Chapter 4
Soil and Substrate Testing to Estimate Nutrient Availability and Salinity Status

4.1 Introduction

In the greenhouse industry methods have been developed for the determination of the nutrient availability and salinity status of soils and substrates. As in other agriculture branches, soil testing has the aim to estimate the availability, including the solubility as well the quantity, of plant nutrients to enable the farmer to get maximum production with minimum fertilizer use. The success of the farmer thereby does not depend only on the precision of the method, but also on the knowledge of the requirements of the crop. Both the utility of the soil testing method and the fertilizer application in relation to the results to get maximum yield will be calibrated in fertilizer experiments. Until lately, farmers based their decision about the amount of fertilizer addition on the costs of the fertilizer and the profits of the expected yield increase. However, in recent years farmers also have to consider the environmental aspects in their decisions. Fertilizer applications should be focussed also on their effects to pollution of soil, water and air. Beside the availability of nutrients, the determinations of characteristics for the salinity status are important and interact with the fertilization programme considered. The definitions given so far are operative for greenhouse crops as well as for crops grown in the field. However, soil testing for greenhouse industry has some specific aspects which will be mentioned beforehand, because they are important in relation to the methods used. The aspects in view for greenhouses are following.

- Testing of soil and substrate is carried out frequently, often several times during the growing period of a crop. Thus, estimation of the release of nutrients over longer periods is not a requirement of the methods applied.
- Nutrients in the soil and the substrate solution form a substantial part of the total ion concentration of these solutions and should be taken into account in the judgement of soil salinity.
- The determination of the total salt status of greenhouse soils and substrates has a central position, because the osmotic potential in the root environment not only is a measure to prevent possible yield reduction, but also a tool for the farmer on crop development and produce quality.

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- Nutrient absorption by many crops in the greenhouse industry are that high that application of the total needs of nutrients of the crop as base dressing will lead to unacceptable high ion concentrations in the root environment. This especially is operative for crops grown in substrate, because of the small rooting volumes common with this growing method. Thus, application of the total fertilizers requirements as a base dressing is mostly impossible.
- For most crops frequent top dressings are possible and can be easily carried out when desirable with any irrigation by fertigation.

In view of these aspects it is understandable that the estimation of the composition of the soil and the substrate solution and by that extraction with water plays an important role in the routine soil testing for the greenhouse industry. Therefore, the Dutch developed and promoted such methods for their greenhouse industry since many years. It is true that water extraction only shows the activity of the elements determined, but considering the frequent determinations and top dressings for most nutrients there are not many arguments for the determination of the capacity of most nutrient elements. Different water extraction methods have been developed and the suitability was often judged in relation to the capability of the method under discussion to estimate the composition of the soil solution.

Soil solution needs some definition with respect to the water content of the soil or the substrate, because these will vary in relation to the growing conditions, especially to the water supply. The water supply in greenhouses during crop growth is characterized by a frequent irrigation, which means that the fluctuations in the water content are relatively small. Van den Ende (1988a) compared the water contents of a great number of greenhouse top soils, grown with tomato with the water content at a pressure head of –6.3 kPa. The study turned out that the water contents were approximately equal. In a later study with soils derived from greenhouses grown with various crops (Sonneveld, et al., 1990) approximately the comparable water contents in the greenhouse soils could be calculated on basis of the loss on ignition as were found in the former study (Van den Ende, 1988b). Therefore, the water content of greenhouse soils under growing conditions has been defined as being the water content at a pressure head at –6.3 kPa. Extended information is given in Section 3.3.

In the greenhouse industry al lot of crops are grown in substrate and the water contents realized are more or less artificial made and depend strongly on the type of substrate and the growing system. For course substrates, like mineral fibres, pumice, foam etc., losing their water at a very high pressure head, the water content at the leak out situation is considered as being the moisture condition at field capacity. For substrates holding their water at somewhat lower pressure head, like peat and peat related substrates, the water content at a pressure head of –1 kPa is considered as being the moisture content at field capacity (Kipp et al., 2000; Sonneveld and Van Elderen, 1994). Detailed information is presented in Section 3.3.

The different soil testing methods generally used in the greenhouse industry are discussed in following sections. Some methods are specifically directed at soil growing, while other methods are suitable for substrate growing. Information about

specific suitability will be given in the description of the methods, while at the end of this chapter a review of the use of the methods will be presented in relation to growing medium and growing system.

4.2 Specific 1:2 by Volume Water Extract

The specific 1:2 by volume extract, henceforth called 1:2 extract, is prepared by filtration of a suspension obtained by adding sufficient field-moist soil to two volume parts of water so that the total volume is increased with one part (Sonneveld et al., 1990), see picture 4.1. When the soil is too dry, before the preparation of the extract some demineralised water will be added to the soil to restore field moist condition. The field moist condition of greenhouse soils is defined in Section 3.3 and agrees with the moisture content at a pressure head of –6.3 kPa. In advance this judgement should be compared with results of the sandbox method, but after some experience the judgement can be carried out visually. The suspension is shaken for 20 minutes. The method is exclusively recommended for greenhouse soils. For a detailed description of the preparation of 1:2 extracts reference is made to De Kreij et al. (2005).

Picture 4.1 Preparation of the specific 1:2 volume extract. Sufficient field-moist soil is added to two parts of water so that the volume is increased with one part

The EC and the concentrations of major nutrient, Na and Cl of the 1:2 extracts were closely correlated with those of the soil solutions. The relationship between the analytical data derived from the 1:2 extract and those from the soil solution are listed in Table 4.1 (Sonneveld et al., 1990). The close and linear relationship

Table 4.1 Regression equations for the relationships between EC and ionic concentrations in the soil solution (y) and those in the 1:2 extract (x) for a series of Dutch greenhouse soils. EC in dS m^{-1} and ions in mmol l^{-1}

Determination	Regression equation	r
EC	$y = 3.12\ x + 0.84$	0.886
NH_4	$y = 3.23\ x + 0.05$	0.782
K	$y = 3.38\ x - 0.80$	0.922
Na	$y = 4.04\ x - 1.12$	0.929
Ca	$y = 2.53\ x + 7.86$	0.811
Mg	$y = 3.48\ x + 1.86$	0.876
NO_3	$y = 5.09\ x + 0.14$	0.899
Cl	$y = 6.15\ x - 2.04$	0.952
SO_4	$y = 1.47\ x + 8.67$	0.779
P	$y = 1.78\ x - 0.09$	0.936

After Sonneveld et al. (1990). *Modified by permission of Springer*

between analytical data of the 1:2 extract allows a universal interpretation based on the composition of the soil solution.

The 1:2 extract, however, has some drawbacks, like the relatively high dilution of the soil solution and the fact that the dilution of the soil solution varies somewhat with the soil type in relation to the organic matter content. The dilution factor, the ratio of the water content of the 1:2 suspension to the water content of the field moist soil, decreased from 6 for mineral soils to 3.5 for soils with a high organic matter content (40%). The overall high water to soil ratio of the 1:2 suspensions bring about dissolution of sparingly soluble salts, mainly $CaSO_4$. This disturbs the estimation of the total ion concentration (EC) and the concentrations of Ca, Mg and SO_4 in the soil solution. Adjustments for soil type and sparingly soluble salts by dilution ratios brought the correlation coefficient above 0.95 for nearly all determinations listed in Table 4.1 (Sonneveld et al., 1990). The still low correlation coefficient found with NH_4 after these adjustment should be explained mainly by the low concentrations of this ion found in greenhouse soils. The average NH_4 concentration in the 1:2 extracts of the samples in the study was 0.10 mmol l^{-1}, and varied between 0.00 and 0.82.

A precise estimation of the EC of the soil solution especially is valuable with respect of the estimation of the osmotic potential, being one of the most important soil characteristics that affect crop development in greenhouses. Sonneveld et al. (1990) has found the equations denoted as formulae (4.1) and (4.2) with correlation coefficients 0.968 and 0.974, respectively.

$$EC_{ss} = 0.908 dEC_{1:2} - 0.089 dSO_{4(1:2)} + 0.68 \tag{4.1}$$

$$EC_{ss} = 2.744 qEC_{1:2} - 0.284 qSO_{4(1:2)} - 0.17 \tag{4.2}$$

In which

EC_{ss} = EC of the soil solution
$EC_{1:2}$ = EC of the specific 1:2 volume extract
$SO_{4(1:2)}$ = SO_4 concentration of the 1:2 extract in mmol l^{-1}
d = dilution factor, being the ratio between the water content of the 1:2 suspension and the water content of the field moist soil
q = the quantity of field moist soil with an under water volume of 1 litre in kg

Addition of the factor d as used in formula (4.1) has the drawback that this factor is difficult to determine, because the water content of the field moist soil should separately be determined. Therefore, formula (4.2) is better applicable, because the quantity of field moist soil used at preparation of 1:2 suspensions can be rather easily determined. The contribution of the d and q values to the increase of the correlation coefficient are more or less equal; which is understandable because d and q were highly correlated ($r = 0.894$).

The relationship between micro nutrient concentrations in the soil solution and in the 1:2 extract was also included in the study (Sonneveld and De Bes, 1986). However, for most of the micro nutrients the ratios between the concentrations in the 1:2 extract and the concentrations in the soil solution differed strongly from those of the macro nutrients and the correlation coefficients were generally much lower varying from 0.318 till 0.984. These results are no reason to suppose a simple and unequivocal interpretation of these elements in the 1:2 extract. The addition of micro nutrients for soil grown crops will be discussed in Chapter 16.

The 1:2 extract is also suitable as an estimator for quantities of water soluble nutrients in the root environment. This is due to the fact that the quantity of water present in the suspension with the preparation of the 1:2 extract is virtually independent on the soil type (Sonneveld, 1990), as is shown with the data of Table 4.2. From the fourth column of this table will be concluded that about 40 m^3 extract is prepared per 100 m^2 for soil types with an organic matter fraction varying between 0.05 and 0.30. Thus, with a concentration of 1 mmol l^{-1} of any element in the 1:2 extract a quantity of 40 mol of that element is water soluble available per 100 m^2 over a depth of 0.25 m.

Table 4.2 Quantities of water present in the suspension with the preparation of the 1:2 extract of different soil types, expressed as m^3 per 100 m^2 over a depth of 25 cm

Mass fraction organic matter	Dry weight per volume[1]	Water content 1:2 suspension[2]	Water volume 1:2 suspension[3]
0.05	1.08	1.40	37.8
0.10	0.86	1.62	39.1
0.20	0.62	2.64	40.9
0.30	0.48	3.46	41.5

[1] kg l^{-1}; [2] g per g dry matter; [3] m^3 per 100 m^2 greenhouse area.

For determinations related to salinity, like EC, Na and Cl, it is evident that calculations to concentrations in the soil solution are most suitable to the purpose. For plant nutrients calculations to available quantities per area also can be meaningful.

The 1:2 extraction has the advantage that it is a quick method and therefore very suitable for routine soil testing. It is used to that purpose for many years in the greenhouse industry. It was tested for greenhouse soils in situ and proved to be suitable for a wide range of soil types. The method was not tested for substrates, because the strongly different physical characteristics of these materials give no single reason for a successful application in this field. A haphazard application easily will leads to a misinterpretation of the analytical data obtained.

4.3 Saturation Extract

The saturation extract is prepared by filtration of a water saturated soil. Saturated soil is prepared by addition of demineralised water to field moist soil under continuous stirring with a spatula (Richards, 1954). The saturated condition is assessed by the glistening appearance of the soil paste if it reflects light and by the rapid disappearance of a diametrical groove drawn with the spatula. The use of field moist soil for the preparation of the saturated paste is preferred to air dry soil, because of the risk of denitrification when air dry soil is used (Van den Ende, 1989a).

The saturation extract has the advantage of a low water to soil ratio, closely related to the water content of soils at field capacity. Thus, the results are only slightly affected by sparingly soluble salts and allow an unequivocal interpretation for a wide range of soil types. The dilution factor, being the water content of the saturated paste to the water content of the field moist soil, varied between 1.8 for mineral soils and 1.5 for soils with a high (30%) organic matter content in studies with greenhouse soils (Van den Ende, 1988a). In another study a dilution factor of 2.0 was calculated for soils with 5% organic matter and 1.6 for soils high (40%) in organic matter (Sonneveld et al.,1990).

In Table 4.3 linear relationships are given for the relation between ionic concentrations in the saturation extract and those in the soil solution. The values of the correlation coefficients of these simple linear regressions are on the same level of about 0.95, as has been found with the 1:2 extract (Section 4.2) after correction for soil type and sparingly soluble salts. This involves a simple interpretation for the analytical data of the saturation extract, which is a big advantage. Therefore, the saturation extract is widely used all over the world, especially for the determination of soil salinity. However, the drawback for routine soil testing is the laborious preparation of the saturated soil suspension.

In soil salinity a rule of thumb is used that the salt concentration of the soil solution is twice that of the saturation extract (Maas and Hoffman, 1977). This factor of 2 between the both concentrations is too high for greenhouse soils, as can be derived from Table 4.3, where a factor of 1.6 is found for the EC, which is more in agreement with the moisture quotients given before. The most likely reason for this low quotient for the concentrations “field moist” and “saturated” is the frequent

Table 4.3 Regression equations for the relationship between EC and ionic concentrations in the soil solution (y) and those in the saturation extract (x) for a series of Dutch greenhouse soils. The EC is expressed as dS m^{-1} and ions in mmol l^{-1}

Determination	Regression equation	r
EC	$y = 1.60\ x - 0.18$	0.958
NH_4	$y = 1.33\ x - 0.01$	0.844
K	$y = 1.54\ x - 0.64$	0.984
Na	$y = 1.62\ x - 0.42$	0.978
Ca	$y = 1.53\ x + 1.03$	0.946
Mg	$y = 1.67\ x + 0.02$	0.943
NO_3	$y = 1.82\ x - 0.27$	0.954
Cl	$y = 1.99\ x - 0.66$	0.975
SO_4	$y = 1.16\ x + 2.76$	0.926
P	$y = 1.20\ x - 0.03$	0.954

From Sonneveld et al. (1990). *Modified by permission of Springer*

irrigation in greenhouses, through which the water content of the soils are continuous on a high level.

The saturation extract is used for soils in situ and accidentally applied for substrates. However, the saturated condition cannot always be easily discerned with substrates. Moreover, the pressure suction of the "field moist" condition between soil and substrate differ principally, as discussed in Section 3.3. Therefore, the right dilution of the substrate solution is not always achieved and misinterpretations are obvious.

4.4 Water Extracts Based on Weight Ratios

For routine testing of greenhouse soils formerly often use was made of different weight ratios of water to air dried soil. To this purpose ratios of 1:1, 1:2 and 1:5 are practised (Carpena et al., 1968; Van den Ende, 19688). Nowadays there is not much reason to practice them. The water to soil ratio in the suspension has no relationship with the water contents of soils under growing conditions, when used for different soil types. Therefore, the analytical data need adjustment to this water content to get an interpretation related to the chemical composition of the soil solution (Van den Ende, 1989b).

This especially counts when high ratios water to soil are used. For example, the ratio between the water content of a 1:5 suspension and the water content of field moist soil, varies for example between 25 for mineral soils and 5 for organic soils (mass fraction organic matter 0.4). Thus, the interpretation of the analytical data will be handicapped by this changing dilution in relation to the soil solution, but also an interpretation based on quantities is troubled, because of the differences of the bulk densities. Both problems especially occur in areas with strongly different soil types.

However, another drawback is the often high water to soil ratio in the suspension, responsible for a strong dissolution of sparingly soluble salts (Reitemeier, 1946). The ratios between the cations in the solution also will change with dilution, by exchange of cations in the solution and on the adsorption complex. Mono valence

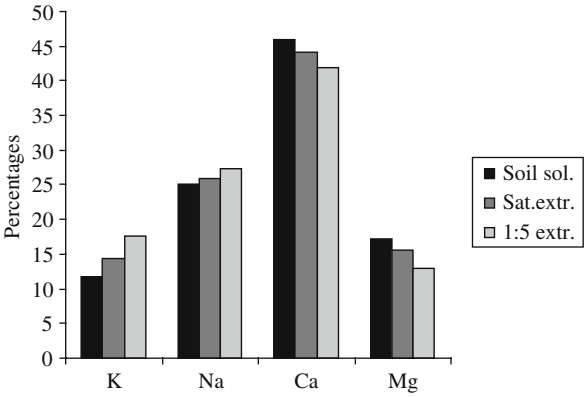


Fig. 4.1 Percentages of cations in soil solution, saturation extract and 1:5 w/w water extract calculated over average values of 75 greenhouse samples. After Van den Ende (1989b)

cations increase and bivalent cations decrease relatively with increasing dilution (Moss, 1963). The effects of this called "dilution and valence effect" of different dilutions with soil testing of greenhouse soils are shown in Fig. 4.1, after data of Van den Ende (1989b). The K and Na concentrations in the extracts increase and the Ca and Mg concentrations decrease relatively with increasing dilution from soil solution to 1:5 extract.

For interpretation in relation to the soil solution the water content of the soil under growing conditions should be known, and for interpretation in relation to quantities of water soluble nutrients the bulk density of the soil should be known. Both parameters will be estimated by the determination of the loss on ignition of the soil (Van den Ende, 1988b; Sections 2.3 and 3.3).

4.5 1:1½ Volume Water Extract

The 1:1½ volume extract is developed for peaty growing media. The extract is prepared by filtration of a suspension of 1 volume of fresh substrate and 1½ volume of water (Sonneveld and Van Elderen, 1994). The volume of the substrate is measured in a ring with a height 5 cm and a volume of at least 100 ml and pressed at 10 kPa. Before measurement of the volume the moisture content of the substrate will be judged and when the substrate is too dry, it will be adjusted with demineralised water to the moisture content at a pressure head of –3.2 kPa, see picture 4.2. In advance this judgement should be compared with results of the sandbox method, but after some experience the judgement can be carried out visually. This adjustment of the moisture content is especially important for substrates as delivered from the producer and not yet used for cultivation, because such material sometimes is very dry.

The analytical data of the 1:1½ volume extract of fifty peaty samples with widely varying characteristic were compared with those of the substrate solution at a pressure head of –1 kPa. The results of this comparison showed very close linear correlations between the data of both extracts for all the likely ions, as shown in Table 4.4. The correlation coefficients for the EC and the major elements varied between 0.912 and 0.992. The dilution effect for the different ions in the substratesolution varied

Picture 4.2 Preparation of the 1:1½ extract of peaty growing media. One volume of growing media is mixed with 1½ volume of water. The moisture contents of the growing media are adjusted to a pressure head of −3.2 kpa

Table 4.4 Regression equations for the relationships between the analytical data of the 1:1½ volume extract (x) and the substrate solution (y) of a series of peaty substrates. EC expressed as dS m^{-1}, major elements as mmol l^{-1} and micro elements as µmol l^{-1}

Determination	Regression equation	r
EC	$y = 2.39\ x + 0.17$	0.982
Major elements		
NH_4	$y = 2.63\ x - 0.10$	0.968
K	$y = 2.52\ x - 0.15$	0.992
Na	$y = 2.51\ x - 0.01$	0.938
Ca	$y = 2.74\ x + 0.60$	0.982
Mg	$y = 2.61\ x + 0.53$	0.961
NO_3	$y = 2.80\ x + 0.59$	0.984
Cl	$y = 2.76\ x - 0.10$	0.972
SO_4	$y = 2.38\ x + 0.52$	0.912
P	$y = 2.38\ x + 0.19$	0.954
Micro elements		
Fe	$y = 2.58\ x + 0.77$	0.836
Mn	$y = 3.51\ x - 0.28$	0.967
Zn	$y = 3.14\ x - 0.26$	0.981
B	$y = 1.44\ x + 6.77$	0.663
Cu	$y = 1.38\ x + 0.38$	0.568
Mo	$y = 0.79\ x + 0.08$	0.471

After Sonneveld C 1994. Unpublished data.

from 2.4 for the determinations of NH_4 and K and 3.2 for Ca (Sonneveld and Van Elderen, 1994). These low dilution factors are an advantage of the 1:1½ extract and implies that the method will not be strongly hindered by dilution effects, as is confirmed by the high correlation coefficients between the analytical data of the 1:1½ extract and the substrate solution. A drawback is the fact that it is not a universal method for all types of substrate. The 1:1½ volume extract method is just suitable for peaty substrates, which means mixtures in which peat is the main component. The presence of a volume fraction up to 25% of different other materials showed to be no hindrance for the application (Sonneveld and Van Elderen, 1994). However, the use of it for substrates with too much a different moisture characteristic, easily results in analytical data that induce misinterpretation.

With the same study the micro nutrients were determined, as shown at the bottom of Table 4.4 (Sonneveld and Voogt, 2009). For Fe, Mn and Zn the results are comparable with those of the major elements, only the regression coefficients of the equations for Mn and Zn were higher than for the major elements. This can be explained by preferential cation adsorption. For B, Cu and Mo the correlation coefficient are much lower than those found with the other elements, which could be explained by analytical errors, caused by the fact that the methods of determination of these elements in the 1:1½ extract was not adjusted to the low levels of these elements in this extract.

The 1:1½ method is based on the fact that substrates with natural organic material as main constituent contain a water content of about 50% by volume at a pressure head of –3.2 kPa and about 60% at –1 kPa. Thus, in the extraction suspension a ratio substrate to water exists of 1:2 v/v, while the dilution in relation to the substrate solution is about 2:0.6, which can be roughly expressed as 3:1. In this way the 1:1½ extract is suitable to express the analytical data as well on substrate volume as on substrate solution (Sonneveld and Voogt, 2009).

4.6 1:5 Volume Water Extract

A universal method for the determination of water soluble elements in substrates has been developed by CEN/TC 223, a European commission for standardisation of analytical methods for soil improvers and growing media. The extract is prepared by extraction of a suspension of 1 volume of substrate and 5 volumes of water (CEN, 2001a. The quantity of substrate used for the preparation of the suspension is based on the so called laboratory compacted bulk density. This bulk density is determined beforehand by filling a cylinder of about 1 litre, dimensions 100 mm diameter and 127 mm height with fresh substrate. The substrate in the cylinder is compacted in a special way by placement of a plunger of a certain weight on top of the filled cylinder, which is comparable with a pressure of about 0.9 kPa (CEN, 2007). A certain volume of the sample, CEN recommend 60 ml, is separated by weighing on basis of the compacted bulk density, determined beforehand. This quantity of substrate is mixed with 5 volumes of water, thus, 300 ml when the CEN recommendation is followed.

The striking characteristic of the CEN method is the high water to substrate ratio, which makes it possible to extract filtrate from the suspension by a simple filtration with all types of substrates. However, the method has the same drawbacks as mentioned before for high water to soil ratios. The dilution in the suspension in relation to the water holding capacity under growing conditions varies from 25 for substrate with a low water holding capacity to 6 for substrate with a high water holding capacity, like for example expanded clay and peat respectively. For an interpretation of the analytical data in relation to the substrate solution the water holding capacity of the substrate under growing conditions should be available (Sonneveld and Voogt, 2001, 2009).

4.7 Extraction of Pre-shaped Substrate by Water

The extraction methods discussed so far are just suitable for unformed material. The ultimate shape and density of such substrates under growing conditions is determined by the dimensions and the filling method of the containers applied in the growing system. However, this is not the case with pre-shaped materials like for example slabs of mineral wool and foams, because such materials got already the form for the growing conditions at the factory. Another situation arises with the so called slabs of pressed peat and coir. True enough, these slabs are pre-shaped on the factory, but the shape will surely significantly change when wetted under growing conditions. In this case the extract preparation offers different possibilities. The first is that the material on the laboratory is carefully pre-wetted with demineralised water up to the leek out condition and extracted as presented for the leek out situation at the end of this section for other pre-shaped substrates. The second option is that the material will be pre-wetted at the laboratory, while granulated by gently stroking of the substrate and by this handlings preventing as much as possible damages on the structure of the original material. After these treatments the substrate is suitable to be extracted by either the 1:1½ or the 1:5 volume methods.

For extraction of pre-shaped substrates a suitable peace of material is cut from the sample and the exact volume is calculated from the dimensions measured. The extraction can be carried out following the 1:5 volume method. With the 1:5 volume method an intensive mixing of substrate and water in the suspension should be ensured, which best can be carried out by unravelling the peace of substrate preventing as much as possible damage on the original components, like the fibres of mineral wool slabs.

Extracts of pre-shaped substrates also can be prepared after saturation to leak out condition. The leak out condition should be determined in a sub-sample. This sub-sample is immersed in water and leaked out until equilibrium is reached. The sample for the extract preparation at the leak out situation is mixed with water at the same water to substrate ratio as found in the sub-sample, and after an overnight storage of the material the extract will be gained by suction or by gently pressing of the substrate. The extraction at the leak out condition nicely links with the extraction during cultivation, when extract is gathered by suction from slabs more or less continuously in a leak out condition under growing conditions.

4.8 Soil and Substrate Solution

The soil and the substrate solution directly supply information about the ion concentrations of the plant root environment. Especially for determinations related to salinity the soil and the substrate solutions provide optimal information and therefore, are often used for research purposes in this field. However, it never has been employed for routine soil testing, because of its difficult and laborious preparation. The methods employed to extract the soil solution from field moist soils varies as listed by Fried and Broeshart (1967). The most suitable method is hydraulic pressing of the soil as described by Van den Ende (1989a). This method is less suitable for soils with low water contents at field capacity, like sandy soils with low organic matter fractions. In such cases the displacement method can be applied.

For substrates, however, the so called substrate solution is often used for routine testing of substrates. This especially is the case for substrates with high water contents at a high pressure head, like mineral fibres and foams (Sonneveld, 1995). During cultivation the crops are irrigated frequently in such substrates, sometimes dozens of times a day, which ensures a stable and high water content in the substrate. Under such conditions the substrate solution easily can be gathered, withdrawing it from the substrate by suction with the aid of a simple syringe. Also with peaty substrates the use of substrate solution is sometimes practiced, because the substrate solution at a pressure head of –1 kP, defined as the moisture condition at field capacity, can be easily pressed out. The method is applied with samples gathered from the greenhouse during cultivation. Before the sample is pressed a careful check on the right moisture condition is required, as well an adjustment with demineralised water when the moisture condition is too low.

Extraction of soil and substrate solution under practical conditions can occur by suction with the aid of cups produced with ceramic or artificial material. The cups are placed in the soil and the soil solution penetrates the wall of the cups as a consequence of the suction applied in the system. A drawback of this method is the accidental placement in the soil or the substrate. Therefore, in view of the great variation of concentrations of salts and nutrients in greenhouse soils and substrates, different placements are necessary scattered horizontally as well vertically. Another drawback is the possible adsorption of some elements that can occur by the material whereof the wall of the cup is produced. The right choice of cups is important to be ensured that the soil solution is not affected by the material from which they are produced (Shen and Hoffland, 2007).

Much research is carried out in hydroponics and the results of experiments are based on the solution in which the plants were grown. Such solutions can be considered as soil and substrate solutions. Many plant nutrition and salinity reactions in soil and substrate growing show a good agreement when compared with the reactions in hydroponics. However, when the matrixes of the soil or the substrate play a part in it, the reactions will differ from those in hydroponics. Such reactions especially occur in the rhizosphere of plant roots. This for example is sometimes the case for the uptake of micro nutrients.

The composition of the substrate solution also can be estimated from the composition of the water supplied to the plant and the drainage water. This method

seemed to be very suitable, because it not only gives an acceptable estimation of the average concentrations in the root environment, but it also informs about lowest and highest concentrations in the root environment, generally supply and drainage in a substrate system, respectively. Especially for interpretation of the EC value knowledge about lowest and highest values are very useful, as will be discussed in Chapter 8.

4.9 Saturated Gypsum Solutions

The dilutions by water extraction of soils and substrates gives always raise to dissolution of sparingly soluble salts and by this an overestimation of the salt status. Gypsum is the most likely salt responsible for this effect. Therefore, some researchers recommended a saturated gypsum solution as extraction solution for the estimation of total soluble salt (Winsor et al., 1963), to mask the effect of gypsum on the determination of the salinity. This, sometimes lead to a remarkable improvement of the estimation of the salinity effect on crops (Fischer, 1992; Massey and Winsor, 1968), especially when high water to soil ratios are used with extraction. In Table 4.5 correlation coefficients are shown for the relationships between the yield of lettuce and the EC measurements in the growing media determined by extraction either with water or by a gypsum saturated solution (Massey and Winsor, 1968). The use of the gypsum solution did not increase the correlation coefficients up to the level found with the saturation extract. Therefore, the use of a saturated gypsum solution as extraction solution has not been found a wide application. Besides, the use of such a solution has drawbacks of which the most likely are following.

- It totally masks the contribution of gypsum to the osmotic potential of the soil solution, assuming that all soil and substrate solution are gypsum saturated under growing conditions. However, this is not the case (Sonneveld et al., 1990).
- The use of sufficiently narrow water to soil ratios became more customary last decennia, which prevent the trouble of overestimation for the greater part.
- The determination of the real concentration of Ca and SO_4 in the soil and substrate extracts is impossible, which blocks the opportunities for adjustment of the

Table 4.5 Correlation coefficients for the relationships between the yield of lettuce in two series of experiments and the EC determined by different extracts. The extracts are derived from a saturated soil suspension, a 2.5:1 v/v water to soil suspension and a 2.5:1 v/v gypsum saturated solution to soil suspension

Salinity test method	Series 5–8	Series 9–12
Saturated	0.954	0.982
1:2.5 v/v water	0.746	0.923
1:2.5 v/v water + gypsum	0.814	0.953

Withdrawn from Massey and Winsor (1968).

estimation of the osmotic potential of soil and substrate solutions on the dissolved gypsum.
- The lack of information about the real concentration of Ca and SO_4 in the extract blocks also the control on these elements by fertilization practices.

In studies with different extraction methods with water (Sonneveld et al., 1990; Sonneveld and Van Elderen, 1994) the suitability of narrow water to soil ratios and the measurement of SO_4 to improve the estimation of the EC of the soil solution is taken into account. The results of these studies are listed in Table 4.6. With a relative high water to soil ratio as used in the specific 1:2 volume extract a precise estimation of the EC of the soil solution will be gained when the dilution factor and the SO_4 concentration are added as explaining variables. Then equal and in this specific are added case even a little higher correlated estimation will be gained than with the saturation extract.

Table 4.6 Comparison of different equations and correlation coefficients to estimate the EC of the soil solution and substrate solution using either the EC of the saturation extract, different variables of the specific 1:2 volume extract or the EC of the 1:1½ volume extract

Equations used to estimate the EC of the soil solution	Correlation coefficients	Variables used
$1.60EC_{se} + 0.18$	0.958	EC_{se} = EC saturation extract
$3.12EC_{1:2} + 0.84$	0.886	$EC_{1:2}$ = EC of the 1:2 extract
$0.601\ dEC_{1:2} + 1.26$	0.944	d = dilution factor
$0.908\ dEC_{1:2} - 0.089\ dSO_{4_{1:2}} + 0.68$	0.968	$SO_{4(1:2)}$ = SO_4 concentration of the 1:2 extract
$2.39EC_{1:1\frac{1}{2}} + 0.17$	0.982	$EC_{1:1\frac{1}{2}}$ = the EC of the $1:1\frac{1}{2}$ volume extract

After Sonneveld et al. (1990); Sonneveld and Van Elderen (1994).

4.10 CAT Extraction

By CEN/TC 223, see the remarks about this commission in Section 4.6, a method for the determination of potentially available nutrients in substrates has been developed. The extract is prepared by extraction of a suspension of 1 volume of substrate and 5 volumes of CAT-extraction solution (CEN, 2001b). The quantity of substrate used for the preparation of the suspension is based on the so called laboratory compacted bulk density, the determination of which is described in Section 4.6. The CAT-solution is a solution of 0.01 mol l^{-1} $CaCl_2$ and 0.002 mol l^{-1} DTPA (diethylene tri-amine penta-acetic acid). The pH of this solution varies between 2.6 and 2.65, but the available pH buffer of the solution is weak.

The quantities of cations extracted by the CAT method will be much higher than the directly water available quantities. Thus, it rather reflects the "capacity" of these nutrients in a substrate than the "activity". This is clear from the data shown in

Table 4.7 Quantities of nutrients (mg l^{-1} substrate) extracted with water or CAT from four different substrates

Substrate	Extraction	NO_3	P	K	Cu	Mn
Composted	Water	25	236	1910	1.3	1.3
bark	CAT	14	290	2727	1.1	10.7
Fertilized	Water	83	31	114	0.0	0.3
clay/peat	CAT	73	35	148	0.7	9.8
Fertilized	Water	57	89	101	0.1	0.2
coarse peat	CAT	54	93	129	1.1	3.3
Composted	Water	67	48	126	0.0	0.4
wood fibre	CAT	65	55	152	1.0	8.5
Average	Water	58	101	563	0.4	0.6
	CAT	52	118	789	1.0	8.1

Withdrawn from CEN (2001a and b).

Table 4.7. Nutrients already dissolved in the substrate solution, like NO_3, are nearly not affected by the CAT solution. P is slightly affected maybe by the low pH buffer of the extraction solution and K by the cation exchange. Cation micro nutrients, like Cu and Mn, will become better soluble in the CAT extract by the low pH, cation exchange and complexion. Especially with Mn the quantities soluble in the CAT extract are strongly increased. This is understandable because most Mn under natural condition occur as manganese oxides, which solubility strongly depend on the pH (Fujimoto and Sherman, 1948; Leeper, 1947). The ratio Cu-CAT/Cu-water showed great variation. Cu can be bound strongly on organic matter, which varies greatly dependent on the type of material and pH (Verloo, 1980).

4.11 Exchangeable Cations

With CAT extraction for different nutrients mostly more cations are released than those present as exchangeable (Sonneveld and De Kreij, 1995). Therefore, for substrates a different method is developed for extraction of just the exchangeable quantities, based on the use of ammonium acetate (Knudsen et al., 1982). The extract is prepared from a suspension of 1:5 v/v fresh substrate and 0.5 mol l^{-1} ammonium acetate (NH_4Ac) solution, respectively. The volume is measured according to the method of CEN (1999a) and the moisture present in the fresh substrate is taken into account with the preparation of the suspension (Kipp et al., 2000). The NH_4Ac solution is buffered at a pH value of 4.65.

Obviously, the determination of exchangeable NH_4 is impossible in the NH_4Ac extract. However, the determination of exchangeable NH_4 in some substrates will be important, in view of the high concentration of this ion that can occur. In such cases instead of NH_4Ac an equivalent concentration of $BaCl_2$ is recommended (Kipp et al., 2000). For greenhouse soils NH_4Ac is also suitable for the determination of exchangeable cations. However, the determination of it is not obvious for

greenhouse soils, because the actual mutual ratios of the cations in the soil solution are of more importance than the total available quantities. Such ratios best can be approximated by water extraction.

4.12 Phosphorus

With the water extractions like the saturation extract, the 1:2 volume extract and the 1:1½ volume extract close relationships were found between the P concentration of these extracts and those of the soil and substrate solutions. Thus, water extraction with a low water to soil and water to substrate ratio is a good method to get informed about the solubility of the P in soil and substrate solutions. However, it mostly does not give a good impression about the total available P and even less about the total storages in soils and substrates. This is clear from the data shown in Fig. 4.2, where the quantities of P extracted with different water to soil ratios of three different soils are shown. The P available in the soil solution, and those extracted with the saturation extract and the 1:2 volume extract is only a small fraction of the total water soluble quantities, extracted by a 1:100 w/w extract. Therefore, the determinations of P at low water to soil ratios only gives an impression of the solubility of P and are not precise estimators of the total water soluble quantities as is shown in Fig. 4.3 for the 1:2 volume extract. Many greenhouse soils are rich on water soluble P and most of the Dutch greenhouse soils shown in Fig. 4.3 contain between 1 and 5 mmol l^{-1} of soil. This means that in the top layer of 0.25 m of these soils a P storage is available between 75 and 400 kg P per ha.

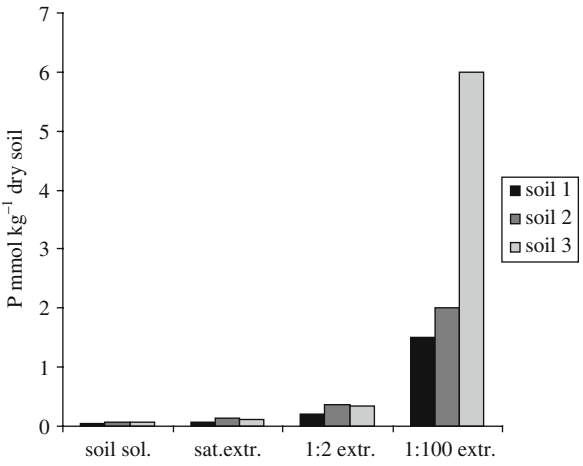


Fig. 4.2 Quantities of P (mmol kg^{-1} dry soil) extracted with different water to soil ratios, soil solution, saturation extract, 1:2 volume extract and 1:100 w/w extract, for three greenhouse soils (1 – peaty soil and 2 + 3 – loam soils)

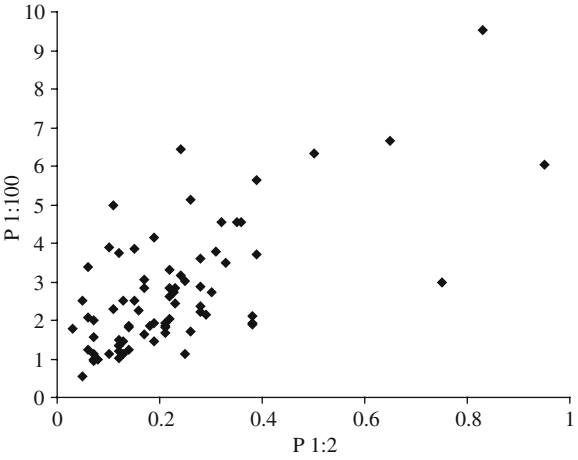


Fig. 4.3 Relationship between the P concentration in the 1:2 volume extract (mmol l^{-1} extract) and the water soluble P at an extraction ratio 1:100 w/w water to soil (mmol l^{-1} soil) for 75 greenhouse soils

In peaty substrates it has been found that often the bulk of the P is available in the substrate solution. In such cases with water extraction the P in the substrate behaves like other anions at dilution with water extraction (Sonneveld and Van Elderen, 1994). However, when clay was a constituent of the peaty substrates, the P behaves more like those in greenhouse soils (Sonneveld et al., 1974) and the concentration of it in the extract is more or less stable at low water to substrate ratios. Another factor that will play a role in P determination in substrate is the time delay between application and determination. Fertilized substrate mainly contains fresh orthophosphate as high soluble H_2PO_4 from fertilizers supplied. The precipitation and occlusion process to bind the P in the labile and non-labile pools is time consuming (Mengel and Kirkby, 1987), while the analysis usually is carried out shortly after addition.

In greenhouse industry often the quantities of labile and non-labile P mainly in soils and sometimes also in substrates are much higher than those that will be absorbed by crops. The determination of that pool is quite important and gives an impression of the "capacity" for long periods. The availability of the compounds should be checked more frequently by determination of the "intensity". Water extraction is the most obvious method for the determination of the "intensity" and for the "capacity" CAT, P-Al (NH_4-lactate-acetic acid) and other extraction methods are used (Alt and Peters, 1992). The suitability of such methods for soils will be discussed further on in Section 16.4.

4.13 pH

The pH is usually determined in a suspension of 1 volume part soil and 2 volume parts of demineralised water. The pH determined in this way showed substantial seasonal variations with field soils (De Vries and Dechering, 1960). Therefore, the

determination of the pH in a solution of 1 mol l^{-1}KCl has been developed, the results of which are less sensitive for these variations. The seasonal variations for greenhouse soils are less than for field soils and so there is no urgency to use this determination for greenhouse soils, but even so used sometimes. The pH_{KCl} is generally lower than the pH determined in a water suspension. However, the differences for greenhouse soils are smaller than for field soils and will be discussed in more detail in Section 16.2.

For substrates CEN developed a method for the determination of the pH in a suspension of 1 volume part substrate and 5 volume parts of water (CEN, 1999b). The wide ratio between water and substrate is reason for deviations with the pH found under moisture conditions as realised in the field. This mainly occurs for substrates with a low buffer capacity. The pH determination for such substrate with water is always problematic and therefore the determination often is carried out with a standard nutrient solution (KIWA, 2003). The result will be discussed further on in Section 11.4.

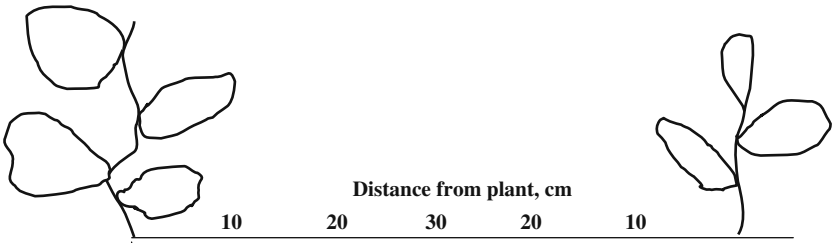
Picture 4.3 Soil sampling in a greenhouse. Generally, the sampling depth is 0.25 m

4.14 Sampling

The results of the analytical data of soils and substrates are affected strongly by the method of sampling. The great variation in the chemical properties from spot to spot requires a special procedure to gather a sample that significantly reflects the composition of the soil and the substrate in the greenhouse. Variations in chemical properties of spots in a greenhouse area can be distinguished in systematic and

in accidental components. Knowledge about the character of the variability is quite important with respect to the instructions to the sampler. Systematic components for example need specific attention and require as well specific actions which will be included in the instructions for the sampler. Systematic variation components can be either included as well avoided with the sampling, dependent on the expected reaction of the crop on such places. Places with a specific deviation, where the soil or the substrate does not contain plant roots will be avoided with the sampling. However, when plants have developed roots in such places mostly they will be systematically included in the sample. However, such will depend on the purpose of the sample and the plant reaction on the deviation, considering the deviations as discussed following and the reaction of the plant on an unequal distribution as presented in Chapter 8.

Examples of systematic variations in soils and substrates in the greenhouse industry are for example the distribution of salts and nutrients with the use of drip irrigation in soil grown crops. In Fig. 4.4 the distribution of NO_3 between the nozzles of a drip irrigation system is shown. The nozzles were placed near the plants and strong accumulations of salts and nutrients occur in the area between plants. Another example is the vertical distribution of salts shortly after fertilization as shown in Table 4.8.



Depth, cm	Distance from plant, cm: 10	20	30	20	10
10	1.2	9.8	7.0		
20	0.8	2.5	3.3		
30	0.7	8.5	7.8		
40	0.7	2.2	2.9		

Fig. 4.4 NO_3 concentrations in the soil (mmol l^{-1} 1:2 volume extract) with drip irrigation at different distances of the irrigation spots. Tomato crop on clay soil, 6 months after planting. After Sonneveld et al. (1991)

Table 4.8 Vertical distribution of nutrients in greenhouse soils shortly after fertilization. Average values of three greenhouses. The concentrations are expressed as mmol l^{-1} 1:2 volume extract

Depth cm	N	P	K
0–8	5.2	0.44	4.2
8–16	4.4	0.15	2.9
16–24	2.9	0.14	1.5
24–40	2.1	0.05	1.0

After Sonneveld, 2009. *Reprinted by permission of the Koninklijke Landbouwkundige Vereniging*

Systematic differences in greenhouses can occur in many other situations, like the differences between growing beds and paths (Van den Ende and Knoppert, 1959; Van der Wees, 1983), irrigation furrows and the dry strips beside them, the vertical distribution of nutrients in the substrate of potted plants grown on flooded benches (Otten, 1994) and variations in pH in substrate systems caused by NH_4 application (Sonneveld and Voogt, 2001). When systematic differences are well known, the decision can be made to take different samples from the same site in such a way that the variation of the sampled object is reflected in the different samples. Other possibilities are an overall sampling with the purpose to get a rough estimation of the average chemical composition of the sampled object and a sampling of selected spots to estimate the composition of specific sites of the object from which crop response is expected. The choice of the sampling method will be made in relation to the purpose of the sampling and the expected reaction of the crop grown or the crop that will be grown in the soil or the substrate object sampled.

In experiments with salinity it was found that spots of high osmotic potential (low EC value) play a dominant role of crop reaction on salinity (Sonneveld and Voogt, 1990; Sonneveld and De Kreij, 1999). Thus, for this item spots of low EC values play a dominant part in the salinity effects of the crop. For nutrient uptake it was found that plants are able to absorb nutrients from high concentrated as well as from low concentrated spots. Thus, in such cases the total available quantity of nutrient in the rooted zone seems to be important (Sonneveld and Voogt, 2001). Thus, with the use of saline water in drip irrigation systems plants will react mainly on the lowest concentration in the spot under the dripper and only secondary on the accumulation of salts in the surrounded soil or substrate. However, nutrients accumulated in the surrounded soil or substrate volume are absorbed by plants and thus, are important for the crops grown.

Descriptions of sampling procedures are sparingly published for the greenhouse industry, perhaps because of the difficulties arising with the great variation in growing systems. In The Netherlands some guide-lines are published (De Kreij et al., 1999; Van den Bos et al., 1999; Van der Wees, 1993).

For an overall sampling of greenhouse soil it is recommended to gather 40 cores at random from the object. This number of cores is based on the theoretical fact that the error of an at random sample decreases with the square root of the number of sampling points. This means for soil sampling in formula:

$$s_n = \frac{s}{\sqrt{n}} \tag{4.3}$$

In which:

s = the standard deviation of the single cores (sub samples)
s_n = the standard deviation of a sample at n cores
n = the number of cores in the sample

The function presented in formula (4.3) is shown in Fig. 4.5. It is evident that the standard deviation at 40 sampling points is reduced to about 15% of the deviation at one sampling point and that a further increase of the sampling point is less effective. The strongest decrease, however, is reached up till 20 sampling points. So, in greenhouse industry 40 cores per sample is preferred, when the sampling is time consuming or difficult to carry out, 20 cores is considered to be sufficient. In such cases a careful handling of less sub samples is preferred above a higher number sub samples less carefully gathered.

For substrate sampling the European standardisation (CEN, 1999a) uses following formula to calculate the number of sub samples, being the number of sample points.

$$n_{sp} = 0.5\sqrt{V} \tag{4.4}$$

In which

n_{sp} = number of sampling points, with the restriction of $12 \geq n_{sp} \leq 30$
V = the nominal quantity of the sampled portion in m^3

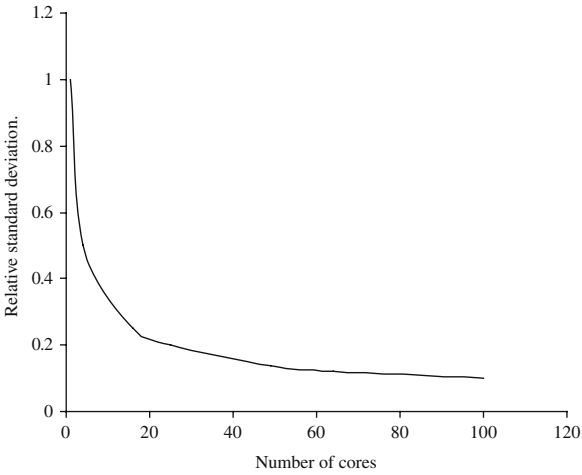


Fig. 4.5 Relationship between the number of cores from which a sample is composed with at random sampling and the standard deviation of the composed sample relative to the standard deviation of a sample composed of a single core, following formula (4.3)

The sampling depth recommended for the greenhouse industry for soil grown crops is mostly restricted to 0.25 m. In substrate growing the thickness of the substrate layer mostly is less than 0.25 m and thus, the sampling is carried out over the whole depth of the layer. With potted plants in flooded benches the upper 2 cm of the substrate is removed from the cores, because of the excessive high salt concentrations in it and the lack of roots in this layer.

In rock wool slabs, foam slabs and other pre-shaped substrates is it impossible to sample the substrate itself. Mostly, the nutrient solution in such substrates can be sucked very easily from the material by a simple syringe. The number of sampling points is the same as with ad random sampling of soils. It is impossible to gather nutrient solution with a syringe from coarse inert substrates, like pumice, perlite, vermiculite, and expanded clay granules. Sampling of the material at such is also problematic during cultivation. Therefore, in such substrates the free nutrient solution at the bottom of the containers or the drainage water will be sampled. In systems with circulating water, like NFT and deep water culture, the circulating solution is sampled. In substrate systems where the nutrient solution is reused, often sampling of the ingoing (supplied) and outgoing (drainage) solution is very useful and gives a good impression of the salt and nutrient status in the root environment (Sonneveld and Voogt, 2001), including highest and lowest salt and nutrient status.

Substrate material sometimes will be sampled on storage. Bulk material will be preferably sampled throughout the depth of the material, with which the top 50 mm is ignored. With the sampling it is important to preserve the characteristics of the material. Therefore, sampling by hand or shovel is more obvious than with an auger in such cases. With packed material is each sampling point a different randomly selected pack. With pre-shaped material a suitable part shall be cut from the slabs with a sharp knife or saw, without disturbing the characteristics of the material (CEN, 1999a).

4.15 Accuracy of Soil Testing

All handlings carried out to produce analytical data of soil testing contribute towards errors. Generally, the errors are distinguished as caused by factors outside and by factors inside the laboratory. The errors caused by factors outside the laboratory are strongly controlled by the handlings carried out with the sampling. The effect of the handlings with the sampling on the total error is mostly much greater than the effects caused by the laboratory handlings (Cline, 1944; Peck and Melsted, 1980; Vermeulen, 1960). Another source of deviations is the accidental laboratory on which the analysis is carried out. This factor is mostly ignored, because it is not evident when the measurement is carried out on only one laboratory. However, the casual handlings on the laboratory can substantially contribute to errors. This for example, was shown with a proficiency testing carried out with a new developed

measurement of the laboratory compacted bulk density (CEN, 2007) with laboratories all over the world. This bulk density was due to the measurements of nutrients in substrates. The data were statistically analysed following the method of ISO (1994) and showed that the repeatability varied between 1.3 and 3.2%, while those for the reproducibility varied between 5.8 and 9.9% (De Kreij and Wever, 2005). The repeatability and reproducibility express the deviations within and between the laboratories, respectively. Herewith, is shown, that the deviations between laboratories can be much greater than those within laboratories.

With sampling the homogeneity of the soil, the working method of the sampler and the number of sampling points are factors that will strongly affect the accuracy of the results. Therefore, a careful instruction to the sampler as mentioned in Section 4.14 is very important to get a goal-directed and accurate sample. The accuracy within the laboratory is determined by the handling with the pre-treatment, the handlings of the analyst, the analytical methods applied and the accuracy of the apparatus involved. In modern routine laboratories with automatic apparatus, besides good instructions, also the choice of apparatus suitable to the purpose, is an important factor to get the required precision of the analytical data (Sonneveld and Voogt, 2009).

In The Netherlands research has been carried out to estimate the size of the errors with soil testing in greenhouses (Sonneveld, 1979). To this purpose some hundreds of greenhouse soils were sampled in duplicate and the samples were analysed also in duplicate at the laboratory. With these results besides the total error also the sampling error and the laboratory error could be estimated separately. The standard deviation was used as a measure for the errors.

The level of the analytical data and the standard deviation were linearly related. The functions calculated for such relationships mostly showed a positive intercept and thus the coefficients of variation were not a constant. Those for the total errors varied from 10 to more than 20% of the results and those resulting from the laboratory analyses varied roughly between 5 and 10%. The contribution of the sampling to the total standard deviation was 2–5 times higher than those of the handlings with the determination on the laboratory.

With substrate sampling and analysis more or less the same experience has been gained as with soil testing. Such has been found for sampling of nutrient solutions in rock wool slabs (Sonneveld and Voorthuizen, 1988). For this type of samples also a linear relationship was found between the total standard deviation and the level of the data, as shown for the determination of K in Fig. 4.6. The coefficients of variation of the total errors lay mostly between 10 and 20% of the results, just like for soil samples. Those for the laboratory analysis varied for most determinations between 2 and 10%. The contribution of the sampling to the standard deviation was sometimes more or less equal to those from the laboratory, but was mostly between 2 and 10 times higher.

The consequences of the effects of errors made by sampling and analyses are often underestimated. Therefore, adequate sampling procedures must be developed and results will be well tested and statistically analysed for the concerning sys-

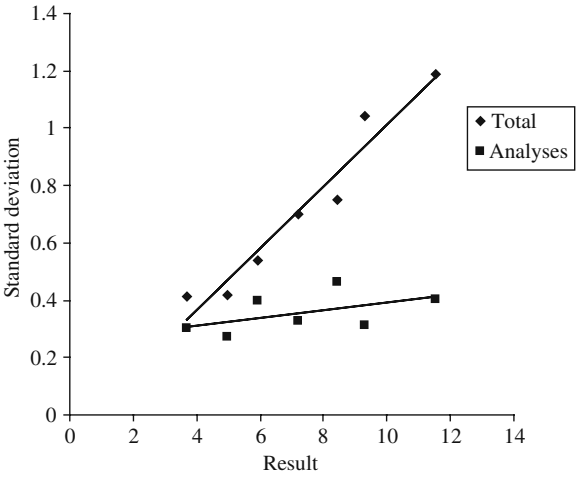


Fig. 4.6 Relationships between the result (mmol l^{-1}) of the K determination in nutrient solutions of rock wool slabs and the standard deviations following sampling and analysis on the laboratory. Total: $s_t = 0.108\ K - 0.065$ and analysis: $s_a = 0.013\ K + 0.257$ was calculated

tem. This is demonstrated by the data of Fig. 4.6. For the example presented first of all should be pointed to the fact that the system has been tested for results of the K determination between 3 and 12. Extrapolation of the regression equations in the low direction soon induces a contribution from the analyses to the total standard deviation higher than the total standard deviation itself, which is impossible. In Table 4.9 some results of the statistical analysis are summarized. The analyses of K were duplicated and the average values were used as the result. Thus, the total standard deviation was compounded following formula (4.5).

$$s_t = \sqrt{s_s^2 + \frac{1}{2}s_a^2} \tag{4.5}$$

In which

s_t = the total standard deviation
s_s = the standard deviation following from sampling
s_a = the standard deviation following the analysis on the laboratory

Table 4.9 Standard deviation as found for the K determination (mmol l^{-1}) in the nutrient solutions of rock wool slabs at two levels of results. s_t, s_a and s_m standard deviation for total, analyses and sampling, respectively. vc is the relative standard deviation (%)

Result	s_t	s_a	s_m	vc_t	vc_a	vc_m	P = 0.95	P = 0.997
3 mmol l^{-1}	0.258	0.296	0.151	8.6	9.9	5.0	2.48 - 3.52	2.23 - 3.77
12 mmol l^{-1}	1.230	0.413	1.195	10.2	3.4	10.0	9.55 – 14.45	8.23 – 15.67

Data derived from Fig. 4.6.

Furthermore, the data in Table 4.9 learns that in this specific case the relative total standard deviation is more or less stable over the range concerned, that the relative standard deviation for the analyses strongly increases with the decrease of the result and that this is upside down for the sampling for this determination.

One should be aware of the fact that the real value (μ) of an analytical result with a confidence level of P lies between limits following formula (4.6).

$$\mu = x \pm u_p s_t \tag{4.6}$$

In which:

$\mu =$ universal value of the result
$x =$ analytical result as found in the sample
$u_p =$ standard normal distributed unit corresponding with a confidence interval of P %
$s_t =$ total standard deviation

A confidence interval of 0.95 and 0.997 corresponds with an u_p value of 2 and 3 respectively. Thus, keeping in mind that s_t often has a value between 10 and 20% of the result it easily can be calculated that the real value (μ) of an analytical result

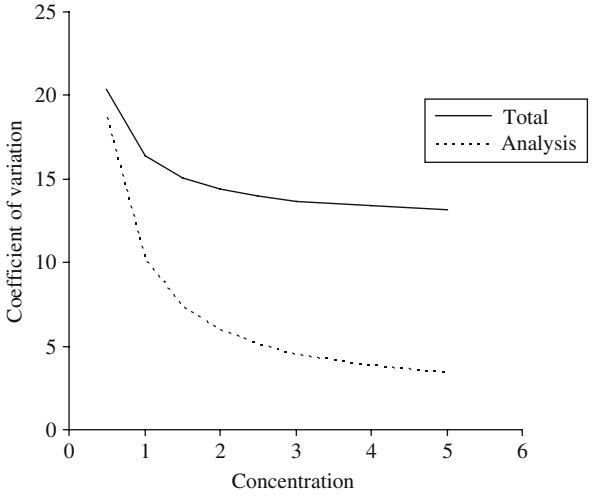


Fig. 4.7 Relationships between the concentration of Cl in nutrient solutions of rock wool slabs (mmol l^{-1}) and the coefficient of variation for the total error (s_t) and the error made by the determination on the laboratory (s_a). Calculated from the relationships $s_t = 0.124$ Cl + 0.040 and $s_a =$ 0.017 Cl + 0.085

mostly lies between the result (x) ± 20 to 40% and nearly always lies between the result (x) ± 30 and 60%. In Table 4.9 are the confidence domains given in last two columns for the specific situation of the values in this table as an example. It shows a relatively favourable situation with a total standard deviation of about 10%. The precision of an analytical determination system can differ strongly and will be tested to the purpose. Such a system is suitable to the purpose, when the relative errors of the methods in the range employed are sufficiently low and this range includes the critical limits for plant development. An example is given in Fig. 4.7, where the relative standard deviation is shown in relation with the level of Cl determinations in nutrient solution of rock wool slabs. The coefficient of variation for the analysis on the laboratory increases strongly for values below 1 mmol l^{-1}, which resulted also in an increase of the total coefficient of variation. Thus, with the determination of Cl reasonable analytical data can be expected for values higher than 1 mmol l^{-1}, which is sufficiently distinct. The critical value for the system is higher as will be discussed in Chapter 7. The determination of Cl for the rock wool system was less precise than the K determination, because the total standard deviation is close to 15%.

4.16 Applications

In this section a review is presented of the applications of the soil and substrate testing methods in relation to systems and growing conditions. In this review only the common growing conditions are presented with general applied testing methods due to the situation. Specific situations will be discussed in the chapters belonging to such situations. Application before planting and during cultivation can differ in the subject under discussion and will be distinguished.

The following methods are suitable for the estimation of the nutrient and salinity status in the root environment of soil, substrate and hydroponics. When appropriate the section where the method is described is mentioned.

1. Specific 1:2 volume extract (4.2)
2. Saturation extract (4.3)
3. Substrate solution by suction with a syringe in the field (4.8)
4. Substrate solution by pressing at field capacity (4.8)
5. 1:1½ v/v extract (4.5)
6. 1:5 v/v extract (4.6)
7. Supplied nutrient solution
8. Drainage water
9. Supernatant solution on bottom of plant container
10. Circulation nutrient solution

Situation	Before cultivation	During cultivation*
Soil	1, 2	1, 2
Natural organic substrate, pre-shaped	5, 6	5, 6, 7+8
Natural organic substrate, loose	5, 6	5, 6, 7+8
Rock wool slabs and cubes	6	3, 7+8
Foam slabs and cubes	6	3, 7+8
Rock wool and foam loose	6	7+8, 9
Course grained mineral substrates	6	7+8, 9
Fine grained mineral substrates	6	6, 7+8
Hydroponics (without any substrate)	-.-	10

* Where 7+8 is mentioned, the compositions of two solutions are necessary; unless the composition of the nutrient solution supplied is known.

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