# Chapter 16
# Nutrient Management of Soil Grown Crops

## 16.1 Introduction

The management of the fertilization of soil grown crops in greenhouses can be distinguished in the addition of fertilizers before cultivation, the base dressing and those added during the cultivations period of the crops, the top dressing. The growing period of the crops in greenhouse production varies strongly. Some vegetable crops like radish and lettuce have a growing period between 4 and 15 weeks mainly dependent on the growing season, whereby different crops can be grown successively in one year. Other vegetable crops like tomato, sweet pepper and cucumber can be grown year round in moderate climatic conditions, while in relatively hot climates, like the Mediterranean area, such crops can be grown for about 8 months, because of the high temperatures in the greenhouses in summer. The length of the growing period of most flower crops shows at least the same variation as those for vegetable in view of the great diversity of these crops grown in greenhouses. For some flower crops the growing period can cover several years, like roses. It will be clear that drastic changes in the soil, like the application of soil improvers, adjustment of the pH, base dressings, flooding and soil tillage only can be carried out between cropping periods in the greenhouse. Some handlings need to be carried out simultaneously, like the addition of less soluble fertilizers as base dressing and the soil tillage. Such fertilizers must be intensively mixed throughout the soil.

The management of the fertilization of greenhouse crops is based on relationships between optimal concentrations in the soil solution and maximum yield of a required quality. Just like discussed in Section 13.1, maximum yield and optimal quality can involve conflicting situations. Therefore, equal considerations are operative for the management of the fertilization of soil grown crops as for the nutrient management of substrate grown crops. The management of the fertilization of soil grown crops is based on the composition of the soil solution, just like with substrate growing. The composition of the soil solution will be estimated by sampling of the soil and analysis by the 1:2 extract as discussed in Section 4.2. A secondary advantage of this soil testing method is that beside the composition of the soil solution also a good estimation of the quantities of plant nutrients available in the root zone can be obtained. Upside down, it is possible to calculate the effects of fertilizers applied

C. Sonneveld, W. Voogt, *Plant Nutrition of Greenhouse Crops*,
DOI 10.1007/978-90-481-2532-6_16,

**Table 16.1** Increase of the concentration of nutrient elements in the 1:2 extract (mmol $l^{-1}$) as expected by the addition of 1 kg per 100 $m^2$ greenhouse area of that element. The calculations are operative for a depth of the root zone of 0.25 m

| Nutrient elements | Expected increase |
|---|---|
| N | 1.79 |
| S | 0.78 |
| K | 0.64 |
| Ca | 0.62 |
| Mg | 1.03 |

on the increase of the nutrient concentrations in the soil extract and successively in the soil solution, as follows from the data presented in Table 4.2, but also can be calculated how much fertilizer will be added to cover together with the calculated storage in the soil the uptake of the crop grown. The effect of addition of 1 kg of a nutrient element per 100 $m^{-2}$ on the analytical data of that element in the 1:2 extract is listed in Table 16.1. The calculations are carried out under conditions that no precipitation and adsorption occur. Deviations from this statement will occur with cations, K, Ca and Mg with respect to adsorption, which effects will be discussed further on in this chapter. P is not listed in the table, because of the low solubility of P compounds in soils.

The model of the relationship between the concentration of a nutrient element in greenhouse soils and the growth, which mostly can be defined as yield has a merely asymptotic character. Which means that yield increases strongly in the low concentration area and does not increase further on above the optimum value. Nutrient concentrations that exceed the optimum value substantially even can reduce the crop development, for example caused by too low osmotic potentials (high EC), toxicity or a reduced uptake of a different element by ionic competition. Therefore, a full asymptotic model satisfies only in an interval without yield reduction in the high range. For field crops an exponential response curve for the relationship between fertilizer application rate and yield has been developed (Neeteson and Wadman, 1987; Neeteson and Zwetsloot, 1989). Comparable response curves have been found between soil solution concentrations in substrate growing in rock wool as well in sand. In this comparison no differences were found between the response curves for rock wool grown and sand grown crops (Sonneveld et al., 2004), indicating that the growth response of crops on nutrient supply between soil and substrate does not differ essentially.

## 16.2 pH

For the determination of the pH in soil different methods are available. Best known is the determination in a soil:water suspension with a ratio 1:2 v/v. However, this method shows considerable fluctuations over the season, mainly caused by the changes in the salt status. Therefore, for a good estimation of the pH status of soils often a KCl solution of 1 mol $l^{-1}$ is used, with which a more stable value is obtained

(De Vries and Dechering, 1960). Generally the values of these so called $pH_{KCl}$ are lower than those pH determined in a water suspension. The difference for field soils amounted on average 0.7 pH unit. For different series of Dutch greenhouse soils (Roorda van Eysinga, 1966c, 1971a, b), the pH water values were on average 0.4 units higher than those in the KCl solution and in another investigation with 75 greenhouse samples an average difference of 0.2 units was found (Sonneveld and Voogt, 1986). The smaller differences detected for greenhouse soils can be explained by the higher salt status of these soils in comparison with field soils.

The recommended value of the pH of soils depends on the soil type, the requirements of the crop and possible growing conditions. The minimum guide $pH_{KCl}$ values recommended for greenhouse soils vary from 6.0 till 6.7 for mineral soils, while for peaty soils a minimum value of 5.5 is recommended (Van den Bos, 1993). For soils with high Mn content like many marine and river clayey soils, a value of at least 6.5 is recommended, to prevent too high uptake of this element. This especially is true for steam sterilised soils, because of the strong release of Mn by this treatment, as discussed in Section 10.4. Soils with a high $CaCO_3$ content often have a pH value above 6.5. High pH values can induce chlorosis, mostly caused by an insufficient availability of Fe and Mn.

For the adjustment of the pH to control too low values generally different types of limestone are used. The quantity necessary depends on the characteristics of the soil, the depth of the root zone that will be adjusted, the bulk density of the soil and the pH difference that will be bridged. With the aid of these factors a method has been developed with which it is possible to calculate the quantities of limestone fertilizer to adjust too low pH values in the soil to values desired by the crop that will be grown (De Vries and Dechering, 1960). Results of such calculations for greenhouse crops are presented by Van den Bos et al. (1999). In Fig. 16.1 results of these calculations are presented for different soil types, dependent of the content of loss on ignition and clay. The quantities of base material that will be added are related to a pH increase of 0.1 units and presented as mol base (lime or hydroxide) per $m^2$. The adsorption capacity of organic matter is much higher than those of clay. Therefore, the quantities necessary by the loss on ignition is four times higher than those by clay. For example on a sandy soil with 5% organic matter lime fertilizer equivalent with 1.08 mol base $m^{-2}$ is required to increase the pH with 0.1 unit. An example of the calculation related to addition of $CaCO_3$ is presented in Formula (16.1). The effective base content of fertilizers generally is expressed as % CaO. 1 mol base is equivalent with 28 g CaO or 20 g Ca.

$$Rq_{CaCO_3} = \frac{1}{2} \times 100.1 \times 1.08 = 54.1 \tag{16.1}$$

In which:

$Rq_{CaCO_3}$= required $CaCO_3$ in g $m^{-2}$ $CaCO_3$ for an increase of the pH with 0.1 unit over a depth of 0.25 m

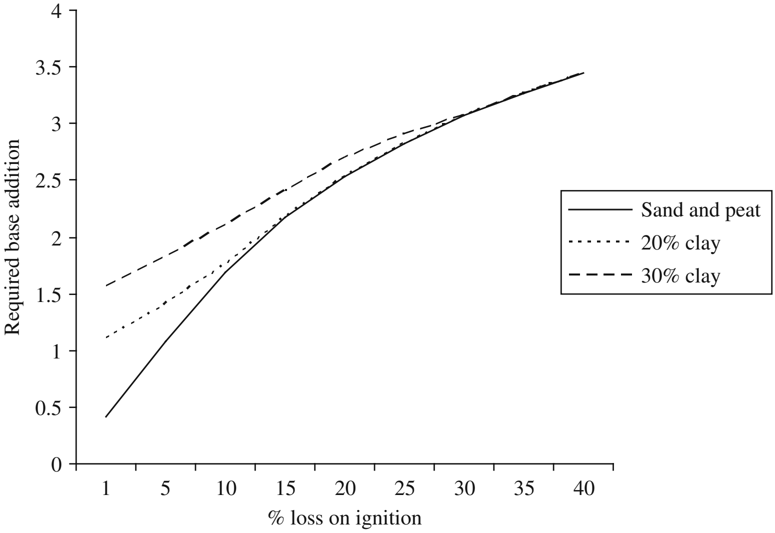

**Fig. 16.1** The quantities of base material (mol $m^{-2}$) necessary to increase the pH value with 0.1 unit over a depth of 0.25 m, dependent on the organic matter (loss on ignition) and clay content of the soil (Van den Bos et al., 1999)

Addition of about 1.5 mol base material per $m^2$ per year is estimated as a maintenance dressing on soils poor in $CaCO_3$. Maximum applications added at once vary between 5 and 15 mol $m^{-2}$ for sandy soils and peaty soils, respectively. When the pH is very low and applications are calculated higher than those mentioned, part of the required lime stone fertilizer will be given in the second year.

## 16.3 Flooding

The salt concentration in the root zone after crop cultivation can be at such a high level that thorough flooding is necessary before a next crop is planted in the greenhouse. This also can be necessary for a smooth out of a horizontal unequal salt distribution in the root zone. This for example especially needs attention when a row crop with walking paths is followed by a crop with a planting pattern that scatters the whole surface, as discussed in Section 6.4. In such cases the soil surface of the walking paths will be broken before flooding, to improve the vertical water transport. Comparable situation occur when a crop grown with drip irrigation is followed by a crop that covers the whole surface. Drip irrigation always bring about an unequal salt distribution, being worst at the end of the growing season, like shown for $NO_3$ in Fig. 4.4. The quantities of water necessary will be calculated following formula (6.5).

The salinity level at which flooding is necessary depends on the crop and the growing conditions aimed at. With crop rotations as described in the foregoing

**Table 16.2** Limits for total salt (EC, dS $m^{-1}$), Na and Cl (mmol $l^{-1}$) concentrations in the 1:2 volume extract. With values higher than the limits presented, flooding is recommended

| | Limits for flooding | |
|---|---|---|
| Crops | EC | Na and Cl |
| Cucumber | 1.8–2.5 | 3–4 |
| Tomato | 2–2.5 | 4–5 |
| Sweet pepper, gerbera | 2 | 3.5 |
| Carnation, rose | 1.5–2 | 3–3.5 |
| Lettuce, endive | 1.5–2 | 3–4 |
| Spinach | 1.8–2.5 | 3–4 |
| Bulbs | 1 | 2 |
| Other crops | 1.5 | 3 |

paragraph, more or less always flooding is recommendable, to prevent an unequal start of the crop. Sometimes under poor light condition an increased salinity level is desired to prevent a too lush growth of the crop at start. The necessity of flooding is mainly based on the total salt, Na and Cl concentrations of the soil. From history rough maximum limits were given for total salt and Cl in the 1:2 volume extract (Sonneveld and Van den Ende, 1971), being an EC value of 2.1 dS $m^{-1}$ for the total salt and 3.3 mmol $l^{-1}$ for Cl. For Na no limit was given, but this will be estimated to be equal to the one for Cl. Later on more detailed limits were supplied by Van den Bos et al. (1999), as summarized in Table 16.2. For some crops a range is given, whereby a decision about flooding can be made within this range dependent on the growing conditions. When the crop will be grown under conditions favourable for salt damage, the low value of the range is maintained.

With leaching also nutrients are washed out, like shown in Table 16.3 (Sonneveld and Van Beusekom, 1974). The ultimate results also depend on the quality of the primary water used for flooding. In the presented situation the water used for flooding had following characteristics: EC 1.2 dS $m^{-1}$, Cl 5 and Mg 0.3 mmol $l^{-1}$. The concentration of any ion in the soil solution never can become lower than those in the

**Table 16.3** The concentration of water soluble total salt (g $kg^{-1}$ dry soil) and of water soluble ions (mmol $kg^{-1}$ dry soil), as affected by flooding with various quantities of water. The walking paths and the cultivation strips were separately sampled

| | Before flooding | | After 150 mm water | | After 450 mm water | |
|---|---|---|---|---|---|---|
| Determination | Path | Strip | Path | Strip | Path | Strip |
| Total salt | 4.2 | 2.3 | 1.1 | 0.8 | 0.6 | 0.6 |
| Cl | 26.9 | 12.4 | 4.02 | 1.97 | 2.05 | 1.71 |
| N ($NO_3$) | 7.11 | 2.14 | 1.11 | 0.46 | 1.36 | 0.50 |
| P | 1.06 | 1.63 | 1.16 | 1.30 | 1.12 | 1.17 |
| K | 2.48 | 2.47 | 1.15 | 0.99 | 0.96 | 1.01 |
| Mg | 2.57 | 0.76 | 0.60 | 0.40 | 0.40 | 0.41 |

The data are derived from a loamy greenhouse soil over a depth of 0.3 m (Sonneveld and van Beusekom, 1974) primary water used for the flooding. With this statement result of a flooding can be checked by sampling and analysis of the Cl concentration in the 1:2 volume extract following the equation presented in Table 4.1. The concentration in the soil solution will be estimated as being the concentration of the primary water used for leaching. Eventually the determination can be carried out in the dry soil and for the calculation Equation (16.2) will be used.

$$Cl_{ds} = \frac{Cl_{rw} wv_f}{\rho} \tag{16.2}$$

In which

$Cl_{ds}$ = Cl content in mmol $kg^{-1}$ dry soil
$Cl_{rw}$ = the Cl concentration of the primary water
$wv_f$ = volume fraction of water of the field moist soil
$\rho$ = the bulk density in kg $l^{-1}$

In the example of Table 16.3, $wv_f$ and $\rho$ were 0.32 and 1.2, respectively. Thus, maximum result is obtained in the presented example with $Cl_{ds}$ of 1.3 mmol $kg^{-1}$ dry soil. This value is approximated after a flooding of 450 mm. The behaviour of $NO_3$ can be compared with that of Cl. The concentration water soluble P will not be affected significantly by leaching, because of the solubility equilibrium of P in the extract and possible release from the storage. The cation concentrations after flooding will be affected by the cations adsorbed on clay and organic matter.

## 16.4 Base Dressings with Nutrients

### *16.4.1 Nitrogen*

Mineral N mainly occurs in greenhouse soils as $NO_3$. $NH_4$ supplied with the fertilizer dressings before crop cultivation is quickly converted to $NO_3$, because of the favourable conditions for this process in greenhouse soils. An exception on this rule happens on sterilised soils, where the bacterial activity is disturbed. This for example has been found after steam sterilisation. With this treatment not only $NH_4$ is released by an intensified decomposition of organic matter, like discussed in Section 10.5, but also the conversion of added $NH_4$ is delayed (Sonneveld, 1969a).

Research to the optimal level of mineral N in greenhouse soils mostly offered values between 3.5 and 7 mmol N $kg^{-1}$ dry soil, which can be converted to values between 2.6 and 5.4 mmol $l^{-1}$ 1:2 volume extract (Sonneveld and Van den Ende, 1971). Such a conclusion was based on extended studies of which results were published by Roorda van Eysinga (1972), who noticed for lettuce 6.5, for tomato 5.5 and for cucumber 7 mmol N $kg^{-1}$ dry soil as optimum values. In different publications Spithost (1965) and Roorda van Eysinga (1971a) noticed an optimum of 3.5 and

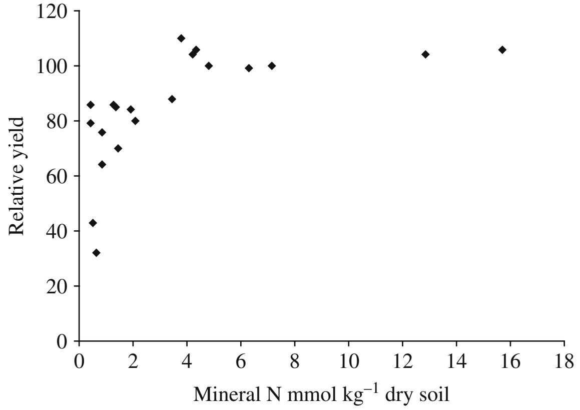

**Fig. 16.2** Relationship between the mineral N content (mmol kg$^{-1}$ dry soil) of different soils and the yield of tomato relative to the optimum yield. Data after Roorda van Eysinga (1971a)

5.5 mmol N kg$^{-1}$ dry soil for tomato, respectively. Kohlrabi produced optimal yields at 7 mmol N kg$^{-1}$ dry soil (Roorda van Eysinga and Mostert, 1972). In Fig. 16.2 an example is shown of the relationship between the mineral N concentration in the soil and the relative yield of tomato, as has been found in a series of experiments by Roorda van Eysinga (1971a). In these experiments the yield as has been gained in the unfertilized plots was related to the yield at optimal N fertilization in every experiment. The soil types in this research were merely of mineral origin, only one peaty soil was included. The figure shows sure enough, that optimum yields were gained in the experiments where the original N concentration was about 5 mmol kg$^{-1}$ dry soil, which agrees with 3.5 mmol l$^{-1}$ in the 1:2 volume extract. A specific effect of N supply is that an ample addition surely reduced the attack by *Botrytis cinerea* of tomato (Roorda van Eysinga, 1966a; Verhoef and Weber, 1965).

### *16.4.2 Phosphorus*

Most greenhouse soils contain much P because of an abundant application of this element and the fact that it is scarcely washed out by an overdose of water. The solubility of P is low in relation to the total amount available. Therefore, the quantity of P determined with a water extraction depends much on the water to soil ration maintained during extraction. The quantities of P extracted by the customary soil testing method of the 1:2 volume extraction in the greenhouse cultivation is only a fraction of the total P in greenhouse soils. In the 1:2 extraction of 75 greenhouse samples on average 0.23 mmol P l$^{-1}$ extract was determined (Sonneveld et al., 1990), while in the same samples with a 1:100 w/w extract 2.73 mmol l$^{-1}$ soil was determined (Sonneveld and Voogt, 1986). On basis of the data presented in Section 4.2 can be calculated that with the 1:2 volume extraction on average 92 mmol m$^{-2}$ and with the 1:100 w/w method 682 mmol m$^{-2}$ greenhouse soil was extracted. The correlation coefficient between the results of both determinations (r = 0.67) was rather low,

**Table 16.4** Coefficients of correlation for the relationships between P-water contents (1:5 w/w, 18°C ) of greenhouse soils and the results of different other P determinations, following Roorda van Eysinga (1971). Pw-values are expressed on the volume and the results of the other determinations on weight of the dry soil

| Determination | Extraction ratio | Mineral soils | Peaty soils |
|---|---|---|---|
| P-value water 50°C | 1:10 w/w | 0.96 | 0.84 |
| Pw-value water 20°C | 1:60 v/v | 0.97 | 0.93 |
| P-$NH_4$ lactate pH 3.75 | 1:20 w/w | 0.89 | 0.71 |
| P-citric acid 1% | 1:10 w/w | 0.90 | 0.51 |
| P-total Fleischmann acid | 1:4 w/w | 0.67 | 0.29 |

which will be explained by the great variation of compounds in which P can occur in soils. Nevertheless, in many cases the results of different P determinations are reasonably correlated, like found by the extended research of Roorda van Eysinga (1971) with Dutch greenhouse soils, especially when mineral and peaty soil types were separated, like shown in Table 16.4. The correlation coefficients for the peaty soils are substantially lower than those for the mineral soils. Comparable results have been found recently with soils from elsewhere, with a different series of determinations (Indiati and Sing, 2001).

The quantities of total P in greenhouse soils are much higher than those available in the different water extracts. In Fig. 16.3 the relationship is shown between the results of the water soluble P contents determined in the 1:5 w/w water extracts and those of the total P determination (Roorda van Eysinga, 1971). With the relationship shown for the sandy soil can be calculated that the quantities of total P easily exceed the water soluble quantities with a factor of about 30. The quantities of total P for different soil types vary strongly and are mostly higher than those found for sand. Average values of 21, 31, 38 and 118 mmol kg$^{-1}$dry soil for sand, sandy loam, clayey loam and clayey peat, respectively were calculated for data of greenhouse soils (Roorda van Eysinga, 1971).

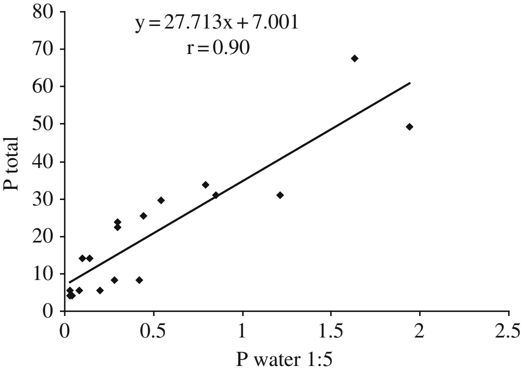

**Fig. 16.3** Relationship between the results of the determination of water soluble P and total P content of a series of sandy greenhouse soils. The contents are expressed as mmol kg$^{-1}$ dry soil. After Roorda van Eysinga (1971)

The analytical data of the different P determinations as mentioned in Table 16.4 reasonable reflect the P uptake. For lettuce the relationship was estimated by an equation of the model presented in Equation (16.3) (Roorda van Eysinga, 1971).

$$y = a \log x + b \tag{16.3}$$

In which

x = result of the P determination of the soil
y = result of the P determination in the crop

The relationship between the P concentration of the soil and the yield was also curve linear and showed a good agreement with the model for the P uptake. Therefore, the relationship between the P concentration in the soil and the yield was approximated by Roorda van Eysinga (1971) by a function according Equation (16.3). However, such a logarithmic model is not logic, because it suggests an increasing yield for values above an optimum nutrient uptake. In Fig. 16.4 the relationship is shown between the water soluble P content of the soil and the relative yield of lettuce for 19 different sandy soils on which experiments with P addition were carried out. The relative yield at the different experimental sites was calculated as mentioned for the N experiments. Maximum yield on the mineral soils was obtained at P concentrations of the soil of about 0.5 mmol kg$^{-1}$ dry soil, determined in the 1:5 water extract. A further increase of the water soluble concentration does not increase the yield. For peaty soils this value was about twice as high. The quantity of dry soil per volume for the peaty soil types was about half of that for the mineral soils. Thus, the quantity of P required per volume of soil is more or less equal for all soils. This suggests that the interpretation will be based on the quantity of P per volume of soil. Thus, the interpretation presented for mineral soils on weight basis is true for all soils when expressed on volume, for the bulk density of mineral soils is roughly around 1. Such an interpretation is supported by Roorda van

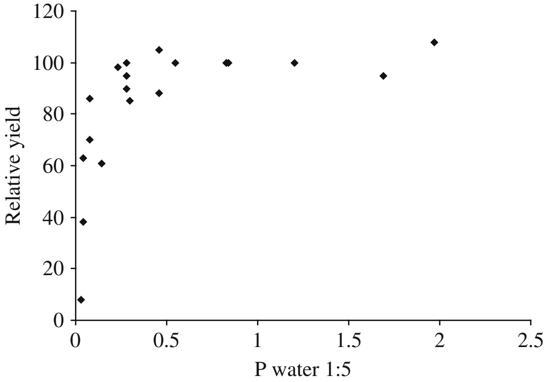

**Fig. 16.4** Relationship between the P concentration of the soil (mmol kg$^{-1}$ dry soil) soluble in 1:5 w/w water extract and the relative yield of lettuce on sandy soils. After Roorda van Eysinga (1971)

Eysinga (1971) with the remark in his report that interpretation of the results of the determination of water soluble P on basis of volume ratios as published by Van der Paauw (1969) and Sissingh (1969) showed less variation than those based on weight ratios. The at the time used data of the P 1:5 water method can be recalculated to data for the nowadays used specific 1:2 v/v method (Sonneveld and Van den Ende, 1971), which result for the 0.5 mmol $kg^{-1}$ soil to a value of 0.14 mmol $l^{-1}$ in the 1:2 extract. Roorda van Eysinga (1972) concluded that lettuce was most sensitive to P supply and the P supply can be omitted above a value of 70 mg $P_2O_5$ and for tomato above 50 mg $P_2O_5$ $kg^{-1}$ dry soil, which can be recalculated to 0.24 and 0.14 mmol $l^{-1}$ in the specific1:2 v/v volume extract.

When the soil is more or less saturated with P, the quantity of soluble P is relatively constant over long periods, like shown by the data of the loam soil in Fig. 16.5. However, when the soil contain less P heavy P applications are necessary to saturate the soil with sufficient P, like shown with the clay soil in Fig. 16.5. During the 3 years that the course of the P concentration in the soils was followed, a fertilizer dressing of 0.8 and 4.0 mol P per $m^2$ was applied on the loam and the clay soil, respectively, while the P applied by soil improvers was estimated on 0.6 and 3.6 mol per $m^2$, respectively. From these data will be concluded that in advance big quantities of P are necessary to bring field soils on the P level required for greenhouse cultivation. Therefore, Roorda van Eysinga (1966) has found huge effects of P application on newly reclaimed soils. He recommended an application of 1.3 mol P $m^{-2}$ per year during the first years of greenhouse cultivation. Afterwards the application will be reduced later to 0.7 mol or lower dependent the on the development of the P status of the soil.

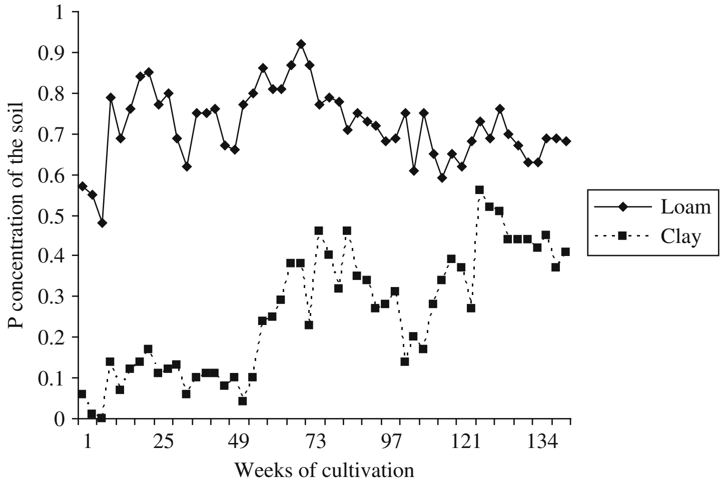

**Fig. 16.5** Course of the P concentration in greenhouse soils (mmol $kg^{-1}$ dry soil) as determined in a 1:5 water extract during 3 successive years. The loam soil was covered by a greenhouse for already many years, while on the clay soil a greenhouse was build from week 1. (Data Sonneveld, 1966, 1967, 1969)

Soils used for greenhouse cultivation during many years often contain much P, by addition of this element by fertilizers and by soil improvers that easily exceeds the uptake. Furthermore the leaching is small and in relation to other macro nutrient negligible as already discussed in Section 16.3. For this reason Roorda van Eysinga (1971) found for a specific group of Dutch greenhouse soils that the age of the greenhouse was a better indication for the determination of the optimum P application than the determination of P by different extraction methods. In older greenhouses P application is scarcely required and usually does not exceed 0.5 mol $m^{-2}$ per year. This also was confirmed by recent experiments with lettuce, radish and chrysanthemum (Van den Bos, 2001, 2004, 2004a; Van Gurp, 1998) whereby comparisons were made with P dressing applied for every crop on average varying between 0 and 350 mmol $m^{-2}$. The experiments for lettuce and chrysanthemum were carried out on two different soils, a clayey soil and a sandy soil, while the experiment with radish crop was carried out on a sandy soil. The pH values of the soils varied between 6.0 and 7.5. In the experiments a great number of crops were successively grown to follow the crop development without P dressing in the long run. With lettuce on the clayey soil 13 crops were grown and on the sandy soil 23 crops, with the radish 25 crops were grown and in both chrysanthemum experiments 14 crops. In the treatments without P addition the P concentration in the 1:2 volume extract was 0.10 mmol $l^{-1}$ in the lettuce experiment on the sandy soil and on the other soils it was about 0.03 mmol $l^{-1}$. The yields in the non fertilized treatments were incidental a shade lower than in the other treatments; on average the difference with the fertilized treatments was 1–4%. In the treatments with the lowest P application the P concentration in the 1:2 volume extract was 0.15 in the lettuce experiment on the sandy soil and varied in the other experiment from 0.03 till 0.07 mmol $l^{-1}$, which resulted to an optimal yield for all crops. Higher applications stimulated the P uptake, but did not increase the yield of the crops. In Table 16.5 some data of the experiments are presented. The lowest P applications in the experiments amounted to about 40 mmol $m^{-2}$ per crop for radish and for chrysanthemum, and about 80 mmol $m^{-2}$ per crop for lettuce. The average P uptake at optimum growth for lettuce, radish and chrysanthemum was 57, 22 and 64 mmol $m^{-2}$ per crop, respectively. Thus, the additions easily exceeded the uptake.

**Table 16.5** Average results of experiments with different P additions. 13 lettuce crops were successively grown on a clayey soil and 14 chrysanthemum crops on a sandy soil at. The P added is expressed as mmol $m^{-2}$ per crop, the P concentration in the 1:2 volume extract ($P_{1:2}$) as mmol $l^{-1}$ extract, the plant weight in g per plant and P concentration of the crop as mmol $kg^{-1}$ dry matter

| Lettuce | | | | Chrysanthemum | | | |
|---|---|---|---|---|---|---|---|
| P added | $P_{1:2}$ | Plant weight | P crop | P added | $P_{1:2}$ | Plant weight | P crop |
| 0 | 0.03 | 320 | 189 | 0 | 0.030 | 82.4 | 115 |
| 84 | 0.07 | 331 | 214 | 40 | 0.042 | 84.8 | 126 |
| 168 | 0.11 | 330 | 231 | 80 | 0.051 | 85.9 | 131 |
| 252 | 0.16 | 331 | 242 | 160 | 0.072 | 86.0 | 139 |
| 336 | 0.22 | 332 | 248 | | | | |

Results of the former research by Roorda van Eysinga (1972) as mentioned before suggested optimum P concentrations in the 1:2 volume extract up to 0.24 mmol $l^{-1}$ for lettuce, being the most sensitive crop for reaction on P fertilization. The more recent research presented in the former paragraph showed optimal yield at P concentrations between 0.04 and 0.07 mmol $l^{-1}$ and in one case at a level of 0.15 mmol $l^{-1}$. Recommendations to growers by Van den Bos et al. (1999) showed guide values of 0.10 mmol $l^{-1}$ in the 1:2 extract, for different crops and growing conditions and on this $P_{1:2}$ level addition of P is scarcely carried out only when the P storage is below the optimum. The concept of P storage is explained in following paragraph.

In greenhouse cultivation mostly correlation coefficients for the relationship between soil P and yield do not differ much for P when determined with water extracts or with mild acid extracts (Roorda van Eysinga, 1971). However, his research with a series of diluvial soils showed higher correlation coefficients for mild acid extraction than for water extraction (Roorda van Eysinga, 1961). Therefore, sometimes P is determined with the aid of $NH_4$-lactate buffered at pH 3.75 in a soil:solution ratio 1:20 w/w and used to determine the P storage (Egnér et al., 1960), the so called P-Al determination. The storage determined with this method is estimated low for concentrations below 10 mmol $kg^{-1}$ dry soil and optimal for concentrations between 15 and 20 mmol $kg^{-1}$ dry soil (Van den Bos, 1993). For greenhouse soils the P fertilization is based on both the storage and the solubility, determined by the P-Al and the P-1:2 extractions, respectively. The determination of P-Al is carried out once in two years, while those of P-1:2 with water is carried out more frequently.

### 16.4.3 Potassium, Calcium and Magnesium

The additions of K, Ca and Mg are mutually related, because these elements are on most soils for the greater part adsorbed on the clay and humus particles in the soils. In greenhouses for K the ratio water soluble/exchangeable mostly varies between 2 and 3 and is possibly higher for clayey soils than for sandy and peaty soils (Roorda van Eysinga, 1963). This means that the addition of one of the cations also affect the concentration of the other cations in the soil solution by exchange from the adsorption complex. Therefore, cations added with fertilizer applications will not always be found back in the soil solution in concentrations in agreement with the addition. A new equilibrium will occur, like shown by the data of Table 16.6 (Sonneveld, 1993). For the peaty soil the increase of the cations in the saturation extract is relatively in equilibrium with the supply, but for the clayey soil the increase of K in the saturation extract is relatively low, while those for the Ca and Mg is relatively high. This is in agreement with the characteristic of clayey soils, where K is strongly adsorbed and thereby is exchanged with Ca and Mg. For that reason often extra K is added in newly built greenhouses on formerly field soils poor on K when the soil contains a high content of clay. Mostly an extra base dressing of 2 till 4 mol K $m^{-2}$ is added, dependent on clay content and the need of the crop, before

**Table 16.6** Addition of nutrient cations (mol $m^{-2}$) with primary dressings of fertilizers and the increase of the cation concentrations in the saturation extract (mmol $l^{-1}$)

| | Clay soil | | Peaty soil | |
|---|---|---|---|---|
| Elements | Addition | Increase | Addition | Increase |
| K | 0.9 | 1.9 | 0.8 | 2.7 |
| Ca | 0.5 | 4.4 | 0.2 | 0.8 |
| Mg | 0.4 | 3.0 | 0.3 | 1.0 |

the start of the first cropping. For soils with a heavy K fixation comparable quantities up to 1600 kg K (4 mol $m^{-2}$) are reported in the literature as being favourable for tomato production (Doll and Lucas, 1973; Schäfer and Siebold, 1972). Insufficient availability of K in soils can strongly affect the fruit quality by an unequal colouring, like for example with tomato (Roorda van Eysinga, 1966a). Optimal yields are derived with water soluble K concentrations of 1.2 till 3.2 mmol $kg^{-1}$ dry soil, for the mainly mineral soils studied in experiments (Roorda van Eysinga, 1966b). Those values can roughly be transformed to concentrations of 0.7 till 1.8 mmol $l^{-1}$ in the 1:2 volume extract, following the information supplied by Sonneveld and Van den Ende (1971). For "high quality" produce higher concentrations are required up to 5.3 mmol $kg^{-1}$ dry soil, which can be recalculated to 3.0 mmol $l^{-1}$ in the 1:2 extract.

The concentrations of Ca and Mg are mostly adjusted to the K concentration maintained. Less specific research had been carried out for the supply of these elements for soil grown crops. There are significant differences between crops for the sensitivity to Mg deficiency, tomato and eggplant for example showed to be sensitive, while sweet pepper seldom shows Mg deficiency symptoms. In soils mostly Ca is sufficiently high as a result of the application with Ca containing fertilizers and soil improvers, the decomposition of $CaCO_3$ and the use of irrigation water that contains Ca. Therefore, the concentrations in the soil solution often exceed strongly those of the K (Sonneveld et al., 1990) and a known addition can be ignored. Mg also is applied to the soil by the sources mentioned for Ca. Nevertheless, less evidently than Ca and sometimes the addition of Mg by fertilization can be necessary. The Mg concentration in the soil mostly is maintained on a certain level in relation to the K concentration, which seems logical. In an investigation with tomato, samples were gathered from places where Mg deficiency was manifested in relation to places in the same greenhouses where the crop was more or less free from symptoms (Sonneveld, 1969b). The results of this investigation are summarized in Table 16.7 and it is indicated that for a sensitive crop like tomato a water soluble mol/mol ratio Mg/K of about 0.9 have to be maintained in the root zone. The general recommendation presented by Sonneveld and Van den Ende (1971) is somewhat lower, and amount to 0.65 for the mol/mol ration in the 1:2 volume extract. The higher ratio found for tomato is in agreement with the sensitivity for Mg deficiency of this crop. The Ca concentration is also important for the Mg uptake (Sonneveld and Voogt, 1991), but the Ca concentration was not included in the investigation discussed.

**Table 16.7** Mg deficiency in tomato as affected by the Mg concentration in the leaves (mmol kg$^{-1}$ dry matter), the Mg water concentration determined in a 1:5 water extract (mmol kg$^{-1}$ dry soil) and the Mg/K mol/mol ratio determined with the 1:5 water extract

| % chlorotic leaf area | Mg in leaves | Water soluble Mg | mol ratio water soluble Mg/K |
|---|---|---|---|
| $\leq$10% | 236 | 2.65 | 0.87 |
| <10 and $\leq$ 45 | 208 | 2.45 | 0.69 |
| > 45 | 129 | 2.10 | 0.64 |

Data after Sonneveld (1969b).

## *16.4.4 Addition of the Base Dressing*

On basis of the experiments carried out with different crops and under different growing conditions guide values for analytical data in the 1: 2 volume extract are set up as recommendations to growers (Van den Bos et al., 1999). In Table 16.8 some examples are listed. Tomato always and radish just in winter are started with nutrient concentrations higher than required for an optimum nutrient uptake to prevent a too lush growth under poor light conditions in winter. With tomatoes at start such easily occur also under bright light conditions. The extra nutrients decrease the osmotic potential in the root environment, whereby the fruit setting and the bulb formation is promoted. The period indicated at the bottom of the table for radish is tuned on the weather conditions in North-West Europe. Under bright light conditions the nutrient status for tomato can be lowered dependent on the crop development and fruit quality. In Appendix E guide values are listed for different crops not presented in Table 16.8.

The quantities of nutrients necessary to bring the soil on the required nutrient level will be calculated with the aid of the analytical data of a soil sample and the data presented in Table 16.1. The calculations can be carried out with the aid of Equation (16.4).

**Table 16.8** Guide values (mmol l$^{-1}$ 1:2 volume extract) for the start of different crops grown in soil

| Crops | K | Ca | Mg | N | $SO_4$ | P | Cl |
|---|---|---|---|---|---|---|---|
| Chrysanthemum | 1.0 | 1.5 | 0.8 | 2.0 | 1.5 | 0.10 | |
| Rose | 1.5 | 2.0 | 1.2 | 4.0 | 1.5 | 0.10 | |
| Tomato | 3.5 | 3.5 | 2.7 | 7.5 | 3.5 | 0.10 | |
| Radish[1] | 2.0 | 1.5 | 0.75 | 2.0 | 2.25 | 0.10 | |
| Radish[2] | 3.0 | 3.0 | 1.0 | 3.0 | 3.5 | 0.10 | 2.0 |

[1] March 15th –August 15th;
[2] August 15th – March 15th.
After Van den Bos et al. (1999).

$$F_M = \frac{A_r - A_a}{Q_e} \tag{16.4}$$

In which:

$F_M$ = required fertilization in kg per 100 $m^{-2}$ for different major elements, expressed as K, Ca, Mg, N or S
$A_r$ = required analytical data in the 1:2 volume extract, see the recommendations in Table 16.8
$A_a$ = the current analytical data as determined in the 1:2 volume extract, under the condition that $A_r > A_a$
$Q_e$ = factor for nutrient addition as given for different elements in Table 16.1

The system is operative for the elements K, Ca, Mg, N and S. For the required analytical data indications are listed in Table 16.8 and Appendix E. For P a separate system is operative, based on the results of the P determination in the 1:2 volume extract, and possible on the P-Al determination. In Table 16.9 the P addition is listed as given by Van den Bos et al. (1999). The quantities of elements can be recalculated to additions of fertilizers listed in Chapter 2. Unequal requirements between anions and cations can be corrected by variations within the addition of $NO_3$ and $NH_4$. However, with these additions the soil pH will be taken into account. On calcareous soils addition of $NH_4$ is recommended, while an ample use of $NH_4$ on soils poor in $CO_3$ easily drops the pH value to unwanted levels. Under these conditions the use of N as $NH_2$ (urea) can be considered, because N applied in this form lowers the pH less than applied as $NH_4$. When the differences between anion and cation addition cannot be eliminated in the N form, mostly the addition of $SO_4$ is adjusted. This anion is often used as a residual factor.

When a soil improver is used, the minerals added with this material will be diminished on the nutrient addition calculated. This is mostly not the case for N, because the N in soil improvers is generally not directly available. The information about the nutrients available in soil improvers in Section 2.3 only gives a global impression.

**Table 16.9** Addition of P (kg P per 100 $m^2$) based on the analytical data of the P-Al and P water (1:2 volume extract)

| P 1:2 extract mmol $l^{-1}$ | P-Al mmol $kg^{-1}$ dry soil | | | | |
|---|---|---|---|---|---|
| | 0–2.8 | 2.9–5.6 | 5.7–11.3 | 11.4–16.9 | >17.0 |
| <0.05 | 4.0 | 3.0 | 2.0 | 1.0 | 0.0 |
| 0.06–0.10 | 3.0 | 2.0 | 1.0 | 0.5 | 0.0 |
| 0.11–0.15 | * | 1.0 | 0.5 | 0.0 | 0.0 |
| 0.16–0.20 | * | 0.5 | 0.0 | 0.0 | 0.0 |
| >0.20 | * | 0.0 | 0.0 | 0.0 | 0.0 |

*very unlikely combination
After Van den Bos et al. (1999).

A chemical analysis of the material is very useful to get a right impression of the nutrients applied with the soil improver used.

## 16.5 Top Dressings

For many crops with a short growing period and limited quantities of nutrient uptake the nutrients available in the soil mostly are sufficient to supply the crop with nutrients until the end of the growing period. Examples of such a situation is the production of lettuce, radish and some flower crops. The uptake of N and K for radish as calculated from a great series of crops (Sonneveld, 1997) was on average 685 and 348 mmol $m^{-2}$, respectively. For a summer grown crop, the level recommended for N as well for K in the 1:2 extract is 2 mmol $l^{-1}$, like listed in Table 16.8. The quantities of N and K available can be calculated by the information presented in Section 4.2 and is at this level 800 mmol $m^{-2}$ for both elements. The uptake of lettuce was on average 785 and 476 mmol $m^{-2}$ for N and K, respectively and this crop is grown at the same nutrient level in the soil. Thus, for this crop the N available at the recommended level is scarcely sufficient. For high yielding year round grown vegetables the uptake easily exceed 7000 mmol N and 4000 mmol K per $m^2$ (Sonneveld, 1997). For such crops at the start of the growing period, only part of the nutrients is available in the root environment and a substantial part will be added by top dressings. Indeed, the uptake of nutrients of year round grown flowers is lower than those of year round vegetables, but higher than can be added at the start of the crop. Utmost, some flower crops survive for several successive years at the same place without the possibility for an in between base dressing.

**Picture 16.1** Cucumber growing in soil with drip irrigation

The aim of the top dressing is the maintaining of a certain nutrient level in the soil for a longer period during crop cultivation. The levels in the soil recommended during crop cultivation are sometimes equal to those at the start, but differ in other cases. These differences can vary dependent on the growing conditions. This for example is the case with tomato grown under the climatic condition in North-West Europe. For this crop the most striking differences occur in the recommendations, as listed in Table 16.10. Values recommended for different crops during crop cultivation are listed in Appendix E. To maintain the nutrient status of the soil the concentrations of nutrients added to the irrigation water is standardized for different crops and is focussed on the uptake and the leaching during crop cultivation. In this way the withdrawal from the soil is more or less automatically compensated with the additions in the irrigation water. Nutrient solutions used for different crops are listed in Appendix E. Dependent on the requirements of crops and soils the $NH_4$ concentration can be adjusted. On very calcareous soils some crops suffer seriously by chlorosis and therefore, increased $NH_4$ concentrations are desirable. Furthermore, the concentrations added will be corrected on the nutrients already available in the primary water. The calculations necessary can be carried out by the system given for substrate growing in Chapter 12. In advance a concentration is added to the irrigation water in agreement with the standardized concentrations mentioned in Appendix E. Concentrations of the nutrients and ratios between them are adjusted during the growing period dependent on the results of soil samples gathered. Mostly every 3–6 weeks a sample is analysed following the 1:2 volume extraction presented in Section 4.2.

Adjustments on basis of the analytical data of soil samples are interpreted following the pathway shown in Fig. 16.6. In the area A-B the standard concentration of a nutrient is added to the irrigation water as mentioned in the standard nutrient solutions in Appendix E. The values A and B are –25% and +25% of the standard value for the 1:2 extract denote as S, respectively. Thus, in this area no adjustment on the standard concentration is applied. This is because of the sampling error estimated, as explained in Section 4.12. When adjustments are carried out in this area, they will be based earlier on the sampling error than on real changes of the concentrations in the root environment. In the area A-0 the concentration is linearly increased up to a maximum of 200%, while in the area B-D the concentration is linearly decreased to zero. The value D is commonly 200% of the standard guide value in the 1:2 extract. The concentration calculated can become very low and difficult to measure precisely by the fertigation system. In such cases the concentration is negligible as indicated

**Table 16.10** Nutrient status as recommended for tomato growing in greenhouse cultivation dependent on the climatic conditions. The data are expressed as mmol $l^{-1}$ of the 1:2 extract

| Period | K | Ca | Mg | N | S | EC |
|---|---|---|---|---|---|---|
| Start | 3.5 | 3.5 | 2.7 | 7.5 | 3.5 | |
| Feb 15th – Dec 1st | 2.2 | 2.5 | 1.7 | 5.0 | 2.5 | 1.4 |
| Dec 1st – Feb 15th | 3.3 | 3.8 | 2.6 | 7.5 | 3.8 | 2.1 |

After Van den Bos et al. (1999).

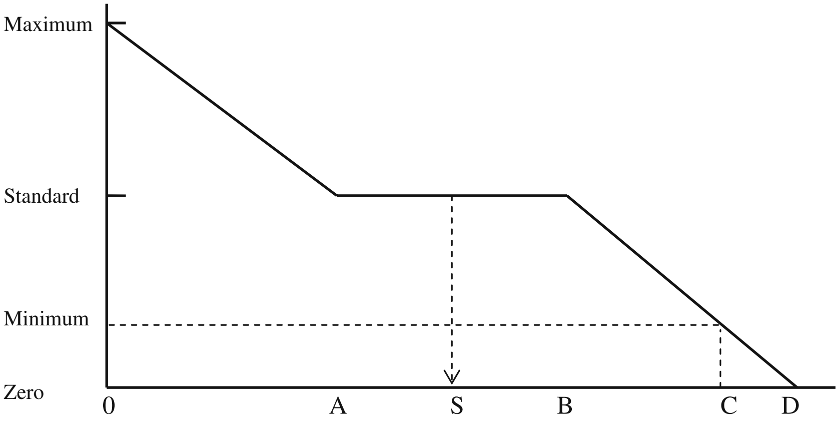

**Fig. 16.6** Relationship between the concentrations added to the irrigation water and the analytical results of the soil sample during the growing period. The value S is the standard concentration in the 1:2 extract. The concentration added to the irrigation water is standard in the area A–B, increases in the area B–0, decreases in the area B–C and is negligible in the area C–D

by the area C-D. The concentration to be added to the crop will be calculated by Equations (16.5) and (16.6).

$$\text{Concentration below A: } X_{ad} = \left(1 + \frac{X_A - X_{an}}{X_A}\right) X_{st} \tag{16.5}$$

$$\text{Concentration above B: } X_{ad} = \left(1 - \frac{X_{an} - X_B}{X_D - X_B}\right) X_{st} \tag{16.6}$$

In which

$X_{ad}$ = the concentration of nutrient X that will be added to the irrigation water
$X_A, X_B, X_D$ = the concentrations of nutrient X in the 1:2 extract as referred in Fig. 16.6, for A, B, and D, respectively
$X_{an}$ = the data in the 1:2 extract of the current soil analysis
$X_{st}$ = the concentration of nutrient X in the standard nutrient solution

In the scheme of Table 16.11 an example of the calculations is presented. The difference between the sum of anions and those of cations of the nutrients calculated in the end can be compensated in this case by partly replacement of $NO_3$ by $NH_4$, which surely is an advantage for cucumber growing in soil, as discussed in Section 15.7.

The recommended nutrient solutions as given in Appendix E, are due to crops grown under conditions of irrigation with sprinkler systems. When grown with

**Table 16.11** Calculation of the nutrient solution supplied with fertigation of a cucumber crop

Derived from Appendix E and calculated from text

| | $NH_4$ | K | Ca | Mg | $NO_3$ | $SO_4$ | EC |
|---|---|---|---|---|---|---|---|
| Guide values 1:2 extract | | 1.8 | 2.2 | 1.2 | 4.0 | 1.5 | 1.0 |
| Nutrient solution | 0.7 | 2.6 | 1.5 | 0.8 | 6.3 | 0.8 | 0.79 |
| Current values 1:2 extract (example) | 0.0 | 2.0 | 2.3 | 0.6 | 2.5 | 2.6 | 0.78 |
| A-B area[1] | | 1.4–2.2 | 1.6–2.6 | 0.9–1.5 | 3.0–5.0 | 1.1–1.9 | |
| D-value[1] | | 3.6 | 4.4 | 2.4 | 8.0 | 3.0 | |
| Calculation[2] of the $X_{ad}$ values | K, Ca, within the limits A-B no adjustment of the concentration<br>Mg 0.3 unit below A, thus increase of the addition<br>$NO_3$ 0.5 unit below A, thus increase of the addition<br>$SO_4$ 0.7 unit above B, thus decrease of the addition | | | | | | |
| Current nutrient solution[2] | 0.8 | 2.0 | 1.5 | 1.0 | 7.3 | 0.1 | |
| Composition primary water | 0.0 | 0.2 | 1.0 | 0.5 | 0.5 | 1.0 | |
| Nutrients to be added[3] | 0.8 | 1.8 | 0.5 | 0.5 | 6.8 | 0.0 | |

[1] Calculated see text;
[2] Calculated following formulae (16.5) and (16.6);
[3] The current nutrients diminished with those in the primary water.

such irrigation systems, crops will utilize substantial quantities of the nutrients supplied with the base dressing. When drip irrigation is used to supply the irrigation water the utilization of the base dressing will be less, because the plant roots utilize restricted soil volumes and by this restricted quantities of the base dressing. Roots merely develop in the wet spots (Mmolawa and Or, 2000) and thus, have no possibilities for nutrient extraction from the dry spots. Therefore, the concentration recommended for drip irrigation systems are 25% higher than those for sprinkler irrigation.

Phosphorus is seldom applied with top dressings. Only when P concentrations <0.10 mmol $l^{-1}$ in the 1:2 extract are determined 0.5 mmol $l^{-1}$ is added and when a level <0.05 is found, 1.0 mmol $l^{-1}$ is added to the irrigation water. This especially is necessary when the P storage (P-Al) in the soil is low, as indicated in Table 16.9. When the storage is high the benefit of such top dressings with P is doubtful.

## 16.6 Environmental Control

A precise and purposeful application of nutrients for soil grown crops is necessary to prevent environmental pollution. The nutrients added as an overdose are not absorbed by the crop and will be leached from the root environment with the irrigation surplus to the groundwater or the surrounding surface water. From the environmental concern special attention is focussed on the release of N and P from agricultural activities (Voogt, 2003). The control on the release of nutrients from soil grown crops commonly cannot be carried out by reuse of the drainage water, like is practiced with cultivation in substrate systems, because in soil grown crops the drainage water mostly cannot be gathered. In specific situations when greenhouses are situated in areas with a ground water table on a depth less than 1 m below the surface often the soil is equipped with a drainage system, from which the drainage water can be gathered and possibly reused. However, also in such situations a completely closed system cannot be realised, because of complication in the hydrology. Following situations can occur.

- When the ground water level by the drain system is lowered below the current ground water level, ground water from surroundings seep into the drainage system and mixes with the drainage water. For this situation see Fig. 16.7A
- As long as this ground water has a low salt content the mixing with the drainage water is no problem. However, when the ground water contains salts the reuse of drainage water is strongly restricted and mostly impossible.
- The influx of ground water can be more than the demand for irrigation and the residual must be discharged to the surface water.
- The current ground water level can be periodically below the drainage system, like shown in Fig. 16.7B In this situation the surplus water from irrigation penetrate the ground water and the drainage system does not function, like always happen in areas with a deep ground water level.
- When the irrigation water used contains substantial concentration residual salts reuse of drainage water is not effective, because of too high concentrations residual salts in the drainage water. See Section 7.8.

Thus, the reuse of drainage water for soil grown crops is not promising. In The Netherlands, where the groundwater table in greenhouse area is often close to the surface the application is restricted. In a survey (Voogt et al., 2008) only one third

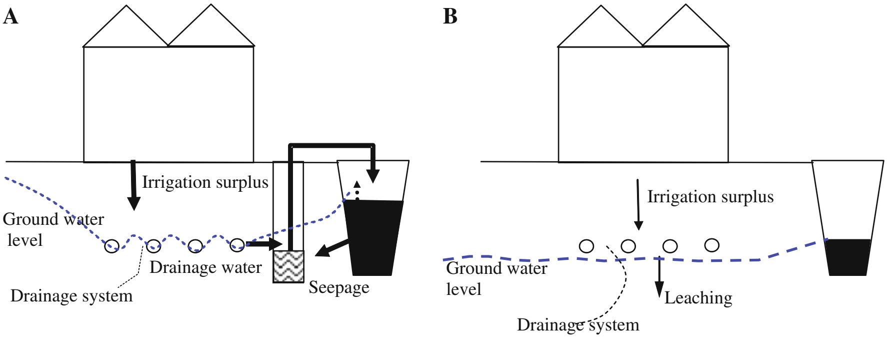

**Fig. 16.7** Simplified schemes of the hydraulic situations in typical Dutch greenhouses with drainage systems. The ground water level is artificially lowered and the drainage discharge is affected by seepage from nearby water in ditches and canals (**A**). The ground water level lowered under the drainage tube level, with which the irrigation surplus penetrates the groundwater (**B**)

**Picture 16.2** Year round chrysanthemum production in soil. In front plants and harvesting at the back-ground

of the greenhouses equipped with a drainage system could reuse substantial parts of the drainage water.

Therefore, to prevent environmental pollution as much as possible a well controlled supply of nutrients and water is very important with the cultivation of soil grown crops in the greenhouse industry. N is washed out quite easily from soils, because it mainly occur as $NO_3$ in soils and thus, completely present in the soil solution. It is transported from the root zone in concentrations equal to those in the soil solution, with which it partly will decompose by denitrification and for the other part is transported to the drain system or to the deeper soil layers. P is transported more difficult than N, because it precipitates with the Ca, Fe and Al in the root zone. However, when the root zone becomes oversaturated with P, it can be transported from the root zone just like N. However, the concentrations in the drainage water are much lower. When the soil once is oversaturated with P it offers problems for long periods, because huge quantities can be accumulated as a storage. For that reason the addition of P to soils is regulated by law in The Netherlands, even the quantities applied with the soil improvers. The quantities of soil improvers that can be added often are restricted by the quantity of P allowed to add to the soil by legislation. In soils with a big P storage, as often occur in greenhouse industry, the quantity of P added with soil improvers preferably will not exceed the uptake by the crop grown, to prevent in this way a further increase of the storage. In a study on five greenhouse holdings where organically grown vegetables were produced the P addition by means of organic fertilizers was on average 111 kg ha$^{-1}$, while the uptake on average was 60 kg ha$^{-1}$ (Voogt, 1999). The great differences among the holdings

**Table 16.12** Addition and uptake of P on five greenhouse holdings producing organically grown vegetables

| Holding | Organic matter added[1] t $ha^{-1}$ | P applied kg $ha^{-1}$ | P uptake kg $ha^{-1}$ |
|---|---|---|---|
| 1 | 30 | 105 | 60 |
| 2 | 6 | 20 | 100 |
| 3 | 61 | 171 | 60 |
| 4 | 31 | 214 | 50 |
| 5 | 7 | 46 | 30 |

[1] expressed as dry organic material

After Voogt (1999). *Reprinted by permission of the International Society Horticultural Science.*

were notable, like shown in Table 16.12. In the organic greenhouse cultivation not only the overdosing of P is problematic, but also N and K often are supplied in too high quantities (Cuijpers et al., 2005). Therefore, organic growing is not a promising technique for an effective use of nutrients beforehand. With this growing method a careful supply of nutrients in relation to the uptake of the crop and a precise irrigation management are required as will be discussed for the regular methods of greenhouse crop production in soil.

The well controlled supply of water and nutrients is seriously hindered by an unequal distribution of water supply and water uptake like discussed in Section 6.3. From this discussion has to be concluded that an optimal water supply for all plants always results to leaching. With respect to the supply of nutrients the same conclusion will be drawn, because even when plants are grown on a sub optimum nutrient supply level, leaching of nutrients has been found, as demonstrated in experiments (Sonneveld and Voogt, 2001). An inquiry investigation in Dutch chrysanthemum greenhouse nurseries confirms this statement (Voogt et al., 2002). Thus, when under this condition nutrients escape from uptake, it surely will occur under conditions of an optimum supply.

However, a precise application of fertilizers sufficient for an optimum production can restrict the leaching of nutrients substantially. To this purpose the development of a model for irrigation and fertilization can be very helpful. The result of the development of such a model for irrigation is shown in Fig. 16.8, in which the relationship is shown between the evaporation measured and calculated following formula (6.1), during the cultivation of five successive chrysanthemum crops (Voogt et al., 2000). Also the fertilization can be approximated quite well by a model, like shown for the N and K uptake of chrysanthemum crops (Voogt, 2001). Best results of a modelled fertigation can be expected with crops grown with a high planting density and a high density of irrigation points. The variation in irrigation and water uptake by the crop is as discussed in Section 6.3 will be best met in this way by mutual equalizing. A fertigation model developed for chrysanthemum growing was evaluated on three greenhouse nurseries, growing year-round chrysanthemum (Voogt et al., 2006). On the nurseries modelled fertigation was compared with the standard fertigation in accordance with common practice. The fertigation following the model substantially increased the efficiency of the use of water and fertilizers. The water use efficiency

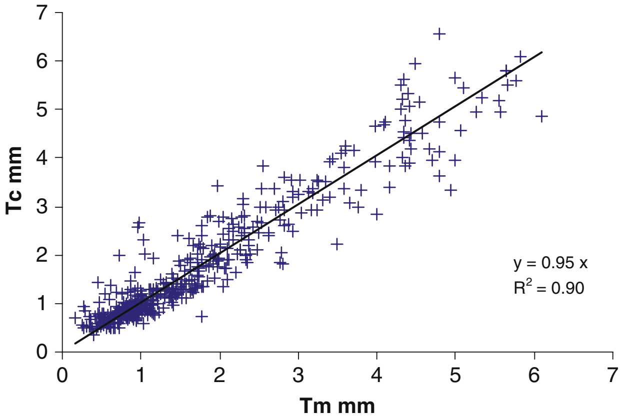

**Fig. 16.8** Relationship between measured (Tm) and modelled (Tc) evapotranspiration, following formula (6.1). The intercept is constrained through the origin and the factor for maximum transpiration (m), plant height was 0.4m. Data from five chrysanthemum crops (Voogt et al., 2000). *Reprinted by permission of the International Society Horticultural Science*

**Table 16.13** Nutrient balance sheet of N supply of an eustoma crop grown at different nutrient levels in a lysimeter experiment. The quantities are expressed as mmol $m^{-2}$

| | N level in the irrigation water supplied mmol $l^{-1}$ | | | | |
|---|---|---|---|---|---|
| Factors | 4.8 | 8.3 | 12.2 | 16.9 | 21.2 |
| Supply[1] | +562 | +971 | +1427 | +1977 | +2480 |
| Uptake crop | −654 | −754 | −762 | −745 | −823 |
| Drainage water | −241 | −372 | −536 | −729 | −981 |
| From soil storage | +726 | +630 | | | |
| Accumulated in soil | | | −108 | −787 | −486 |
| Ratio +/− | 0.69 | 0.70 | 0.99 | 1.14 | 0.92 |

[1] Supplied with irrigation water.
Data Van den Bos (1999).

increased on average from 0.78 to 0.87 and the efficiency of N addition increased on average from 0.74 to 1.00. However, the variation among the nurseries was substantial. The water use efficiency varied between 0.79–0.97 and 0.64–0.94 for the modelled irrigation and the standard fertigation, respectively. The N fertilisation surplus showed a variation of –0.26 to +0.24 and –0.15 to +0.86 for the modelled and standard fertigation, respectively. This resulted for the modelled fertigation to a surplus up to 210 kg N $ha^{-1}$ and for the standard fertigation up to 740 kg N $ha^{-1}$. The surplus in this experiment was calculated from the difference between the N supplied with fertigation and the N uptake measured. Thus, by modelling the efficiency of water and nutrients can be improved substantially, but not completely prevented.

The N surplus as calculated in the investigation discussed, not always is discharged to the ground or surface water. As mentioned, part of the N surplus can get lost by denitrification, which especially occurs in the deeper soil layers (Heinen, 2006; Postma, 1996). Denitrification follows from the results of an experiment in which the optimization of the fertilization of eustoma was studied (Van den Bos, 1999). The crop was grown at different nutrient levels in a lysimeter system, with a full control on addition, uptake and leaching of water and nutrients. The lysimeters were filled with sandy loam soil over a depth of 0.45 m. The water in which the nutrients at different concentrations were added was supplied with drip irrigation, only a small part of the water was supplied with an overhead sprinkler system at start of the crop. The drip system was provided with about 15 nozzles per m$^2$. The results of the nutrient balance sheets of the different treatments are listed in Table 16.13. The total water supply in all treatments was 117 l m$^{-2}$ and the drainage was 29.5 l m$^{-2}$. Despite a high density of the drippers a leaching fraction of 0.25 occurred and therewith a discharge of N between 241 and 981 mmol m$^{-2}$ was measured, agreeing with 34 and 137 kg ha$^{-1}$, respectively. The plant weight was not significantly affected, as shown in Fig. 16.9, while with the lowest supply the N concentration in the plant was lower than in the other treatments, indicating that the N supply was on the critical level in this treatment. The average ratio between the supply factors (+) and the discharge factors (−) in Table 16.13 is 0.89. This gap in the balance sheet will be explained by denitrification. The ratio varies strongly as shown in the last line of the table. Calculations made plausible that this can be explained by deviations with the estimating of the storages in the soil. Relatively small sampling errors reflect great difference in the estimations, because of the big soil volume in operation. Thus, in this experiment it was also proved, that the level of nutrient supply strongly affect the environmental pollution. Thus, a careful adjustment of the fertilization to the requirements of the crop can strongly reduce the environmental pollution by nutri-

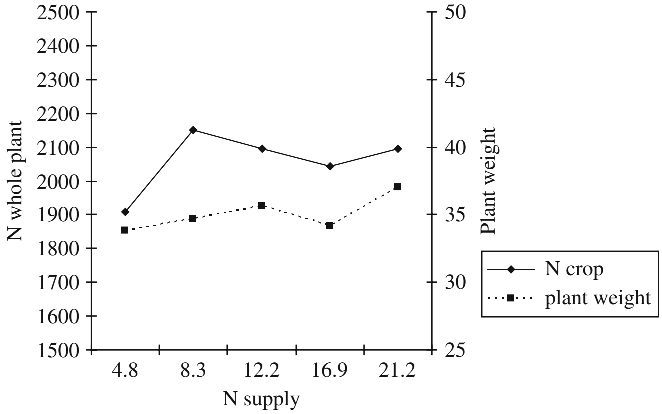

**Fig. 16.9** N concentration of whole plants (mmol kg$^{-1}$ dry matter) and the plant weight (g) of eustoma as affected by the N supply (mmol l$^{-1}$) in the irrigation water. Data Van den Bos (1999)

**Table 16.14** Balance sheet of the water management as has been found in a typical Dutch greenhouse on a loamy soil grown with radish and cut flowers, during 4 successive years. The quantities of water are expressed as $m^3$ $ha^{-1}$ $year^{-1}$

| | Water supplied | | | | | Water withdrawn | | | |
|---|---|---|---|---|---|---|---|---|---|
| Factors | 1996 | 1997 | 1998 | 1999 | Factors | 1996 | 1997 | 1998 | 1999 |
| Irrigation | 8654 | 10106 | 8168 | 8141 | Transpiration[1] | 7065 | 7114 | 6869 | 6996 |
| Capillary rise | 1328 | 324 | 388 | 1800 | Via drainage system | 5350 | 6319 | 4798 | 5826 |
| Seepage | 3273 | 3310 | 3250 | 3614 | To ground water | 841 | 307 | 139 | 734 |
| Total | 13255 | 13740 | 11806 | 13556 | Total | 13255 | 13740 | 11806 | 13556 |

[1] Including evaporation from soil surface
Data after Voogt et al. (2000a).

ents. However, it cannot completely prevent for soil grown crops, when the drainage water cannot be reused. This is shown with the balance sheet of the water supply of a greenhouse presented in Table 16.14. The situation in this greenhouse concerns a typical Dutch situation with the groundwater level close to the soil surface, which means that part of the year seepage occur, because of the a high water level in the canals and ditches. Under these conditions the water in the greenhouse soil is artificial lowered below the level of the surrounding area by a small pumping-engine placed on a drain tube system.

### *16.6.1 Heavy Metals*

Besides the restrictions on the addition of soil improvers imposed by the P concentration, other restrictions are set by the heavy metals possibly present in such materials. Part of this problem is already discussed in Section 2.3, where acceptable total concentrations in soil improvers are discussed. In The Netherlands the contamination of soils with heavy metals is regulated on basis of the type of soil improver and the concentrations of heavy metals in soils itself. To this purpose the Dutch government developed reference values for total concentrations of heavy metals for soils related to the adsorption capacity of the soil (LAC werkgroep, 1991). They are listed in Table 16.15 and will be estimated as rough guide values, because the uptake by plants is only poorly reflected by the total concentrations.

The availability of total concentrations of heavy metals to plants, indeed, depends on the adsorption capacity of soils and thus, the availability to plant on sandy soils is much higher than those on loamy soils, like shown with the relationship in Fig. 16.10 (Smilde et al., 1992). However, the determinations of heavy metals in weak extraction solutions often reflect much better the availability to plants than the total concentrations, like shown by Smilde et al., (1992) with a solution of 0.1 mmol $l^{-1}$ $CaCl_2$. The uptake of heavy metals depend on much more factors

**Table 16.15** Calculation of the reference values for total concentrations of heavy metals and As, following the regulations of the Dutch government. The reference values are calculated on basis of the % clay (particles < 2μm) and % organic matter (OM) of the soils and are expressed as mg kg$^{-1}$ dry soil

| Elements | Reference value |
|---|---|
| Cd | 0.4 + 0.007(Clay + 3OM) |
| Cr | 50 + 2Clay |
| Cu | 15 + 0.6(Clay + OM) |
| Hg | 0.2 + 0.0017(2Clay + OM) |
| Ni | 10 + Clay |
| Pb | 50 + Clay + OM |
| Zn | 50 + 1.5(2Clay + OM) |
| As | 15 + 0.4(Clay + OM) |

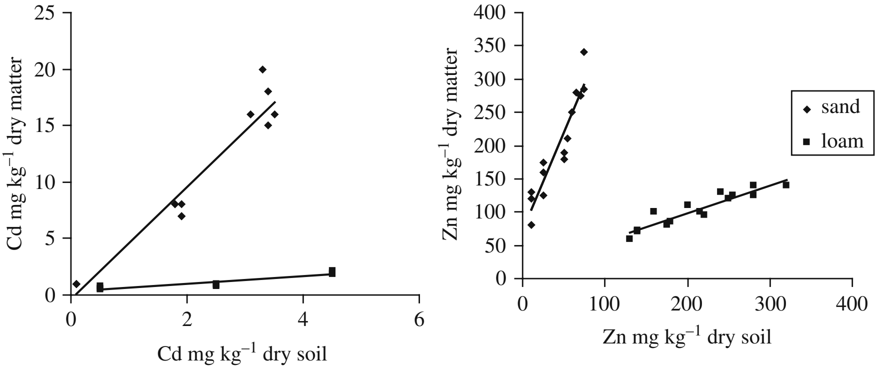

**Fig. 16.10** Relationships between total Cd and Zn concentrations in soil on the one hand and those in plant tissues of maize on the other hand, dependent on soil type. Data after Smilde et al. (1992). *Modified by permission of Springer*

than just the clay and organic matter contents. The pH value of the soil for example is an important factor. The uptake of heavy metals by plants is often strongly aggravated by decreasing pH levels. The values calculated by the data of Table 16.15 are focussed on pH values estimated as being normal for a good agricultural practice (GAP). Furthermore, the crop involved plays an important part as well as the distribution within the plant (Smilde, 1976; Sonneveld and De Bes, 1984).

The type of soil improvers used and the quantities allowed to be added is controlled by regulations varying for different countries, but mostly based on the concentration of heavy metals in soils, comparable with data as listed in Table 16.15, and those in the soil improver, as discussed in Section 2.3.

## References

Cuijpers W J M Voogt W and Koopmans C J 2005. Balancing crop requirements and fertilization strategy in organic greenhouse cultivation of sweet pepper. *In*: Research Sustainable production Systems. Proc. First Scientic Conference ISOFAR 2005, Adelaide Australia, 513–516.

De Vries O and Dechering F J A 1960. Grondonderzoek. Bedrijfslaboratorium voor Grond- en Gewasonderzoek Mariendaal-Oosterbeek. Ceres, Meppel.

Doll E C and Lucas R E 1973. Testing soils for potassium, calcium, and magnesium p 133–151. *In*: Walsh L M and Beaton J D (eds) Soil Testing and Plant Analysis. Soil Sci. Soc Amer. Madison, USA.

Egnér H Riehm H and Domingo W R 1960. Untersuchungen über die chemische Bodenanalysen als grundlage für die beurteilung des Nährstoffzustandes der Böden. II Chemische Extractionsmethoden zur Phosphor- und Kalibestimmung. K. Landbr. Högsk. Annlr. 26, 199–215.

Heinen M 2006. Simplified denitrification models: overview and properties. Geoderma 133(3–4) 444–463.

Indiati R and Singh B R 2001. Phosphorus extractability of heavily fertilized soils from Norway. Comm. Soil Sci. Plant Anal. 32, 1629–1641.

LAC werkgroep 1991. LAC – signaalwaarden. Ministerie Landbouw, Natuurbeheer en visserij's-Gravenhage, 42pp.

Mmolawa K and Or D 2000. Root zone solute dynamics under drip irrigation: A review. Plant Soil 222, 163–190.

Neeteson J J and Wadman W P 1987. Assessmant of economically optimum application rates of fertilizer N on the basis of response curves. Fertilizer Res. 12, 37–52.

Neeteson J J and Zwetsloot H J C 1989. An analysis of the response of sugar beet and potatoes to fertilizer ÿitrogen and soil mineral nitrogen. Neth. J. Agric. Sci. 37, 129–141.

Postma, 1996. Stikstofverlizen door denitrificatie op praktijkbedrijven met jaarrondchrysant. NMI, rapport c 96.11 juli 1996, 44pp.

Roorda van Eysinga J P N L 1961. Beoordeling van de fosfaattoestand van diluviale zandgrond voor de teelt van kropsla. Verslagen van Landbouwkundige Onderzoekingen, Centrum Landbouwpublicaties en Landbouwdocumentaties, Wageningen, 67.6, 26pp.

Roorda van Eysinga J P N L 1963. Vergelijking van K-water en K-HCl in bijmestmonsters van kassen. Instituut voor Bodemvruchtbaarheid Groningen, Rapport 20, 6pp.

Roorda van Eysinga J P N L 1966. Cultuurtechniek en bemesting, tuinbouwkundig bezien. Cultuurtechnisch Tijdschrift 5, 185–188.

Roorda van Eysinga J P N L 1966a. Mineral fertilization, yield and quality of vegetables. Proceedings of the 8th International Potash Congress, Brussels. International Potash Institute, Bern. 217–233.

Roorda van Eysinga J P N L 1966b. Bemesting van tomaten met kali. Verslagen van Landbouwkundige Onderzoekingen 677. Centrum Landbouwpublicaties en Landbouwdocumentaties, Wageningen, 37pp.

Roorda van Eysinga J P N L 1966c. Bemesting van Kropsla onder glas met bloedmeel en kalkammonsalpeter. Verslagen van Landbouwkundige Onderzoekingen 681. Centrum Landbouwpublicaties en Landbouwdocumentaties, Wageningen, 18pp.

Roorda van Eysinga J P N L 1971. Determination of the phosphate status of soils in the Naaldwijk area for growing lettuce in glasshouses. Agricultural Research Reports 753. Centre Agric. Publish. Doc. Wageningen, 25pp.

Roorda van Eysinga J P N L 1971a. Fertilization of tomatoes with nitrogen. Centre Agric. Publishing Doc., Wageningen, 17pp.

Roorda van Eysinga J P N L 1971b. Fertilisation of tomatoes with phosphate. Agricultural Research Reports 755. Centre Agric. Publish. Doc. Wageningen, 10pp.

Roorda van Eysinga J P N L 1972. Fertilization of glasshouse food crops with nitrogen, phosphorus and potassium. Colloquium Proceedings No 2. Potassium Institute Ltd Bern, 1–9.

Roorda van Eysinga J P N L and Mostert M 1972. De bemesting, in het bijzonder die met stikstof, van koolrabi onder glas. Bedrijfsontwikkeling 3, 391–393.

Schäfer P and Siebold M 1972. Influence of increasing potash application rates on yield and quality of the spring wheat "Kolibri". Results from a potash fixing location. Bayer. Landw. Jahrb. 49, 29–39.

Sissingh H A 1969. Die Lösung der Bodenphosphorsäureng bei waszriger Extraktion in Verbindung mit der Entwicklung einer neuen P-Wasser-Methode. Langw. Forsch. 23 Sonderheft 2, 110–120.

Smilde K W 1976. Toxische gehalyen aan zware metalen (Zn, Cu, Cr, Ni, en Cd) in grond en gewas. Instituut voor Bodemvruchtbaarheid, Nota 25, 36pp.

Smilde K W Van Luit B and Van Driel W 1992. The extraction by soil and absorption by plants of applied zinc and cadmium. Plant Soil 143, 233–238.

Sonneveld, 1966. Onderzoek naar het verloop van grondanalysecijfers (1964–1965). Proefstation voor de Groenten- en Fruitteelt onder Glas te Naaldwijk. Intern verslag 1966, 8pp.

Sonneveld, 1967. Onderzoek naar het verloop van grondanalysecijfers (1965–1966). Proefstation voor de Groenten- en Fruitteelt onder Glas te Naaldwijk. Intern verslag 1967, 7pp.

Sonneveld, 1969. Onderzoek naar het verloop van grondanalysecijfers (1966–1967). Proefstation voor de Groenten- en Fruitteelt onder Glas te Naaldwijk. Intern verslag 1969, 10pp.

Sonneveld C 1969a. De invloed van het stomen op de stikstofhuishouding van de grond. Tuinbouwmededelingen 32, 197–203.

Sonneveld C 1969b. Magnesiumgebrek bij tomaat. Praktijkonderzoek 1962. Proefstation voor de Groenten- en Fruitteelt onder Glas te Naaldwijk. Intern verslag 1966, 10pp.

Sonneveld C and Van den Ende J 1971. Soil analysis by means of a 1:2 volume extract. Plant Soil 35, 505–516.

Sonneveld C and Van Beusekom J 1974. Het doorspoelen van een lichte zavelgrond. Proefstation voor Groenten- en Fruitteelt onder Glas Naaldwijk. Intern verslag 1974, 677, 10pp.

Sonneveld C and De Bes S S 1984. Micro nutrient uptake of glasshouse cucumbers grown on rockwool. Comm. Soil Sci. Plant Anal. 15, 519–535.

Sonneveld C and Voogt W 1986. Grondonderzoek op basis van waterige extractie. Deel 1: methoden en resultaten. Proefstation voor Tuinbouw onder Glas Naaldwijk. Intern verslag 1986, 13, 36pp.

Sonneveld C Van den Ende J and De Bes S 1990. Estimating the chemical composition of soil solutions by obtaining saturation extracts or specific 1:2 by volume extracts. Plant Soil 122, 169–175.

Sonneveld C and Voogt W 1991. Effects of Ca-stress on blossom-end rot and Mg-deficiency in rockwool grown tomato. Acta Hort. 294, 81–88.

Sonneveld C 1993. Verschillen bij de bemesting van grond en substraat. *In*: Plantevoeding in de Glastuinbouw. Proefstation voor Tuinbouw onder Glas te Naaldwijk, Informatiereeks no 87, 34–39.

Sonneveld C 1997. Mineralenopname bij teelten onder glas. Proefstation voor Bloemisterij en Glasgroente, Naaldwijk. Intern verslag 81, 35pp.

Sonneveld C and Voogt W 2001. Chemical analysis in substrate systems and hydroponics – use and interpretation. Acta Hort. 548, 247–259.

Sonneveld C Van den Bos A L and Voogt W 2004, Modelling osmotic salinity effects on yield characteristics of substrate grown greenhouse crops. J. Plant Nutr. 27, 1931–1951.

Spithost L S 1965. Stikstofanalyse en stikstofbemesting van een zandgrond voor de teelt van tomaten. Verslagen van Landbouwkundige Onderzoekingen. Pudoc Wageningen 671, 23pp.

Van den Bos A 1993. Betekenis analysecijfers in kasgrond. *In*: Plantevoeding in de Glastuinbouw. Proefstation voor Tuinbouw onder Glas te Naaldwijk, Informatiereeks no 87, 89–95.

Van den Bos A L 1999. EC-niveau bij de teelt van Eustoma in kasgrond. Proefstation voor de Bloemisterij en Glasgroente Naaldwijk, The Netherlands, 41pp.

Van den Bos A L De Kreij C and Voogt W 1999. Bemestingsadviesbasis grond. Proefstation voor Bloemisterij en Glasgroente, Naaldwijk, Brochure PPO.171, 54pp.

Van den Bos A 2001. Minimalisatie Fosfaatbemesting – Onderzoek met botersla op Proeftuin Westmaas. Proefstation voor Bloemisterij en Glasgroente, Naaldwijk. Intern Rapport 235, 19pp.

Van den Bos A L 2004. Minimalisatie van fosfaatbemesting – Onderzoek met radijs op een praktijkbedrijf. Praktijkonderzoek Plant en Omgeving Wageningen UR. Rapport 32pp.

Van den Bos A L 2004a. Minimalisatie van fosfaatbemesting – Onderzoek met chrysanten op twee praktijkbedrijven. Praktijkonderzoek Plant en Omgeving Wageningen UR. Rapport 36pp.

Van der Paauw F 1969. Entwicklung und Verwertung einer nuen Wasserextraktionsmethode für die Bestimmung der pflanzenaufnehmbaren Phosphorsäure. Landw. Forsch. 23 Sonderheft 2, 102–109.

Van Gurp, H A J M 1998. Minimalisatie van fosfaatbemesting bij botersla 1992–1998. Proeftuin Zuid-Nederland, Rapport I-24, 32pp.

Verhoef K and Weber L 1965. *Botrytis* in tomaten. Proefstation voor de Groente en Fruitteelt onder Glas te Naaldwijk, The Netherlands. Jaarverslag 1965, 143–144.

Voogt W 1999. Water and mineral balances of organically grown vegetables under glass. Acte Hort. 506, 51–57.

Voogt W Kipp J A De Graaf R and Spaans L 2000. A fertigation model for glasshouse crops grown in soil. Acta Hort. 537, 495–502.

Voogt W De Graaf R Van der Burg A A M De Graaf R Van Oosten R 2000a. Water-, stikstof- en natriumbalans bij teelten in kasgrond. Intern Rapport Proefstation voor Bloemisterij en Glasgroente Naaldwijk The Netherlands, 40pp.

Voogt W 2001. Improving the N efficiency in soil grown glasshouse crops, by using the fertigation model. Proc. 2001 Dahlia Greidinger Symposium, Intern. Fert. Soc. Lisbon, 59–62.

Voogt W Assinck F Balendonck J Blom-Zandstra G Heinen M and De Zwart F H 2002. Minimalisering van de uitspoeling bij teelten in kasgrond. Praktijkonderzoek Plant & omgeving, sector glastuinbouw, Naaldwijk, The Netherlands, Rapport 543, 34pp.

Voogt W 2003. Nutrient management in soil and soil-less culture in The Netherlands: towards environmental goals. Proc. 529 Dahlia Greidinger Symposium Izmir Turkey, 2003. The Intern. Fertiliser Soc., 1–27.

Voogt W Steinbuch F and Van Winkel A (2006). Evaluation of the "fertigation model", a decision support system for water and nutrient supply for soil grown greenhouse crops. Acta Hort.718, 531–538.

Voogt W Sterk F and Vermeulen T 2008. Teelt in kasgrond; Nederland anno 2007. Rapport Wageningen UR glastuinbouw, Bleiswijk, The Netherlands, 43pp.