USING SOIL AND FOLIAR ANALYSIS TO DIAGNOSE THE NUTRITIONAL STATUS OF URBAN TREES

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Abstract. During the past years, increased knowledge about the nutritional status of solitary trees has led to the development of soil and foliar analysis as a tool for the assessment of both chloride damage and nutrient deficiencies in The Netherlands. Data on threshold levels per tree species and element proportions are summarized. This enables the arborist to distinguish between various causes that exhibit similar symptoms (such as potassium deficiency, chloride damage and drought). The state of the art for the use of of soil and foliar analysis in arboriculture is briefly discussed and threshold values are presented.

When city-trees are planted with the aim of reaching a desired shape, size and amenity value within an acceptable period of time, the tree site has to meet several minimal demands. Briefly, these are sufficient levels of primary requirements such as light, air, temperature, moisture and nutrient elements, and a sufficient absence of threats such as diseases, pests and anthropogenic factors (vandalism, etc.). When the tree's demands are insufficiently met, stagnation of growth will normally result. In the worst possible scenario, the tree is subjected to a premature death.

Many of the causes of growth stagnation can be attributed to unfavourable site factors, such as deficits in the supply of moisture and nutrients. These result from both insufficient water to infiltrate into the soil or to rise from the ground water by capillary movement, and a too low level of chemical soil fertility, notably of nitrogen and potassium (8,11,12,13,15,16,17). However, growth stagnation is often closely linked to restrictions of the rootable soil volume (as a result of a too high density or penetration resistance), or deficits in the oxygen supply to the roots, or a combination of these factors (10,11,18).

A diagnostic investigation into the influence of the aforementioned factors on any observed stagnation of growth is often a time consuming job, when city trees and especially street trees are concerned. For a comprehensive study of the pattern of root development, pavements have to be removed (and replaced afterwards). Also, much of the digging has to be done by hand to prevent costly damage to underground utilities.

In addition, experience has already shown that the pattern of root development of street trees can often be very capricious and the pathways (such as frost cracks, undergound cable gutters, and sewage systems) that the roots have been able to use over the course of time to escape to better surroundings, such as the front gardens of houses, are not known in advance. This problem decreases representativeness of the observations, and thus the statistical reliability of such a study.

Unfortunately, such heterogenity also forms an additional restriction on the suitablity of a number of research methods such as chemical soil analysis and the determination of soil density. Nevertheless, these methods generally appear to provide sufficient information about the undesirable situation, provided that the results are interpreted with some skill and knowledge.

Soil Analysis

Soil samples are usually collected from the rooted or nonrooted zones of the soil (depending on which zone one is interested in). As a standard the samples are analysed for pH-KCl, the content of organic matter and phosphorus, available potassium and magnesium, and possibly the total nitrogen content and the so-called C-figure (see below) when one is interested in, respectively, the quality of the organic matter and the actual salt contamination of the soil. Determination of the availability of calcium is usually not necessary as the pH generally provides a global indication for the availability of this element.

The results of soil analysis however, are more difficult to interpret than the results of a foliar analysis. In the first place, the availability of some elements also depends on the physical conditions of the soil. Frequently water logging, or insufficient levels of soil oxygen, for example, have negative effects on the uptake of K and the rate of N mineralization. Secondly, the uptake of some of the elements, especially N, depends on the extension of the root system (8,11). Thirdly, usable references and criteria for the interpretation of the results of soil analysis have been derived from forest research.

These are relatively scarce and often not sufficiently tested. Also, many of the critical values for nutrient deficiencies are derived from research that focused on the assessment of levels at which trees still react to fertilization with an increase of growth. These levels are as a rule higher than those at which one still may speak about healthy or "acceptable" growth and development. Therefore, the results of soil analysis at urban trees (for which acceptable growth and amenity value are generally more important than optimal production) are less helpful than the results of foliar analysis in providing an exact explanation for a growth stagation caused by nutrient deficencies. Nevertheless, it continues to be a useful method to quantify the soil fertility of a growing site or a growing substrate for a new planting of trees. For the estimation of a sufficient presence of nutrition elements in the soil, the following criteria can be globally used.

pH-KCl. The pH-KCl of the soil is assessed by stirring a soil sample with a 1 M KCl solution in specified weight ratio (generally 1:2.5). The pH from this suspension is measured. As a rule of thumb, the pH-KCl value is about 0.8 lower than the pH value measured in a soil suspension in water (pH-w).

A pH-KCl value between 4.5 and 6.5 is "normal". Any value above this is considered "high" and below it is "low". The meaning of these values is partly physiological and partly statistical. For most tree species a pH-KCl value between 4.5 and 6.5 is optimal. To what extent one can speak of "too high" or "too low" is also determined by the individual species of trees (2,5,6,14,).

Organic matter. The organic matter content of the soil is assessed by dry combustion or by chemical oxidation. A content less than 3.0% is "low" and above that "sufficient". However, this threshold level is rather arbitrary because it can not be regarded apart from the volume of rooted soil. As a guideline for "tree pit soil" or plant-hole-filling for street trees, the sufficient content of organic matter in the soil lies somewhere between 2.5, when loam content (= the percentage of particles < 0.050 mm) is 20%, and 4.5% when loam content is 0%. This guideline also takes into account the water supplying capacity of the soil.

Phosphorus. As a rule, the P-supplying properties of forest soils are assessed by determining the total amount of P present (expressed by the P-total figure), because in forestry in the Netherlands this is a better and more studied standard for the supply of phosphorus than other P-extraction methods. A P-total figure over 40 mg P_2O_5 per 100 grams of soil is regarded as "sufficient" for high demanding tree species. For medium demanding tree species a threshold level of 30 mg is acceptable, and for low demanding species a level of 20 mg.

On the other hand, for woody plants in short rotation cropping, such as nursery crops, more often the P-AL figure is used. A P-AL figure of less than 10 mg P_2O_5 per 100 grams of soil is "low", 10-20 mg is "moderate" and above 20 mg is "good". (According to preliminary preparation of data from soil analyses in nurseries, it can be globally considered that at a not too high pH of the soil P-total = 20 + 1.5 x P-AL).

The P-AL value is assessed by extracting the soil with a solution of 0.1 M ammoniumlactate and 0.4 M acetic acid. The P-total is assessed by extracting the soil with a mixture of strong acids.

Potassium. The "available K" (K-HCl) of the soil is assessed by extracting the soil with a mixture of 0.1 M hydrochloric acid and 0.4 M oxalic acid. The K-HCl 0.1 M figure can only be evaluated in conjunction with the content of % of particles < 0.016 mm in the soil. This criterion "< 0.016 mm" is derived from agriculture research stations in The Netherlands.

% particles < 0.016 mm				
< 10	10-20	21-40	> 40	
K-HCl (mg K/100 g soil)				Rating
< 5	< 8	< 11	< 14	Low
5-8	8-12	11-14	14-17	Moderate
9-12	13-17	15-21	18-25	Good
> 12	> 17	> 21	> 25	High

The situation is more complicated when K-fixating (river)clay is present in the soil. The K-HCl figure might then look too favourable.

Magnesium. The Mg-NaCl 0.5 M figure for sandy soils is evaluated independent from the content of silt and lutum particles in the soil. The values are ranked as follows:

Mg-NaCl (mg Mg per kg soil)	Rating
< 30	Low
30-60	Moderate
> 60	Good

The Mg content is assessed by extracting the soil in a 0.5 M solution of sodium chloride. Its application is based on results from agricultural research.

Chloride. Not only the salt content in the soil itself, but also the concentration of salt in the water present in the soil is of major importance for the occurence of salt damage. Therefore, the so-called C-figure (grams of salt (NaCl) per liter of soil moisture in the rooted zone) is used to assess possible salt damage. The concentration above which salt damage is evident varies per species of trees. Examples for some common species are presented in Table 1 (3,7).

Because the moisture content, and thus the C-figure, can fluctuate during the growing season, preference is given to foliar analysis instead of soil analysis for the assessment of eventual salt damage.

Table 1. Critical levels of the C-figure of the soil for the estimation of the occurence of salt damage for some common deciduous trees.

Rating of symptoms

I: No visual damage observed

II: Threshold level for the occurence of visual damage

III: Visual damage (leaf-necrosis, leaf-shedding, twig-dieback)

IV: Heavy damage or initial stages of death

Tree species	*C-figure (g NaCl/l soil moisture)* I	II	III	IV
Acer pseudoplatanus	0-2	2-3	3-9	9-12
Aesculus hippocastanum	0-2	3	> 3	...
Fagus sylvatica	0-2	2-4	4-10	> 7
Fraxinus excelsior	0-3	3-4	4-11	7-11
Platanus x acerifolia	0-2	2-6	6-10	6-10
Populus x *euramericana* (*)	0-1	1-2	2-6	> 6
Quercus robur	0-5	5-10	> 10	...
Salix alba	0-2	2-6	6-12	4-12
Tilia x vulgaris	0-4	4	> 4	...
Ulmus x hollandica (*)	0-2	2-4	4-7	> 8

(*) : All cultivars
... : Value insufficiently known

[There are various other methods to examine the salt content of a soil substrate. Among these, measuring the electrical conductivity of a soil-water mixture is most widely used, both in forestry and arboriculture. Most soil laboratory measure the conductivity of a 1:5 soil-water mixture (the EC1:5). Globally, it shows that $EC_{1:5} \times 12 = EC_S$, in which EC_S is the value of conductivity of an extract of a water saturated soil sample. The latter method is used by most of the soil laboratories in the USA. In forestry in the Netherlands however, this method has not been extensively studied and therefore insufficient exact criteria are known to consider a soil as "safe". Another drawback of the method is that the actual water content of the soil is not taken into consideration. Nevertheless it can be a practical and simple method, provided that the electrical conductivity is mainly influenced by the presence of salt (sodiumchloride. As a rough approach (and no more than that) one may consider that in a moist soil (about field capacity) the C-figure is half of the EC_S value and in less moisten soils between 2/3 and 3/5 of the EC_S value (EC_S expressed as mmho/cm). Both in dry and very wet soils, the C-figure cannot be calculated from the EC_S value (3)].

Foliar Anaylsis

In the Netherlands, chemical leaf analysis has gradually become more important than chemical soil analysis in studies on the supply of nutrient elements to trees. This change was based on the philosophy that the total amount of elements is a less important factor than the availability of elements. Also, when using this method it is not necessary to know anything beforehand about the rooting pattern of the tree.

For foliar analysis a sample of fully developed leaves is usually analysed for the content of the macronutrients N, P, K, Ca, Mg and sometimes Cl. The content of micronutrients is normally not analysed because, thusfar, deficiencies of these never have been observed at urban trees in The Netherlands.

As a rule, foliar analysis is carried out in the period between the beginning of August and mid-September, because in this period the concentration levels of the nutrition elements are more or less constant. The period for foliar analysis of evergreen conifers is somewhat different (from the beginning of October to the end of December). When only the content of chloride is examined, in both conifers and deciduous trees, the period of sampling may start earlier, namely from the moment that visual symptoms of Cl damage appear.

Critical Cl-levels in the leaves of some common tree species above which chloride damage is normally evident are presented in Table 2. The following factors (listed in order of importance) are used to interpret the results of foliar analysis, and to rank the supply of nutrition elements as sufficient, nearly sufficient or insufficient.

-The absolute levels. These may vary with species of tree. Examples are presented in Tables 3a to 3d. Generally the element Ca is not considered, because Ca-deficiency of urban trees has never been observed thusfar in the Netherlands, and also because the exact threshold levels below which Ca-deficiency is evident are still insufficiently known. Nevertheless the determination of the Ca content is included in the analysis because it may give additional and conclusive information for the estimation of the status of K.

-The proportion of the element content to that of the content of N. Even at sufficient levels of P, K and Mg there might be a relative deficiency when the N-level is too high. Threshold values to estimate this are presented in Table 4.

-The cation-quotients for the assessment of relative deficiencies of K (with regard to Ca) and Mg (with regard to K). Threshold values for these are presented in Table 5.

Table 2. Critical values of the chloride content in the leaves for the estimation of the occurence of salt damage for some common deciduous trees.

Tree species	Cl-content (g Cl/kg dry matter) Healthy	Threshold (*)	Visual damage
Acer pseudoplatanus	0-6	6-12	12-35
Aesculus hippocastanum	0-7	7-11	11-32
Fagus sylvatica	0-5	5-7	7-32
Fraxinus excelsior	0-4	4-10	10-30
Platanus x acerifolia	0-11	11-16	16-42
Populus x euramericana (**)	0-7	7-13	13-39
Quercus robur	0-5	5-6	6-12
Salix alba	0-5	5-6	6-12
Tilia x vulgaris	0-6	6-9	9-28
Ulmus x hollandica (**)	0-7	7-15	15-35

(*) : Between these levels visual symptoms may or may not appear, depending on climatic factors and the time in the growing season.
(**): All cultivars

Conclusions

Arboricultural research in recent years has provided arborists and city foresters a number of analytical methods. It has become possible to estimate with more accuracy and efficiency the causes of growth stagnation or the suitability of a site for the planting of trees. One must realize, however, that none of these methods suffices on its own. For example, foliar analysis appears to be the most accurate method to assess deficiencies in the uptake of nutrient elements, but this method does not give indication of how the deficiencies can be corrected. To know whether fertilization is of any use, more should be known about the chemical soil fertility and other chemical and physical soil factors that might influence the uptake of available nutrients.

For example, when the uptake of K is restricted or inhibited by frequent or permanent water logging, the application of a fertilizer might have less

Table 3a. Provisional values of the content of foliar nitrogen (g per kg dry matter) for the estimation of N-deficiency in the leaves in the period from early August to mid-September (4,8,9).

Tree species	N-Supply Too low	Low	Normal	Optimal
Acer campestre	< 15	15 - 17	18 - 22	> 22
Acer negundo	< 13	13 - 16	17 - 22	> 22
Acer platanoides	< 17	17 - 22	23 - 27	> 27
Acer pseudoplatanus	< 17	17 - 22	23 - 27	> 27
Acer saccharinum	< 13	13 - 18	19 - 27	> 27
Aesculus hippocastanum	< 14	14 - 18	19 - 22	> 22
Alnus glutinosa	< 22	22 - 25	26 - 30	> 30
Alnus incana	< 20	20 - 24	25 - 30	> 30
Betula pendula	< 18	18 - 22	23 - 30	> 30
Carpinus betulus	< 15	15 - 19	20 - 27	> 27
Corylus avellana	< 18	18 - 22	23 - 25	> 25
Corylus colurna	< 18	18 - 22	23 - 30	> 30
Crataegus laevigata	< 15	15 - 18	19 - 22	> 22
Crataegus monogyna	< 15	15 - 18	19 - 22	> 22
Fagus sylvatica	< 18	18 - 20	21 - 28	> 28
Fraxinus excelsior	< 18	18 - 22	23 - 28	> 28
Gleditsia triacanthos	< 16	16 - 19	20 - 25	> 25
Juglans nigra	< 15	15 - 20	21 - 26	> 26
Juglans regia	< 20	20 - 25	26 - 35	> 35
Liquidambar styraciflua	< 14	14 - 17	18 - 28	> 28
Liriodendron tulipifera	< 20	20 - 25	26 - 30	> 30
Malus domestica (*)	< 17	17 - 22	23 - 25	> 25
Platanus x acerifolia	< 15	15 - 19	20 - 26	> 26
Populus alba (*)	< 14	14 - 18	19 - 25	> 25
Populus x canescens (*)	< 14	14 - 17	18 - 25	> 25
P. x euramericana (*)	< 22	22 - 25	26 - 28	> 28
Populus nigra (*)	< 20	20 - 24	25 - 28	> 28
Populus tremula	< 15	15 - 18	19 - 25	> 25
Prunus avium (**)	< 15	15 - 18	19 - 26	> 26
Prunus cerasus	< 15	15 - 18	19 - 26	> 26
Prunus domestica	< 18	18 - 21	22 - 25	> 25
Pyrus communis (*)	< 18	18 - 23	24 - 28	> 28
Quercus palustris	< 18	18 - 20	21 - 28	> 28
Quercus robur	< 18	18 - 20	21 - 28	> 28
Robinia pseudoacacia	< 20	20 - 25	26 - 30	> 30
Salix alba (*)	< 18	18 - 21	22 - 28	> 28
Salix triandra	< 18	18 - 22	23 - 30	> 30
Salix viminalis	< 20	20 - 22	23 - 30	> 30
Sorbus aria	< 15	15 - 18	19 - 22	> 22
Sorbus aucuparia	< 15	15 - 18	19 - 22	> 22
Tilia americana	< 21	21 - 26	27 - 31	> 31
Tilia cordata	< 17	17 - 20	21 - 24	> 24
Tilia x euchlora	< 17	17 - 21	22 - 26	> 26
Tilia platyphyllos	< 17	17 - 21	22 - 28	> 28
Tilia x vulgaris	< 17	17 - 24	25 - 28	> 28
Ulmus carpinifolia	< 18	18 - 22	23 - 27	> 27
Ulmus glabra	< 18	18 - 22	23 - 27	> 27
Ulmus x hollandica (*)	< 18	18 - 22	23 - 27	> 27

*: All cultivars

**: Provisionally, these criteria also apply to other species as those that are listed in the table

Table 3b. Provisional values of the content of foliar phosphorus (g per kg dry matter) for the estimation of P-deficiency in the leaves in the period from early August to mid-September (4,8,9).

Tree species	P-Supply Too low	Low	Normal	Optimal
Acer campestre	< 1.0	1.0 - 1.2	1.3 - 1.5	> 1.5
Acer negundo	< 1.0	1.0 - 1.2	1.3 - 1.5	> 1.5
Acer platanoides	< 1.0	1.0 - 1.5	1.6 - 2.2	> 2.2
Acer pseudoplatanus	< 1.0	1.0 - 1.5	1.6 - 2.2	> 2.2
Acer saccharinum	< 1.0	1.0 - 1.3	1.4 - 1.9	> 1.9
Aesculus hippocastanum	< 1.0	1.0 - 1.2	1.3 - 1.5	> 1.5
Alnus glutinosa	< 1.0	1.0 - 1.5	1.6 - 2.0	> 2.0
Alnus incana	< 1.0	1.0 - 1.5	1.6 - 2.0	> 2.0
Betula pendula	< 1.0	1.0 - 1.5	1.6 - 2.0	> 2.0
Carpinus betulus	< 1.0	1.0 - 1.2	1.3 - 2.0	> 2.0
Corylus avellana	< 1.0	1.0 - 1.4	1.5 - 1.8	> 1.8
Corylus colurna	< 1.2	1.2 - 1.5	1.6 - 2.1	> 2.1
Crataegus laevigata	< 1.0	1.0 - 1.3	1.4 - 1.6	> 1.6
Crataegus monogyna	< 1.0	1.0 - 1.3	1.4 - 1.6	> 1.6
Fagus sylvatica	< 1.0	1.0 - 1.3	1.4 - 1.6	> 1.6
Fraxinus excelsior	< 1.0	1.0 - 1.5	1.6 - 2.0	> 2.0
Gleditsia triacanthos	< 1.0	1.0 - 1.4	1.5 - 1.8	> 1.8
Juglans nigra	< 1.0	1.0 - 1.4	1.5 - 2.1	> 2.1
Juglans regia	< 1.2	1.2 - 1.8	1.9 - 2.4	> 2.4
Liquidambar styraciflua	< 1.0	1.0 - 1.2	1.3 - 2.0	> 2.0
Liriodendron tulipifera	< 1.2	1.2 - 1.7	1.8 - 2.1	> 2.1
Malus domestica (*)	< 1.3	1.3 - 1.5	1.6 - 2.0	> 2.0
Platanus x acerifolia	< 1.0	1.0 - 1.4	1.5 - 1.8	> 1.8
Populus alba (*)	< 1.0	1.0 - 1.5	1.6 - 1.8	> 1.8
Populus x canescens (*)	< 1.0	1.0 - 1.5	1.6 - 1.8	> 1.8
P. x euramericana (*)	< 1.2	1.2 - 1.5	1.6 - 2.0	> 2.0
Populus nigra (*)	< 1.0	1.0 - 1.5	1.6 - 2.0	> 2.0
Populus tremula	< 1.0	1.0 - 1.3	1.4 - 1.8	> 1.8
Prunus avium (**)	< 1.0	1.0 - 1.3	1.4 - 1.7	> 1.7
Prunus cerasus	< 1.0	1.0 - 1.4	1.5 - 1.8	> 1.8
Prunus domestica	< 1.0	1.0 - 1.3	1.4 - 1.7	> 1.7
Pyrus communis (*)	< 1.1	1.1 - 1.3	1.4 - 1.7	> 1.7
Quercus palustris	< 1.0	1.0 - 1.2	1.3 - 2.0	> 2.0
Quercus robur	< 1.0	1.0 - 1.3	1.4 - 1.7	> 1.7
Robinia pseudoacacia	< 1.1	1.1 - 1.3	1.4 - 2.1	> 2.1
Salix alba (*)	< 1.0	1.0 - 1.4	1.4 - 2.0	> 2.0
Salix triandra	< 1.0	1.0 - 1.6	1.7 - 2.1	> 2.1
Salix viminalis	< 1.0	1.0 - 1.6	1.7 - 2.1	> 2.1
Sorbus aria	< 1.0	1.0 - 1.2	1.3 - 1.6	> 1.6
Sorbus aucuparia	< 1.0	1.0 - 1.2	1.3 - 1.6	> 1.6
Tilia americana	< 1.0	1.0 - 1.7	1.8 - 2.2	> 2.2
Tilia cordata	< 1.0	1.0 - 1.4	1.5 - 2.0	> 2.0
Tilia x euchlora	< 1.0	1.0 - 1.4	1.5 - 1.8	> 1.8
Tilia platyphyllos	< 1.0	1.0 - 1.5	1.6 - 2.0	> 2.0
Tilia x vulgaris	< 1.0	1.0 - 1.5	1.6 - 2.0	> 2.0
Ulmus carpinifolia	< 1.0	1.0 - 1.5	1.6 - 1.9	> 1.9
Ulmus glabra	< 1.0	1.0 - 1.5	1.6 - 1.9	> 1.9
Ulmus x hollandica (*)	< 1.0	1.0 - 1.5	1.6 - 1.9	> 1.9

*: All cultivars

**: Provisionally, these criteria also apply to other species as those that are listed in the table

Table 3c. Provisional values of the content of foliar potassium (g per kg dry matter) for the estimation of K-deficiency in the leaves in the period from early August to mid September (4,8,9).

Tree species	K-Supply			
	Too low	Low	Normal	Optimal
Acer campestre	< 4	4 - 8	8.5 - 14	> 14
Acer negundo	< 4	4 - 8	8.5 - 14	> 14
Acer platanoides	< 7	7 - 11	11.5 - 15	> 15
Acer pseudoplatanus	< 7	7 - 11	11.5 - 15	> 15
Acer saccharinum	< 4	4 - 9	9.5 - 18	> 18
Aesculus hippocastanum	< 4.5	4.5 - 8.5	9 - 14	> 14
Alnus glutinosa	< 4	4 - 7.5	8 - 20	> 20
Alnus incana	< 4	4 - 6	6.5 - 20	> 20
Betula pendula	< 4	4 - 7	7.5 - 9	> 9
Carpinus betulus	< 4	4 - 6	6.5- 9	> 9
Corylus avellana	< 5	5 - 10	10.5 - 16	> 16
Corylus colurna	< 5	5 - 7	7.5 - 16	> 16
Crataegus laevigata	< 4	4 - 6	6.5 - 14	> 14
Crataegus monogyna	< 4	4 - 6	6.5 - 14	> 14
Fagus sylvatica	< 4.5	4.5 - 7	7.5 - 15	> 15
Fraxinus excelsior	< 6	6 - 10	10.5 - 15	> 15
Gleditsia triacanthos	< 4	4 - 9	9.5 - 16	> 16
Juglans nigra	< 5	5 - 10	10.5 - 20	> 20
Juglans regia	< 5	5 - 12.5	13 - 23	> 23
Liquidambar styraciflua	< 4	4 - 6	6.5 - 18	> 18
Liriodendron tulipifera	< 5	5 - 8	8.5 - 15	> 15
Malus domestica (*)	< 7	7 - 12	12.5 - 16	> 16
Platanus x acerifolia	< 4	4 - 6	6.5 - 17	> 17
Populus alba (*)	< 4	4 - 7	7.5 - 16	> 16
Populus x canescens (*)	< 4	4 - 7	7.5 - 16	> 16
P. x euramericana (*)	< 5	5 - 12	12.5 - 15	> 15
Populus nigra (*)	< 5	5 - 8	8.5 - 15	> 15
Populus tremula	< 5	5 - 8	8.5 - 16	> 16
Prunus avium (**)	< 6	6 - 10	10.5 - 17	> 17
Prunus cerasus	< 6	6 - 10	10.5 - 17	> 17
Prunus domestica	< 6	6 - 12	12.5 - 15	> 15
Pyrus communis (*)	< 6	6 - 12	12.5 - 15	> 15
Quercus palustris	< 4	4 - 6	6.5 - 8	> 8
Quercus robur	< 4	4 - 6	6.5 - 8	> 8
Robinia pseudoacacia	< 4	4 - 7	7.5 - 20	> 20
Salix alba (*)	< 6	6 - 10	10.5 - 19	> 19
Salix triandra	< 7	7.5 - 10	10.5 - 19	> 19
Salix viminalis	< 6	6.5 - 8	8.5 - 19	> 19
Sorbus aria	< 4	4 - 6	6.5 - 14	> 14
Sorbus aucuparia	< 4	4 - 6	6.5 - 14	> 14
Tilia americana	< 5	5 - 10	10.5 - 19	> 19
Tilia cordata	< 8	8 - 10	10.5 - 15	> 15
Tilia x euchlora	< 6	6.5 - 10	10.5 - 15	> 15
Tilia platyphyllos	< 6	6.5 - 10	10.5 - 15	> 15
Tilia x vulgaris	< 6	6.5 - 10	10.5 - 15	> 15
Ulmus carpinifolia	< 6.5	6.5 - 12	12.5 - 18	> 18
Ulmus glabra	< 6.5	6.5 - 12	12.5 - 18	> 18
Ulmus x hollandica (*)	< 6.5	6.5 - 12	12.5 - 18	> 18

*: All cultivars

**: Provisionally, these criteria also apply to other species as those that are listed in the table.

Table 3d: Provisional values of the content of foliar magnesium (g per kg dry matter) for the estimation of Mg-deficiency in the leaves in the period from early August to mid September (4,8,9).

Tree species	Mg-Supply			
	Too low	Low	Normal	Optimal
Acer campestre	< 0.8	0.8 - 1.2	1.3 - 2.2	> 2.2
Acer negundo	< 0.6	0.6 - 1.2	1.3 - 2.2	> 2.2
Acer platanoides	< 0.8	0.8 - 1.6	1.7 - 2.7	> 2.7
Acer pseudoplatanus	< 0.8	0.8 - 1.6	1.7 - 2.7	> 2.7
Acer saccharinum	< 0.7	0.7 - 1.4	1.5 - 2.7	> 2.7
Aesculus hippocastanum	< 0.7	0.7 - 1.1	1.2 - 2.7	> 2.7
Alnus glutinosa	< 1.3	1.3 - 1.6	1.7 - 2.5	> 2.5
Alnus incana	< 1.1	1.1 - 1.5	1.6 - 2.5	> 2.5
Betula pendula	< 1.0	1.0 - 1.3	1.4 - 1.6	> 1.6
Carpinus betulus	< 0.8	0.8 - 1.2	1.3 - 2.7	> 2.7
Corylus avellana	< 0.9	0.9 - 1.8	1.9 - 2.5	> 2.5
Corylus colurna	< 1.2	1.2 - 1.6	1.7 - 3.0	> 3.0
Crataegus laevigata	< 0.8	0.8 - 1.4	1.5 - 2.2	> 2.2
Crataegus monogyna	< 0.8	0.8 - 1.4	1.5 - 2.2	> 2.2
Fagus sylvatica	< 1.0	1.0 - 1.5	1.6 - 2.3	> 2.3
Fraxinus excelsior	< 0.9	0.9 - 1.6	1.7 - 2.8	> 2.8
Gleditsia triacanthos	< 0.8	0.8 - 1.4	1.5 - 2.5	> 2.5
Juglans nigra	< 1.0	1.0 - 2.0	2.1 - 3.0	> 3.0
Juglans regia	< 1.2	1.2 - 1.8	1.9 - 3.5	> 3.5
Liquidambar styraciflua	< 0.7	0.7 - 1.2	1.3 - 2.8	> 2.8
Liriodendron tulipifera	< 1.0	1.0 - 1.8	1.9 - 3.0	> 3.0
Malus domestica (*)	< 1.0	1.0 - 2.0	2.1 - 3.0	> 3.0
Platanus x acerifolia	< 0.8	0.8 - 1.4	1.5 - 2.6	> 2.6
Populus alba (*)	< 0.8	0.8 - 1.4	1.5 - 2.5	> 2.5
Populus x canescens (*)	< 0.8	0.8 - 1.4	1.5 - 2.5	> 2.5
P. x euramericana (*)	< 1.2	1.2 - 1.7	1.8 - 2.8	> 2.8
Populus nigra (*)	< 1.0	1.0 - 1.8	1.9 - 2.8	> 2.8
Populus tremula	< 0.8	0.8 - 1.4	1.5 - 1.7	> 1.7
Prunus avium (**)	< 1.2	1.2 - 1.5	1.6 - 2.6	> 2.6
Prunus cerasus	< 1.2	1.2 - 1.5	1.6 - 2.6	> 2.6
Prunus domestica	< 1.2	1.2 - 1.8	1.9 - 2.5	> 2.5
Pyrus communis (*)	< 1.2	1.2 - 1.8	1.9 - 2.8	> 2.8
Quercus palustris	< 0.9	0.9 - 1.5	1.6 - 2.8	> 2.
Quercus robur	< 1.3	1.3 - 1.5	1.6 - 2.8	> 2.8
Robinia pseudoacacia	< 1.0	1.0 - 1.5	1.6 - 2.2	> 2.2
Salix alba (*)	< 0.9	0.9 - 1.6	1.7 - 2.8	> 2.8
Salix triandra	< 0.9	0.9 - 1.6	1.7 - 3.0	> 3.0
Salix viminalis	< 1.0	1.0 - 1.6	1.7 - 3.0	> 3.0
Sorbus aria	< 0.8	0.8 - 1.4	1.5 - 2.2	> 2.2
Sorbus aucuparia	< 0.8	0.8 - 1.4	1.5 - 2.2	> 2.2
Tilia americana	< 1.0	1.0 - 1.5	1.6 - 3.0	> 3.0
Tilia cordata	< 0.8	0.8 - 1.1	1.1 - 2.4	> 2.4
Tilia x euchlora	< 0.8	0.8 - 1.1	1.2 - 2.4	> 2.4
Tilia platyphyllos	< 0.8	0.8 - 1.2	1.3 - 2.8	> 2.8
Tilia x vulgaris	< 0.8	0.8 - 1.2	1.3 - 2.8	> 2.8
Ulmus carpinifolia	< 0.9	0.9 - 1.6	1.7 - 2.7	> 2.7
Ulmus glabra	< 0.9	0.9 - 1.6	1.7 - 2.7	> 2.7
Ulmus x hollandica (*)	< 0.9	0.9 - 1.6	1.7 - 2.7	> 2.7

*: All cultivars

**: Provisionally, these criteria also apply to other species as those that are listed in the table.

Table 4: Critical values of the proportion of nutrition elements to N (= 100) in the leaves for the estimation of relative nutrient deficiency (with regard to N) for deciduous trees.

Element	Supply		
	Optimal	Sufficient	Insufficient
N	100	100	100
P	10-14	5-10	< 5
K	50-100	25-50	< 25
Mg	10	5-10	< 5

Table 5: Critical values of the cation-quotients in the leaves for the estimation of relative deficiencies of K (with regard to Ca) and Mg (with regard to K) for deciduous trees.

	Normal	Possible deficiency	Deficiency
K/Ca	3.5-1.0	0.5-1.0	> 0.5
K/Mg	1-- to 9	7 to 9-12	12-20

effect than desired. In these circumstances it is generally more useful to first correct the situation by providing sufficient drainage for the soil. Also, too much chloride in the leaves does not give an indication of how the chloride has reached the tree. To understand this, more should be known about the topography of the site, and other possible influences like proximity to the sea (wind, brackish ground water) or the presence of nearby traffic, etc.

In brief, the methods presented here have to be applied with skill, knowledge and common sense.

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Résumé. La connaissance accrue sur le statut nutritionnel d'arbres solitaires a permis le développement de l'analyse foliaire comme outil pour évaluer les dommages par le chlore et les déficiences d'éléments nutritifs. Des tables sur lesquelles on retrouve des données sur les niveaux des seuils par espèce d'arbre et par élément sont devenues disponibles pour la pratique courante. Dans cet article, les possibilités et les limites de l'analyse de sol, de l'analyse foliaire et de la recherche sur les propriétés physiques du sol, tel que la résistance à la pénétration, sont présentées et brièvement discutées avec une emphase mise sur leur emploi pratique dans les études de diagnostic sur les problèmes des arbres en milieu urbain.

Zusammenfassung. Zunehmende Kenntnisse über den Nährstoffhaushalt von Solitärbäumen hat zu der Entwicklung von Blattanalysen geführt, die als Werkzeug für die Beurteilung von Chlorschäden und Defizieten in der Nährstoffversorgung dienen. Tabellen, in welchen die Daten über die Schwellenwerte pro Baumart und die Elementenproportionen aufgefühert sind, sind für den praktischen Gebrauch erhältlich. In dieser Arbeit sind die Spannweite und die Einschränkungen der Bodenanalyse, Blattanalyse und der Forschung in physikalischen Bereichen des Bodens aufgezeigt und kurz diskutiert, mit besonderem Hinweis auf ihren praktischen Nutzen in Studien über Diagnose bie Stadtbaumprobleme.