Chapter 15
Fertigation in Soil Grown Crops

15.1 Introduction

The word fertigation is derived by a composition from the words fertilization and irrigation and the action expressed by it is exactly what the word suggests: fertilization and irrigation in one activity. Since long years fertigation is a common practise in greenhouse industry. The development of this method of fertilizer supply originated from the fifties of the 20th century. In these years a beginning was made with drip irrigation and the small spots wetted by this type of irrigation did not offer any possibilities for top dressings by hand. Therefore, with the introduction of drip irrigation also fertilizer diluters were introduced with which concentrated fertilizer solutions could be added to irrigation water streams. Different diluter systems have been developed, but the dilutions realised with these systems were not very precisely. This was not a strong handicap in the beginning, because the water irrigated was supplied by drip irrigation and did not touch the plant canopy. Thus, an accidental somewhat high concentration of fertilizers in the irrigation water did not affect the plant negatively. Afterwards, control and adjustments on the applied quantity of fertilizer always was possible and utmost, in that period the addition was still traditionally based on quantities of fertilizer per area. Later on, when overhead irrigation by sprinkler irrigation was developed, as a matter of course precise dilutions were required. This was essential for overhead sprinkling to prevent leaf damage by possibly high concentrations of fertilizers, as a result of an inaccurate function of the equipment. This precise addition of fertilizers was developed by on line measurement of the electrical conductivity (EC) of the irrigation water combined with injectors for the dosage of concentrated nutrient solution in the water stream. The increase of the EC in the irrigation water was used as a unit for the fertilizer concentration. The once attuned concentration is controlled by proportional adjustment of the injectors on basis of continuously measurements of the EC.

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15.2 Technical Equipment

The outline of an installation for fertilizer addition to irrigation water is shown in Fig. 15.1. Water and fertilizer solution is transported to the plant by suction and pressure of the pump installation. Mostly different reservoirs with concentrated fertilizer solutions are at disposal. A concentrated solution can be the solution of a single fertilizer as well a mixture of several fertilizers. Concentrated fertilizer solution is supplied by the injector from the reservoir from which the stopcock is opened. The injector is controlled by the command centre and realizes the required fertilizer concentration in the irrigation water by the results of continuous measurements of the EC. With the nowadays modern apparatus a more or less constant fertilizer concentration in the irrigation water is ensured. The concentration of fertilizers in the reservoirs is not critical, because the eventual concentration of fertilizers realised in the irrigation water for the plant is determined by the set point on the command centre. In common practice the fertilizer concentration of the stock solution in the basins mostly varies between 10 and 15% and preferably should not exceed the saturation point.

The control on the addition of the fertilizers to the irrigation water is based on the relationship between the EC of a solution and the concentration of specific mineral fertilizer or fertilizer mixture in it. This relationship reflects an increasing EC with an increasing concentration of fertilizer and can be linearly approximated within certain limits. The relationship depends on the type of the mineral salt(s) of which the fertilizer is composed and the temperature of the solution in which the EC measurement is carried out. The effect of the temperature on the EC is automatically compensated by the apparatus and the results are related to those at a temperature of 25°C. Thus, the EC reflected by the apparatus is directly connected with the concentration of each specific fertilizer. The missing link is the relationship between the

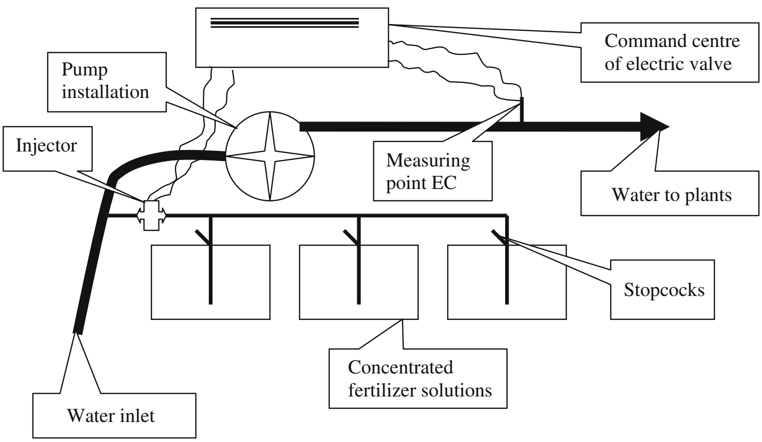
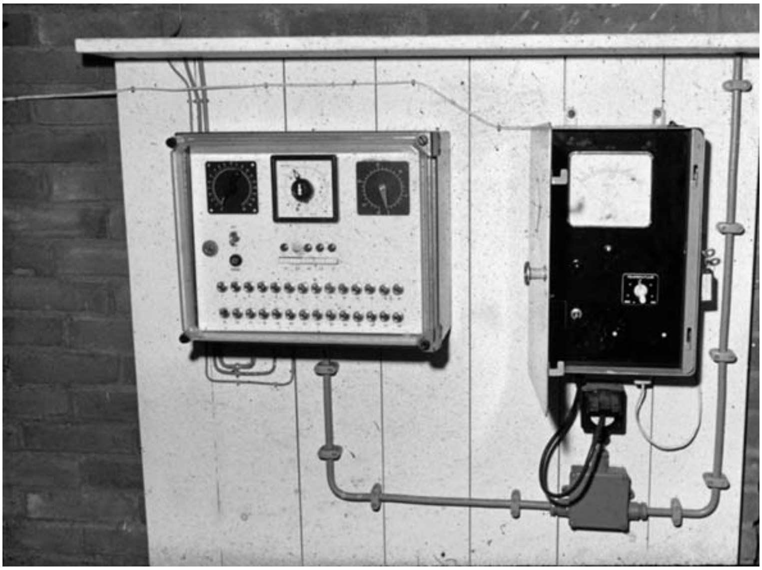


Fig. 15.1 Installation for addition of fertilizers to irrigation water

required concentration and the EC. This relationship, however, is separately published for different mineral salts and fertilizers (Sonneveld et al., 1966).

With the operation of the installation, the EC of the irrigation water without fertilizer addition is firstly measured. Secondly the grower should know what EC agrees with the fertilizer concentration that is required. The sum of both values is the EC set point on the command centre.

Sometimes, in the fertilizer solution mineral acids like HNO_3, H_2SO_4 or H_3PO_4 are incorporated in the nutrient stock solution to neutralize possible high carbonate concentrations in the primary irrigation water. For the chemical reaction and application, see Section 12.4. Such only can be recommended when an inline measurement of the pH is incorporated in the installation, to prevent accidentally too low pH values in the irrigation water. Such values are dangerous for the above ground part of the crop with overhead irrigation, but also for the roots with spot irrigation. It is experienced that the intensive water supply close to the roots in such cases seriously will damage the roots. The use of HNO_3 is most obvious in such cases, because S and P are often sufficiently available in greenhouses soils during cultivation. The neutralization of carbonate in water with acids makes this water aggressive, caused by the released CO_2 left behind in the water. Such water strongly promotes corrosion of metal parts of the equipment in the greenhouse. Therefore, the technical equipment of the full irrigation system, dosing unit and irrigation lines, preferable should be free of metal fittings.



Picture 15.1 A simple instrument for measurement of the conductivity used with fertigation of soil grow crops

15.3 Fertilizers and Addition

Solutions of electrolytes conduct electricity. As mentioned before, this conductivity depends on the temperature of the solution, the concentration of ions and the character of the ions. Temperature differences are compensated automatically by the apparatus in function. It is widely agreed that the results are related to 25°C. With respect to the character of the ion the valence and the activity affect the electric conduction and when the concentration is expressed on mass/mass basis, also the atomic weights play an important part. In Fig. 15.2 the relationship between concentrations of KNO_3, K_2SO_4 and $MgSO_4.7H_2O$ (Epsom salt) solutions in mg l^{-1} on the one hand and the EC of these solutions on the other hand are shown. The relationships for KNO_3 and K_2SO_4 are more or less equal, but those for $MgSO_4.7H_2O$ differ much. This can be explained by the high quantity of crystalline water, connected to the $MgSO_4$ molecule and the low activity of both the Mg and the SO_4 ion, which activity strongly decreases with increasing concentration. At very low concentrations the relationship between concentration and EC is somewhat curve linear, which especially counts for salts containing ions with a low activity coefficient like Mg, Ca and SO_4. But for most fertilizers, the relationships for concentrations between 0.5 and 8 g l^{-1} can be linearly approximated. This offered the opportunity to introduce the concept of specific fertilizer EC values (EC_f), being the increase of the EC of a solution by addition 1 g of that specific fertilizer (Sonneveld, 1976 and 1982). Specific EC values of different fertilizers (EC_f) are listed in Table 15.1. Urea is not a mineral salt and thus, does not conduct electricity. However, it is a highly soluble compound and suitable for fertigation. Therefore, only urea mixed in a desirable ratio with a mineral fertilizer can be used for fertigation.

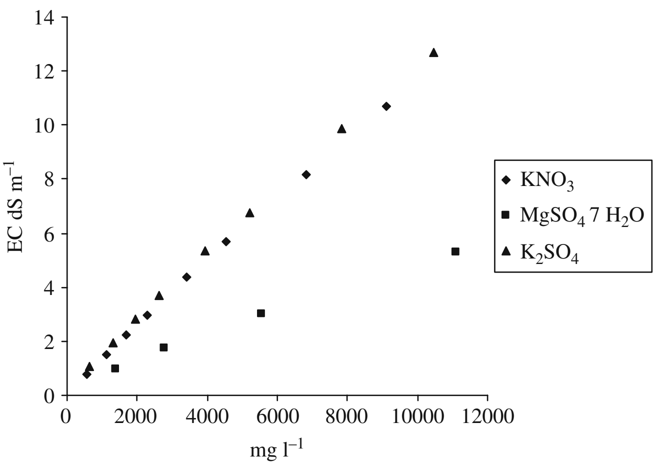


Fig. 15.2 Relationship between concentrations of KNO_3, K_2SO_4 and $MgSO_4.7H_2O$ (mg l^{-1}) and the EC (dS m^{-1}) of the solution

Table 15.1 Specific EC values of fertilizers, expressed as the increase of the EC followed by addition of every 1 gram fertilizer per litre water. The values are applicable to concentrations between 0.5 and 8 g l^{-1}

Fertilizer	Chemical composition	Specific EC value (EC_f)
Potassium nitrate	KNO_3	1.35
Calcium nitrate	$5(CaNO_3)_2.2H_2O.NH_4NO_3$	1.24
Ammonium nitrate	NH_4NO_3	1.64
Ammonium sulphate	$(NH_4)_2SO_4$	1.90
Urea	$CO(NH_2)_2$	0.00
Mono potassium phosphate	KH_2PO_4	0.68
Mono ammonium phosphate	$NH_4H_2PO_4$	0.86
Potassium sulphate	K_2SO_4	1.54
Magnesium sulphate	$MgSO_4.7H_2O$	0.94
Magnesium nitrate	$Mg(NO_3)_2.6H_2O$	0.84

After Sonneveld (1982).

Beside the traditional single fertilizers, there are numerous compound fertilizers suitable for fertigation. The EC_f values of these fertilizers are divers and depend on the mineral salts used for the composition. The EC_f values are determined by the producer and will be mentioned on the packing. Compound fertilizers also are obtained by mixing of traditional single fertilizers in the same basin. Not all fertilizers can be mixed together in the same stock solution. Ca containing salts must be separately kept from SO_4 or P containing types, because these components precipitate as $CaSO_4$, $CaHPO_4$ or $Ca_3(PO_4)_2$. In Table 15.2 some examples of the mixing of fertilizers are given. The data necessary for the calculations can be

Table 15.2 Examples of the preparation of compound fertilizers with determined ratios of nutrients by mixing of single fertilizers

Fertilizers used	Parts to the total	Contribution to nutrients in %			Contribution to EC_f of the mixture
		N	K	Mg	
Required composition N:K:Mg = 1:1:0.5					
KNO_3	0.275	3.6	10.5		0.371
NH_4NO_3	0.197	6.9			0.323
$MgSO_4.7H_2O$	0.528			5.2	0.496
Contribution to the total		10.5	10.5	5.2	1.190
Required composition N:K:Mg = 1:2:0.5					
KNO_3	0.469	6.1	17.8		0.633
NH_4NO_3	0.080	2.8			0.131
$MgSO_4.7H_2O$	0.451			4.5	0.424
Contribution to the total		8.9	17.8	4.5	1.188

found in Section 2.2, where the compositions of fertilizers are given and in Table 15.1, where the EC_f values of the single fertilizers are listed. The mixtures composed in this way are mostly cheaper than the compound fertilizers produced by factories.

Fertilizers suitable for fertigation must be easily soluble in water and may not contain significant insoluble residues, because of blocking if the irrigation system and pollution of the crop by overhead irrigation. Some fertilizers are available in various trade marks and qualities. For fertigation it is advisable to use high quality types, preferable without any insoluble component. Especially when the fertilizer is used with drip irrigation, the insoluble components easily block the narrow canals in the nozzles. This quickly causes an uneven water distribution by the drippers.

The addition of P to the irrigation water should be prevented as much as possible, especially if the pH of the irrigation water is above 6.5 and it contains some Ca, which often occurs in water used for irrigation of soil grown crops. P easily precipitates under these conditions and blocks the nozzles of drip irrigation systems. Moreover, P easily precipitates in the top soil layer and scarcely arrives at the roots. Therefore, the required P is preferably given as a base dressing. Only in specific cases P is supplied as a top dressing as will be discussed in Section 16.5.

15.4 Leaf Damage

With overhead irrigation leaves of crops can be damaged by necrosis followed by too high concentrations of mineral salts. This was already experienced with foliar sprays used to correct nutrient disorders during crop cultivation. Fertilizers containing NH_4 or urea were most aggressive when used for foliar application (Sonneveld, 1962). Overhead irrigation showed comparable results by the occurrence of leaf scorch, which was most evident with NH_4 containing fertilizers (Van der Post and Sonneveld, 1961). In advance it was concluded that fertilizers like $(NH_4)_2SO4$ could be applied with overhead sprinkling at a concentration of ½ atmosphere (50 kPa) osmotic pressure (Sonneveld and van den Ende, 1967). The NH_4 concentration of such a solution agrees with 5 mmol NH_4 l^{-1}. This is in good agreement with experiments carried out later on in which leaf scorch occurred at comparable NH_4 concentrations as shown in Fig. 15.3 (Sonneveld and Voogt, 1981). Up till a concentration of 4 mmol NH_4 l^{-1} there was hardly any leaf scorch. At higher concentrations the symptoms increased linearly with increasing concentrations. From this it will be concluded that with overhead sprinkling of NH_4 containing fertilizers a very precise control on the concentration is required to prevent leaf scorch. It is well known that the occurrence of leaf scorch is also affected by the type of crop, the crop condition and the climatic conditions. The effect of these factors on the occurrence of leaf scorch cannot be estimated quite well and therefore, the use of NH_4 containing fertilizers with overhead irrigation should be prevented as much as possible. Fertilizers containing N as NO_3 are much more safe with overhead fertigation than those containing N as NH_4.

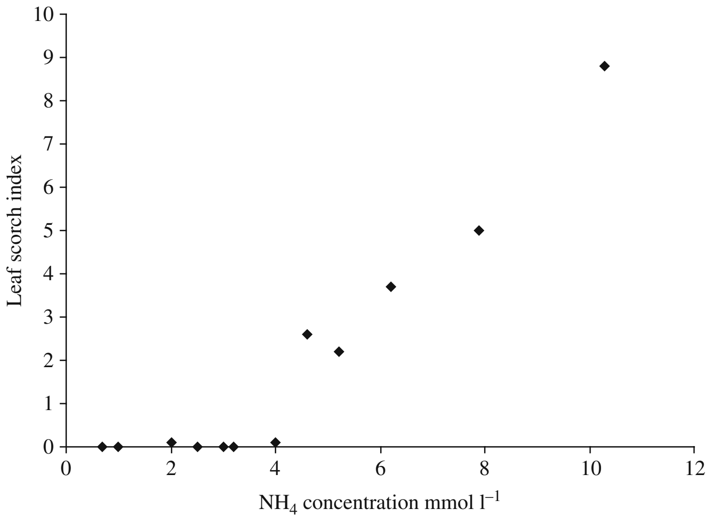


Fig. 15.3 Relationship between the NH_4 concentration in the sprinkling water with overhead irrigation and the leaf scorch of tomato. Index for leaf scorch: 0 – no and 10 – serious. Derived from Sonneveld and Voogt (1981). *Reprinted by permission of the Koninklijke Landbouwkundige Vereniging*

15.5 Irrigation Systems

The irrigation systems used for fertigation differ much in capacity and configuration (Heemskerk et al., 1997). Generally the systems can be divided in three groups, like following.

- Systems with which the whole soil surface in the greenhouse is irrigated. The overhead sprinkler irrigation system is the most representative system for this. Generally, the spray lines are highly placed in the greenhouse, some metres above the soil surface, to obtain as much as possible an equal distribution of water over the whole greenhouse area. This system is widely used for crops with a high planting density in combination with a short growing period, like many cut flowers and leafy vegetables. When crops grow up until the same level as the spray lines, the distribution of water in the second growth stage is hindered by the height of the crop. The spray lines then often are lowered to about 30 cm above the soil surface of the growing bed, between the plant rows. Generally, at that growth stage the lower leaves of the crop are removed, like for tomato, or sufficiently senescent as for sweet pepper and cucumber. In this way, sufficient space becomes available for the spray lines (Picture 15.2) of the irrigation system under the active growing part of the crop.
- Systems with which strips are irrigated by low levelled spray lines or lay-flat tubes. The width of the strip wetted by low levelled spray line irrigation mostly is larger than with lay-flat irrigation. In both situations the tube is situated between

Picture 15.2 Low level sprinkler irrigation used with strip irrigation of soil grown crops

the plant rows or in the growing beds. Sometimes the tubes are placed in shallow gullies to restrict the wetted area. These systems are used for fruit vegetables and for cut flowers with a long growing period.

- Systems with which spots are irrigated. Only small spots of the area are wetted by irrigation, like with drip irrigation systems. These systems often are used for crops with a low planting density like fruit vegetables.

With overhead sprinkling the whole area of the greenhouse is fertilized and high quantities of fertilizer are necessary to correct the nutrient status of the soil. With strip and spot irrigation only part of the greenhouse area is in use and adjustments of the nutrient status are easier to realise, because of the much smaller volume used by the plant roots. Thus, with respect to the management of the nutrient status the strip and sprinkler irrigation is preferable. Another advantage is the fact that during cultivation the crop is not wetted by the irrigation and paths remain dry. This is an advantage for the workers in the greenhouse, while the fact that the crop remains dry with the irrigation also is an advantage for the crop. In experiments with irrigation systems yields showed a tendency to be higher with strip and spot irrigation than with overhead irrigation (Van den Ende and De Graaf, 1974).

15.6 Nutrient Distribution and Irrigation Systems

In relation to the water distribution also the distribution of the nutrients in the soil shows great variability. This is clear from the data shown in Table 15.3, where the analytical data are shown of samples gathered from dry and wet spots with strip

Table 15.3 Contents of water soluble nutrients of a sandy soil over a depth of 0.25 m. Samples were gathered separately from dry and wet spots with strip irrigation of a tomato crop. Contents are expressed as mmol kg^{-1} dry soil

	N		K		Mg	
Weeks after planting	Wet	Dry	Wet	Dry	Wet	Dry
12	5.7	6.4	3.2	3.8	2.0	3.7
17	2.9	9.3	2.5	4.5	1.5	5.7
24	2.9	11.4	1.9	6.2	1.5	7.7

After Van den Ende and De Graaf (1974). *Modified by permission of the International Society Horticultural Science*

irrigation of tomato (Van den Ende and De Graaf, 1974). On the wet spots the nutrient concentrations in the soil are quickly adjusted to the concentrations in the nutrient solution added, while on the dry spots permanent accumulation occur. The distribution of NO_3 in a greenhouse soil with drip irrigation already is shown in Fig. 4.4 (Sonneveld et al., 1991). The wet spots are restricted to relatively small areas in which the concentration is low, while in the surrounding area strong accumulation occurs. The plant distance was 0.60 m, thus the NO_3 concentration in the 1:2 volume extract fluctuated between 0.7 and 9.8 in a volume of 0.3 m diameter and 0.4 m depth. Comparable results were found by Al-Harbi et al. (2005); Hoffman (1986); Oster et al. (1984) and Papadopoulos (1988).

Apparently, the nutrient concentrations on small distances with strip and spot irrigation differ that much, that it is not realistic to take a random sample for the determination of the nutrient status of the soil. It is likely that for sampling during the growing period two samples are necessary to get an impression of the nutrient status: one from the wet places and one from the dry places. These samples will represent the highest and the lowest nutrient concentrations available to plants. However, supposing that the concentration of the soil solution under the drippers is in equilibrium with the nutrient solution added, often one sample can be considered as enough. In that case, the samples will be gathered from the verges of the wet places, being the places where active roots are in contact with accumulated nutrients. Dependent on the situation other considerations will play a part too, as discussed in Section 4.14. Interpretation of the results presented, should be made on basis of the discussion about effects of unequal distribution of nutrients presented in Chapter 8. The water uptake is mainly determined by the low concentrated parts, while for the nutrient uptake the high concentrated parts are important. Thus, there should be equilibrium between the concentration supplied and the accumulation in the dry spots. On the one hand, an unlimited accumulation in the dry spots is senseless and induces high environmental pollution of nutrients when the soil is leached after the cropping period. On the other hand, too low concentrations in the drip solution to prevent accumulation in the dry parts can affect for example fruit quality of the produce. Details for interpretation will be presented in Chapter 16.

15.7 The Use of NH_4 and NH_2 Fertilizers

Fertilizers containing NH_4 are widely used in greenhouse culture, in case of fertigation, urea is also a suitable fertilizer. In greenhouse soils NH_4 supplied is quickly converted to NO_3, due to abundant microbial activity and high soil temperature. Noticeable concentrations of NH_4 only will be found during the first weeks after steam sterilisation of greenhouse soils (Sonneveld, 1979). With the nitrification process following conversion occurs.

$$NH_4 + 2\,O_2 + H_2O \rightarrow NO_3 + 2\,H_3O \qquad (15.1)$$

Thus, with the conversion of NH_4 to NO_3 considerable concentrations of acid are released, which will lower the pH of the soil.

With the use of N in the form of urea – $CO(NH_2)_2$ – this compound is converted to NH_4 by hydrolyses as following.

$$CO(NH_2)_2 + 2H_2O \rightarrow NH_4 + CO_2 + H_2O \qquad (15.2)$$

The CO_2 released with this reaction will be neutralized by the nitrification of the NH_4 that follows the on the hydrolysis step. Hydrolyses of NH_2 can be disturbed by absence of Ni (Marschner, 1997). Under such conditions high concentrations NH_2 can occur, which can be toxic to crops. Such low Ni is not logic under soil grown conditions. It never has been noticed in greenhouse crops.

It can be supposed that with frequent application of NH_4 containing irrigation water, the plant absorbs a substantial part of the N as NH_4. In this case the acidification of the soil will be equal to the acidification by nitrification of NH_4. Instead of NO_3 the plants absorbs NH_4, by which the cation absorption is increased and the plant releases H_3O instead of OH with the absorption of NO_3 (Van Beusichem, 1984). Thus, the absorption of one NH_4 is equivalent with two H_3O ions in comparison with the absorption of one NO_3 ion. Naturally, this only is true under the condition that the total N uptake of the crop is not affected.

Effects of different N forms on development of soil grown crops and on soil characteristics are shown by the results of an experiment with different flower and vegetable crops (Van den Bos, 1991). During a serie of years vegetables and flowers were grown with drip irrigation with a continuous supply of 8 mmol N per litre of water. In the different treatments the N was partly supplied as NO_3 and partly as NH_4 or NH_2, as shown in Table 15.4. In one treatment the N was completely supplied as NO_3, which treatment acted as control. The experiment was carried out in containers with calcareous loamy sand with about 3% $CaCO_3$ and a pH of 7.0. In a period of 7 years 4 different vegetable and 4 different flower crops were grown. The yields of most crops did not show significant differences. The gerbera crop, however, showed great differences in yield between the treatments in which the N was completely given as NO_3 and partly as NH_4 or NH_2. The total weight of the flowers harvested at the treatment with 50% NH_4 with the cultivar Bismut was about 40% higher than at the treatment with a full NO_3 fertilization. This may be explained

Table 15.4 Yield and leaf colour of two gerbera cultivars as affected by different N forms. The yield is expressed by the number of flowers per plant and the flower weight in g. The leaf colour is expressed by an index; 0 – completely yellow and 10 – completely green

	Bismut			Eoliet		
N form	Number	Weight	Colour index	Number	Weight	Colour index
100% NO_3	38	21	4.6	47	25	7.1
75% NO_3 and 25% NH_4	44	22	6.0	50	25	8.4
50% NO_3 and 50% NH_4	51	22	7.3	54	23	8.7
75% NO_3 and 25% NH_2	41	21	4.7	47	25	7.6
50% NO_3 and 50% NH_2	44	22	5.4	43	25	8.0

After Van den Bos (1991).

by the reduction of chlorosis in the leaves, caused by the NH_4 related pH decrease in the root environment. The effect of NH_2 addition is much lower than those of NH_4, which is understandable because of the restricted effect of this N form on the pH of the soil. The cultivar Eoliet is less affected by the N form, because this cultivar is not sensitive for chlorosis. With NH_2 supply no positive effect on the production is found with cultivar Eoliet.

The use of NH_4 accelerates the decomposition of carbonates in soils and suppresses the pH, while the concentrations soluble Ca and Mg increases, as shown in Table 15.5. With the use of NH_2 comparable effects have been found in the soil, but to a lesser extent. The uptake of Mn was surely improved by the NH_4 addition, while the Fe uptake was scarcely affected. However, the total Fe concentration in plants as determined in this experiment often is not a right measure for the activity of this element in the plant, see Section 5.4. The activity of Fe in plants can be affected by many factors and the supply of NH_4 as N form surely is one of them (Sonneveld and Voogt, 1994). Thus, the effect on the chlorosis can be explained by Mn uptake, but also the activity of Fe in the plant plays a part.

Table 15.5 The carbonate content in the soil, expressed as % $CaCO_3$ of the dry soil, the pH (water) during the growing period, the concentrations Ca and Mg (mmol l^{-1} in the 1:2 volume extract) and the concentration Mn and Fe in young gerbera leaves (mmol kg^{-1} dry matter)

					Young leaves			
	Soil				Bismut		Eoliet	
N form	$CaCO_3$	pH	Ca	Mg	Fe	Mn	Fe	Mn
100% NO_3	3.6	7.4	0.8	0.4	0.80	0.25	0.96	0.29
75% NO_3 and 25% NH_4	2.7	6.6	1.2	0.5	0.83	0.35	0.92	0.54
50% NO_3 and 50% NH_4	2.0	6.3	2.7	0.8	0.91	1.13	1.09	1.31
75% NO_3 and 25% NH_2	3.4	7.1	1.0	0.4	0.82	0.24	1.01	0.33
50% NO_3 and 50% NH_2	3.2	7.0	1.2	0.4	0.81	0.29	0.95	0.34

After Van den Bos (1991).

The data presented show that with crops sensitive to chlorosis grown in calcareous soils the yield and the leaf colour surely can be improved by the use of substantial quantities of NH_4. In soils rich on carbonate relatively high NH_4 concentrations have to be used to get sufficient effect. However, in such cases no overhead irrigation can be applied in view of the risk of leaf scorching, as discussed in Section 15.4. The risk of NH_4 toxicity in the root environment under these conditions is negligible because of the usually quick nitrification process in greenhouse soils.

15.8 Concentrations

The concentration of nutrients added to the irrigation water necessary for an optimal yield depend on factors like crop, irrigation system, base dressing and growing conditions. Required concentrations for different crops and growing conditions will be discussed in Chapter 16. In this section some general remarks are presented.

In a series of experiments with strip irrigation with fruit vegetable crops different fertilizer mixes, containing N, K and Mg, were added to the irrigation water (Sonneveld and Voogt, 1981). The nutrients were continuously supplied to the irrigation water and the EC was increased by the addition of different nutrients with values between 0.45 and 1.80 dS m^{-1}. The crop yield was highest in the range between 0.45 and 0.90 dS m^{-1}, which is comparable with concentrations of 0.3 and 0.5 g l^{-1} when no Mg was given and between 0.4 and 0.8 g l^{-1} when Mg was added. With higher concentrations up till 1.8 dS m^{-1} in the irrigation water often the yield was reduced varying from 0 until 18% compared to the lowest concentration. The EC in the wet strip was increased from 0.99 to 1.71 dS m^{-1} in the 1:2 volume extract at the 0.45 and 1.8 dS m^{-1} application in the irrigation water, respectively. Thus, relatively small increases of the EC in the soil by over fertilization seriously reduced the yield, caused by a decreased osmotic potential of the soil solution like occur with salinity.

The fertilizer application did not only affect the yield, but also the quality of the produce as has been found with salinity experiments. Higher application of fertilizer improved the quality of the fruits like a reduction of the uneven ripened tomato fruits and an improved colour index of cucumber fruits. On the other hand, the quality can be negatively affected by high concentrations of nutrients which will increase for example the incidence of blossom-end rot of tomatoes and sweet pepper, like shown in Table 15.6. It can be expected that beside the decreased osmotic potential with the increase of the fertilizer concentrations the increased addition of NH_4 play a part in the occurrence of blossom end rot. The ratio NH_4/N was not affected with the increased concentrations, but often NH_4 is preferentially absorbed by crops and can specifically affect in this way the Ca uptake. See also Chapter 9.

The addition of Mg to the nutrient solution is recommended, especially for crops sensitive to Mg deficiency, like tomato and eggplant. In the experiments of Sonneveld and Voogt (1981) the fertilizer additions with and without Mg did not always show significant yield differences. However, when there were significant

Table 15.6 Percentages blossom-end rot in tomatoes and sweet pepper as affected by the application of different fertilizer concentrations applied in the irrigation water with strip fertigation

Fertilizer concentration dS m^{-1}	Tomato 1979	Sweet pepper 1974	Sweet pepper 1976
0.45	0.10	2.2	1.3
0.90	0.16	2.7	1.4
1.35	0.56	3.9	5.6
1.80	1.38	6.2	9.3

After Sonneveld and Voogt (1981).

yield differences between the nutrient solutions, mostly the addition of Mg was favourable. Further, the fertilizer mixture with a low N:K ratio mol/mol 9/4 on the whole showed a higher yield than the ratio 10/2.5. The necessity of the addition of nutrients other than N, K and Mg will depend much on the chemical composition of the irrigation water and of the soil. Many types of irrigation water contain sufficient Ca and SO_4 to supply the crop, and in many greenhouse soils these elements including P are abundantly available. When P is required, because of too low a P status of the soil, a pre-planting application will cover mostly plant requirements of this element (Bar Yosef et al., 1995).

With respect to micro elements it was experienced in The Netherlands that the addition with fertigation is generally not required. Most of these elements are sufficient present in soil or irrigation water. The poor availability caused by high pH values in the soil is more likely the problem than the presence in the soil. This especially counts for Fe and Mn for crops sensitive to chlorosis, like rose and gerbera. The uptake of these elements depends strongly on the pH. Therefore, control of the pH by addition of NH_4 will be mostly sufficient to ensure the micro nutrient uptake by the crop. The addition of NH_4 to improve the uptake of these elements is very effective, not only with respect to the lowering of the pH of the bulk of the soil as discussed before, but especially with respect to the pH drop in the rhizosphere (Hinsinger et al., 2003; Junk, 1987). The supply of NH_4 as N form lowers the pH on the root surface much more than in the bulk soil and this strongly improves the micro nutrient uptake. The first thinkable micro element to be considered for addition will be B, if this element is not sufficiently available in the irrigation water and the natural background concentration in the soil is poor. B is easily washed out by an intensive water supply, which occurs in the wet spots with drip irrigation.

The elements and the concentrations of these to be added to the irrigation water connected to optimum yield depend not only on the factors already mentioned, but also on the definition of optimal yield. Especially in greenhouse production optimum yield is not a matter of maximum production, as the quality of the produce is at least important as the production in greenhouse industry. Such means that not always the concentrations connected with maximum yield are most favourable. Growers sometimes have to make a choice between yield and quality, which are not always in the same line. In the experiments with vegetable fruit crops presented by Sonneveld and Voogt (1981) a mixture of N, K, Mg and SO_4, mol ratios 9, 4, 1.6, and 1.6 at concentrations between 0.45 and 0.90 were mentioned to be optimal. This addition agreed with concentrations in mmol l^{-1} 3.7–7.4 N, 1.6–3.3 K, 0.7–1.3 Mg and 0.7–1.3 SO_4 for a continuous supply. The highest concentrations mentioned agreed rather well with the uptake concentration calculated for the crops grown in the experiments. The fact that with lower concentrations comparable results were obtained can be explained by utilization of the dressing by soil grown crops. Later findings showed much higher uptake concentrations, which can be explained by increasing yields over years (Sonneveld, 1997). However, with fertigation it is not necessary that the concentrations in the irrigation water always cover the uptake concentration. With soil grown crops plants always will utilize nutrients from the storage, which is substantial in the soil. Another factor that can be taken into account is the required over supply of water, which brings also extra nutrient in the soils. However, the ultimate decision on the concentration to be added, depends on the momentary crop condition and the equilibrium between yield and quality aimed at. The discussion so far is based on experiments with fruit vegetable crops. The uptake concentration of many ornamental crops is often lower than those of vegetables and it is logical that the addition of fertilizers for flower crops will be in agreement with this lower uptake.

The uptake of micro nutrients by greenhouse crops grown in soil mostly cannot be controlled by soil analysis, because the methods of soil analysis available insufficiently predict the uptake of these elements by crops. This is shown by the data of an investigation in which the results of soil analysis were compared with the micro nutrient concentrations in the crops (Sonneveld and Voogt, 2001). The results are shown in Table 15.7. The correlation coefficients are poor, only for Mn and B some significant values were found. Water and a solution of $CaCl_2$/DTPA were compared as extraction solutions. The correlation coefficients for the water extract were higher than those for the $CaCl_2$/DTPA extract. The relationship for B is shown in Fig. 15.4. The reason for the poor correlations will be the great variation of soil types, crops, cultivars and growing conditions in greenhouse industry.

Table 15.7 Correlation coefficient for the relationship between micro nutrient concentration in soil extracts; 1:2 volume extract and $CaCl_2$/DTPA extract, and in plant tissues

Elements	1:2 extract water	1:10 extract w/w $CaCl_2$/DTPA
Fe	–0.262	–0.152
Mn	0.518	0.206
Zn	–0.258	–0.189
B	0.714	0.465
Cu	–0.221	–0.045
Mo	0.152	–0.108

After Sonneveld and Voogt (2001).

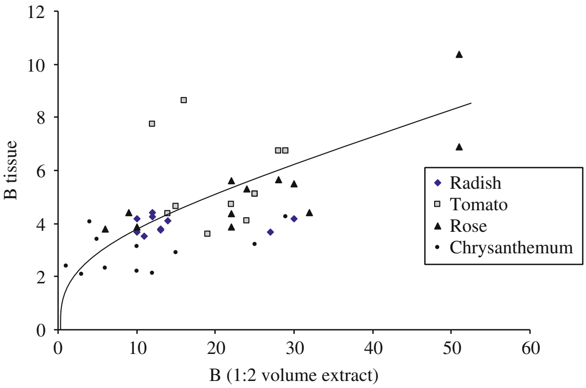


Fig. 15.4 Relationship between B concentrations in the 1:2 volume extract (μmol l^{-1} extract) and B concentrations of young fully grown leaves (mmol kg^{-1} dry matter) of different greenhouse crops. After Sonneveld and Voogt (2001)

15.9 Use of Tissue Tests

In view of the poor correlations commonly found between the results of soil testing methods on micro nutrients and the uptake of these elements by greenhouse crops tissue tests can be a helpful tool for the grower in the decision whether these elements should be included in the fertilization programme. In investigations of Sonneveld and Voogt (2001) mentioned in last section, micro nutrient concentrations of crops were determined to check the availability of these elements in soils used for greenhouse cultivation in The Netherlands. Four different crops were tested, for each crop on 10–12 different nurseries samples of soils and plant tissues were gathered. With the sampling the general instructions were followed. This means that for tomato, rose and chrysanthemum young fully developed leaves were sampled, while for radish the full top was used, except the oldest ring of leaves. The samples were rinsed with a detergent solution and afterwards washed with demineralised water. The average and extreme values found for the tissue samples of the different crops are listed in Table 15.8. The results for the crops concerned can be compared with the guide values as tabulated in Table 5.6 and Appendix B. The results show clear differences between crops and for different elements the average concentration is lowest for the rose crop. Striking differences are found between the lowest and highest values of the Mn concentrations for all crops. This can be explained by steam sterilisation, which at times occurs for all crops in the Dutch greenhouse industry. The first year after steam sterilisation the availability of Mn remains high and even can induce toxicity, as discussed in Section 10.4. The lowest Mn concentrations found for tomato and rose are rather low to ensure a healthy crop growth. This also is the case for Zn with tomato and B with radish, tomato and chrysanthemum. Among the Cu and Mo concentrations are also rather low values. However, for these elements restricted information is available about critical values for greenhouse crops. The Mo concentrations found with the rose crop are strikingly lower

Table 15.8 Average and extreme (in brackets) concentrations of micro nutrients of different greenhouse crops as has been found on Dutch nurseries. The concentrations are expressed as mmol kg^{-1} dry matter

	Crops			
Elements	Radish	Tomato	Rose	Chrysanthemum
Fe	2.20 (1.76–2.52)	1.86 (1.20–2.43)	0.92 (0.64–1.69)	1.83 (1.46–2.26)
Mn	1.82 (0.56–6.69)	2.58 (0.26–9.13)	1.65 (0.36–3.83)	4.05 (0.78–9.77)
Zn	1.24 (0.49–2.09)	0.39 (0.29–0.49)	0.42 (0.29–0.49)	1.11 (0.66–1.46)
B	3.96 (3.54–4.43)	5.55 (3.60–8.62)	5.34 (3.80–10.36)	2.92 (2.09–4.24)
Cu	0.106 (0.091–0.140)	0.138 (0.086–0.287)	0.077 (0.043–0.100)	0.208 (0.142–0.335)
Mo	0.022 (0.010–0.036)	0.019 (0.002–0.064)	0.004 (0.002–0.008)	0.034 (0.004–0.079)

After Sonneveld and Voogt (2001).

than those with the other crops. It is not yet clear whether for this crop Mo application is necessary. The commonly somewhat lower pH of the soils used for rose growing only can explain part of the difference in the uptake.

When the concentration of micro nutrients is too low, a higher replacement of NO_3 by NH_4 will be considered firstly, because the uptake of most of those elements depends on the pH of the soil.This, for example, is recommended for Mn preferably, as the uptake strongly reacts on the pH of the soil, while addition of Mn to the soil is very ineffective at a high pH. Secondly, the addition of micro nutrients to the irrigation water can be recommended. Fe will be added in chelated form. Mostly the form of EDDHA is preferred, because Fe deficiency in soil grown crops is commonly connected with a high pH of the soil.

When no deficiency symptoms are visible but plant tissue concentrations are low the concentrations recommended for fertigation for the different elements lay between 50 till 100% of the concentrations used for substrate cultivation as listed in Appendix C. With visible deficiency symptoms in the crop firstly 200% of these concentrations can be added for one or two weeks.

For macro nutrients the use of tissue tests is less obvious in the management of the fertilization of soil grown crops, because soil testing mostly inform sufficiently the availability of these elements to greenhouse crops.

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