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MANUAL

on

methods and criteria for harmonized sampling, assessment,
monitoring and analysis of the effects of air pollution on forests

Part XVI

Quality Assurance and Control in Laboratories

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1 Introduction

Chemical analyses are an essential part of monitoring activities related to observations and measurements of nutrients and pollutants fluxes in forest ecosystems. The value of data collected under the framework of the ICP Forests programme depends to a great extent on the quality of the analytical work carried out in supporting laboratories across Europe. To gain full comparability of the spatial and temporal variability in the data, every effort must be taken to ensure accuracy of the analytical measurements.

To that end, considerable efforts have been made over the last number of years to improve the quality of laboratory analyses in the various monitoring programmes within the framework of the ICP Forests programme. The Soil & Soil Solution, Deposition and Foliage & Litterfall expert panels and the Working Group on QA/QC in Laboratories have carried out a number of ring tests and held extensive discussions on harmonising analytical methodology, including the most appropriate quality control (QC) and quality assurance (QA) to be employed by participating laboratories. All ringtest results are stored in the PCC database and can be linked to the monitoring data. Presented quality assurance and control tools remain in line with the overall QA approach within the ICP Forests, as outlined in the Part III of the Manual.

2 Scope and application

This paper presents all the QC methods that have been devised for the relevant fields of analytical chemistry. The aim is to provide those laboratories carrying out analyses of deposition, soil solution, soil, foliage and litterfall within the ICP Forests programme with a complete overview of the QC options that can be applied in their laboratories.

The QA programme in each laboratory should be based on both: internal and external quality control. Among the range of internal control methods that can be employed, the use of reference materials is highly recommended (Chapter 3.1) as an extremely valuable tool to ensure accuracy of analytical results. Although the use of Certified Reference Materials can be limited by expense and availability in large quantities alternative Reference Materials, such as National or Local Reference Materials can be used on a routine basis to confirm the analytical methods accuracy and precision over time. The variation and the quality of the analytical results can be controlled with the use of control charts. The different types of control charts available, their construction and application are described in Chapter 3.2. The determination of the detection- and quantification limits is described in Chapter 3.3.

Analytical data must be validated prior to data submission to confirm the correctness of analyses and reduce the risk of errors. A wide range of data consistency checks are detailed depending on the type of matrix analysed (Chapter 3.4, 3.4.1-3.4.3), based on the relationship between the chemical components and/or chemical and physical properties of the samples.

Participation by laboratories in external inter-calibration exercises plays an integral role in the laboratory's QA programme (Chapter 3.5). Otherwise known as 'ring tests', they are carried out on a periodic basis and assess the performance of the participating laboratories as well as help to ensure the comparability of the data produced by different laboratories over time. Laboratories encountering difficulties with analytical methodology and/or associated QA/QC programmes are encouraged to take full advantage of the range of proposals contained within this document, which include the exchange of analytical expertise, and experiences between laboratories.

Evaluation of the quality performance of the participating laboratories within ICP Forests will be conducted through the use of quality indicators outlined in Chapter 3.6. Information gathered on the laboratories quality assurance processes/activities will be linked via quality reports with the submission of data to ICP Forests each year (see Chapter 3.7).

3 Quality assurance and control tools

3.1 Reference materials

Within the ICP Forests programme the use of control charts for each variable and matrix is mandatory. In order to produce these control charts, a reference material is necessary.

There are two types of reference material:

- 1 Reference Materials (RM): a material, sufficiently homogeneous and stable with respect to one or more specified properties, which has been established to be used in a measurement process: for the calibration of a measurement system, the assessment of a measurement procedure, for assigning values to materials, and quality control (ISO Guide 30, 2015)
- 2 Certified Reference Materials (CRM): reference material, characterized by a metrologically valid procedure for one or more specified properties, accompanied by a certificate that provides the value of the specified property, its associated uncertainty, and a statement of metrological traceability. (ISO Guide 30, 2015). The CRM can be of national or international origin. A list of commercially available CRMs is given in Annex I.4.

Reference materials are available in a range of types and prices. CRMs are expensive and should be used only when really needed: e.g. calibration, method validation, measurement verification, evaluating measurement uncertainty, and for training purposes. In many cases, however, the concentrations are not within the ranges encountered in daily practice. National Reference Materials are, in many cases, easier to acquire and are often not as expensive as CRMs. They are usually issued by national laboratories, and are extremely useful for ensuring laboratory quality within a country.

Furthermore, laboratories must use matrix-matched control samples of demonstrated stability to demonstrate internal consistency over time, e.g. through control charts. The analyte concentrations of these samples do not need to be accurately known or traceable. However, traceability would be a bonus. Here, again, CRMs or ring test samples can be used.

The Local Reference Materials (LRMs) are prepared by the laboratory itself for routine use and can be easily and cheaply prepared in large quantities. They can often also be prepared within the concentration ranges for the more important parameters. These LRMs are extremely important for QA/QC activities, mainly for use in **control charts** (see Chapter 3.2), if there is a need to maintain a constant (stable) quality over a long-time scale.

The following reference materials can be used in each field of interest:

3.1.1 Reference material for water analysis (deposition and soil solution)

One common approach is to use natural samples that are preserved with stabilising agents (e.g. low chloroform concentrations), after first ensuring that their use does not cause interferences in the analytical methods or has an adverse effect on other activities performed in the laboratory. The use of natural samples makes it possible to have concentrations close to those normally measured. It is advisable to use two standards for each type of analysis,

one of medium-low and one of medium-high concentrations, in relation to the range normally analysed. The stability of LRMs should be tested; their stability for individual ion species may vary.

One very cheap method for preparing an LRM is to buy mineral water that has chemical characteristics close to the range normally measured. Before you can use an LRM, however, you first have to validate your method with a CRM. You should run your LRM together with the CRM or a ring test sample so as to determine the conventional true value.

For deposition samples, mineral water derived from volcanic bedrock has very similar concentrations. For soil solution samples, a specific type of mineral water has to be selected in accordance with the prevailing soil types in the monitoring network. The advantage of using mineral water is that they are relatively stable over time as long as the bottles of the same batch are stored in a dark place. However, mineral water does not contain dissolved organic carbon (DOC) in a form similar to that occurring in either deposition or soil solution samples.

3.1.2 Reference material for foliar and litterfall analysis

The matrix properties and the analyte concentrations of the reference material should be similar to those of the samples from the regional/national network. As there is only a limited number of certified forest-tree foliage reference material available worldwide, agricultural plant material with similar matrix and analyte concentrations, e.g. flour, hay, cabbage, olive leaves, apple leaves, can be used as an acceptable substitute. However, check the analyte concentrations before placing the order. (A list of commercially available CRM's is given in Annex 5.3).

“Old” foliage ring test samples are also stable enough and extensively analysed for use as reference material in method validation.

One good cheap method for producing a high quality LRM is to prepare foliage material for use as a ring test sample. In the ring tests, the Forest Foliar Co-ordinating Centre (FFCC) always utilises dried, powdered foliage samples from one type of tree (leaves/needles) or a homogenized litterfall sample (one litterfall fraction). Therefore, the laboratory should initially separate the needles (one needle set)/leaves from the branches and dry, mill and pre-homogenise the material (dry weight min. 4-5 kg) prior to dispatch to the FFCC (<http://www.ffcc.at/>)

The FFCC homogenizes the sample again, divides it up and uses it in one of the subsequent ring tests. The advantage for the laboratory is in having a large amount of reference material with a similar element concentration as their normal samples and known accuracy of the mean concentration.

3.1.3 Reference material for soil analysis

Soil samples of former I ring tests are stable enough and extensively analysed for use as reference material in method validation. The FSCC (Forest Soil Co-ordination Centre) and the Croatian Forest Research Institute CFRI) always utilises dried, milled/sieved samples from different soil type (different ranges in CaCO₃ content and OC content) for the ring test program (see Annex 1.3: list of commercially available reference materials).

3.1.3.1 Preparation of local reference material for soils

Due to the type of soil samples and the nature of the two-step analysis, LRM samples are needed for both the solid phase (to control the quality of digestion) and the liquid phase (to control the quality of the chemical analyses).

- Solid phase:

Take several large (10 to 50 kg) samples from one site (organic and mineral, preferably by genetic horizon). Dry all the sampled material and homogenise the samples several times to ensure a uniform homogeneous sample. Split or riffle each sample into several parts and store in a cool, dry place. It may be worthwhile preparing several sets of the individual soil types and concentration ranges occurring in the country (e.g. one for clay soils in the coastal area with high sea salt concentrations, and one for sandy soil from an inland site).

- Liquid phase:

After digestion of larger amounts of the solid phase LRM, store the solution (liquid phase) in a cool, dark place.

In general, no control with high analyte concentrations is necessary because the errors are normally associated with lower concentrations. Solutions with excessively high concentrations often have to be diluted in order to fit within the ranges for which the analysers have been calibrated.

The amount of LRM has to be large enough to be used for an extended period of time (preferably up to one year). The amount needed annually will depend on the type of analytical equipment and methods used by the laboratory. The sample should be stored in such a way that no or minimal changes occur over time.

3.1.3.2 Calibration of local reference material for soils

After the preparation of the LRM, a test run has to be performed with correctly calibrated equipment. A number of replicates (e.g. 5 for the solid and 30 for the liquid phase) have to be analysed for all relevant parameters, and at least one (but preferably more) national or international reference samples. The absolute accuracy is determined for each parameter on the latter samples. The standard deviation (SD) calculated from the results of analysis of the LRM should be as small as possible. The results of the first test run should be treated according to the ISO standard 7870-2 (2013, Control charts - Shewhart control charts). The mean value of the parameters for the LRM is of less importance, but it should be within the same range as the values of the samples that will be subsequently analysed.

Each parameter now has its own SD, which allows evaluation of the parameters and the relevance of the analysis by the method in question. If the SD is significantly larger than the expected values, then the relevance of analysing the parameter by the selected method is low. Other methods/equipment may have to be used to analyse the parameter within an acceptable range.

This procedure should be repeated whenever equipment is changed, important components are replaced, or when temporal trends appear in the results. The absolute values obtained from the national and international reference material are extremely importance in the former case.

3.1.3.3 Use of local reference material for soils

After successful calibration, a systematic re-analysis of the LRM (liquid phase) is included in every batch or series of samples. Depending on the number of samples to be analysed and the methods and equipment used, this could be in the range of one LRM per 10 to 30 real samples to be analysed. For the solid phase (digestion and analysis) this could be reduced to one LRM per 30 to 50 samples to be analysed.

The results of the repeated analysis of the LRM permit evaluation of the stability of the method/equipment over time. Therefore, it is strongly recommended to plot on a graph the LRM result of every analysis over time (see ISO 7870-2, 2013 and Chapter 3.2).

3.2 Control charts

Within the ICP Forests programme the use of control charts for each parameter and matrix is mandatory.

Control charts form an important practical aspect of internal QC in the laboratory. Using reference materials (see Chapter 3.1) the quality of the method can be checked immediately, while control charts are a useful tool for checking the quality and the variation in quality over a longer time scale. The laboratory runs control samples together with the real samples in an analytical batch and, immediately after the run is completed, the control values are plotted on a control chart. There are various types of control chart available (for details see the ISO 7870-2, 2013). The most commonly used control charts are the **mean charts** and **range charts** for laboratory control standards, and the **blank charts** for background or reagent blank results.

In addition, the control charts can be used for calibration, method validation and comparison, estimation of measurement uncertainty and limit of detection, checking the drift of equipment, comparison or qualification of laboratory personnel, and evaluation of proficiency tests.

For more information about the use of control charts see Nordtest report TR 569, 2012.

3.2.1 Mean Charts (X-Charts)

The main aim of the means chart is to check the repeatability of the measurements in every batch of analyses. It is constructed from the average and standard deviations of a standard, determined from a solution of one or more analyte(s), or a natural sample, that is sufficiently stabilised to keep the concentrations constant over time for at least 2-4 months. In the case of deposition samples, the choice of preservative (e.g. inorganic acids or chloroform) is determined by the analyte of interest and the conditions under which the analyses are carried out. It is advisable to use more than one control chart, at different concentration levels for each analyte.

The means chart is prepared on the basis of the first 20 to 25 measurements used to calculate the mean concentration (X_m) and the standard deviation (s). These variables are used to evaluate the upper and lower warning levels (UWL, LWL) and the upper and lower control levels (UCL, LCL). It is a common practice to use $\pm 2s$ and $\pm 3s$ limits for the warning limit (WL) and control limit (CL), respectively (Figure 1). For variables with a non-normal distribution, transformation to a normal distribution may be necessary.

Assuming that s is correctly estimated, 95% of the measurements should fall within the range of $X_m \pm 2s$ (WL) and 99% in the range of $X_m \pm 3s$ (CL). In long-term routine analyses, on the other hand, UWL and LWL may be chosen by the analyst on the basis of experience with previous control charts or according to specific goals that are to be reached in the analyses.

The means chart can also incorporate a target or nominal value of the analyte in the case of reference material with the reported concentration. The target control limits may also be used, and the laboratory results then be compared with these values.

If measurement uncertainty is determined for an analyte as a part of method validation, this value can be added to a means chart. Measurement uncertainty limits in the chart should lie between the warning and control limits ($2s$ and $3s$), in most case nearer the warning limit. The results of a control sample should not exceed the measurement uncertainty limits and, in the case of a synthetic control sample, they should remain between these limits. A target or nominal value can also be used with the measurement uncertainty limits. Because measurement uncertainty is proportional to the concentration of the analyte, different measurement uncertainty limits should be used for different control charts of the same analyte. With this type of x-chart it is possible to check that the set measurement uncertainty is achievable in the course of time.

Every batch of analyses should include one or more measurements of the standard for the control chart. This measurement is plotted on the control chart: if a measurement exceeds the CL, the analysis must be repeated immediately. If the repeat is within the CL, then the analysis can be continued; if it exceeds the CL, the analysis should be stopped and the problem rectified. In regard to the WL: if two out of three successive points exceed the WL, then an additional standard should be analysed. If the concentration is less than the WL, the analysis can be continued; if it exceeds the WL, then the analysis should be stopped and the problem rectified.

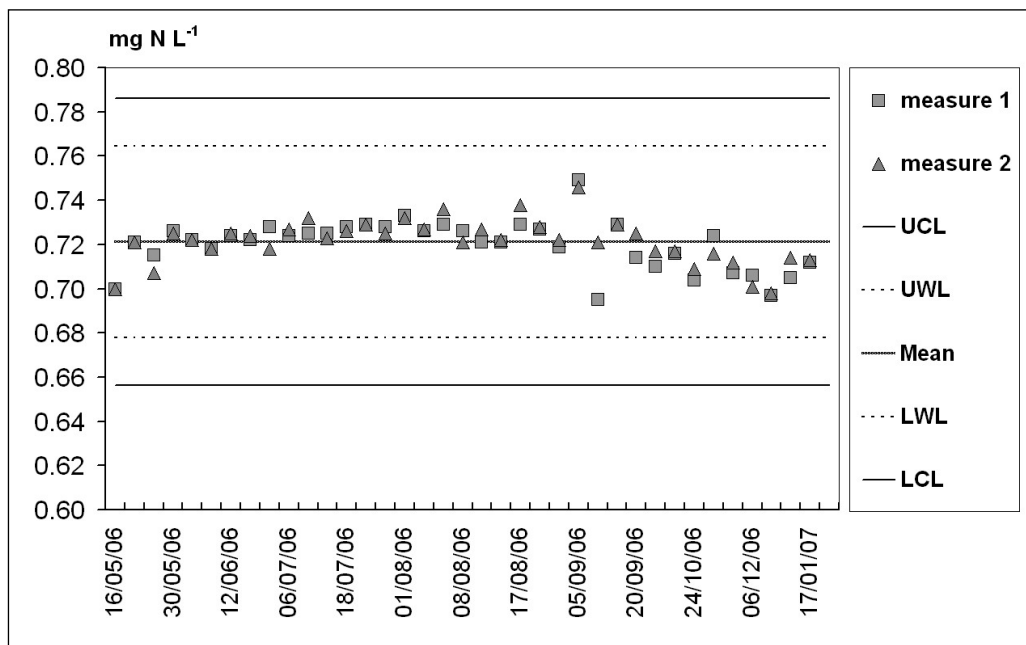


Figure 1: Example of a control chart using mean concentrations. Mean concentration, LWL, UWL lower, upper warning limit; LCL, UCL lower, upper control limit, calculated on the basis of experience with previous control charts (R.S.D. = 3 %)

3.2.2 Range Charts (R-Charts)

The difference between two (or more) determinations on the same sample can also be described on a graph. This R chart is used for checking the repeatability of the analysis, usually of duplicate determinations. As the range is normally proportional to the sample concentration, it will therefore be more appropriate to use a control chart where the control value is the relative range r %.

3.2.3 Blank Charts

A blank is defined as a solution of the purest available water that contains all the reagents used for the analysis, but not the analyte. The solution should be subjected to all the steps of the analysis (filtration, digestion, addition of reagents) up until the final measurement. The blank signal then indicates the sum of the analyte released in the different phases of the process, and a check must be made in order to exclude the possibility of occasional contamination. An example of a blank chart is shown in Figure 2. The chart makes it possible to compare the blank values obtained in different batches of analyses at different times; an abnormally high blank value indicates the presence of contaminants at some stage of the process. The upper limit of acceptance is chosen by the analyst, either based on a previous set of analyses (e.g. two times the mean values of the blank absorbance) or on the dispersion of values around the mean.

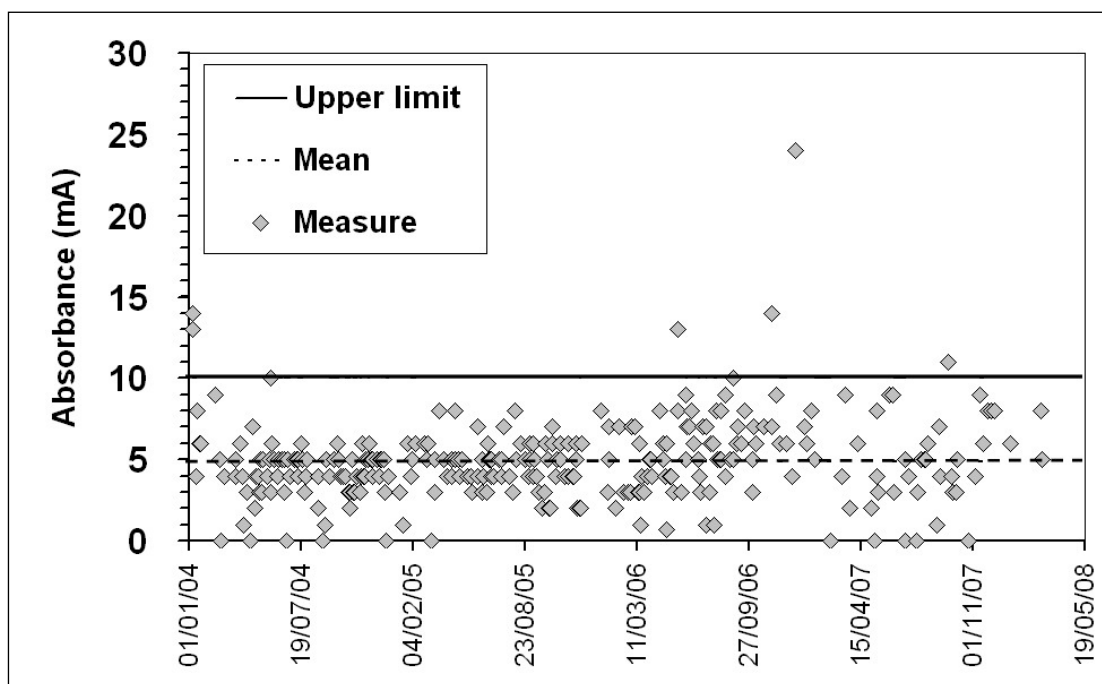


Figure 2: Example of a blank chart

The standard deviation (s_b) of the blanks makes it possible to determine the detection limit (LOD) and the quantification limit (LOQ) of the analytical method. The LOD in most instrumental methods is based on the relationship between the gross analyte signal S_t , the field blank S_b , and the variability in the field blank (s_b). The limit of detection and quantification may be defined by the extent to which the gross signal exceeds S_b :

$$\text{LOD} = S_t - S_b \geq K_d s_b$$

$$\text{LOQ} = S_t - S_b \geq K_q s_b$$

Recommended values for K_d and K_q are 3 and 10, respectively (Analytical Methods Committee, 1987, Currie, L.A. 1999a).

3.3 Detection and quantification limits

Detection and quantification capabilities are fundamental performance characteristics of any chemical measurement process (Currie, 1999b). For each matrix (soil, water, foliage) and each analytical method, the limit of detection (LOD) and quantification (LOQ) should be determined by each laboratory.

The limit of detection (LOD) is the smallest measure, x_L , that can be detected with reasonable certainty for a given analytical procedure.

The value of x_L is given by the equation:

$$x_L = x_{bi} + Ks_{bi}$$

where x_{bi} is the mean of n blank measurements, s_{bi} is the standard deviation of n blank measurements, and K is a numerical factor chosen according to the confidence level desired (IUPAC, 1997). For LOD, this K factor is commonly set at 3 (see also K_d in Chapter 3.2.3). The LOD is the concentration at which we can decide whether an element is present or not. It is the point where we can just distinguish a signal from the background (Thomsen et al., 2003).

It is recommended that the number of blank measurements (n) is higher than 30, preferably determined under within-lab reproducibility conditions (e.g. different operators, different runs on different days).

The limit of quantification (LOQ), also referred to as the quantitation limit, is generally agreed to begin at a concentration equal to 10 standard deviations of the blank ($K_q = 10$). Therefore, LOQ is 3.3 times LOD. Quantitatively, the relative standard deviation (RSD) of repeated measures is 10% at the LOQ, and 33% at the LOD (Thomsen et al., 2003). This is in fact a statistical simplification of the uncertainty problem near the lower measurements limits, as explained by Currie (1999a), but in practice it is a useful approximation.

Table 1: IUPAC recommendations for uncertainty associated with limits of detection and quantification (after Thomsen et al., 2003).

		Absolute SD	Relative SD
Limit of detection	LOD	3σ	33%
Limit of quantification	LOQ	10σ	10%

Similar results can also be obtained using the standard deviation of the signal of the lowest calibration standard, instead of the standard deviation of the signal of blank samples. This method should be used in particular when the signal of blank samples is very low, as in the case of ion chromatography. A further possibility is the use of the Hubaux-Vox method for calculating LOD from the error associated to the calibration regression.

A distinction should be made between instrument detection/quantification limits and method (or matrix) detection limits. Generally, instrument detection limits (IDLs) are based on a clean matrix. Method/matrix detection limits (MDL) consider real-life matrices such as soil, organic matter and rainwater. Spectroscopists commonly accept that the MDL can be anywhere from about two to five times greater than the IDL.

Therefore, labs should clearly mention whether the reported limits are instrument or matrix detection limits. In the case of environmental research, MDLs are more meaningful than IDLs.

Measurement precision and concentration (or content) are often clearly related, as shown in Figure 3. Generally, as the concentration or content of the analyte decreases, the precision for determination, as expressed in the relative standard deviation increases. When empirically precision data are gathered for each concentration or content level, a graph may be constructed as in Figure 3. Each data point represents the RSD of 8 to 20 replicate measurements per level.

When a curve is fitted with a suitable equation (e.g. $y = a x^{-b}$), the limits of detection and quantification may be estimated from this equation by determining the limits at the RSD values of 30% and 10%, respectively. These limits are illustrated in Figure 3, whereby total N can be reliably determined in this example at concentrations above the LOQ, whereas determination becomes highly uncertain between the LOD and LOQ. The curve can be constructed using the standard deviation obtained from control charts at different concentration. When the matrix effect is negligible, the standard deviation of the signal of the calibration standards can also be used.

An example of application of the LOD and LOQ estimation method for the determination of carbon by the Walkley-Black method in forest soils can be found in De Vos et al. (2007).

This empirical method is time-consuming and laborious. However, it immediately shows the matrix detection and quantification limits for real-life samples under specific laboratory conditions.

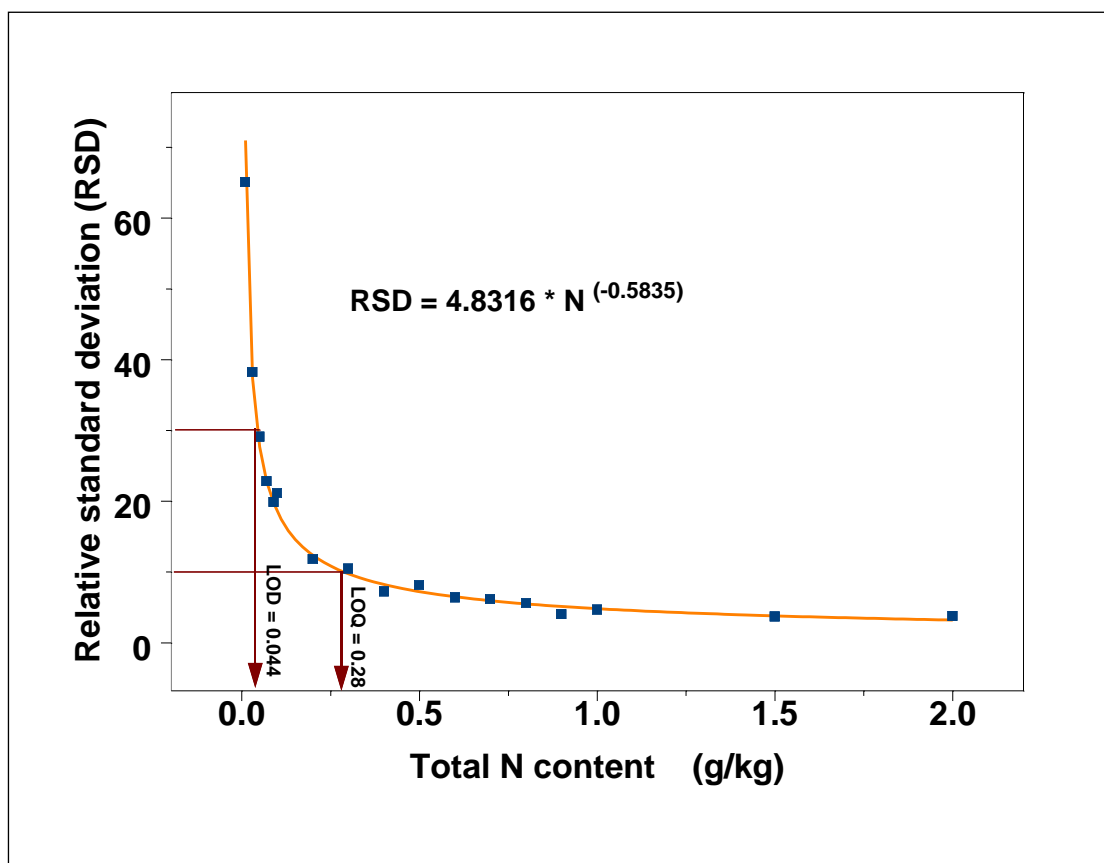


Figure 3: Relationship between measurement precision (RSD) and N concentration in a test mineral soil sample

3.4 Checking analytical data

These checks should help the laboratory to detect possible wrong results. So it can be needed to repeat the analysis once more and correct or confirm the result.

3.4.1 Checking results of water samples

The analytes present in deposition and soil water samples and in soil extracts are mainly in ionic form. This enables the use of at least two checks on the consistency of the analysis results obtained for individual samples: i.e. the calculation of the ion balance, and comparison of the measured conductivity with the conductivity calculated from the sum of each ion. A third consistency test, which is only valid for deposition samples, employs the ratio between the Na^+ and Cl^- concentrations, which should normally be relatively close to the value in seawater. A fourth check, aimed at identifying analytical errors, is based on the relationship between the different forms of nitrogen analysed. Other statistical procedures that employ the relationship between the equivalent sum of ions (cations, anions) and conductivity can be applied to the datasets. These are based on the relative similarity of the ratio between certain ions in deposition samples, due to their common origin (e.g. Na^+ and Cl^- from sea spray, SO_4^{2-} and NO_3^- from combustion processes, Ca^{++} and alkalinity from soil dust). However, these methods require a relatively large set of data for the same type of precipitation before they can be applied to the results of single analyses in order to identify outlier values.

Examples of the application of these checks on sets of data from different sites in Europe have been reported by Mosello et al. (2005, 2008).

Most of the calculations needed to use the validation check, starting from concentration values, can be simplified by using a worksheet file similar to the one given on the ICP Forests web site (<https://www.icp-forests.net/about-us/experts-committees/committees/working-group-on-quality-assurance-and-quality-control-in-laboratories/soil-ringtest-and-qa/qc-information>; see also Chapter 5.1).

3.4.1.1 Ion balance

3.4.1.1.1 Ion balance without DOC

Each laboratory performs checks on the chemical analyses by calculating the ion balance (for bulk open field and wet only deposition) and comparing the measured and calculated conductivity (for bulk open field [BOF] and wet only deposition, throughfall [THF] and stemflow [STF]) values in order to validate the results. However, these checks are not always applicable to soil water samples due to the presence of aluminium and other metals as various ionic species, especially at a pH < 5 (see Chapter 3.4.1.1.3).

If the threshold values of these checks are exceeded, then the analyses must be repeated. If the result is confirmed but the threshold values are still exceeded, then the results must be accepted.

The ion balance is based on the equivalent concentration of anions vs. the concentration of cations ($\Sigma \text{ Cat}$ vs. $\Sigma \text{ An}$):

$$\begin{aligned}\Sigma \text{ Cat} &= [\text{Ca}^{++}] + [\text{Mg}^{++}] + [\text{Na}^+] + [\text{K}^+] + [\text{NH}_4^+] + [\text{H}^+] \\ \Sigma \text{ An} &= [\text{HCO}_3^-] + [\text{SO}_4^{--}] + [\text{NO}_3^-] + [\text{Cl}^-] + [\text{Org}^-]\end{aligned}$$

The contribution of fluoride to the ionic balance is normally insignificant.

The limit of acceptable errors varies according to the total ionic concentration and the type of solution. The percentage difference (PD) is defined as:

$$\text{PD} = 100 * (\Sigma \text{ Cat} - \Sigma \text{ An}) / (0.5 * (\Sigma \text{ Cat} + \Sigma \text{ An}))$$

The limits adopted in the ICP Forests/EU Forest Focus programmes are given in Table 2.

Table 2: Acceptance threshold values in data validation based on ion balance and conductivity (see definition of CD [the percentage difference between measured and calculated conductivity] in Chapter 3.3.1.2)

Conductivity (25 °C)	PD	CD
<10 $\mu\text{S cm}^{-1}$	$\pm 20\%$	$\pm 30\%$
<20 $\mu\text{S cm}^{-1}$	$\pm 20\%$	$\pm 20\%$
>20 $\mu\text{S cm}^{-1}$	$\pm 10\%$	$\pm 10\%$

The conversion factors required to transform the units used in the ICP Forests Manual Part XIV (Deposition) into $\mu\text{eq L}^{-1}$ are given in Table 3.

Table 3: The conversion factors used in converting the concentrations used in the ICP Forests Deposition Monitoring Programme to $\mu\text{eq L}^{-1}$, and the values of equivalent ionic conductivity at infinite dilution

	Unit (ICPF standard)	Conversion factor to $\mu\text{eq L}^{-1}$	Equivalent conductance at 20°C	Equivalent conductance at 25°C
			kS cm ² eq ⁻¹	kS cm ² eq ⁻¹
pH	Unit	10(6-pH)	0.3151	0.3500
Ammonium	mg N L ⁻¹	71.39	0.0670	0.0735
Calcium	mg L ⁻¹	49.9	0.0543	0.0595
Magnesium	mg L ⁻¹	82.24	0.0486	0.0531
Sodium	mg L ⁻¹	43.48	0.0459	0.0501
Potassium	mg L ⁻¹	25.28	0.0670	0.0735
Alkalinity	$\mu\text{eq L}^{-1}$	1	0.0394	0.0445
Sulphate	mg S L ⁻¹	62.37	0.0712	0.0800
Nitrate	mg N L ⁻¹	71.39	0.0636	0.0714
Chloride	mg L ⁻¹	28.2	0.0680	0.0764

Bicarbonate is calculated from total alkalinity (Gran's alkalinity) in relation to pH, assuming that total alkalinity is determined only by inorganic carbon species, protons and hydroxide:

$$\text{TAlk} = -[\text{H}^+] + [\text{OH}^-] + [\text{HCO}_3^-] + [\text{CO}_3^{2-}]$$

This definition is not completely correct in the case of high organic carbon concentrations ($\text{DOC} > 5 \text{ mg C L}^{-1}$), and in the presence of metals (Al, Fe, Mn etc.) that may contribute to alkalinity or to the cation concentrations (see Chapters 3.4.1.1.2 and 3.4.1.1.3). This sets limits on the use of the ion balance check in validating the analyses for certain types of solution, as summarised in Table 4.

Table 4: Applicability of the validation tests for different types of solution

	Ion balance	Ion balance DOC corrected	Conductivity	Na/Cl ratio	N test
Bulk open field	Y	Y	Y	Y	Y
Wet only	Y	Y	Y	Y	Y
Throughfall	N(3)	Y	Y	Y	Y
Stemflow	N(3)	Y	Y	Y	Y
Soil water	N(3)	N(4)	Y(2)	N	Y
Surface water	Y(1)	Y	Y	N	Y

(1) If $\text{DOC} < 5 \text{ mg C L}^{-1}$ and negligible metal concentrations

(2) If metal concentrations are negligible.

(3) see chapter 3.4.1.1.2

(4) see chapter 3.4.1.1.3

Examples of comparisons between ΣCat and ΣAn are given in Figure 4 for different types of solution. The departure from zero of the ion balance for different types of deposition sample is shown, illustrating the failure of the check in the case of Throughfall (THR) and Stemflow (STF) samples.

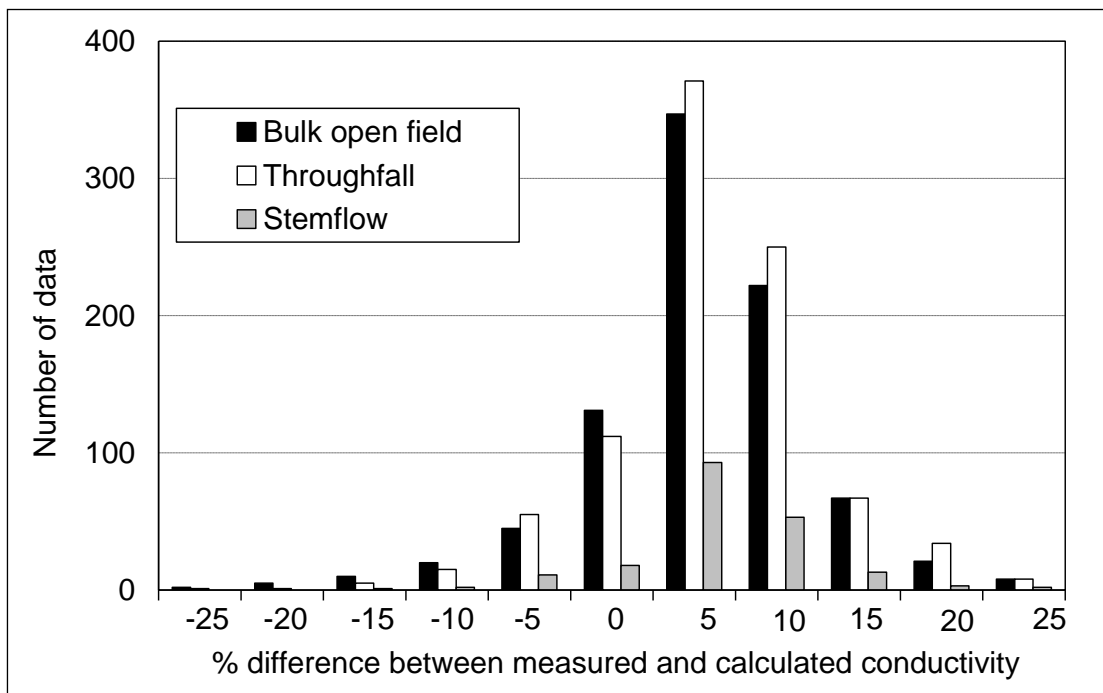
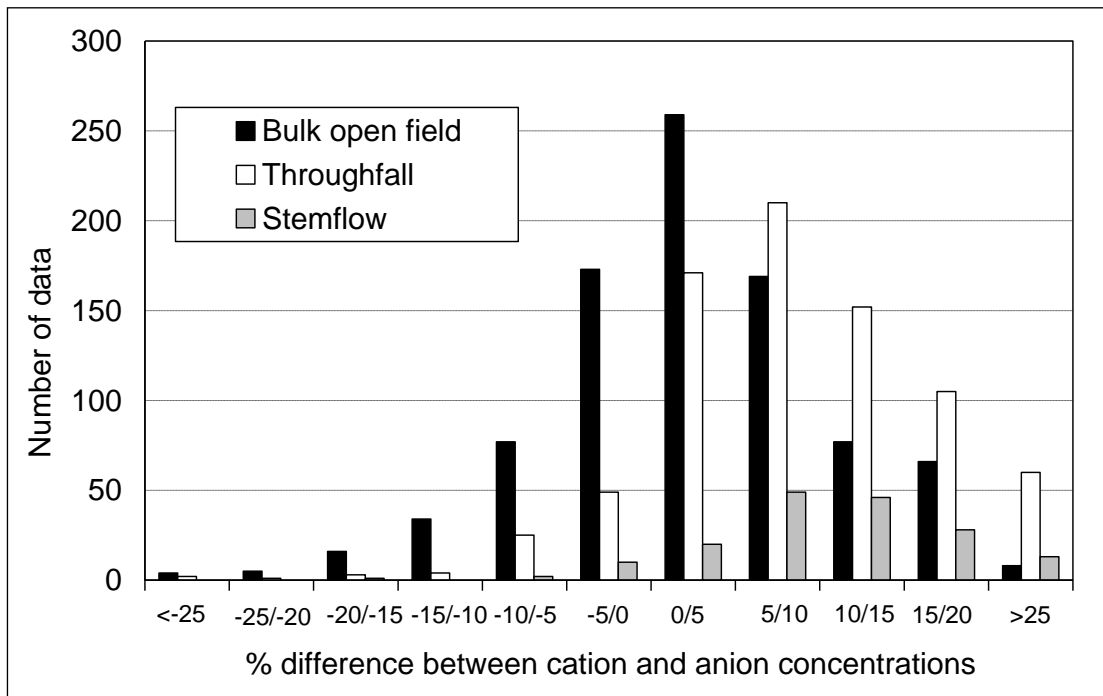


Figure 4: Departure from zeron of the percentage difference between Σ Cat and Σ An (PD) (above), and (below) of the percentage difference between measured and calculated conductivity (CD) for different types of deposition sample

3.4.1.1.2 Ion balance with DOC

Figure 4 clearly illustrates the failure of the ion balance check in the case of THR and STF samples. This is also the case for soil water samples (not shown in figure) in which, in addition to high DOC concentrations, elevated concentrations of metals may also be present (see Chapter 3.4.1.1.3).

The ion balance test can be used to evaluate the ionic contribution of DOC (all solutions are filtered through 0.45 µm membrane filters before analysis) (Mosello et al., 2008). This study was carried out as part of the activities of the WG on QA/QC in laboratories regularly performing the chemical analysis of deposition and soil water samples within the framework of the ICP Forests and the EU/Forest Focus Programmes. About 6000 chemical analyses of bulk open field, throughfall and stemflow samples, which contained complete sets of all ion concentrations, alkalinity, conductivity and DOC, carried out in 8 different laboratories, were used to calculate empirical relationships between DOC and the difference between the sum of cations and the sum of anions. The aim was to determine the formal charge per mg of organic C. The samples covered a wide range of geographical and climatic conditions, as well as variables such as the proximity of the sea (chloride concentration) and the type of vegetation for THR and STF.

Regression coefficients were obtained for the data sets from each laboratory, as well as for all the data combined, as follows:

$$\Sigma \text{Cat} - \Sigma \text{An} = \delta_1 \text{DOC} + \delta_0$$

where the units are µeq L⁻¹ for the sum of ions and δ₀, mg C L⁻¹ for DOC, and µeq (mg C)⁻¹ for δ₁. The regressions were not significant for BOF, because of the relatively high error associated with the low DOC concentrations. In contrast, the regressions were statistically highly significant for THR and STF in all the 8 laboratories.

In the next step, the charge contribution of DOC was determined as:

$$[\text{Org}^-] = \beta_1 * \text{DOC} + \beta_0$$

where [Org⁻] (µeq L⁻¹) is the ionic contribution of DOC. The value of PD was calculated again using the Σ An value including [Org⁻], and evaluated using the threshold values given in Table 2.

An example of the regression coefficients, β₁ and β₀, as well as the appropriate statistical parameters, is given in Table 5. The coefficients were further tested using an independent set of data from each laboratory. Comparison of the differences between the individual laboratories and the overall regression coefficients showed that the coefficients were generally applicable for deposition samples, and also suitable for estimating the contribution of organic acids in the ion balance test. This means a considerable improvement in the applicability of the ion balance as a validation criterion for samples with high DOC concentrations. The improvement in the ion balance check in an example data set is shown in Figure 5. This evaluation can also be found in the annexed Excel file (downloadable from: <https://www.icp-forests.net/about-us/experts-committees/committees/working-group-on-quality-assurance-and-quality-control-in-laboratories/soil-ringtest-and-qa/qc-information>), which contains examples of analysis validation.

Table 5: Statistical parameters of the regression equations for determining the DOC contribution to the ion balance. THR = throughfall, STF = stemflow, N = number of samples, σ = standard deviation.

	Units	Broadleaves		Conifers
		THR	STF	THR
N	-	1454	597	1657
pH range	U	4.0 - 7.9	3.8 - 8.1	4.1 – 7.0
pH mean \pm σ	U	5.8 \pm 0.6	5.6 \pm 0.6	5.3 \pm 0.5
DOC range	Mg C L-1	0-37	1-39	0-40
DOC mean \pm σ	Mg C L-1	8 \pm 6	11 \pm 7	10 \pm 7
Σ Cat range	μ eq L-1	37-2736	30-5287	13-2601
Σ Cat mean \pm σ	μ eq L-1	418 \pm 321	593 \pm 539	316 \pm 278
Σ An range	μ eq L-1	29-2606	22-5303	10-2584
Σ An mean \pm σ	μ eq L-1	377 \pm 304	545 \pm 523	279 \pm 265
Σ Cat - Σ An range	μ eq L-1	258	263	225
Σ Cat - Σ An mean \pm σ	μ eq L-1	41 \pm 59	48 \pm 58	37 \pm 41
Slope β_1	μ eq (mg C)-1	6.8 \pm 0,16	5.04 \pm 0.25	4.17 \pm 0.11
Intercept β_0	μ eq L-1	-12.32 \pm 1,63	-6.67 \pm 3.29	-5.01 \pm 1.32
P-value		<0.0001	<0.0001	<0,0001
R2		0.56	0.4	0.47

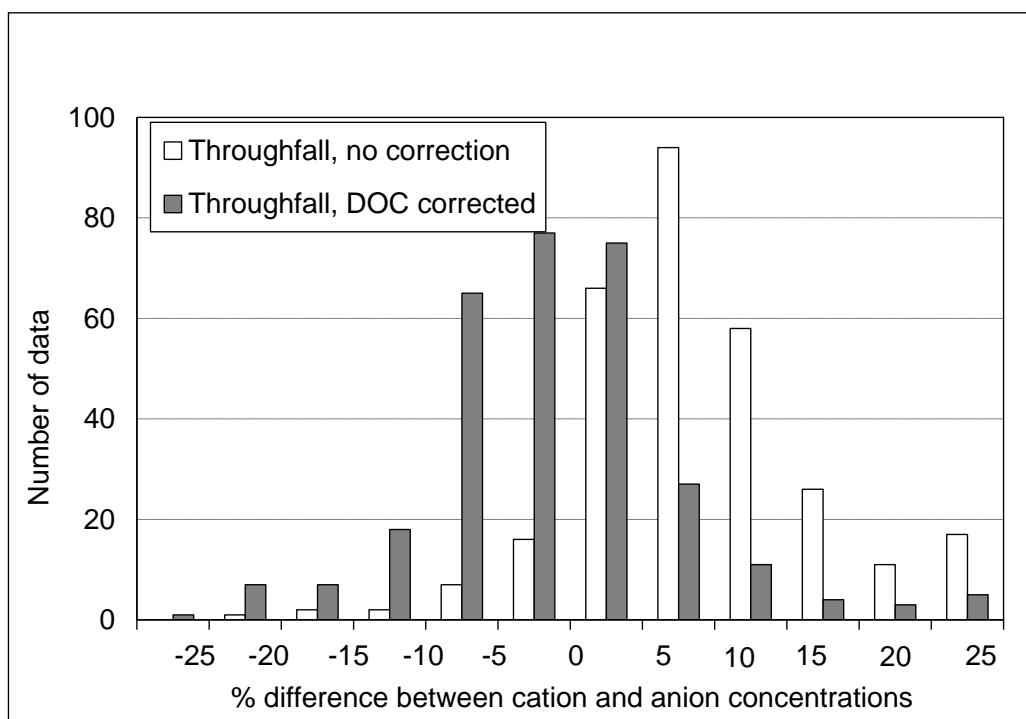


Figure 5: Departure from zero of the percentage difference between Σ Cat and Σ An (PD, see text) without and with DOC correction

3.4.1.1.3 Ion balance with DOC and metals

The ion balance for soil water samples is more complicated owing to the presence of metals (e.g. Al, Fe, Mn), their species (e.g. Al^{3+} , $\text{Al}(\text{OH})^{2+}$, $\text{Al}(\text{OH})_2^+$, Fe^{3+} , $\text{Fe}(\text{OH})^{2+}$, $\text{Fe}(\text{OH})_2^+$), their oxidation state (e.g. $\text{Fe}^{3+}/\text{Fe}^{2+}$; iron complexed with organic matter can occur in both oxidised and reduced forms and the reduced forms can exist under oxidising conditions when complexed with organic matter; see e.g. Clarke and Danielsson, 1995) and metal complexes with DOC (e.g. DOC-Fe, DOC-Al, DOC-Mn) in the solution.

The calculation of bicarbonate from total alkalinity (see Chapter 3.4.1.1.1) is not completely correct because it is influenced by the different species of DOC in the solution.

Therefore calculation of the formal charge per mg of organic C from the difference between the sum of cations and the sum of anions, as described in Chapter 3.4.1.1.2 for throughfall samples, also has to take into account the metals, their species and their complexes with DOC:

$$\begin{aligned} \Sigma \text{Cat} + \Sigma \text{Met (all inorg. species)} + \Sigma \text{Met (from DOC complexes)} \\ = \Sigma \text{An} + \Sigma \text{Org}^- \text{ (from DOC complexes)} \end{aligned}$$

where:

$\Sigma \text{Met} = \text{Al}^{3+} + \text{Al}(\text{OH})^{2+} + \text{Al}(\text{OH})_2^+ + \text{Fe}^{3+} + \text{Fe}(\text{OH})^{2+} + \text{Fe}(\text{OH})_2^+ + \text{Mn}^{2+} + \text{Mn}(\text{OH})^+$ (and other inorg. species)

$\Sigma \text{Met (from DOC complexes)} = \text{Al-DOC} + \text{Fe-DOC} + \text{Mn-DOC}$

$\Sigma \text{Org}^- \text{ (from DOC complexes)} = \text{DOC-Fe} + \text{DOC-Al} + \text{DOC-Mn}$

Normally only the total concentrations of the metals and the total concentration of DOC are measured in soil solution samples. Therefore calculation of the formal charge per mg of organic C using the following formula overestimates the formal charge of DOC when the highest possible charge for the metals (Al^{3+} , Fe^{3+} , Mn^{2+}) is used and there is no correction for bicarbonate:

$$\Sigma \text{cat} + \Sigma \text{met}_{\text{total}} - \Sigma \text{an} = \delta_1 \text{ DOC}_{\text{total}}$$

In a study conducted by the WG on QA/QC in Laboratories, about 6200 chemical analyses on soil solution samples (complete sets of all ion and total metal concentrations, alkalinity, conductivity and DOC, carried out in the laboratories of 6 countries, were used to calculate empirical relationships between DOC and the difference between the sum of cations and metals and the sum of anions. The aim was to determine the formal charge per mg of organic C. The samples cover a wide range of geographical and climatic conditions. The results are shown in Figure 6:

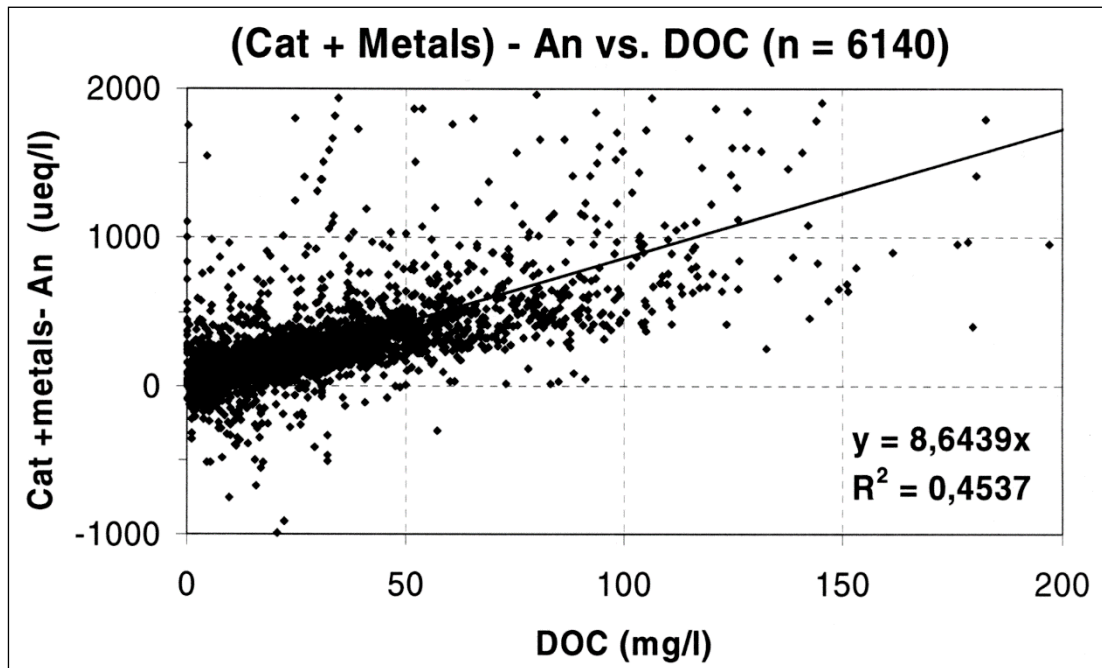


Figure 6: Calculation of the formal charge of DOC in 6140 soil solution samples from 5 countries (Germany, Finland, France, Norway and the United Kingdom)

When the calculated charge factor for DOC was included in the ion balances of these soil solution samples, 64 % of the samples had equal ion balances (within +/- 10 %) while only 30 % of the samples had equal ion balances without using the DOC correction.

The results are different in the individual countries and at different pH values. Therefore the charge factor value obtained here can only be used as a first step in the procedure. It would be better to calculate the charge factor for specific countries or for similar types of plot. The chemical composition of DOC varies with depth down the soil profile (e.g. it is more polar at greater depth, Clarke et al., 2007), so the charge factor is also likely to vary with depth.

3.4.1.2 Conductivity check

Conductivity is a measure of the ability of an aqueous solution to carry an electric current. This property depends on the type and concentration of the individual ions and on the temperature at which conductivity is measured. It is defined as:

$$K = G * (L/A)$$

where G = is the conductance (unit: ohm^{-1} or siemens; ohm^{-1} is sometime written as mho), defined as the reciprocal of resistance, A (cm^2) is the electrode surface area, and L (cm) is the distance between the two electrodes. The units of K are $\text{ohm}^{-1} \text{cm}^{-1}$. In the International System of Units (SI), conductivity is expressed as millisiemens per meter (mS m^{-1}); this unit is also used by the IUPAC and accepted as the Nordic standard. The unit $\mu\text{S cm}^{-1}$, where $1 \text{ mS m}^{-1} = 10 \mu\text{S cm}^{-1} = 10 \mu\text{mho cm}^{-1}$, is also widely used in practice. The unit adopted in the ICP Forests programme is $\mu\text{S cm}^{-1}$, and the reference temperature 25 °C.

Conductivity depends on the type and concentration (activity) of the ions in solution; the capacity of a single ion to transport an electric current is given, in standard conditions and in ideal conditions of infinite dilution, by the equivalent ionic conductance (λ_i , unit: $\text{S cm}^2 \text{equivalent}^{-1}$).

Careful, precise conductivity measurement is an additional way of checking the results of chemical analyses. It is based on comparison between measured conductivity (CM) and the conductivity calculated (CE) from the individual ion concentrations (c_i), multiplied by the respective equivalent ionic conductance (λ_i)

$$CE = \sum \lambda_i c_i$$

The ions used in the conductivity calculations are the same as those used in calculating the ion balance; the values of λ_i for the different ions at temperatures of 20 and 25°C are given in Table 3. As the concentrations are expressed in $\mu\text{eq L}^{-1}$, λ_i is given as $\text{kS cm}^2 \text{eq}^{-1}$ in order to obtain the conductivity in $\mu\text{S cm}^{-1}$. The percentage difference, CD, is given by the ratio:

$$CD = 100 * (CE - CM) / CM$$

At low ionic strength (below $100 \mu\text{eq L}^{-1}$) in deposition samples, the discrepancy between measured and calculated conductivity should be no more than 2% (Miles & Yost 1982).

At an ionic strength higher than $100 \mu\text{eq L}^{-1}$ (approximately at conductivity higher than $100 \mu\text{S cm}^{-1}$) it is necessary to use activity instead of concentration. This can be done by first calculating the ionic strength (I_s , meq L^{-1}) from the individual ion concentrations as follows:

$$I_s = 0.5 \sum c_i z_i^2 / w_i$$

where:

c_i = concentration of the i -th ion in mg L^{-1} ;

z_i = absolute value of the charge for the i -th ion;

w_i = gram molecular weight of the i -th ion.

In the range 100 - $500 \mu\text{eq L}^{-1}$ the Davies correction of the activity of each ion can be used, as proposed e.g. by Stumm and Morgan (1981) and A.P.H.A., A.W.W.A., W.E.F. (2005):

$$y = 10^{-0.5 \left(\frac{\sqrt{I_s}}{1 + \sqrt{I_s}} - 0.3 I_s \right)}$$

Finally, the corrected conductivity is calculated as:

$$CE_{\text{corr}} = y^2 CE = y^2 \sum \lambda_i c_i$$

Immediate comparison of the measured and calculated conductivity makes it possible to identify single outlier values (see example in the annexed Excel file).

Figure 4 shows the departure from zero of the CD values for different types of deposition sample. The pattern is different from that for the ion balance: the CD values do not show any great asymmetry for BOF, THR, or STF. The reason for this is that dissolved organic matter (DOM), which causes an imbalance between the cation and anion concentrations, does not contribute significantly to conductivity.

In conclusion, a plot of measured and calculated conductivity is useful in the routine checking of a set of analyses. Departure of the results from linearity suggests the presence of analytical or some other kind of error.

3.4.1.3 Na/Cl ratio check

In many parts of Europe sea salt is a major contributor of sodium and chloride ions in deposition and, as a result, the ratio between the two ions is similar to that of sea salt. This is true even in parts of Europe situated far from the sea, as has been shown from a statistical study conducted on more than 6000 samples covering the area from Scandinavia to South Europe (Mosello et al., 2005). In the validation file

(downloadable from: <https://www.icp-forests.net/about-us/experts-committees/committees/working-group-on-quality-assurance-and-quality-control-in-laboratories/soil-ringtest-and-ga/qc-information>), samples with a ratio outside the range given below are marked as

possible failures, and checks and/or re-analyses should be carried out. The ratio is calculated by expressing the concentrations on a molar (or equivalent) basis.

$$0.5 < (\text{Na/Cl}) < 1.5$$

If the Na/Cl ratio results systematically fall outside this range, this may be due to poor analytical quality in the measurement of low concentrations of sodium and chloride.

In some localised areas, where there are other sources of Cl and/or Na (e.g. from anthropogenic activities), the Na/Cl ratio might be different from that of sea salt. Where this is suspected, it is recommended to carry out a study to confirm whether this is true or not.

3.4.1.4 N balance check

The test is based on the fact that total dissolved nitrogen (DTN) concentration must be higher than the sum of nitrate (N-NO₃), ammonium (N-NH₄) and nitrite (N-NO₂) concentrations. Although the measurement of nitrite is not mandatory in the ICP Forests programme, the following relationship must be verified, within the limits of analytical errors and whatever unit is used:

$$[\text{N-NO}_3] + [\text{N-NH}_4] < [\text{DTN}]$$

If the relationship does not hold true, then the determination of one of the forms of nitrogen must be erroneous. However, if DON is very low, DTN may be approximately equal to NO₃-N + NH₄-N. In this case, normal (random) analytical errors may result in a slightly negative value of ([DTN] – ([NO₃-N] + [NH₄-N])), without there being any major problem with the analyses.

3.4.1.5 Comparison between measured conductivity and ion concentrations

Samples with similar ionic ratios and different ionic concentrations should show linear correlation between conductivity and the sum of cations and anions. The linearity is valid if the H⁺ concentration is low (i.e. pH higher than 5.0). However, because of the high specific electric conductance of H⁺ (0.35 kS cm² eq⁻¹ at 25 °C, Table 3), compared to that of the other ions (range 0.044-0.080 kS cm² eq⁻¹), small variations in H⁺ concentrations produce relatively strong variations in conductivity. In these cases, a conductivity value corrected for the contribution of hydrogen ion can be used:

$$C_{\text{H}^+ \text{ correct}} = \text{CM} - \lambda_{\text{H}^+} [\text{H}^+] = \text{CM} - 0.35 * 10^{-\text{pH}}$$

where the conductivities are expressed as μS cm⁻¹ at 25°C and [H⁺] as μeq L⁻¹ (Figure 7).

Results diverging from linearity should be carefully checked in order to see whether there have been any mistakes in the analyses or in the data processing, or whether the values of some important ions are missing from the calculation.

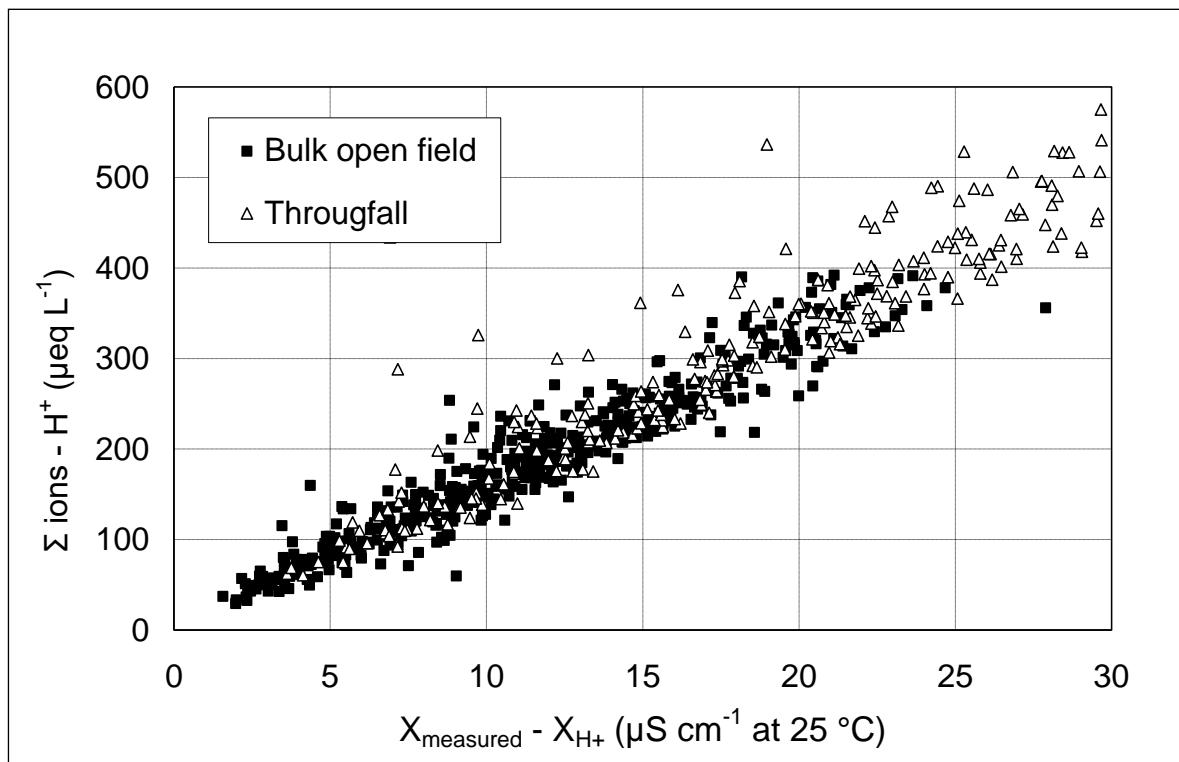
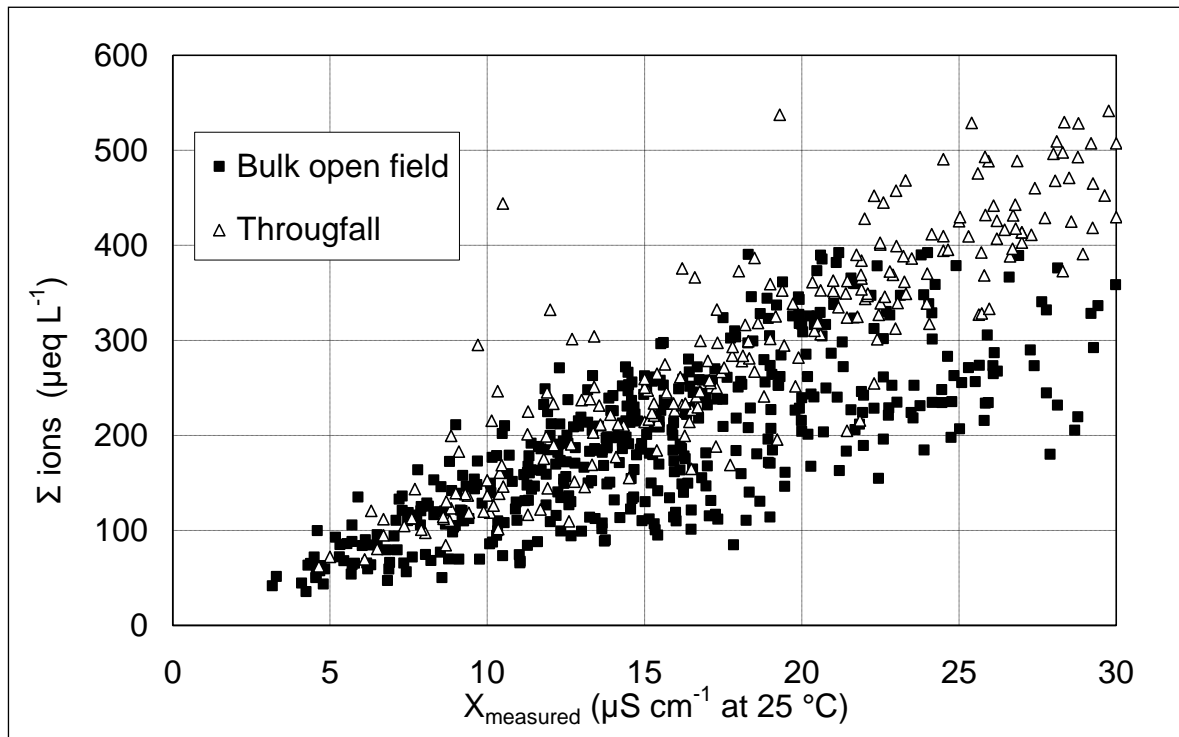


Figure 7: Examples of the relationships between conductivity and $\Sigma \text{ Cat}$ or $\Sigma \text{ An}$, above without the correction for H^+ contribution to conductivity, and below with the correction

3.4.1.6 Phosphorus concentration as a contamination check

If bird droppings contaminate the precipitation/throughfall/stemflow sample, this will considerably alter the chemical composition of the sample. The concentrations of PO₄³⁻, K⁺, NH₄⁺ and H⁺, for instance, will be affected. A phosphate concentration of 0.25 mg l⁻¹ has been suggested as the threshold value for open field sample contamination by bird droppings (Erisman et al., 2003). High phosphorus concentration can also be due low rain fall, dust, pollen release, leaf burst or other natural events. In case of relevant bird dropping, it is expected that other parameter would be affected, such as K, ammonium, total N, pH or alkalinity. Contamination by bird droppings is not always easily visible, so it may sometimes be detected only after the chemical analyses have been performed.

3.4.2 Checking results of organic and mineral soil samples

An important step in laboratory QA/QC is to check whether the result of an analysis is within the expected range and that the general relationships between soil variables are valid. Therefore two quality check procedures are recommended: **plausible range checks** and **cross-checks**.

3.4.2.1 Plausible range checks for organic and mineral soil samples

For each variable, there is a 95 % probability that the analytical result will fall within the plausible min-max range given in Table 6. Values outside this range may occur, but they need to be validated (e.g. checking of equipment and method, dilution factor, reported unit, sample characteristics, signs of contamination). Re-analysis may be necessary when no obvious deviations are found in order to ensure that the results are correct.

Specific plausible ranges have been developed for organic material (forest floor, peat) and mineral soil samples. The number of significant decimal places for each variable is in accordance with the reporting format given in the ICP Forests Manual Part X (Sampling and Analysis of Soil).

Generally, the lower limit of the min-max range depends on the limit of quantification (LOQ) which is, in turn, determined by the instrument, method and dilution factor used. Instead of merely mentioning 'LOQ', we have listed the average LOQ values reported by the soil laboratories that participated in the 4th FSCC Ring test (Cools et al., 2006) as this was found to be more informative. Laboratories with lower LOQ values than the average will be able to quantify lower concentrations reliably. However, each laboratory should always report concentrations lower than its LOQ as "-1" and reporting the LOQ concentration to the required number of decimal places in the data quality report.

The maximum value of the plausible range is determined by the maxima (mainly 97.5 percentile values) in the European forest soil condition database. Information on the methods and data evaluation can be found in the Second European Forest Soil Condition Report (De Vos and Cools, 2011). As it encompasses all the European soil types, this range is relatively broad.

Table 6. Revised plausible ranges for organic and mineral forest soil samples at the European level. Percentiles are based on Regression on Order Statistics (ROS) taking into account left-censored data (< LOQ). The number of decimal places indicates the required precision for reporting. Values in bold are modifications compared to of Part XVI of the ICP Forests Manual (König et al. 2010). The symbol ↑ or ↓ indicate an increase or a decrease.

Parameter	Unit	Organic sample*			Mineral soil sample**		
		LOQ	Min	Max	LOQ	Min	Max
Moisture content	%wt	0.1	<0.1	10	0.1	<0.1	10
Particle size: clay	%wt	-	-	-	0.5	0.5	51.3↓
Particle size: silt	%wt	-	-	-	0.5	1.5↑	73.0↓
Particle size: sand	%wt	-	-	-	0.5	4.0↑	100
Bulk density ¹	kg m ⁻³	-	50	800	-	380↑	1800
pH-CaCl ₂	-	-	2.6↑	6.9↓	-	2.9↑	7.7↓
pH-H ₂ O	-	-	3.3↑	6.9↓	-	3.7↑	8.4↓
CaCO ₃	g kg ⁻¹	3	0↓	360↓	3	0↓	660↓
Organic carbon	g kg ⁻¹	1.2	93.0↓	590.0↑	1.2	0.4↓	150.0↓
Total N	g kg ⁻¹	0.5	4.3↑	32.0↑	0.1	0.05↓	10.0↓
Free H ⁺	cmol _c kg ⁻¹	0.1	0.10↑	17.50↑	0.1	<0.10↓	3
Exchangeable acidity	cmol _c kg ⁻¹	0.1	0.05↓	22.50↑	0.1	0.05↓	11.80↑
Exchangeable K	cmol _c kg ⁻¹	0.03	0.01↓	5.30↑	0.03	0.006↓	1.30↓
Exchangeable Ca	cmol _c kg ⁻¹	0.03	0.17↓	146.00↑	0.03	0.005↓	47.00↑
Exchangeable Mg	cmol _c kg ⁻¹	0.03	0.19	21.50↑	0.03	0.002↓	7.15↑
Exchangeable Na	cmol _c kg ⁻¹	0.03	0.005↓	2.35↑	0.03	0.002↓	0.45↓
Exchangeable Al	cmol _c kg ⁻¹	0.02	0.002↓	16.60↑	0.02	0.018↓	9.00↑
Exchangeable Fe	cmol _c kg ⁻¹	0.02	0.0001↓	5.20↑	0.02	0.0004↓	0.70↓
Exchangeable Mn	cmol _c kg ⁻¹	0.02	0.0005↓	5.70↓	0.02	0.001↓	0.70↓
Extractable P	mg kg ⁻¹	35	80.0↑	2100.0↓	35	35.0↓	1320.0↓
Extractable K	mg kg ⁻¹	80	4.0↓	5900.0↑	80	100.0↑	9250.0↓
Extractable Ca	mg kg ⁻¹	50	210.0↑	50000.0↓	50	20↓	140000.0↓
Extractable Mg	mg kg ⁻¹	35	120.0↑	7600.0↓	35	75.0↑	30500.0↓
Extractable S	mg kg ⁻¹	20	460.0↑	6750.0↓	20	10.0↓	1100.0↓
Extractable Na	mg kg ⁻¹	20	4.0↓	540.0↓	20	12.0↓	650.0↓
Extractable Al	mg kg ⁻¹	10	140.0↑	26000.0↓	10	1100.0↑	55250.0↑
Extractable Fe	mg kg ⁻¹	10	140.0↑	42500.0↓	10	880.0↑	62500.0↓
Extractable Mn	mg kg ⁻¹	2	0.8↓	3600.0↓	2	8.0↑	1950.0↓
Extractable Cu	mg kg ⁻¹	1	0.2↓	75.0↓	1	0.3↓	55.0↓
Extractable Pb	mg kg ⁻¹	2.5	0.03↓	245.0↓	2.5	1.0↓	110.0↓
Extractable Ni	mg kg ⁻¹	1	0.06↓	45.0↓	1	0.5↓	80.0↓
Extractable Cr	mg kg ⁻¹	1	0.1↓	95.0↓	1	1.0↓	80.0↓
Extractable Zn	mg kg ⁻¹	2	0.8↓	300.0↓	2	2.5↑	165.0↓
Extractable Cd	mg kg ⁻¹	0.5	<0.01↓	2.2↓	0.5	<0.01↓	2.5↓
Extractable Hg	mg kg ⁻¹	0.03	<0.01↓	1.65↓	0.03	0.02↓	2.25↑
Total K	mg kg ⁻¹	80	50.0↓	25000.0↑	80	2000↑	50000
Total Ca	mg kg ⁻¹	50	50.0↑	65000.0↑	50	350.0↑	200000.0↓
Total Mg	mg kg ⁻¹	35	100.0↑	42000.0↑	35	180.0↑	42000.0↓
Total Na	mg kg ⁻¹	20	<20.0	15000.0↑	20	400.0↑	20000.0↑
Total Al	mg kg ⁻¹	10	100.0↑	50000	10	4000.0↑	100000
Total Fe	mg kg ⁻¹	10	100.0↑	25000.0↓	10	700.0↑	65000.0↓
Total Mn	mg kg ⁻¹	2	20.0↑	3500.0↓	2	15.0↑	2000.0↓
Reactive Al	mg kg ⁻¹	50	90↑	12500↑	50	170↑	10300↑
Reactive Fe	mg kg ⁻¹	50	170↑	40000↑	50	100↑	13000↑

* Organic samples comprise those of OL, OF, OH, OFH, Hf, Hs, Hfs, H05, H51, H01, H12, H24 and H48 layers

** Mineral samples comprise those of M01, M12, M24 and M48 layers

¹ Bulk density was added to the plausible range list

For some parameters, national plausible ranges will be narrower due to the restricted set of soil and humus types and their local characteristics. It would be worthwhile developing regional plausible ranges specifically for soil samples originating from the region.

If the values obtained in the analyses are outside the plausible range, the values should be marked with a flag for further investigation by the head of the laboratory and/or the responsible scientist. The head of the laboratory should be able to make comments in their report on possible reasons for the deviating value(s).

3.4.2.2 Cross-checks between soil variables

Because different parameters are determined on the same soil sample and many soil variables are auto-correlated, cross-checking is a valuable tool for detecting erroneous analytical results. Obviously, soils high with a high organic matter content should have high carbon and (organically bound) nitrogen concentrations. Calcareous soils should have elevated pH values, high exchangeable and total Ca concentrations, but low exchangeable acidity.

Simple cross-checks have been developed for easy verification and detection of erroneous results.

3.4.2.2.1 pH check

The soil reaction of organic and mineral soil material is measured potentiometrically in a suspension of a 1:5 soil:liquid (v/v) mixture of water ($\text{pH}_{\text{H}_2\text{O}}$) or 0.01 mol/l calcium chloride ($\text{pH}_{\text{CaCl}_2}$). The actual pH ($\text{pH}_{\text{H}_2\text{O}}$) and potential pH ($\text{pH}_{\text{CaCl}_2}$) are generally well correlated. Outliers may be detected using simple linear regression.

Theoretically, without taking measurement uncertainty into account, the difference between both pH measurements should be less than 1 pH-unit. In practice, the difference between both pH measurements is generally less than 1.2 pH-unit, with $\text{pH}_{\text{CaCl}_2}$ always less or equal to $\text{pH}_{\text{H}_2\text{O}}$.

Check algorithm: $0 < [\text{pH}_{\text{H}_2\text{O}} - \text{pH}_{\text{CaCl}_2}] \leq 1.2$

Note that for peat soils, the difference between both pH measurements may be higher, up to 1.5 pH-units.

3.4.2.2.2 Carbon check

According to the ICP Forests Manual Part X (Soil sampling and analysis), the recommended method for C determination is dry combustion using a total analyser (ISO 10694, 1995). In general, total organic carbon is obtained by subtracting inorganic carbon (TIC) from total carbon (TC), both of which are determined by the same analyser.

Inorganic carbon can be estimated from the carbonate measurement (ISO 10693, 1995) using a calcimeter (Scheibler unit).

Check algorithm: $[\text{C}_{\text{CaCO}_3} + \text{TOC}] \leq \text{TC}$ with $\text{C}_{\text{CaCO}_3} = \text{CaCO}_3 \times 0.12$

and

Check algorithm: $\text{C}_{\text{CaCO}_3} \approx \text{TIC}$

The latter check cannot be performed if the carbonate concentration is below the LOQ (3 g kg^{-1} carbonate or 0.36 g kg^{-1} TIC).

3.4.2.2.3 pH-Carbonate check

Routinely determining carbonate in soil samples with low pH values is a waste of time and resources. Carrying out a fast, cheap pH measurement can be used to decide whether carbonates are present and carbonate analysis is necessary.

For an organic sample ($> 200 \text{ g kg}^{-1}$ TOC):

Check algorithm: if $\text{pH}_{\text{CaCl}_2} < 6.0$ then $\text{CaCO}_3 < 3 \text{ g kg}^{-1}$ (= below LOQ)

For a mineral soil sample:

Check algorithm: if $\text{pH}_{\text{H}_2\text{O}} < 5$ then $\text{CaCO}_3 < 3 \text{ g kg}^{-1}$ (= below LOQ)

or: if $\text{pH}_{\text{CaCl}_2} < 5.5$ then $\text{CaCO}_3 < 3 \text{ g kg}^{-1}$ (= below LOQ)

Conversely, if $\text{pH}_{\text{CaCl}_2} > 6$, quantifiable amounts of carbonate are most likely present in the sample.

3.4.2.2.4 C/N ratio check

Most of the nitrogen in a forest soil sample is organically bound. Carbon and nitrogen are linked through the C/N ratio of organic matter, which varies within a specific range.

For an organic sample ($> 200 \text{ g kg}^{-1}$ TOC):

Check algorithm: $5 < \text{C/N ratio} < 100$

For a mineral soil sample:

Check algorithm: $3 < \text{C/N ratio} < 75$

3.4.2.2.5 C/P ratio check

Similarly to C/N, the C/P ratio varies within expected ranges for organic and mineral soil samples.

For an organic sample ($> 200 \text{ g kg}^{-1}$ TOC):

Check algorithm: $100 < \text{C/P ratio} < 2500$

Note that for peat soils, the C/P ratio may be greater than 2500. In the 5th FSCC soil ring test, the C/P ratio of the peat sample was ca. 4500.

For a mineral soil sample:

Check algorithm: $8 < \text{C/P ratio} < 750$

3.4.2.2.6 C/S ratio check

The C/S ratio varies within specific ranges for organic samples only.

For an organic sample ($> 200 \text{ g kg}^{-1}$ TOC):

Check algorithm: $20 < \text{C/S ratio} < 1000$

3.4.2.2.7 Extracted/total element check

In both organic and mineral soil samples the concentration of the aqua regia extractable elements K, Ca, Mg, Na, Al, Fe and Mn (semi-total extraction) should be less than their total concentrations after complete dissolution (total analysis).

Therefore:

Check algorithm: **Extracted element by aqua regia \leq Total element**

for the elements K, Ca, Mg, Na, Al, Fe and Mn.

3.4.2.2.8 Reactive Fe and Al check

Acid oxalate extractable Fe and Al indicate the active (\approx "amorphous") Fe and Al compounds in soils. Their concentration should be less than the total Fe and Al concentration.

Check algorithm:

Reactive Fe \leq Total Fe

Reactive Al \leq Total Al

For mineral soil samples, reactive Fe is usually less than 25 % of the total Fe, and reactive Al less than 10 % of the total Al.

3.4.2.2.9 Exchangeable element/total element check

The elements bound to the cation exchange complex in the soil are also readily extracted using Aqua regia. Therefore, the concentration of exchangeable cations should always be lower than their Aqua regia extractable concentration.

A conversion factor is needed to convert from $\text{cmol}_{(+)} \text{kg}^{-1}$ to mg kg^{-1} .

Check algorithm: $(K_{\text{exch}} \times 391) \leq \text{Extracted K}$

Check algorithm: $(Ca_{\text{exch}} \times 200) \leq \text{Extracted Ca}$

Check algorithm: $(Mg_{\text{exch}} \times 122) \leq \text{Extracted Mg}$

Check algorithm: $(Na_{\text{exch}} \times 230) \leq \text{Extracted Na}$

Check algorithm: $(Al_{\text{exch}} \times 89) \leq \text{Extracted Al}$

Check algorithm: $(Fe_{\text{exch}} \times 186) \leq \text{Extracted Fe}$

Check algorithm: $(Mn_{\text{exch}} \times 274) \leq \text{Extracted Mn}$

In general, the ratio between an exchangeable element and the same extracted element is higher in organic matrices than in mineral soil.

3.4.2.2.10 Free H⁺ and Exchangeable acidity check

Two checks can be applied to Free H⁺ and Exchangeable acidity (EA).

Check algorithm: **Free H⁺ < EA**

Check algorithm: **EA \approx Al_{exch} + Fe_{exch} + Mn_{exch} + Free H⁺**

For mineral soil samples, Free H⁺ is usually < 60 % of the Exchangeable acidity.

3.4.2.2.11 Particle size fraction sum check

According to the ICP Forests Manual Part X (Sampling and analysis of soil), laboratories have to report the proportion of sand, silt and clay fractions in mineral soil samples. However, different methods are used for determining each fraction. After shaking with a dispersing agent, sand (63 μm -2 mm) is separated from clay and silt with a 63 μm sieve (wet sieving).

The clay (< 2 µm) and silt (2-63 µm) fractions are determined using the standard pipette method (sedimentation).

When correctly applying the Soil manual procedure (SA03) (ICP Forests Manual Part X (Sampling and analysis of soil), which is based on ISO 11277 (2009) and includes the correction for the dispersing agent, the sum of the three fractions should be 100 %. The mass of the three fractions should equal the weight of the fine earth (0- 2mm fraction), minus the weight of carbonate and organic matter which have been removed.

Check algorithm: $\Sigma [\text{clay (\%)}, \text{silt (\%)}, \text{sand (\%)}] = 100 \%$

Ensure that the clay, silt and sand fractions are reported in the right format as mistakes occur regularly, even in ring tests.

3.4.3 Checking results of foliage and litterfall samples

In comparison to the quality checks for the analytical results on soil, deposition and soil solution samples, devising robust procedures for checking foliage and litterfall analytical data is relatively difficult. In unpolluted areas, the concentration range of analytes in foliage is usually small compared with that in other matrices and so most of the results are plausible.

Correlations between elements in foliage could be one possible tool for checking analytical results, but this is only suitable in cases where the sample plots are located very close to each other and have similar soil characteristics and the same tree species. As a result, this is probably not a useful procedure for checking the results in a European-wide survey.

3.4.3.1 Plausible range check for foliage

In order to provide the laboratories carrying out foliage analyses with support on QA/QC issues, a preliminary list of plausible ranges for the element concentrations in foliage was agreed on at the 4th Expert Panel Meeting in Vienna 1997. However, these limits were very broad (see: [http://bfw.ac.at/600/pdf/ Minutes_4.pdf](http://bfw.ac.at/600/pdf/Minutes_4.pdf)).

In order to improve the list and put it on a more sound statistical basis, the Forest Foliar Coordinating Centre removed 5% of the lowest and 5% of the highest results from the European Level I database. 90% of all the submitted Level I results fell within these limits. As the manual covers a large number of different tree species, it was necessary, in order to obtain sufficient data for meaningful statistical analysis, to group them into the main tree genera (Stefan et al., 1997). The new limits were adopted at the Expert Panel Foliage and Litterfall meeting in Madrid/Spain (2007).

The Joint Research Centre was asked to carry out a statistical evaluation on the submitted Level II results in order to obtain statistical information about the concentration range for different tree species. The 5% and the 95% percentile limits for each tree species were calculated. 90% of the submitted results fell within these limits (see Table 7). Results falling outside these limits should be checked and, if necessary, be re-analyzed. For the optional parameters As, Co, Cr, Hg and Ni there are at the moment not enough values in the database to calculate these plausible range check limits.

The report of the Level I foliage survey (Stefan et al., 1997) clearly shows that element concentrations in foliage vary considerably in different parts of Europe. There is thus a need to calculate these limits for each country/laboratory using their own results. This would result in narrower limits that would provide a more reliable tool for detecting non-plausible results.

Table 7: Plausible range of element concentrations in the foliage of different tree species* and leaf types calculated from the Level II data sets The figures express the lower and upper bound of the respective range. They are computed from the Level II data sets as 5 - 95 percentile from survey years 2011-2020. Default ranges are calculated generally for all tree species and leaf types and are listed at the bottom of the table.

Tree species	Leaf type	As	B	C	Ca	Cd	Co	Cr	Cu	Fe	Hg
		ng/g	µg/g	g/100g	mg/g	ng/g	µg/g	µg/g	µg/g	µg/g	ng/g
<i>Abies alba</i>	0	-	13.38 - 40.76	51.71 - 54.58	2.49 - 11.36	16.42 - 427.87	-	-	1.78 - 5.98	25.30 - 120.50	-
	1	-	13.85 - 38.65	51.17 - 54.66	3.21 - 17.82	-	-	-	1.61 - 5.07	35.60 - 139.40	-
<i>Fagus sylvatica</i>	0	-	10.81 - 42.73	47.62 - 53.05	3.17 - 15.35	27.76 - 160.12	0.02 - 0.11	0.14 - 0.76	4.45 - 10.76	59.00 - 129.90	-
<i>Fraxinus excelsior</i>	0	-	20.90 - 29.50	46.13 - 47.63	12.68 - 25.52	-	-	-	6.36 - 12.45	61.40 - 88.20	-
<i>Picea abies</i>	0	-	7.10 - 35.68	49.80 - 53.68	1.33 - 7.46	14.81 - 123.05	0.03 - 0.43	0.14 - 1.80	1.78 - 4.38	20.90 - 78.50	6.88 - 20.60
	1	-	5.20 - 25.10	49.62 - 53.83	1.75 - 9.79	15.00 - 125.84	0.03 - 0.26	0.19 - 1.96	1.61 - 3.98	24.90 - 96.30	13.11 - 32.36
<i>Picea sitchensis</i>	0	-	5.77 - 27.85	50.98 - 52.87	0.58 - 4.64	1.60 - 33.00	-	-	2.04 - 4.16	28.50 - 49.50	-
	1	-	6.21 - 25.58	51.21 - 53.12	1.25 - 6.73	4.00 - 31.40	-	-	2.11 - 4.37	29.50 - 84.50	-
<i>Pinus nigra</i>	0	-	-	51.93 - 54.63	1.38 - 4.98	-	-	-	-	-	-
	1	-	-	52.12 - 55.01	2.30 - 7.28	-	-	-	-	-	-
<i>Pinus pinaster</i>	0	-	-	50.37 - 52.40	1.48 - 2.74	-	-	-	1.78 - 5.03	23.40 - 44.80	-
<i>Pinus sylvestris</i>	0	-	10.00 - 33.11	49.34 - 54.12	1.64 - 4.98	58.34 - 258.26	0.06 - 0.26	0.11 - 0.96	2.70 - 5.18	29.50 - 70.40	-
	1	-	9.77 - 39.21	50.04 - 54.76	2.74 - 8.24	62.75 - 294.60	0.04 - 0.22	0.17 - 0.91	2.40 - 4.81	39.70 - 94.70	-
<i>Pseudotsuga menziesii</i>	0	-	-	51.21 - 53.50	2.51 - 4.44	-	-	-	2.95 - 4.96	43.90 - 108.20	-
	1	-	-	51.45 - 54.04	3.58 - 6.38	-	-	-	2.64 - 4.14	75.40 - 168.30	-
<i>Quercus cerris</i>	0	-	12.38 - 75.49	46.85 - 54.64	3.76 - 9.68	-	-	-	-	76.80 - 140.10	-
<i>Quercus ilex</i>	0	-	-	46.21 - 51.29	1.16 - 10.32	-	-	-	-	-	-
<i>Quercus petraea</i>	0	-	17.89 - 59.59	47.10 - 51.50	3.66 - 9.06	28.72 - 100.00	-	-	2.64 - 8.85	61.10 - 136.80	-
<i>Quercus robur</i>	0	-	22.76 - 73.80	46.27 - 53.19	4.76 - 14.26	23.90 - 130.64	-	-	3.99 - 11.00	58.20 - 211.90	-
Default		1.80 - 221.30	5.20 - 75.49	44.18 - 57.00	0.58 - 25.52	1.60 - 609.70	0.02 - 0.67	0.11 - 4.47	0.27 - 16.46	1.80 - 221.30	6.55 - 62.85

Tree species	Leaf type	K	Mg	Mn	N	Ni	P	Pb	S	Zn
		mg/g	mg/g	µg/g	mg/g	µg/g	mg/g	µg/g	mg/g	µg/g
<i>Abies alba</i>	0	3.40 - 8.40	0.71 - 2.62	136.30 - 2546.80	11.00 - 16.30	-	0.79 - 2.51	0.10 - 1.57	0.90 - 1.50	19.70 - 59.70
	1	2.90 - 7.00	0.46 - 2.50	173.50 - 3924.00	11.80 - 16.80	-	0.72 - 2.00	-	0.90 - 1.40	19.60 - 58.40
<i>Fagus sylvatica</i>	0	3.80 - 10.60	0.56 - 2.75	172.60 - 3260.00	18.60 - 28.20	0.29 - 3.68	0.81 - 1.82	0.14 - 1.46	1.10 - 2.10	15.10 - 41.00
<i>Fraxinus excelsior</i>	0	10.80 - 20.70	2.17 - 3.69	11.90 - 40.20	19.20 - 25.80	-	1.64 - 2.20	0.15 - 0.61	2.90 - 4.80	8.70 - 19.00
<i>Picea abies</i>	0	2.60 - 8.30	0.57 - 1.76	223.60 - 2485.00	10.20 - 17.10	0.38 - 5.60	0.98 - 2.07	0.06 - 0.84	0.70 - 1.20	12.50 - 49.00
	1	2.60 - 7.00	0.36 - 1.60	238.90 - 3175.30	9.40 - 16.10	0.40 - 4.87	0.79 - 1.84	0.11 - 1.04	0.70 - 1.20	9.20 - 55.60
<i>Picea sitchensis</i>	0	5.60 - 10.90	0.65 - 1.29	89.80 - 313.70	10.20 - 17.20	-	1.30 - 2.02	0.05 - 0.37	0.80 - 1.20	13.50 - 26.50
	1	4.00 - 8.10	0.52 - 1.20	99.00 - 394.80	11.40 - 18.70	-	1.14 - 1.77	0.05 - 0.49	0.90 - 1.30	9.60 - 18.40
<i>Pinus nigra</i>	0	3.70 - 10.00	0.75 - 2.19	-	8.10 - 17.90	-	0.79 - 1.53	-	0.80 - 1.30	-
	1	3.10 - 6.50	0.54 - 1.57	-	10.20 - 18.60	-	0.73 - 1.11	-	0.70 - 1.30	-
<i>Pinus pinaster</i>	0	3.20 - 7.20	1.16 - 1.91	37.40 - 426.00	6.30 - 14.00	-	0.59 - 1.16	-	0.60 - 1.00	16.90 - 38.40
<i>Pinus sylvestris</i>	0	3.70 - 7.00	0.58 - 1.33	168.20 - 1309.80	12.10 - 19.10	0.47 - 3.96	1.07 - 1.78	0.08 - 0.65	0.80 - 1.30	26.20 - 59.90
	1	3.30 - 6.30	0.40 - 1.13	241.90 - 1978.50	12.40 - 19.20	0.27 - 2.91	0.99 - 1.64	0.17 - 0.78	0.80 - 1.30	27.50 - 80.20
<i>Pseudotsuga menziesii</i>	0	5.40 - 8.40	0.97 - 1.58	494.00 - 2281.00	14.90 - 18.80	-	1.05 - 1.46	-	1.00 - 1.50	12.80 - 37.10
	1	4.50 - 6.40	1.08 - 1.56	780.00 - 4037.00	15.80 - 23.40	-	0.95 - 1.19	-	1.20 - 2.00	18.70 - 40.70
<i>Quercus cerris</i>	0	2.10 - 9.90	0.30 - 2.44	348.90 - 1399.30	18.30 - 29.00	-	0.97 - 2.32	-	1.20 - 2.70	18.50 - 29.00
<i>Quercus ilex</i>	0	0.90 - 8.30	0.39 - 2.68	-	9.00 - 24.80	-	0.39 - 1.37	-	0.90 - 2.20	-
<i>Quercus petraea</i>	0	4.40 - 10.10	0.99 - 2.18	725.90 - 3520.00	19.40 - 27.90	-	0.87 - 2.10	0.15 - 0.87	1.10 - 1.90	12.10 - 25.60
<i>Quercus robur</i>	0	5.00 - 12.20	1.22 - 2.95	269.50 - 2556.50	19.10 - 29.20	1.11 - 2.69	1.01 - 2.65	0.14 - 7.12	1.30 - 1.90	12.70 - 28.80
Default		0.93 - 20.71	0.21 - 5.53	4.40 - 4151.40	5.94 - 29.19	0.27 - 7.00	0.18 - 3.09	0.05 - 15.49	0.56 - 4.80	5.81 - 106.98

* Plausible ranges for *Quercus pyrenaica*, *Quercus suber*, *Pinus contorta*, *Pinus halepensis* and *Pinus pinea* can be found in the previous Manual Part XVI, Version 2020-1 (<https://www.icp-forests.net/manual>)

3.4.3.2 Plausible range check for litterfall

Developing tolerable limits for litterfall is a more difficult task than that for foliage. Following collection, litterfall is sorted into different fractions – at a minimum two, foliar and non-foliar litter. Most countries sort the litterfall into three fractions – foliage, wood and fruit cones & seeds. Litterfall can then be analyzed either as a pooled sample or per fraction.

The plausible range of the results of the chemical analysis of litter must be much bigger than for foliage. An important fraction in the litter is the foliar fraction, and for this fraction plausible ranges for selected tree species, based on the expert experience, are given in Table 8. Plausible ranges for non-foliar fraction in litterfall are given in the Manual part XIII (Ukonmaanaho et al., 2020).

Table 8: Plausible range of element concentrations based on 5th and 95th percentile of respective measured values in the ICP Forests Litterfall Database in the foliar-litter of different tree species*

Tree Species (Foliar litter)	Limit	C	N	S	P	Ca	Mg	K	Zn	Mn	Fe	Cu	Pb	B	Cd	As	Cr	Co	Ni
		g/100g	mg/g	mg/g	mg/g	mg/g	mg/g	mg/g	mg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	ng/g	ng/g	µg/g	µg/g
<i>Betula pendula</i>	Low	52.0	7.0	0.5	0.7	4.6	0.6	0.8	74	384	52	4.0							1.5
	high	56.0	23.0	1.7	2.9	13.7	3.5	7.6	237	1960	334	8.7							8
<i>Fagus sylvatica</i>	Low	46.4	7.9	0.7	0.3	4.2	0.6	1.6	20.8	900	91	3.8	0.4	13.3	45.6	40	0.4	0.1	0.9
	high	53.3	24.3	1.6	1.6	18.7	2.6	7.3	49.6	3400	338	12.1	5.1	42.0	233	289	3.0	0.4	6.3
<i>Quercus frainetto</i>	Low	43.4	7.0	0.8	0.4	10.1	1.7	1.0											
	high	56.0	15.5	1.5	1.2	18.8	2.2	7.1											
<i>Quercus petraea</i>	Low	43.9	7.0	0.6	0.3	4.3	1.0	1.3	13.1	273	72.4	3.8	0.3	15.5	20			0.1	1.3
	high	53.0	27.4	1.9	1.9	15.4	3.3	9.1	45	4879	454	23.2	49.0	123	158			0.8	11.5
<i>Quercus robur</i>	Low	39.8	6.4	0.6	0.4	4.2	1.1	2.0	11.1	161	84	1.2	0.3		31				
	high	53.2	27.2	3.9	2.7	25.0	3.5	15.3	44.0	3126	300	23.7	54		155				
<i>Picea abies</i>	Low	48.3	6.2	0.6	0.4	2.6	0.3	1.1	14.3	287	28.3	1.4	0.3	7.1	30		0.2	0.06	1.0
	high	53.2	14.7	1.2	1.3	14.3	1.4	3.6	87.0	2200	402	6.5	13.6	31.7	176		5.2	1.8	6
<i>Pinus sylvestris</i>	Low	49.0	4.6	0.4	0.3	3.2	0.4	0.8	25	205	54	1.5	0.4	8.3	78	50	0.3	0.1	0.5
	high	55.3	16.7	1.3	1.3	11.1	2.0	4.5	73	2639	304	10.0	2.0	46.4	250	347	1.7	1.2	9.7

*Plausible range of element concentrations in the foliar-litter of *Castanea sativa*, *Fraxinus excelsior* and *Abies cephalonica* can be found in the previous Manual Part XVI, Version 2020-1 (<https://www.icp-forests.net/manual>)

3.4.4 Analyses in duplicate

Performing duplicate analyses represents a very worthwhile quality check. The samples or digestion solutions/extracts are measured twice independently for the individual parameters, the results are compared, and their repeatability determined.

As this is a very time-consuming and expensive procedure when the number of samples is large, it may be sufficient to analyse only part of the samples in duplicate. If this is adopted, the samples should be randomly selected and analysed again at the end of the batch. Thus, one can check repeatability on the one hand and make sure that samples weren't mistakenly exchanged during the course of the analysis. If a mistake was determined, all samples in the batch will need to be re-analysed in duplicate.

3.4.5 Avoidance of contamination

The contamination of samples can occur at any stage from the field to the final analysis result, including sampling in the field during, transportation to the laboratory, and the pre-treatment and analysis of the samples in the laboratory.

3.4.5.1 Water analyses

As outlined deposition samples can become contaminated during the sampling period, e.g. as a result of bird droppings, and the laboratory should be informed about signs of such contamination (see Chapter 3.4.1.6). The transfer of deposition and soil water samples in the

field from the sampling devices to the bottles used for transportation to the laboratory is another stage where contamination of the samples can occur. The best way to avoid this problem is to transport the collection devices (bottles, bags etc.) directly to the laboratory, if possible. The most important point during this step, as well as throughout the whole sample preparation procedure in the laboratory, is to avoid skin contact with the samples by using disposable gloves (non talc), and the use of clean equipment (e.g. glass- and plastic ware).

Special care must be taken when filtering the samples, and at least separate plastic tubing (if used) and/or filtering devices for different types of sample (bulk, throughfall, stem flow, soil solution) should be used. Rinsing the filter capsule or funnel between the samples with the next sample, as well as with purified water, is highly recommended. If this is not possible, then an adequate amount of the next sample should be discarded after filtering before taking a sample for analysis. Control samples (ultra pure water) should be used after every 20 to 30 samples depending on the type of filtering system. It is always recommendable to start working with cleaner samples (e.g. bulk first with low analyte concentrations) and continue with the other types of sample in sequential order. Attention should also be paid to the different characteristics of the individual sample plots and their specific concentrations.

It is important that filters used are appropriate to the analyses to be carried out, e.g. paper filters can affect ammonium and DOC determinations through contamination and the release of paper fibres that of course contain C. In some cases, the opposite may occur: sample loss through adsorption on filters. For the filtration of samples on which DOC is to be determined, glass fibre filters are recommended.

The filters and the amount of ultra pure water needed to rinse off possible contaminants should be tested and checked by using blank charts. The filters should be handled with clean forceps.

One highly recommendable procedure is to use a separate set of bottles for preparing the standard solutions for every single type of analysis. If the pH or conductivity value for a sample is exceptionally high, then it is recommendable to inform the persons carrying out the other analyses (which are usually performed later) about the “atypical” sample.

3.4.5.2 Organic and mineral soil analyses

Samples of organic and mineral soil material need several preparatory steps prior to analysis. Contamination can occur in each of these steps.

Cleanliness of equipment, glass- and plastic-ware, is a prerequisite for avoiding contamination and conforming with good laboratory practice.

Milling and/or sieving is the first step in the pre-treatment of organic and mineral soil samples.

The milling equipment is one possible source of contamination. Metals, especially, may be released through abrasion of the inner compartments or sieves. In the laboratory responsible for preparing the FSCC ring test samples, the use of a hammer-mill system with a titanium rotor and a stainless steel sieve was tested for milling organic samples. Milling resulted in elevated Ni and Cr concentrations of up to 3.6 and 2.2 mg kg⁻¹, respectively, whereas for manual pulverization the increase was below 0.6 mg kg⁻¹ for both metals. Although no systematic contamination was observed, the degree of contamination appeared to be a function of the hardness of the sample material (wood, bark) and the age of the sieve. The use of titanium rotors and sieves is therefore recommended, as well as periodical replacement of the sieves.

According to the ICP Forests Manual Part X (Sampling and analysis of soil), mineral soil samples should not be milled, but sieved with a 2 mm sieve. These sieves should be clean, with no traces of rust (i.e. oxidation on their metallic parts). Attention should be paid to

ensure that no residues from tools (crusher, pestle, brush, cleaning equipment) end up in the samples as a result of thorough cleaning by brushing or wiping. This also holds true for other equipment (sample divider, mixer, splitter, riffler). When pre-treating silty or clayey soil samples, appropriate ventilation methods (i.e. air extraction equipment) should be used to avoid contamination of other samples or equipment via the air as well as for the health and safety of the laboratory technician.

If a separate container is used to weigh and transfer sub-samples to extraction vessels, then it should be carefully brushed clean between samples to avoid cross-contamination. All glass- and plastic-ware should be cleaned by rinsing with a dilute acid solution or appropriate cleaning agent. Rinsing twice with distilled or de-ionized water and drying before re-use is a common practice.

Ions adsorbed on the inner surfaces of extraction flasks or sample bottles coming into contact with extracts may be a source of contamination for subsequent analyses using the same containers.

Finally, some types of filter paper used for filtration may contain contaminants. Many laboratories encounter problems with Na^+ or other cations. Careful analysis of blanks and the filter material may indicate problematic elements that enhance the background noise.

3.4.5.3 Foliar and litterfall analyses

There are many possible contamination sources in foliage and litterfall analyses. A short overview is given in Table 9.

Table 9: Possible contamination sources in foliage and litterfall analyses for some elements

Element	Possible contamination source
N	NH_3 from the laboratory air (only if the Kjeldahl method is used), reagents
S	Water (distilled or deionised), reagents
P	Dishwasher (detergent), water (distilled or deionised), reagents
Ca	Soil contamination from sampling, water (distilled or deionised), glassware, reagents
Mg	Soil contamination during sampling, water (distilled or deionised), glassware, reagents
K	Dishwasher (detergent), water (distilled or deionised), glassware, reagents
Zn	Soil contamination during sampling, Dishwasher (detergent), water (distilled or deionised), glassware, dust, reagents
Mn	Reagents
Fe	Soil contamination during sampling, water (distilled or deionised), glassware, dust, reagents
Cu	Water (distilled or deionised), glassware, reagents
Pb	Soil contamination during sampling, glassware, dust, reagents
Cd	Soil contamination during sampling, glassware, dust, reagents
B	Water (distilled or deionised), glassware, reagents
Co, Cr, Ni	Instruments made of stainless steel used in sampling, pre-treatment etc., soil contamination during sampling
Hg	Soil contamination during sampling, glassware, dust, reagents

3.5 Inter-laboratory quality assurance

In addition to the quality assurance carried out within each laboratory, there are also quality checks and procedures that can be used between different laboratories. These include ring tests, as well as the exchange of expertise and analytical methods employed between laboratories. In the case of international programmes, especially, the use of identical

analytical methods and regular ring tests are of particular importance in ensuring comparability and joint evaluation of the data.

3.5.1 Inter-laboratory comparison tests (ring tests)

A series of inter-laboratory comparison tests is an excellent tool for improving the quality of the data produced by the participating laboratories over time. There are the twin benefits of improved expertise in using harmonised analytical methods as well as the use of the remaining ring test sample material as reference material for subsequent analyses.

In instances where the analytical data generated in environmental monitoring or long-term ecological research programmes are of poor quality, then this may prevent the detection of trends, resulting in delays of up to three decades before they can be identified (Sulkava et al., 2007). To address this issue, tolerable limits for the deviation of the individual test result from the comparison mean value were selected for each variable measured. Results falling outside the tolerable limits indicate problems in the analytical procedure, or more general quality problems in the laboratory. The tolerable limits were set in order to act as a driving force to reduce measurement uncertainty and increase the comparability of results among the participating laboratories. As a result, the tolerable limits have, in some cases, been adjusted downwards in order to maintain their role as a driver for quality improvement as an increasing number of the laboratories meet this quality requirement.

Within the ICP Forests programme the participation and if needed a re-qualification in different ring tests is mandatory for all laboratories which are analysing samples from the ICP Forests programme.

In order to participate in the ring tests, each laboratory has to register on-line. Information about the registration procedure will be sent to all responsible persons for the ring tests in the laboratory, the NFC and the ring test will be announced on the ICP Forests webpage.

These ring tests are carried out between the involved laboratories at regular intervals in order to ensure comparability of analytical data. This involves the dispatch several samples to the participating laboratories. Prior to the dispatch of the ring test samples to the participating laboratories, the samples must be checked for homogeneity, and should be analysed using previously agreed analytical methods. The current list with the agreed analytical method codes is online available in the explanatory items from the LQA files of the different surveys (see: <https://icp-forests.org/documentation>).

The participating laboratories should carry out the ring tests as a part of their normal laboratory analysis runs so that the functioning of their normal routine activities can be checked.

For the standard evaluation the median value is used as target value of the ringtest. For the extended evaluation the outlier free mean value of all labs results is used as target value. For this extended evaluation there are a number of computer programs on the market that comply with standards such as DIN 38402/42 (2005-09), and these can be used for evaluating the analysis data. Custom-made programmes can also be used. The deviation from the target value and the coefficient of variation must be reported for each parameter and for each sample. The used evaluation procedures can be found for each survey on the ICP Forests QA/QC webpage.

In order to evaluate the results of ring tests and of the participating laboratories, tolerable limits from the target value, expressed as a percentage for each parameter and method, have to be determined. As a rule, the permitted deviations for double-stepped analytical methods (e.g. digestion/extraction and subsequent determination of the element concentration in the solution) are significantly larger than for direct element determination. A special procedure was foreseen for result below the limit of quantification. A maximum acceptable limit of quantification (LOQ) was set to avoid the use of not sensitive enough

analytical methods. If a LOQ above this limit is reported the laboratory will fail for this parameter/sample combination.

All laboratories participating within ICP Forests monitoring programme will get/can download a qualification report after taking part in a ring test. In this report, information about the analysed and not analysed parameters and the passing of the qualification criteria for each parameter will be listed.

The qualification criterion is that 50 % or more of the results of all ring test samples for a particular parameter must be within the appropriate tolerable limit.

The WG on QC/QA in Laboratories and the various expert panels of the ICP Forests programme have proposed tolerable limits for all samples and parameters. They are described in detail in the following chapters.

Laboratories without qualification for all parameters have to requalify by reanalysis of the ring test samples and can receive help through the assistance program for laboratories organized by the Working Group QA/QC in Laboratories. The laboratories have to report the new results to the organizers of the ring test together with the original reports of the analytical instruments and information about weight factors, dilution factors, control charts etc. and information about the reasons for the bad results during the ring test and the measures against similar errors in future. The ring test organizers will then decide about the report from the laboratory. If the results are within the tolerable limits and the submitted additional information is consistent the laboratory will receive a requalification report.

When a lab did not qualify and did not make efforts to requalify, ICP Forests PCC will send a letter to the National Focal Centre and inform them about the consequence that their data possibly cannot be used for evaluations on an European level.

The results of the ring tests are integrated in the database of the PCC (see 3.7). This means that the bad ring test results will be marked as disqualified and this information can be used as a selection criterion for the monitoring data used in evaluations.

3.5.1.1 Water (deposition and soil solution) ring tests

Water ring test samples, have been stabilized (i.e. by means of filtration through a 0.45 µm membrane filter and addition of appropriate acid where required). When mailed to the laboratories, the samples have to be packed in non-breakable flasks, and water samples should be kept cool during transportation. It is necessary to set a time period for completion of analysis and reporting of results. This avoids chemical/biological changes in the samples which, in turn, would lead to differences in the results.

Contact address, time schedule, evaluation procedure and older ring test reports from the *Atmospheric deposition and soil solution Working Ringtest programme* are available under <https://www.icp-forests.net/about-us/experts-committees/committees/working-group-on-quality-assurance-and-quality-control-in-laboratories/atmospheric-deposition-and-soil-solution-working-ringtest-programme>.

The tolerable limits and maximum acceptable LOQ for water ringtests are given in Table 10. In case of very low concentrations (more than 33% of the laboratories reports a LOQ) this parameter/sample combination will be manually excluded from the evaluation.

Table 10: Tolerable Limits and max. accept. LOQ for water ring tests (Kowalska, 2026)

Parameter	Unit	Conc. Range low	Tolerable Limit low	Conc. Range high	Tolerable Limit high	max. LOQ
Alkalinity	µeq/l	≤ 100	± 40%	>100	± 25%	10
Ammonium	mg-N/l	≤ 0.25	± 25%	> 0.25	± 15%	0.08
Calcium	mg/l	≤ 0.25	± 20 %	> 0.25	± 15%	0.2
Chloride	mg/l	≤ 1.5	± 25 %	> 1.5	± 15%	0.2
Conductivity (at 25 C)	µS/cm	≤ 10	± 20 %	> 10	± 10%	5
Dissolved Organic Carbon	mg-C/l	≤ 1	± 30 %	> 1	± 20%	1
Magnesium	mg/l	≤ 0.25	± 25 %	> 0.25	± 15%	0.1
Nitrate	mg-N/l	≤ 0.5	± 25 %	> 0.5	± 15%	0.08
pH	pH	> 5	0.1 units	≤ 5	0.2 units	-
Phosphate	mg P/l	≤ 0,1	± 20 %	> 0,1	± 20%	0.1
Potassium	mg/l	≤ 0.5	± 25 %	> 0.5	± 15%	0.4
Sodium	mg/l	≤ 0.5	± 25 %	> 0.5	± 15%	0.1
Sulphate	mg-S/l	≤ 1	± 20 %	> 1	± 10%	0.1
Total Nitrogen	mg-N/l	≤ 0.5	± 40 %	> 0.5	± 20%	0.5
Aluminium	mg/l	≤ 0.1	± 30 %	> 0.1	± 15%	0.05
Iron	mg/l	≤ 0,02	± 30 %	> 0,02	± 30 %	0.02
Manganese	mg/l	≤ 0.025	± 15%	> 0.025	± 10%	0.01
Cadmium	µg/l	≤ 1	± 40 %	> 1	± 30%	0.1
Cobalt	µg/l	≤ 1	± 40 %	> 1	± 30%	0.1
Chromium	µg/l	≤ 1	± 40 %	> 1	± 20%	0.5
Copper	µg/l	≤ 2	± 40 %	> 2	± 20 %	1
Nickel	µg/l	≤ 1	± 40 %	> 1	± 20 %	0.5
Lead	µg/l	≤ 1	± 40 %	> 1	± 25 %	0.5
Zinc	µg/l	≤ 30	± 35 %	> 30	± 25 %	10

3.5.1.2 Soil ring tests

Contact address, time schedule, evaluation procedure and older ring test reports from the *Soil Ring test programme* are available under <https://www.icp-forests.net/about-us/experts-committees/committees/working-group-on-quality-assurance-and-quality-control-in-laboratories/soil-ringtest-and-ga/qc-information>. The used tolerable limits and maximum acceptable LOQ for soil ring tests are given in Table 11. In case of very low concentrations (more than 33% of the laboratories reports a LOQ) this parameter/sample combination will be manually excluded from the evaluation.

Table 11: Tolerable Limits and max. accept. LOQ for soil ring tests (Jakovljević, 2026)

Parameter	Unit	Conc. Range low	Tolerable Limit low	Conc. Range high	Tolerable Limit high	max. LOQ
Moisture	%	≤1.0	25	>1.0	15	0.2
Particle size clay	%	≤10.0	50	>10.0	35	1
Particle size silt	%	≤20.0	45	>20.0	30	1
Particle size sand	%	≤30.0	45	>30.0	25	1
pH _{CaCl2}	pH	≤ 1	5	> 1	5	-
pH _{H2O}	pH	≤ 1	5	> 1	5	-
CaCO ₃	g/kg	≤50	130	>50	40	5
OC	g/kg	≤25	20	>25	15	2
Total N	g/kg	≤1.5	30	>1.5	10	0.2
Exchangeable Acidity	cmol(+)/kg	≤1.00	90	>1.00	35	0.25
Exchangeable Al	cmol(+)/kg	≤0.50	105	>0.50	30	0.1
Exchangeable Ca	cmol(+)/kg	≤1.50	65	>1.50	20	0.1
Exchangeable Fe	cmol(+)/kg	≤0.02	140	>0.02	50	0.1
Exchangeable K	cmol(+)/kg	≤0.10	45	>0.10	30	0.1
Exchangeable Mg	cmol(+)/kg	≤0.25	50	>0.25	20	0.1
Exchangeable Mn	cmol(+)/kg	≤0.03	45	>0.03	25	0.1
Exchangeable Na	cmol(+)/kg	≤ 1	80	> 1	80	-
Free H	cmol(+)/kg	≤ 1	100	> 1	100	0.25
Extractable Al	mg/kg or ppm	≤2500	50	>2500	20	50
Extractable Ca	mg/kg or ppm	≤500	70	>500	30	100
Extractable Cd	mg/kg or ppm	≤0.25	100	>0.25	55	1
Extractable Cr	mg/kg or ppm	≤10	40	>10	25	3
Extractable Cu	mg/kg or ppm	≤5	40	>5	15	2
Extractable Fe	mg/kg or ppm	≤2500	40	>2500	15	50
Extractable Hg	mg/kg or ppm	≤ 1	75	> 1	75	0.05
Extractable K	mg/kg or ppm	≤500	60	>500	40	100
Extractable Mg	mg/kg or ppm	≤500	60	>500	15	70
Extractable Mn	mg/kg or ppm	≤150	30	>150	15	8
Extractable Na	mg/kg or ppm	≤75.0	65	>75.0	50	100
Extractable Ni	mg/kg or ppm	≤10	40	>10	15	3
Extractable P	mg/kg or ppm	≤150	45	>150	20	50
Extractable Pb	mg/kg or ppm	≤ 1	30	> 1	30	5
Extractable S	mg/kg or ppm	≤ 1	35	> 1	35	50
Extractable Zn	mg/kg or ppm	≤20	40	>20	20	4
Reactive Al	mg/kg or ppm	≤750	30	>750	15	100
Reactive Fe	mg/kg or ppm	≤1000	30	>1000	15	100
Total Al	mg/kg or ppm	≤20000	35	>20000	10	50
Total Ca	mg/kg or ppm	≤1500	20	>1500	15	100

Total Fe	mg/kg or ppm	≤7000	20	>7000	10	50
Total K	mg/kg or ppm	≤7500	15	>7500	10	100
Total Mg	mg/kg or ppm	≤1000	60	>1000	10	70
Total Mn	mg/kg or ppm	≤200	25	>200	10	8
Total Na	mg/kg or ppm	≤1500	20	>1500	10	100
Oxal P	mg/kg or ppm	≤ 1000	30 %	30 %	30 %	100

3.5.1.3 Plant (foliar, litterfall and ground vegetation biomass and nutrients) ring tests

Contact address, time schedule, evaluation procedure and older ring test reports from the *Needle/Leaf Interlaboratory Comparison Programme* are available under <https://www.icp-forests.net/about-us/experts-committees/committees/working-group-on-quality-assurance-and-quality-control-in-laboratories/foilage-and-litterfall-ringtest-and-qa/qc-information>. The used tolerable limits and maximum acceptable LOQ for plant ring tests are given in Table 12. In case of concentrations below the “lowest evaluated result” this parameter/sample combination will be manually excluded from the evaluation.

Table 12: Tolerable Limits and max. accept. LOQ and evaluation limit for foliage and litterfall ring tests (Fürst 2026)

Parameter	Unit	Conc. Range low	Tolerable Limit low	Conc. Range high	Tolerable Limit high	max. LOQ	Lowest evaluated result
Arsenic	ng/g	≤ 50	30%	> 50	20%	50	20
Boron	µg/g	≤ 5.0	30%	> 5.0	20%	1	-
Cadmium	ng/g	≤ 50	30%	> 50	30%	50	20
Calcium	mg/g	≤ 3.0	15%	> 3.0	10%	0.5	-
Carbon	g/100g	≤ 10	5%	> 10	5%	10	-
Chromium	µg/g	≤ 1	35%	> 1	25%	1	0.5
Cobalt	µg/g	≤ 0.1	35%	> 0.1	25%	0.1	0.05
Copper	µg/g	≤ 1	20%	> 1	20%	1	1
Iron	µg/g	≤ 20	30%	> 20	20%	5	-
Lead	µg/g	≤ 0.50	40%	> 0.50	30%	0.50	0.20
Magnesium	mg/g	≤ 0.50	15%	> 0.50	10%	0.3	-
Manganese	µg/g	≤ 20	20%	> 20	15%	5	-
Mercury	ng/g	≤ 50	30%	> 50	20%	20	10
Nickel	µg/g	≤ 1	30%	> 1	20%	1	0.50
Nitrogen	mg/g	≤ 5.0	15%	> 5.0	10%	2	-
Phosphorous	mg/g	≤ 0.50	15%	> 0.50	10%	0.3	-
Potassium	mg/g	≤ 1.0	15%	> 1.0	10%	0.5	-
Sulphur	mg/g	≤ 0.50	20%	> 0.50	15%	0.3	-
Zinc	µg/g	≤ 20	20%	> 20	15%	5	-

3.5.2 Exchange of knowledge and expertise amongst laboratories

The inter-laboratory comparisons conducted within the framework of ICP Forests are aimed at testing the proficiency of the laboratories, i.e. evaluating the comparability of the results and, if possible, identifying the main causes of errors. The laboratories must be involved in

discussions on the outcome of the ring tests in order to assess and where necessary optimise their analytical quality.

Laboratories with unacceptable results in ring tests will be invited to participate in an assistance programme organised by the WG on QA/QC in Laboratories. Close cooperation between these laboratories and laboratories with good laboratory practices is considered to be an effective way of improving laboratory proficiency.

When determining the scope for assistance, it is necessary to take into account, not only the results of the ring test but the current state of the implementation of a quality programme in the laboratory, as well as the analytical methods used in the laboratory in question. Such information will be ascertained beforehand from a questionnaire that the laboratory will be obliged to complete. The assistance will consist of a few days' visit to the laboratory, as well as a return visit, in order to identify and rectify easily detectable problems in the laboratory organisation and/or specific analytical processes.

It is essential that the members of the staff actually involved in the analytical work participate in the assistance programme.

The initial step of the assistance programme will entail drafting a list of analytical problems, with the emphasis on specific parameters analysed in the ICP Forests monitoring programme. Following from the inter-laboratory exchange visits, a short report will be produced detailing the laboratory's activities, the analytical problems encountered and suggestions about how best they can be remedied. Through this assistance programme, the laboratory will be provided with sufficient information to enable them to make improvements in the quality of their analytical results.

3.5.2.1 Exchange of analytical expertise

All laboratories are strongly invited to share their experience through internal **info-sheets**, developed as an easy tool for the exchange of information among laboratories about studies carried out in the laboratory which otherwise would not be published. The info-sheets are short Word files containing concise information about method comparison, development and implementation of new methods, material tests (e.g. on contamination or adsorption problems), sample pre-treatment, sample storage and technical information. Thus the work performed in one laboratory can help to avoid duplication in others.

The circulation of information between the WG on QA/QC in Laboratories and the participating laboratories is ensured through the WG's own **website**. This information, including details about past and ongoing ring tests, Excel files for QA/QC, downloadable scientific publications, analytical info-sheets, relevant contact addresses and useful links can be found at <http://icp-forests.net/group/qualityinlaboratories>.

A forum for sharing analytical experience is the bi-annual meeting of the heads of the laboratories. All laboratories are invited to give a presentation about their analytical work, the methodical problems and about their experience with new instrumentation.

3.5.2.2 Exchange of samples

The exchange of a limited number of routine samples between two laboratories is a simple and easy way to test the quality and comparability of the methods used. About 20 routine samples should be analysed in each laboratory and the results compared. This ensures that differences in the analytical methods used and problems encountered can be quickly and easily be identified, and steps taken to rectify the situation.

3.6 Quality indicators

The development of the quality over time can be followed by using quality indicators.

While, there are a number of quality indicators that can be used to evaluate the development of the participating laboratories QC/QA programme within ICP Forests, only 2 indicators were ultimately selected:

- Percentage of the results of a ring test within tolerable limits -
- Percentage of the results of a ring test with a precision <10% (not applicable to water ring tests)

They can be determined from results of the ring tests.

3.6.1 Percentage of the results of a ring test within tolerable limits

In each ring test, the number of results within the tolerable limits for all mandatory parameter will be related as a percentage to the total number of possible results. Where results are missing, they will be counted as outside the tolerable limit. It is expected that the percentage of results within the tolerable limits should increase as the laboratories analytical expertise improves over time.

3.6.2 Percentage of the results of a ring test with a precision <10%

Normally, the precision (i.e. the repeatability of a result within a laboratory) should be <10 % for all parameters. In ring tests, with the exception of water samples, each sample typically has to be analysed 3 or 4 times. Therefore, where possible, the precision for each parameter can be calculated. The number of times the precision is <10 % can then be determined as a percentage of the total number of results where this calculation could be made.

Ideally, the precision <10 % should be between 90 to 100 % for all parameters analysed and should become constant over time.

3.7 Quality reports

In the ICP Forests monitoring programme it is mandatory to submit a LQA-File with the monitoring data from deposition, foliage, litterfall, ground vegetation biomass and nutrients, soil and soil solution. To ensure the linkage to the monitoring data, the quality report must have the same key information as the data submission report (e.g. plot No., country code, year, lab code). The quality information parameters which have to be reported are:

- country code
- year
- plot No.
- start and end date (needed for linking to the ring test results)
- lab code
- LOQ for each parameter (if needed) in the same units of the monitored parameter
- method codes (coded like in ring test reports) for each parameter,
- mean and standard deviation (%) for each parameter from control charts (if a laboratory use more than one control chart for a parameter it has to submit only data from one control chart in a normal concentration range) in the same units of the monitored parameter.

The quality report forms are part of the data submission forms (see ICP Forests Manual Part XVII Data submission forms).

A summary of each ring test is submitted from the ring test provider after the re-qualification period to PCC. This file contains the following information:

- survey code (e.g. FO, LF, SS, SO, DE)
- survey year (link to the corresponding LQA-File)
- ring test number
- method codes (should be the same like in the LQA-File)
- lab code (link to the corresponding LQA-File)
- ring test result (percentage of correct results)
- ring test result (percentage of correct results) after re-qualification

4 References

- Analytical Methods Committee. 1987. Recommendations for the definition, estimation and use of the detection limit. *Analyst*, 112: 199-204
- A.P.H.A., AWWA & WEF. 2005. Standard methods for the examination of water and wastewater. 21th ed. American Public Health Association, Washington.
- Clarke, N., Danielsson, L.-G. 1995. The simultaneous speciation of aluminium and iron in a flow-injection system. *Analytica Chimica Acta*, 306: 5-20.
- Clarke, N., Wu, Y. and Strand, L.T. 2007. Dissolved organic carbon concentrations in four Norway spruce stands of different ages. *Plant and Soil*, 299: 275-285.
- Cools, N., Verschelde, P., Quataert, P., Mikkelsen, J. and De Vos, B. 2006. Quality Assurance and Quality control in Forest Soil Analysis: 4th FSCC Interlaboratory Comparison. INBO.R.2006.6. Forest Soil Coordinating Centre, Research Institute for Nature and Forest, Geraardsbergen, Belgium. 66 pages + annexes (on CD-Rom).
- Currie, L.A. 1999a. Nomenclature in evaluation of analytical methods including detection and quantification capabilities (IUPAC recommendations 1995). *Analytical Chimica Acta*, 391: 105-126.
- Currie, L.A. 1999b. Detection and quantification limits: origins and historical overview. *Analytical Chimica Acta*, 391, 127–134.
- De Vos, B., Lettens, S., Muys, B., Deckers, S. 2007. Walkley-Black analysis of forest soil organic carbon: recovery, limitations and uncertainty. *Soil Use and Management* 23 (3): 221-229.
- De Vos, B., Cools, N. 2011. Second European Forest Soil Condition Report Survey. INBO.R.2011.35. Research Institute for Nature and Forest, Brussel. D/2011/3241/286 Report N° INBO.R.2011.35 ISSN: 1782-9054
- DIN 38402. 2005. Deutsche Einheitsverfahren zur Wasser-, Abwasser- und Schlammuntersuchung – Allgemeine Angaben (Gruppe A) Ringversuche, Auswertung (A42).
- Erisman, J.W., Möls, H., Fonteijn, P., Geusebroek, M., Draaijers, G., Bleeker, A. and van der Veen, D. 2003. Field intercomparison of precipitation measurements performed within the framework of the Pan European Intensive Monitoring Program of ICP Forests. *Environ. Pollut.* 125: 139-155.
- Fürst, A. 2019. 21st Needle/Leaf Interlaboratory Comparison Test 2018/2019, Austrian Research Center for Forests (ISBN 978-3-903258-12-9), Vienna/Austria.
- ISO 5725-2. 1994. Accuracy (trueness and precision) of measurement methods and results - Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method. International Organization for Standardization. Geneva, Switzerland. (available at www.iso.ch)

- ISO 7870-2. 2013. Control charts – Part2: Shewhart control charts. International Organization for Standardization. Geneva, Switzerland. (available at www.iso.ch)
- ISO 10693. 1995. Reviewed and confirmed in 2016. Soil Quality – Determination of carbonate content – Volumetric method. International Organization for Standardization. Geneva, Switzerland. 7 p. (available at www.iso.ch)
- ISO 10694. 1995. Reviewed and confirmed in 2016. Soil Quality – Determination of organic and total carbon after dry combustion (elementary analysis). International Organization for Standardization. Geneva, Switzerland. 7 p. (available at www.iso.ch)
- ISO 11277. 2009. Soil Quality – Determination of particle size distribution in mineral soil material – Method by sieving and sedimentation. International Organization for Standardization. Geneva, Switzerland. 30 p. (available at www.iso.ch)
- ISO Guide 30, 2015. Reference materials - Selected terms and definitions. International Organization for Standardization. Geneva, Switzerland. 8 p. (available at www.iso.org)
- IUPAC 1997. Compendium of chemical terminology, 2nd ed. Blackwell, Oxford.
- König N, Kowalska A, Brunialti G, Ferretti M, Clarke N, Cools N, Derome J, Derome K, De Vos B, Fürst A, Jakovljević T, Marchetto A, Mosello R, O'Dea P, Tartari GA, Ulrich E, 2010: Quality Assurance and Control in Laboratories. 53 pp. Part XVI. In: Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. UNECE, ICP Forests Programme Co-ordinating Centre, Hamburg. ISBN: 978-3-926301-03-1.
- Miles, L.J. & K.J. Yost. 1982. Quality analysis of USGS precipitation chemistry data for New York. *Atmosph. Env.*, 16: 2889-2898.
- Mosello, R., M. Amoriello, T. Amoriello, S. Arisci, A. Carcano, N. Clarke, J. Derome, N. Koenig, G. Tartari, E. Ulrich. 2005. Validation of chemical analyses of atmospheric deposition in forested European sites. *J. Limnol.*, 64: 93-102.
- Mosello, R., T. Amoriello, S. Benham, N. Clarke, J. Derome, K. Derome, G. Genouw, N. Koenig, A. Orrù, G. Tartari, A. Thimonier, E. Ulrich, A-J Lindroos. 2008. Validation of chemical analyses of atmospheric deposition on forested sites in Europe: 2. DOC concentration as an estimator of the organic ion charge. *J. Limnol* 67: 1-15
- Nordtest report TR 569. 2012. Internal Quality Control – Handbook for Chemical Laboratories. ISSN 0283-7234 / Edition 4 (Approved 2012-01)
- Stefan, K., Fürst, A., Hacker, R., Bartels, U. 1997. Forest Foliar Condition in Europe - Results of large-scale foliar chemistry surveys, ISBN 3-901347-05-4, EC-UN/ECE -FBVA 1997.
- Stumm, W. & J.J. Morgan. 1981. Aquatic chemistry. Wiley & Sons, New York: 780 pp.
- Sulkava, M., Luysaert, S., Rautio, P., Janssens, I. A., Hollmén J. 2007. Modeling the effects of varying data quality on trend detection in environmental monitoring Elsevier Science Direct, *Ecological Informations* 2, 167-176.
- Thomsen, V., Schatzlein, D. & Mercurio, D. 2003. Limits of detection in spectroscopy. *Spectroscopy*, 18, 112–114. van Reeuwijk, L.P and Houba, V.J.G. 1998. Guidelines for Quality Management in Soil and Plant Laboratories. FAO Soils Bulletin – 74. FAO. Rome.
- Ukonmaanaho, L., Pitman R, Bastrup-Birk A, Breda N, Rautio P, 2020: Sampling and Analysis of Litterfall., Part XIII. In: Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. UNECE ICP Forests Programme Co-ordinating Centre, Eberswalde, ISBN: 978-3-926301-03-1. [<http://www.icp-forests.org/Manual.htm>] , 15 p.

Annex I

I.1 Excel worksheet for ion balance (with and without DOC correction), conductivity, N balance and Na/Cl ratio checks.

The Excel worksheet permits different quality checks to be performed, as described in the text (Chapter 3.4.1). It can be downloaded from the ICP Forests website (<https://www.icp-forests.net/about-us/experts-committees/committees/working-group-on-quality-assurance-and-quality-control-in-laboratories/atmospheric-deposition-and-soil-solution-working-ringtest-programme>). It can be used as a tool for checking the results and as a file for data storage, according to the requirements of the operator and the procedure for data handling in the laboratory. The sheet contains green cells in which new data are to be entered using the units given at the top of the column. The units are the same as those in the ICP Forests database, and the correct use of units is essential for all further checking (ion balance, measured/calculated conductivity check etc.) of the results. Information about the type of sample (BOF, THR, STF) and the type of forest cover on the plot (BL = broadleaves, CON = conifers) is required for DOC correction of the ion balance calculation. They are used as strings for the calculations, and therefore they must be entered correctly.

After entering the data in the green cells, the sheet calculates the **ion balance** (in accordance with the method described in Chapter 3.4.1.1.1) and the **calculated conductivity**, with and without correction for the ion strength (Chapter 3.4.1.2). The results of the tests are expressed in the worksheet as OK (test passed) or NO (test not passed) in the columns highlighted in yellow. The **DOC contribution to ion balance** is calculated using the empirical regressions described in Chapter 3.4.1.1.2. Selection of one of the three alternative regression equations is based on the codes depicting the type of sample and the type of forest cover, as given in Table 5.

The principles and validation criteria for the **Na/Cl ratio** and **N forms balance** (i.e. N balance check) are described in Chapters 3.4.1.3 and 3.4.1.4. The **graphs** help in interpreting the results and identifying outliers. There are three graphs in the Excel worksheet: one for the ion balance, one for the comparison between measured and calculated conductivity, and one for the Na/Cl ratio. Other graphs can easily be added by the analysts themselves, e.g. for the comparison between measured conductivity and sum of anions or sum of cations and the conductivity corrected for the contribution of H⁺ and the sum of cations, with H⁺ excluded (Figure 7).

The Excel worksheet includes a sheet (**notes**) giving the meaning of the acronyms and a summary of the adopted validation criteria.

The theoretical and statistical bases applied in developing the validation criteria for deposition data in the worksheet are based on thousands of full analysis sets provided by different laboratories, and are representative of different forest types and climatic conditions in Europe, ranging from northern Finland to southern Italy. The results of this work have been published in two papers (Mosello et al., 2005, 2008).

I.2 Excel worksheet for control charts

The Excel worksheet that can be used for creating control charts (Chapter 3.2.1), can be downloaded from the ICP Forests website (<https://www.icp-forests.net/about-us/experts-committees/committees/working-group-on-quality-assurance-and-quality-control-in-laboratories/atmospheric-deposition-and-soil-solution-working-ringtest-programme>): click on “Excel file with instruction and example of control chart use”. It also includes instructions on how to use the worksheet.

I.3 List of commercially available reference materials

Reference material	Matrix	Type	Comments	Supplier
ERM-CA408	water	simulated rain water	low contents	European Commission, Directorate-General Joint Research Centre Directorate F – Health, Consumers and Reference Materials Reference Materials Unit Retieseweg 111 B-2440 Geel Belgium E-Mail: jrc--rm- distribution@ec.europa.e u Webpage: https://ec.europa.eu/jrc/e n/reference-materials
ERM-CA616	water	Ground water	high carbonate content	see above
ERM-CA615	water	Groundwater	metals	see above
BCR-142R	soil	light sandy soil		see above
BCR-143R	soil	sewage sludge amended soil	heavy metal pollution	see above
BCR-146R	soil/organic material	sewage sludge of industrial origin	heavy metal pollution	see above
BCR-320R	soil	channel sediment		see above
FSCC RM1	soil	loamy forest soil	moderate concentrations , rather acid	ICP Forests Soil Coordinating Centre Gaverstraat 4 9500 Geraardsbergen Belgium Nathalie.Cools@inbo.be
Sample A from the 8 th soil inter- laboratory test (ICP Forests)	soil	terra rossa - red soil		Croatian Forest Research Institute Division for forests ecology Dr Tamara Jakovljević Cvjetno naselje 41 10450 Jastrebarsko Croatia Email:tamaraj@sumins.h r Webpage:www.sumins.h r
Sample C from the 8 th soil inter- laboratory test (ICP Forests)	soil	loam	High carbon content	see above
Sample E from the 9 th soil inter-	soil	forest floor	OC 10-20%	see above

Reference material	Matrix	Type	Comments	Supplier
laboratory test (ICP Forests)				
1570a	plant	spinach leaves	Trace elements	European Commission, Directorate-General Joint Research Centre Directorate F – Health, Consumers and Reference Materials Reference Materials Unit Retieseweg 111 B-2440 Geel Belgium E-Mail: jrc--rm-distribution@ec.europa.eu Webpage: https://ec.europa.eu/jrc/en/reference-materials
1573a	plant	tomato leaves		see above
Sample 3 from the 11 th needle/leaf inter-laboratory test (ICP Forests)	plant	maple leaves		Federal Research and Training Centre for Forests, Natural Hazards and Landscape Mr. Alfred Fürst Seckendorff-Gudent Weg 8 A-1131 Vienna Austria E-Mail: alfred.fuerst@bfw.gv.at Web: www.ffcc.at Order per fax: +43-1-87838-1250
Sample 4 from the 21 st needle/leaf inter-laboratory test (ICP Forests)	plant	beech leaves (litter fall)	& heavy metals	see above
Sample 3 from the 16 th needle/leaf inter-laboratory test (ICP Forests)	plant	pine needles		see above
Sample 2 from the 19 th needle/leaf inter-laboratory test (ICP Forests)	plant	spruce needles	& heavy metals	see above

I.4 Definitions and terminology

accuracy – the closeness of agreement between a test result and the accepted reference value.

NOTE: The term accuracy, when applied to a set of test results, involves a combination of random components and a common systematic error or bias component. (ISO 3534-1:1993)

action limits – the limits on a control chart, normally set at three standard deviations either side of the mean.

blank – is defined as the sample without the analyte.

blank determination - an analysis of the sample without the analyte or attribute, or an analysis without the sample e.g. going through all steps of the procedure with the reagents only. (van Reeuwijk and Houba, 1998)

blank chart – a type of control chart used to detect the possibility of occasional contamination with the use of blank.

calibration – operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication. (JCGM 2012)

control levels/limits – the limits on a control chart such that, when data points fall outside them, special causes of variation must be suspected. These are normally three standard deviations either side of the mean.

control sample – (sequence – control sample) a sample with an extreme content of the analyte but falling within the working range of the method. It is inserted at random in a batch to verify the correct order of the samples. (van Reeuwijk and Houba, 1998)

conventional true value – quantity value attributed by agreement to a quantity for a given purpose. (JCGM 2012)

error (measurement error) – measured quantity value minus a reference quantity value (JCGM 2012)

or:

the collective noun for a departure of the result from the true value. (van Reeuwijk and Houba, 1998)

homogeneity - the degree to which items (e.g. tested substance) are similar.

instrument limit of detection (IDL) – the concentration equivalent to a signal, due to the analyte of interest, which is the smallest signal that can be distinguished from background noise by a particular instrument. The IDL should always be below the method detection limit, it is not used for compliance data reporting, but may be used for statistical data analysis and comparing the attributes of different instruments. (Standard Methods, 18th Edition)

interlaboratory comparison - organization, performance and evaluation of tests on the same or similar test items by two or more laboratories in accordance with predetermined conditions. (ISO/IEC 17043:2010)

limit of detection (LOD) - measured quantity value, obtained by a given measurement procedure, for which the probability of falsely claiming the absence of a component in a material is β , given a probability α of falsely claiming its presence. (JCGM 2012)

limit of quantification (LOQ) – performance characteristic that marks the ability of a CMP to adequately “quantify” an analyte (...) The ability to quantify is generally expressed in terms of the signal or analyte (true) value that will produce estimates having a specified relative standard deviation (RSD), commonly 10%. (IUPAC:1997)

local reference material (LRM) – a material prepared and standardized in a laboratory, used especially for daily control of analytical process.

or:

a local reference sample (in-house) for which one or more property values have been established by the user laboratory, possibly in collaboration with other laboratories. The

sample should be sufficiently stable and homogeneous for the properties concerned (van Reeuwijk and Houba, 1998)

matrix - the components of material system, except the analyte. Used to refer to the physical and chemical nature of the specimen, the substances present, and their concentrations. (Westgard J.O., 2003)

mean chart (X-chart) – a control chart used to check the repeatability of the measurements. In this chart the sample means are plotted in order to control the mean value of a variable.

measurement uncertainty – non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used. (JCGM 2012)

(method) validation – verification, where the specified requirements are adequate for an intended use. (JCGM 2012)

nominal value - rounded or approximate value of a characterizing quantity of a measuring instrument or measuring system that provides guidance for its appropriate use. (JCGM 2012)

outlier - an observation that is numerically distant from the rest of the data.

precision – the closeness of agreement between independent test results obtained under prescribed conditions. (ISO 3534-1:1993)

random errors - a component of measurement error that in replicate measurements varies in an unpredictable manner. (JCGM 2012)

range chart (R-chart) – a type of control chart used to check the repeatability of the analysis, usually of duplicate determinations. In this chart, the sample ranges are plotted in order to control the variability of a variable.

reference material (RM) – a secondary reference material or substance, one or more of whose property values are accurately determined by number of laboratories with a stated method, and which values are accompanied by an uncertainty at a stated level of confidence. The origin of the material and the data should be traceable (van Reeuwijk and Houba, 1998)

or:

a material, sufficiently homogeneous and stable with reference to specified properties, which has been established to be fit for its intended use in measurement or in examination of nominal properties. (JCGM 2012)

repeatability conditions – conditions where independent test results are obtained with the same method on identical test material in the same laboratory by the same operator using the same equipment within short intervals of time. (ISO 3534-1:1993)

or:

condition of measurement, out of a set of conditions that includes the same measurement procedure, same operators, same measuring system, same operating conditions and same location, and replicate measurements on the same or similar objects over a short period of time. (JCGM 2012)

replicate result - the result of replicated measurement. (van Reeuwijk and Houba, 1998)

reproducibility conditions – conditions where test results are obtained with the same method on identical material in different laboratories by different operators using different equipment. (ISO 3534-1:1993)

or:

condition of measurement, out of a set of conditions that includes different locations, operators, measuring systems, and replicate measurements on the same or similar objects. (JCGM 2012)

systematic error – a component of measurement error that in replicate measurements remains constant or varies in a predictable manner. (JCGM 2012)

traceability- a property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards through an unbroken chain of comparison (PAC, 1995, 67, 1699 (Nomenclature in evaluation of analytical methods including detection and quantification capabilities (IUPAC Recommendations 1995))

warning limits – the limits on a control chart, normally set at two standard deviations either side of the mean.

Annex II Minor changes after 2020

Date	Minor change to latest published version in 2020	Affected sections of this document
07/2022	To be consistent with the Manual Part XII on Sampling and Analysis of Needles and Leaves, Table 7 and Table 8 was updated. (Plausible ranges of element concentrations were fully updated with new values by Alfred Fürst in April 2021)	Table 7, 8
04/2026	Updated links	
04/2026	Updated numbers	Table 10, 11, 12