volume extract, but the regression coefficient differed seriously among the crops. The effect of the supplied nutrient solution on the nutrient content in the plant was very different among the crops like shown in Fig. 14.7. The N-level in the plant tissue differed considerable, being with *Poinsettia* the highest and with *Asplenium* the lowest contents. With *Asplenium*, a significant increase in the N content in the plant was found with increasing N supply, but the content decreased at the highest additions. For *Poinsettia, Kalanchoë* and *Codiaeum* the increase was gradual, but still of significance and consistent. With Begonia, however, the uptake was hardly affected. The results obtained with K showed more differences than for N. Especially with *Asplenium* and *Codiaeum* the K contents are strongly increased in relation to the supply, while with the other crops the uptake was scarcely affected by increased concentrations in the root environment. Results of the experiments are used to adjust the target values for the concentrations in the root environment and also for the recommended adjustments in case of deviations from the target values for EC and nutrient concentration in the root environment. It should be realised that a low uptake of a mineral element

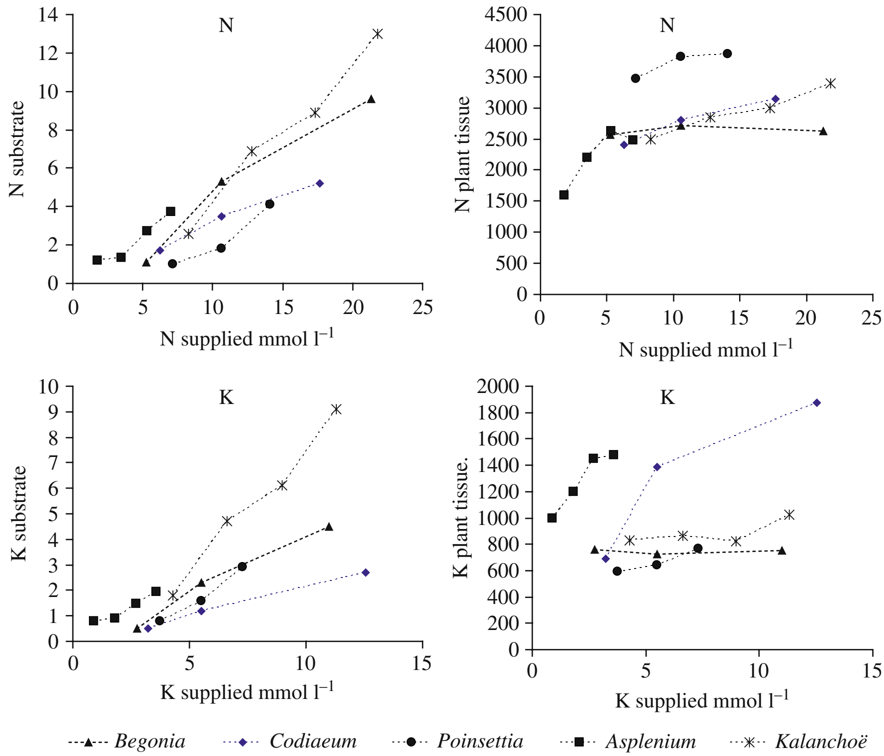

Fig. 14.7 N and K in the substrate (mmol l^{-1} in the1:1½ extract) and the N and K content in the plant (mmol kg^{-1} dry matter) as affected by the N and K concentration (mmol l^{-1}) in the supplied nutrient solution in an ebb and flood system with five different crops. Data derived from a series of experiments of Straver (1991, 1991a, b; Mulderij, 1993, 1994)

by a crop easily results in accumulation in the substrate, as found in closed rock wool systems with cut flower production (Sonneveld and Voogt, 2001). This effect will be aggravated by the small substrate volume used with potted plant production. This contradiction is unavoidable and should be considered in the judgement of the recommendations based on analytical data of substrate samples gathered during cultivation.

Obviously, the management of the nutrient supply is linked strongly to the irrigation. In ebb and flood systems this has some implications. The nutrient concentrations in the fertigation water are for various reasons often higher than the uptake concentrations of the nutrients (see Chapter 12). In contrast to closed systems with overhead irrigation, the excess of nutrients of potted plants in ebb and flood systems accumulate strongly specifically in the top layer of the substrate. Redistribution of these nutrients within the system is limited, especially Ca, K and P accumulate in the top layer (Otten, 1994). Therefore, the concentration of nutrients in the irrigation water should be closely attuned to the crop demand. However, despite a careful application, evaporation from the substrate surface easily causes accumulation of nutrients in the top layer, and reduces the availability to plants. The nutrient supply also should be adjusted to this phenomenon. Accumulation in the top layer is also affected by the irrigation practices. A regularly wet substrate surface on top of the containers aggravates the evaporation and thus, the accumulation of salts. This is demonstrated by Otten (1994) in an experiment with *Ficus Benjamini* grown in a flooded bench system with two irrigation frequencies and two nutrient levels. The P uptake was scarcely affected, while the quantity of P accumulated in the substrate is increased with frequent irrigation and the increased EC of the irrigation water, like shown in Fig. 14.8. Comparable results were gained also with all other nutrients. De Kreij and Straver (1988) also showed that increasing irrigation frequency with *Codiaeum* with flooded bench irrigation increased the total fresh weight of the plants but also the accumulation in the pot, especially in the top layer. This effect of irrigation frequency on nutrient accumulation was confirmed in an experiment with *Begonia,* (De Kreij, 1989). The pattern of salt accumulation is strongly affected by the irrigation method. This is demonstrated in an experiment with *Poinsettia,* Cox (2001) overhead irrigation and ebb and flood irrigation. At the lowest N concentration no accumulation and no difference in EC occured at all between the top and bottom sample of the substrate. However, the EC in the top layer of the pot increased tremendously with increasing N supply when irrigated by ebb and flood, as shown in Fig. 14.9, while growth and quality on the ebb and flood irrigation was not negatively affected. Consequently the high salt accumulation in the top layer does not affect plant growth, likely due to an escape from high salinity spots as discussed in Chapter 8. However, such a salt accumulation on the top of the pots can cause serious problems in the post-harvest phase at the consumer, when the plants are

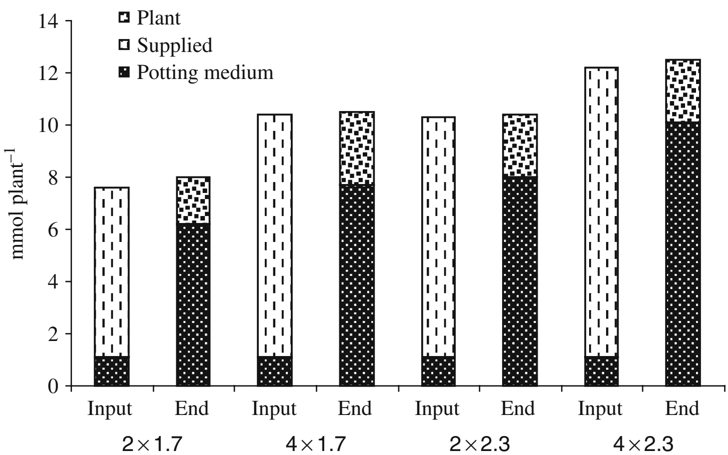

Fig. 14.8 The amount of the P accumulated in the substrate and in the plant and the cumulative amount added to the substrate as affected by the irrigation frequency (twice or four times a week) and the EC of the nutrient solution added (1.7 or 2.3 d S m^{-1}) after 11 weeks, with *Ficus benjamini* as test crop. Data after Otten (1994)

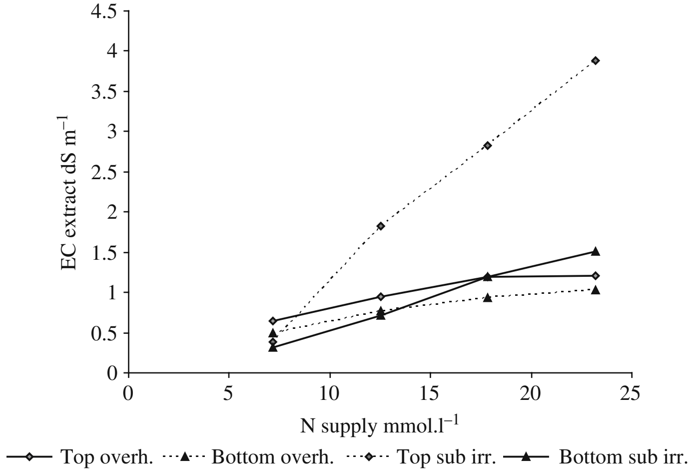

Fig. 14.9 Effects of N supply and irrigation method, viz. overhead sprinkler irrigation and sub irrigation on flooded benches, on the accumulation of nutrients in the substrate, (top = upper 2 cm, bottom = bottom 4 cm of the growth medium) expressed as EC in the 1:2 v/v extract of *Poinsettia* grown under increasing nutrient supply. After Cox (2001). *Modified by permission of Marcel Dekker*

irrigated as commonly from top and the salts will be moved down. In this case the extreme high salt concentrations from top reach the active roots developed at the low concentration at the bottom of the pot. These roots are not yet adjusted to such high concentrations and the plant can seriously suffer by osmotic shock. This has been demonstrated by Verberkt and van den Berg (1993). Impatiens was grown during 9 weeks in 12 cm plastic pots with a volume 0.64 l. The irrigation was carried out with nutrient solutions of different concentrations. The plant reaction on salt accumulation in the pot was studied in a post-harvest experiment, in which plants

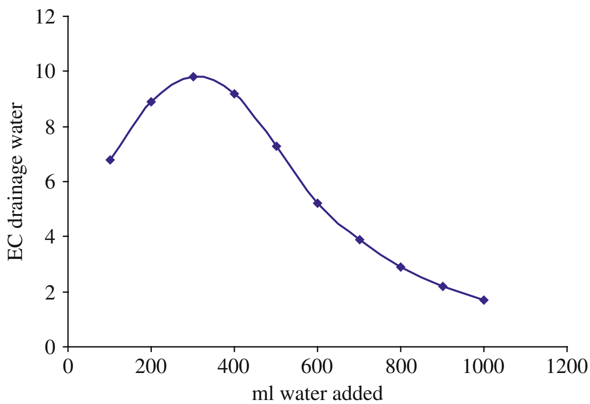

Fig. 14.10 Course of the EC dS m^{-1} of the drainage water during leaching of the substrate in the pots grown with *Impatiens* for the post harvest experiment. Treatment 6.45/2.83 as presented in Table 14.9. Data of Verberkt and Van den Berg (1993)

Table 14.9 Post harvest conditions of *Impatiens* plants as affected by the EC in the substrate and different post harvest treatments. Index: (–) no damage on the plants; (+) light symptoms of leaf burn and wilting; (++) moderate symptoms and (+++) severe symptoms

Post harvest treatments		EC substrate 1:1½ extract top/bottom			
Leaching	Water supply	0.79/0.42	1.95/0.57	4.84/2.08	6.45/2.83
Yes	Bottom	–	–	–	+
Yes	Top	–	–	–	+
No	Bottom	–	–	+	++
No	Top	–	+	+++	+++

Data Verberkt and Van der Berg (1993).

were compared grown at the different EC values during cultivation (Verberkt and Van den Berg, 1993). In the post-harvest experiment plants were compared after a leaching yes or no with 1 l of demineralised water per plant and with watering either from top or from bottom during the post harvest period. The course of the EC in the drainage water during the leaching treatment is shown in Fig. 14.10 and the results of the plant condition after 12 days are listed in Table 14.9. The maximum value of the EC in the drainage water occurred with the addition of 0.2 l water, being the moment that the substrate solution from the top layer arrived at the bottom. Watering from top induces more damage than watering from bottom, which is understandable because of the high EC from top that is washed to the lower part of the pot where the active roots are present. Leaching is effective, but cannot prevent the damage at all.

14.8 Environmental Aspects

The original growing system of potted plants characterized by individual plants grown in individual pots with restricted root volume inevitably leads to low water and nutrient use efficiencies, as discussed in Section 6.3 and induces environmental problems. The change over to flooded benches and concrete floors with the possible reuse of run-off and drainage water improved the efficiencies considerably. In an inventory on the water and fertilizer use of nurseries with different irrigation

Table 14.10 Average N and P use at nurseries with different irrigation systems, with three different crops

	N use kg ha^{-1} yr^{-1}			P use kg ha^{-1} yr^{-1}		
Crop	Flooded bench	Sprinkler	Drip irrgation	Flooded bench	Sprinkler	Drip irrgation
Kalanchoë	640	1105	814	220	266	208
Ficus	886	1282	861	255	342	267
Spathiphyllum	623	852	644	138	223	163

After Van Gemert and Ploeger (1993).

Table 14.11 N and P balance sheet calculated from the total N and P in the substrate at the start and at the delivery stage of the crop, the monitored fertilization and the N and P uptake by the crop. Five potted green plant species were grown, viz. *Dieffenbacchia, Dracaena, Hedera,* palms, and *Nephrolepis* in flooded benches or concrete floor (closed systems and almost closed systems) or with overhead sprinklers (open systems)

	N kg ha^{-1} yr^{-1}			P kg ha^{-1} yr^{-1}		
Factors	Closed	Almost closed	Open	Closed	Almost closed	Open
Intput						
Potting soil	461	473	789	35	26	58
Top dressing	531	471	988	146	72	297
Total	992	943	1777	181	98	355
Output						
Potting soil	566	554	958	55	38	85
Plant	251	167	305	53	29	83
Output	816	721	1262	108	67	168
Unexplained	176	223	515	73	31	187
Total	992	943	1777	181	98	355

After Van der Burg and De Kreij (2002, 2003).

systems it appeared that the differences in N and P use of nurseries with potted plants were considerable, as shown in Table 14.10 by Van Gemert and Ploeger (1993). With overhead sprinklers the N use was 25–80% higher than with ebb and flood. For P the differences were smaller, because the P supply was mainly added by base dressing. In a consecutive study Van Gemert (1995) concluded that even within a group of nurseries furnished with closed systems the differences are substantial. Nevertheless the fertilizer use decreased by 35–60% in case of reuse of run-off water. However, reuse of run-off and drainage water is not commonly practiced, because of the possibility of an out break of root diseases. Disinfestation of the run-off and drainage water is necessary, as discussed in Section 10.10. Big differences in use of fertilizer among nurseries were also reported by Van der Burg and De Kreij (2002; 2003) in an investigation of mineral balances of N and P with green foliage plants, the data of which are summarized in Table 14.11. They concluded that the differences were due to crop characteristics, irrigation regime and the growing system used. Remarkably, the quantity for N in the potting mixture at the start was already 40–60% of the total quantity made available to the crop, while for P this was only 20–30%. At the termination of the crop 70–80% of the total N output is present in the potting soil. For P this has increased to 50–60%. This indicates the strong accumulation of nutrients in the potting soil as discussed earlier. Mind that these data are based on total analysis, a major part of the N and P is part of the organic matter and not readily available to the plants. The gap between the total input and total output was large and for the open systems it amount for N to one third of the total input and for P even to 50%. The gap of 18% and 40% for N and P respectively for the closed system indicate that in this system also considerable losses occur. This gap could be partly due to denitrification for

N, as Agner and Schenck (2005) showed that denitrification losses in potted plant production can be considerable. However, part of the gap will be explained by leakages or unattended leaching. For the open system the gap between input and output of course will be merely explained by the drain to waste.

Apart from the direct leaching, it is relevant to note that due to the strong accumulation in the substrate, a great part of the nutrients escape literally from the plant reach and in this way escape from the nutrient management of the crop. Virtually, it causes a reduction of the nutrient use efficiency and it is questionable whether the non-used fertilizers should be seen as harmful to the environment or not. In fact the consumer could alleviate the problem as the plants will be irrigated from the top and some of the nutrients become available again.

14.9 Special Aspects

Some potted plants require specific treatments. The flower colour of the pink/blue varieties of *Hydrangea* is known to vary greatly from pink to red and from purple to blue. The blue colouring is promoted by the addition of Al to the substrate and is supplied as $Al_2(SO_4)_3$. However this is not always effective. Van Leeuwen et al. (1994) demonstrated that the pH also is of great importance. A reduced pH level in combination with the supply of Al better guarantees the blueing, which is possible either by a close control on the liming treatment or by the supply of extra NH_4 (Van Leeuwen, 1999). Beside the supply of the quantity of Al also the time of the addition is important, which was studied in an experiment with different supplies of Al during the growing period. The results clearly showed that an early supply gave the best results, like shown by the data listed in Table 14.12 (Van Leeuwen et al., 2003). From the research data, target values for Al in plant tissue were defined. At least 20 – 40 mmol kg^{-1} dry matter should be present in full grown leaves.

Bromeliads form an important group of potted plants and are present with many species, varying in botanical types. Among them are terrestrial plants as well as epiphytes. These plants all originate from very infertile soils and the growth rate is subsequently low. *Bromeliaceae* differ from other potted plants in many ways. Some of the types developed a so called tank, like *Guzmannia*, *Vriesea* and *Aechmea*, in which they collect water and nutrients, which are absorbed by the leaves (Endres and Mercier, 2001). However, when planted in a substrate, the plants develop a root

Table 14.12 Al content in leaf tissue and flower colour as affected by Al treatment during several phases in the growing period of blue *Hydrangea* species (after Van Leeuwen et al., 2003). Flower colour visually judged, ranging from 0 = bad, 4 = good

Application period in days after planting	5–15	5–25	5–35	15–25	15–35	15–45
Al supply g/plant	4.5	4.5	4.5	4.5	4.5	4.5
Al plant mmol kg^{-1} dry matter	18.8	15.6		12.2	6.1	
Flower colour	3.4	3.5	3.3	3.1	2.8	2.2

Table 14.13 Total fresh weight and flower weight in g per plant of *Aechmea, Guzmania* and *Vriesea* species as affected by EC in the nutrient solution applied to the substrate by ebb and flood and by foliar application

	Aechmea		*Guzmania*		*Vriesea*	
EC nutrient solution dS m^{-1}	Plant	Flower	Plant	Flower	Plant	Flower
By ebb and flood						
0.0	497	40.5	120	51	172	48
0.5	508	40.6	105	51	182	50
1.5	578	40.4	115	46	171	46
2.5	587	39.9	115	47	166	43
By foliar application						
0	561	40.4	106	47	161	46
1	518	39.8	116	48	173	44

After Mulderij (1994).

system, which has shown to be capable to absorb water and nutrients (Kämpf, 1982). Nevertheless, it is common practice to use foliar application by means of overhead sprinklers. It was questioned whether these crops can be grown in an ebb and flood systems with solely nutrient solution application to the substrate. An investigation was carried out with *Aechmea, Guzmania and Vriesea,* grown in a standard potting mixture with only micro nutrients as a base dressing in an ebb and flood system. As treatments nutrient solutions with EC values of 0, 0.5, 1.5 and 2.5 dS m^{-1} were compared in combination with two treatments of leaf applications, viz 0 and 1 dS m^{-1}. The results as presented in Table 14.13 show that bromeliads are able to absorb sufficient nutrients either by roots or by leaves or in a combination of both. The results between foliar and root applications were small. With *Guzmania* and *Vriesea* the growth was slightly better with leaf application; with *Aechmea* the opposite effect was found. With *Guzmania* and *Vriesea* increasing EC was slightly negative, with *Aechmea* higher plant fresh weights were found with increasing EC values. An advantage of root zone application is less risks on salt crystallization on the leafs, which often occur in *Bromeliaceae* (Mulderij, 1994).

14.10 Plant Propagation

Plant propagation occurs generally in very small substrate volumes. All types of substrates are used, dependent on the requirements of the cultivation method and the substrates used in the production phase. The combination of substrates with strong different pressure heads on the moisture in the substrates can induce problems during cultivation. When plants propagated in a substrate with a high pressure head on the moisture are placed in a substrate with a much lower pressure head on the moisture, the water is instantly sucked from the propagating cube or pot and the water storage in the propagating volume is strongly reduced, while the plant roots have penetrated not yet the substrate on which the plant cubes are placed. This requires specific attention of the water supply during the starting phase. Therefore, combination of propagation in rock wool cubes for peat mixture substrates is less desirable. Upside down, when plants are propagated in peaty substrate and are placed on rock wool slabs, the peaty material sucks much water from the slabs into the propagating volume. The propagating material becomes too wet during the growing season, which easily induces difficulties by stem rot. This occurs for example when plants raised in peaty substrate cubes are placed on rock wool slabs. A side effect of such a combination is the high evaporation from the continuously wet pot and tremendous salt accumulations in the material just around the stem of the plant, when a possible nozzle of the irrigation system is not placed on the propagating cube.

Mineral substrates are not fertilised beforehand, but saturated with a nutrient solution, before plants or seeds are brought in. The cubes are saturated with nutrient solution of a concentration agreeing with an EC value between 1.5 and 2.5 dS m^{-1}, dependent on the plant type. The composition of the nutrient solution varies less for plant types, because of the short duration of the propagating period. For the propagation of vegetable plants in rock wool cubes the composition presented in Table 14.14 (Sonneveld and Straver, 1994) is often applied and will be suitable for the propagation of many flower plants too. Adjustment of the NH_4 concentration is advisable dependent on the substrate characteristics, the crop requirements and the growing period to keep the pH within acceptable values. During cultivation the concentration can be adjusted dependent on the measurements of the EC in the solution in the cubes. For vegetable plants often higher EC values up to 4.0 dS m^{-1} are maintained, to prevent a too lush growth of the young plants. The relationship between the EC supplied and the weight of tomato plants in an experiment of Boertje (1981) is shown in Fig. 14.11 for a spring-summer propagation period. The plant weight was highest with the supply of a nutrient solution with an EC of 1.8, while the EC of the solution in the cubes was about 4.8 during the propagation period. In a comparable experiment with propagation in winter also highest plant weights were obtained at an EC of 1.8 dS m^{-1}, but the plants were too luxurious and pale of colour. Good quality tomato plants were obtained at an EC of 2.7 and 3.6 in the supplied solution under the poor light conditions during winter in The Netherlands (Boertje, 1980).

Table 14.14 Composition of the nutrient solution for the propagation of vegetable plants in rock wool cubes

Macro nutrients mmol l^{-1}		Micro nutrients µmol l^{-1}	
NH_4	1.25	Fe	25
K	6.75	Mn	10
Ca	4.5	Zn	5
Mg	3.0	B	35
NO_3	16.75	Cu	1
SO_4	2.5	Mo	0.5
H_2PO_4	1.25		

Data of Sonneveld and Straver (1994).

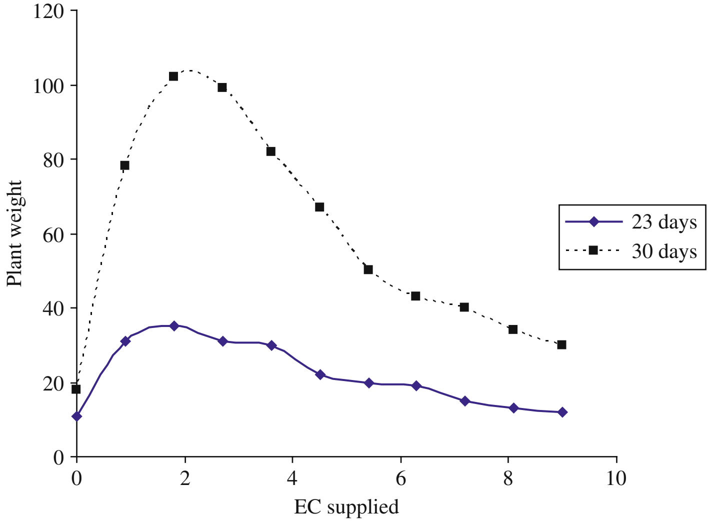

Fig. 14.11 Relationship between the EC of the nutrient solution supplied during propagation of tomato in rock wool cubes and the plant weight at 23 and 30 days after start. Data of Boertje (1981)

Comparable results are gained with the propagation of plants in substrates composed from natural organic materials (Boertje, 1975). Tomato plants grown in 1.2 l pots filled with organic potting compost under different fertilization regimes showed optimal growth with an application of 1–2 kg m^{-3} of a fertilizer mix N-P-K of 16-5-17. Beside this mix, the standard applications of lime, micro nutrients and P were added. Within the given range the fertilizer addition and the pot size can be adjusted to the expected plant size. Higher addition seriously decreased the growth. Under the given conditions tomato plants could be grown up to a plant weight of 50 g fresh weight, without top dressing. The use of small pots and low fertilizer applications quickly induce requirements for top dressings during propagation.

Peaty substrates are commonly fertilized with sufficient nutrients for the start and the first growing period of the propagation. Addition of fertilizers during the propagation can be necessary and depend on the ratio between the substrate volume used, the desired plant size and the plant type (Klapwijk and Mostert, 1992). For sowing and rooting of cuttings peaty substrates are lightly fertilized. For the raising of flower plants peaty substrates are moderately fertilized and for the raising of vegetable plants often heavily fertilized substrates are used. For definitions of the nutrient status see Table 11.12.

Some young plant types seem to be extremely sensitive for Mo deficiency, when propagated in peaty potting substrates. The addition of this element in peaty potting substrates surely is required for the raising of many young plants. Experience have been gained by tomato, lettuce and cauliflower (Van den Ende and Boertje, 1972) from which crops the last is best known as being most sensitive to Mo deficiency. See also the remarks about this in Section 11.4.3. The deficiency especially occurs if

Table 14.15 Index figures for Mo deficiency as affected by the pH of the growing medium and the addition of Mo as $(NH_4)_6Mo_7O_{24}.4H_2O$. Index: 0 – no symptoms and 10 – serious Mo deficiency

	Tomato μmol Mo l^{-1}		Lettuce μmol Mo l^{-1}	
pH	0	34	0	34
4.4 – 4.7	9	0	10	0
5.5 – 5.7	2	0	8	0
6.4 – 6.5	0	0	6	0

Data derived from Van den Ende and Boertje (1972). *Modified by permission of the International Society Horticultural Science*

the potting substrate is merely composed from high moor peat types (Roorda, 1965) and especially with low pH values (Boertje, 1979). Robinson (1987) even stated that healthy plants can be grown when the pH of the growing medium is sufficiently high. In Table 14.15 results are shown of an experiment with the propagation of young lettuce and tomato plants. Mo was yes or no added to the substrate at different pH levels. At a sufficient high value of the pH the symptoms of Mo deficiency completely disappeared for tomato, but not for lettuce. With the addition of 34 mmol m^{-3} Mo no symptoms were found at all pH levels. Lettuce seemed to be more sensitive than tomatoes. Thus, the quantities as mentioned in Table 11.15 suffice for nearly all crops.

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