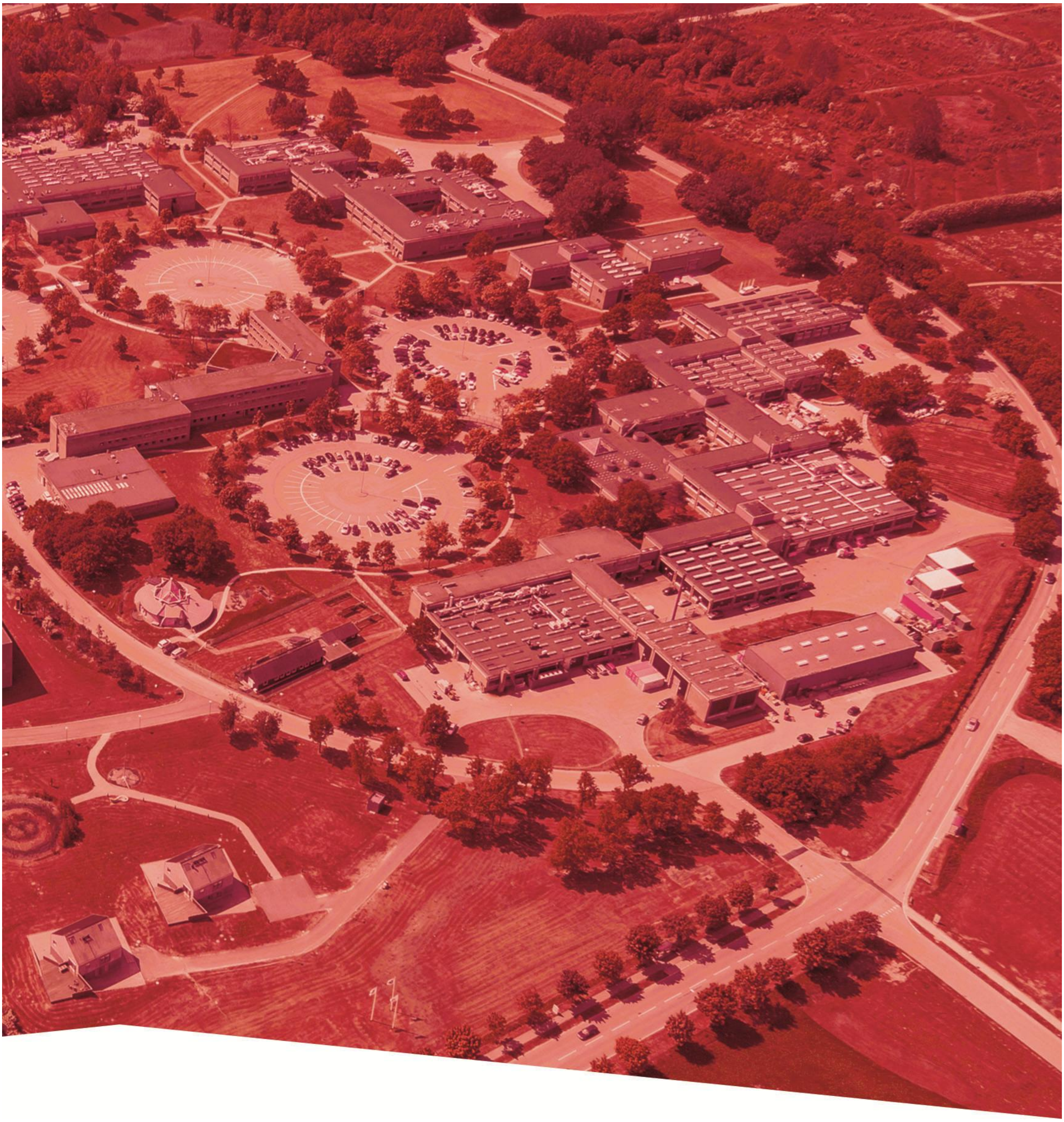

EURAMET P1685

Pilot study: Intercomparison of Soil Moisture Measurement

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Intercomparison of Soil Moisture Measurement

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September 2025

1. Introduction

This report gives the results and analysis of the interlaboratory comparison (ILC) performed in the joint research project (JRP) 21GRD08 SoMMet, "Metrology for multi-scale monitoring of soil moisture", as in accordance with its Activity 1.2.5.

The aim of the intercomparison is to test the measurement standards and methods developed by the partners in the project using soil samples.

The measurand is defined as the water mass fraction on wet basis, w_{water}. That is:

$$w_{water} = m_{water}/m_{sample},$$

where m_{water} is the mass of the water and m_{sample} is the mass of the original wet sample.

The intercomparison is carried out as a pilot study according to EURAMET Guide No. 4 Version 2.0 (04/2021) and DS/EN ISO/IEC 17043:2010

Four laboratories have participated in the analysis of soil moisture measurements in organic and inorganic soil samples.

The analysis shows no significant differences between the results obtained from the different laboratories for neither organic nor inorganic soil samples in all but a single metric – the median analysis for organic soil, where a single laboratory shows a significant difference towards the results of the other laboratories.

1.1. Participating laboratories

Danish Technological Institute (DTI), DK, Pilot

Centre Technique des Industries Aérauliques et Thermiques (CETIAT), FR

Český Metrologický Institut (CMI), CZ

Türkiye Bilimsel ve Teknolojik Arastırma Kurumu, Ulusal Metroloji Ensitüsü (TUBITAK-UME), TR

2. Protocol

The intercomparison was carried out according to the following scheme:

- The pilot laboratory prepared homogeneous soil samples of two soil types, organic and inorganic
- The pilot laboratory assessed the sample homogeneity using the loss-on-drying (LoD) method on 10 evenly spaced samples for each of the two soil types.
- The pilot laboratory shipped 10 samples of both organic and inorganic soil to each participating laboratory, including 3 samples of both organic and inorganic soil to be returned for testing the stability of the water content during shipping using the loss-on-drying (LoD) method.
- All laboratories measured water mass fraction of the soil samples using a primary measurement standard. In addition, the pilot laboratory measured the soil samples returned to the pilot laboratory by the participating laboratories.
- When all measurements had been performed, the pilot laboratory analysed the result

A copy of the protocol can be found in appendix 4.

All measurements were carried out in the period from January to April 2025.

3. Assessment of the homogeneity and stability of the samples

To account for homogeneity of the material, 10 samples were measured using Loss on Drying (LoD) at Danish Technological Institute. The homogeneity of the samples was calculated as the standard deviation of the measurements:

$$u_{homogeneity} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(\bar{x}_{homogeneity} - x_{homogeneity,i}\right)^2}$$

Here, $\bar{x}_{homogeneity}$ is the average value of the n =10 samples and $x_{homogeneity,i}$ is the value of the i'th sample.

The stability of the samples $(u_{stability})$ was assessed using 12 samples. 4 samples were shipped to each of the 3 external participating laboratories, who shipped them back to DTI after completing their regular measurements (but without opening the 4 samples packaging). At DTI, the water content was evaluated using LoD. $u_{stability}$ is now calculated as the standard deviation of the 12 samples:

$$u_{stability} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(\bar{x}_{stability} - x_{stability,i}\right)^2}$$

Here, $\bar{x}_{stability}$ is the average value of the n =12 samples and $x_{stability,i}$ is the value of the i'th sample.

Data for homogeneity and stability assessment can be found in appendix 2 and 3.

4. Data analysis

The main analysis of the data in this protocol is performed as a Degree of Equivalence between the laboratories, i.e. as a bilateral intercomparison between all participating laboratories.
In Section 5, further analysis are performed, namely

- E_n-values calculated using different reference values (weighted mean, un-weighted mean, median)
- χ^2-test to reveal if there is a general consistency on the reference values

4.1. Reported data

The reported measurements from the participating laboratories are summarized in Table 1 and Table 3. Here, the standard uncertainty on the mean value has been calculated as $u_{\bar{x}} = s(x)/\sqrt{n}$ where s(x) is the experimental standard deviation and n is the number of measurements performed by the laboratory.

Table 1: Reported values for organic soil

Laboratory	Mean Value	Reported average uncertainty (*k* = 1)	Standarddeviation of Mean	Combined Uncertainty	Expanded Uncertainty (*k* = 2)
	%w	%w	%w	%w	%w
CETIAT	18.73	0.26	0.09	0.28	0.56
CMI	19.13	0.08	0.08	0.12	0.23
DTI	18.77	0.23	0.10	0.25	0.50
TUBITAK-UME	18.79	0.18	0.06	0.19	0.38

Table 2: Sample stability and homogeneity for organic soil

Homogeneity	Stability
%w	%w
0.03	0.02

Table 3: Reported values for inorganic soil

Laboratory	Mean Value	Reported average uncertainty (*k* = 1)	Standard deviation of Mean	Combined Uncertainty	Expanded Uncertainty (*k* = 2)
	%w	%w	%w	%w	%w
CETIAT	18.78	0.39	0.21	0.44	0.89
CMI	19.38	0.07	0.04	0.08	0.17

DTI	19.23	0.24	0.04	0.24	0.48
TUBITAK-UME	19.49	0.14	0.05	0.15	0.30

Table 4: Stabilty and homogeneity for inorganic soil

Homogeneity	Stability
%w	%w
0.15	0.05

The probability density functions (PDF) for the participating laboratories are seen in Figure 1 and Figure 2. The PDF includes homogeneity and stability of the samples.

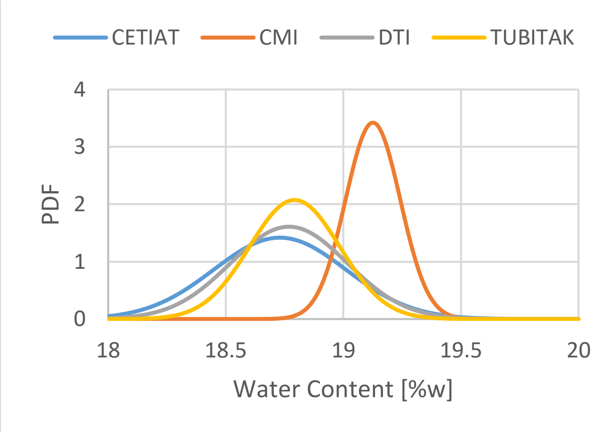

Figure 1: Probability density functions for the participating laboratories for *organic* soil

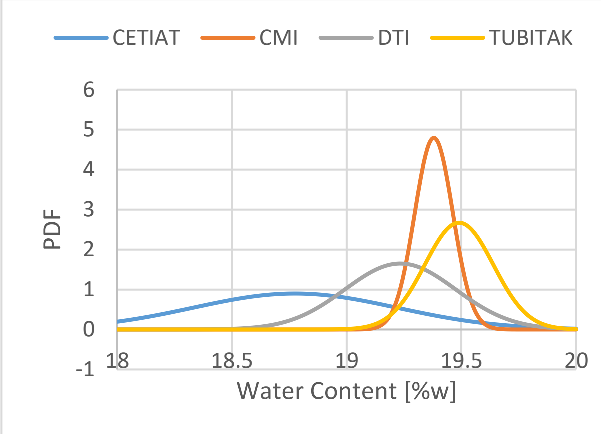

Figure 2: Probability density functions for the participating laboratories for *inorganic* soil

The reported mean values (%w) along with their expanded uncertainties are shown in Figure 3 and Figure 4.

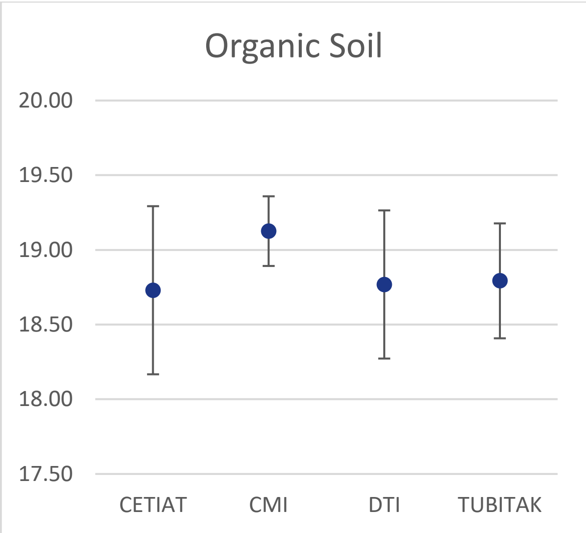

Figure 3: Reported mean value and expanded uncertainties for organic soil

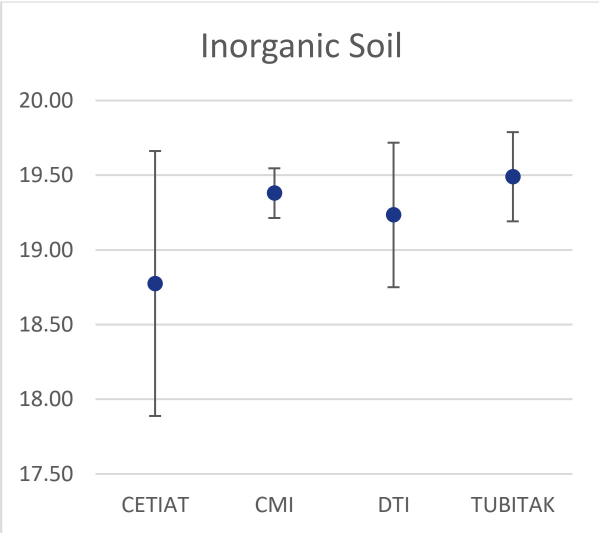

Figure 4: Reported mean value and expanded uncertainties for inorganic soil

4.2. Bilateral Degree of Equivalence

The bilateral Degree of Equivalence (DoE) is found using the following equation:

$$DoE = \frac{\bar{x}_i - \bar{x}_j}{2 \cdot \sqrt{u(\bar{x}_i)^2 + u(\bar{x}_j)^2 + u_{stability}^2 + u_{homogeneity}^2}}$$

for any two laboratories, i and j.

The uncertainty for the individual laboratory was taken as:

$$u(\bar{x}_i) = \sqrt{u_{i,reported}^2 + u_{i,\bar{x}}^2}$$

i.e. as the combination between the average stated uncertainty ($u_{i,reported}^2$) and the uncertainty of the mean of the reported values ($u_{i,\bar{x}}^2$).

The results from the bilateral DoE is seen in

Table 5 and Table 6. Two laboratories are considered to have comparable results, if the DoE is in the range [-1;1]. If the DoE is outside this range, the laboratories are considered to have obtained different measurement values.

Table 5: Degree of Equivalence for organic soil

DoE Organic

	CETIAT	CMI	DTI	TUBITAK
CETIAT		0.64	0.05	0.09
CMI	-0.64		-0.65	-0.73
DTI	-0.05	0.65		0.04
TUBITAK	-0.09	0.73	-0.04	

Table 6 Degree of Equivalence for inorganic soil

DoE Inorganic

	CETIAT	CMI	DTI	TUBITAK
CETIAT		0.71	0.47	0.80
CMI	-0.71		-0.24	0.24
DTI	-0.47	0.24		0.40
TUBITAK	-0.80	-0.24	-0.40	

From

Table 5 and Table 6 it is seen, that all participating laboratories are agreeing on a bilateral level for both organic and inorganic soil.

5. Analyses based on a consensus reference value

As mentioned in Section 4, further analysis is made on the reported data. These analysis attempt to find a consensus value, which all laboratories can be compared to.

With only 4 participating laboratories, any consensus value will have strong correlations to any reported mean value. Because of this, the following analysis should only be considered as good estimates. To obtain a proper consensus value, considerably more participating laboratories are required (preferably more than 20).

5.1. $\boldsymbol{E}_{\mathbf{n}}$-values

As a deciding value, E_{n}-values are calculated for both organic and inorganic soil.

A reference value based on consensus is found using three different methods for both soil types: Weighted mean, un-weighted mean, and median.

5.1.1. Reference value using the weighted mean

Under the assumption of having laboratories of equal quality, a weighted mean can be used as the reference value for analyzing the results. The weighted mean is found based on the equation

$$\bar{x}_{pt} = \frac{\sum_{i=1}^{n} w_i \bar{x}_i}{\sum_{i=1}^{n} w_i}$$

with weights

$$w_i = 1/u_i^2$$

where u_i is the stated uncertainty from the i'th laboratory.

The uncertainty of the mean value is found as

$$u(\bar{x}_{pt}) = \sqrt{\left(\sum_{i=1}^{n} \frac{1}{u_i^2}\right)^{-1} + u_{homogeneity}^2 + u_{stability}^2}$$

For each laboratory in the interlaboratory comparison, the relevant E_n-value can be found as

$$E_n = \frac{\bar{x}_i - \bar{x}_{pt}}{2 \cdot \sqrt{u(\bar{x}_{pt})^2 + u(\bar{x}_i)^2}}$$

For organic soil, the mean value, $\bar{x}_{pt}$= 18.97 with an uncertainty $u(\bar{x}_{pt})$ = 0.096, while it for inorganic soil is $\bar{x}_{pt}$ = 19.38 and $u(\bar{x}_{pt})$ = 0.18.

This leads to the following E_n-values:

Table 7 E_n -values for organic soil with weighted reference values

Laboratory	$E_n - value$
CETIAT	-0.6
CMI	0.7
DTI	-0.5
TUBITAK-UME	-0.6

Table 8 E_n -values for inorganic soil with weighted reference values

Laboratory	$E_n - value$
CETIAT	-0.9
CMI	0.0
DTI	-0.3
TUBITAK-UME	0.3

For the organic soil, all participants get numerical value of E_n lower than 1 and no laboratories are failing.

For the inorganic soil, all participants get numerical value of E_n lower than 1 and no laboratories are failing.

5.1.2. Reference value using the mean value

Since there is a large difference between the stated uncertainties from the individual laboratories, some laboratories will affect the weighted mean significantly more than others. With as few participants as are present in this ILC, a weighted mean might not be trustworthy.

Because of this, E_n-values with unweighted means, $\bar{x}_{pt}$, are also investigated. In this case, the reference value and the uncertainty of the reference value is taken as

$$\bar{x}_{pt} = \frac{1}{n}\sum_{i=1}^{n} \bar{x}_i$$

$$u(\bar{x}_{pt}) = \sqrt{u_{stability}^2 + u_{inhomogeneity}^2 + var(\bar{x}_i)}$$

$var(\bar{x}_i)$ being the variance of the reported mean values.

This approach gives mean values $\bar{x}_{pt}$ = 18.85 for organic soil with uncertainty $u(\bar{x}_{pt})$ = 0.19 and $\bar{x}_{pt}$ = 19.22 for inorganic soil with uncertainty $u(\bar{x}_{pt})$ = 0.35.

These values for mean and uncertainty give the following E_n-values

$$E_n = \frac{\bar{x}_i - \bar{x}_{pt}}{2 \cdot \sqrt{u(\bar{x}_{pt})^2 + u(\bar{x}_i)^2}}$$

Table 9 E_n-values for organic soil with un-weighted mean

Laboratory	$E_n - value$
CETIAT	-0.2
CMI	0.6
DTI	-0.1
TUBITAK-UME	-0.1

Table 10 E_n -values for inorganic soil with un-weighted mean

Laboratory	$E_n - value$
CETIAT	-0.4
CMI	0.2
DTI	0.0
TUBITAK-UME	0.4

For this analysis, all laboratories still obtain $|E_n| < 1$ for both soil types

5.1.3. Reference value using the median value

A more robust statistic for evaluating the participating laboratories is using the median values rather than a mean value.

The median provides a robust reference in the presence of possible outliers, helping to reduce undue influence from individual laboratories' results; however, with so few participants, even a single deviating laboratory can disproportionately impact consensus metrics.

The reference value and uncertainty for the median value is taken as

$$\bar{x}_{pt} = median(x_i)$$

i.e. the median of all reported values from all laboratories

$$u(\bar{x}_{pt}) = \sqrt{u_{stability}^2 + u_{inhomogeneity}^2 + \left(\frac{1.9}{\sqrt{n-1}} \cdot MAD\right)^2}$$

For an explanation of MAD, see Müller, (Müller, 2000).
In this calculation, the MAD is based on all reported values.

This approach gives median value $\bar{x}_{pt}$ = 18.78 for organic soil with uncertainty $u(\bar{x}_{pt})$ = 0.08 and $\bar{x}_{pt}$ = 19.28 for inorganic soil with uncertainty $u(\bar{x}_{pt})$ = 0.17.

These values for mean and uncertainty give the following E_n-values

Table 11 E_n-values for organic soil with median

Laboratory	$E_n - value$
CETIAT	-0.1
CMI	1.6
DTI	-0.1
TUBITAK-UME	0.2

Table 12 E_n-values for inorganic soil with median

Laboratory	$E_n - value$
CETIAT	-0.4
CMI	0.2
DTI	-0.1
TUBITAK-UME	0.4

As for the results using the mean value as reference, this analysis also shows that for organic soil, CMI has a numeric value of E_n larger than 1 (1.6), while all other laboratories have satisfactory results. For inorganic soil, all laboratories show satisfactory results.

5.2. χ^2-analysis

For all the reference values found in Section 5.1, a χ^2-value is calculated to see if the results are consistent with each other, i.e. if the results agree on the reference value.

For this analysis, a χ^2-value is found as

$$\chi^2 = \sum_{i=1}^{n} \frac{(\bar{x}_i - \bar{x}_{pt})^2}{u(\bar{x}_i)^2}$$

This value is compared to a reference value, χ^2_{ref}, which depends on the degree of freedom for χ^2. With 4 values of $\bar{x}_i$, there are 3 degrees of freedom, giving a reference $\chi^2_{ref} = 7.82$

For each of the reference values found in Section 5.1, the results are:

Table 13 χ^2-values for the different $\bar{x}_{pt}$

	Soil type	χ^2	Consistency
Weighted mean	Organic	4.00	Yes
	Inorganic	2.32	Yes
Un-weighted mean	Organic	0.78	Yes
	Inorganic	7.99	No
Median	Organic	16.82	No
	Inorganic	0.53	Yes

According to the above analysis, all consensus values, $\bar{x}_{pt}$ for both soil types are consistent with regards to the available data, apart from inorganic soil, analyzed with an un-weighted mean, and organic soil, analyzed using the median.

Differences between methods (weighted mean, unweighted mean, median) should be interpreted with caution due to the low number of participating laboratories. The relatively low number of participating laboratories limits the robustness of the consensus value estimates.

6. Conclusion and discussion

The EURAMET P1685 pilot study successfully carried out an interlaboratory comparison of soil moisture measurements for both organic and inorganic soil samples using gravimetric water content as the measurand. The study involved four participating laboratories (DTI, CETIAT, CMI, and TUBITAK-UME) and was conducted according to EURAMET Guide No. 4 and DS/EN ISO/IEC 17043:2010.

The sample homogeneity and stability were assessed. Homogeneity and stability assessments confirmed that the sample materials were suitable for interlaboratory comparison, with very low standard deviations (≤ 0.15 % w/w).

The bilateral Degrees of Equivalence (DoE) indicate that there are no significant differences between any pair of participants for both soil types.

Statistical analysis using consensus reference values (weighted mean, unweighted mean, median) highlighted that:

- For inorganic soil, all laboratories' results were consistent with each other for all reference values.
- For organic soil, one laboratory displayed a significant deviation in the median analysis ($E_n > 1$)

The median in general provides a robust reference in the presence of possible outliers, helping to reduce undue influence from individual laboratories' results; however, with so few participants, even a single deviating laboratory can disproportionately impact consensus metrics.

Differences between methods (weighted mean, unweighted mean, median) should be interpreted with caution due to the low number of participating laboratories. The relatively low number of participating laboratories limits the robustness of the consensus value estimates and future intercomparisons would benefit from a higher number of participants to enable more reliable group statistics.

Future work would also include more detailed analyses of participants' uncertainty budgets and development of a guideline on how to develop the uncertainty analyses.

Remark: Some typographical errors have been corrected on 3/2-2026.

7. Acknowledgement

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or EURAMET. Neither the European Union nor the granting authority can be held responsible for them.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

The project has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.

METROLOGY PARTNERSHIP

EURAMET

8. References

Müller, J. W. (2000). Possible Advantages of a Robust Evaluation of Comparisons. *Journal of Research of the National Institute of Standards and Technology*, 551-555.

Appendix 1 – Data reported by the participants

CETIAT Inorganic

Name of participant:	LNE-CETIAT
Method ID:	**Electrolysis of phosphoric acid in the presence of water**
Date of reporting:	19-03-2022

MEASUREMENT RESULTS

Report results for at least 7 samples obtained with a single measurement system.

	Water mass fraction			Ambient conditions			
Sample number	Estimate [%w]	Expanded unc. (k=2)	Date of measurement	Temperature [°C]	Humidity [%rh]	Pressure [hPa]	Additional information
1	18.66	0.78	19-02-2025	22±1	47±7	ambient pressure	the average weight of the sample is around 0,0207 g, time analysis 30 min, temperature analysis 60 °C ± 1 °C, flow rate 80 ml/min, one value is based on an average of three measurements
2	18.96	0.74	20-02-2025	22±1	47±7	ambient pressure	the average weight of the sample is around 0,0204 g, time analysis 30 min, temperature analysis 60 °C ± 1 °C, flow rate 80 ml/min, one value is based on an average of three measurements
3	18.09	0.84	10-03-2025	22±1	47±7	ambient pressure	the average weight of the sample is around 0,0194 g, time analysis 30 min, temperature analysis 60 °C ± 1 °C, flow rate 80 ml/min, one value is based on an average of three measurements
4	19.43	0.77	20-02-2025	22±1	47±7	ambient pressure	the average weight of the sample is around 0,0205 g, time analysis 30 min, temperature analysis 60 °C ± 1 °C, flow rate 80 ml/min, one value is based on an average of three measurements
5	19.19	0.86	06-02-2025	22±1	47±7	ambient pressure	the average weight of the sample is around 0,0209 g, time analysis 30 min, temperature analysis 60 °C ± 1 °C, flow rate 80 ml/min, one value is based on an average of three measurements
6	18.32	0.69	19-02-2025	22±1	47±7	ambient pressure	the average weight of the sample is around 0,0204 g, time analysis 30 min, temperature analysis 60 °C ± 1 °C, flow rate 80 ml/min, one value is based on an average of three measurements

Average	**18.78**	**0.78**
Max	**19.43**	
Min	**18.09**	
Number of readings	**6**	**6**
Std	**0.52**	
Std of mean	**0.21**	

CETIAT Organic

Name of participant:	LNE-CETIAT						
Method ID:	**Electrolysis of phosphoric acid in the presence of water**						
Date of reporting:	19-03-2022						
MEASUREMENT RESULTS							
Report results for at least 7 samples obtained with a single measurement system.							
	Water mass fraction			Ambient conditions			
	Estimate	Expanded	Date of	Temperature	Humidity	Pressure	
Sample number	[%w]	unc. (k=2)	measurement	[°C]	[%rh]	[hPa]	Additional information
1	18.45	0.70	24-01-2025	22±1	47±7	ambient pressure	the average weight of the sample is around 0,0232 g, time analysis 35 min, temperature analysis 105 °C ± 1 °C, flow rate 80 ml/min, one value is based on an average of three measurements
2	19.02	0.45	22-01-2025	22±1	47±7	ambient pressure	the average weight of the sample is around 0,0240 g, time analysis 35 min, temperature analysis 105 °C ± 1 °C, flow rate 80 ml/min, one value is based on an average of three measurements
3	18.85	0.42	27-01-2025	22±1	47±7	ambient pressure	the average weight of the sample is around 0,0196 g, time analysis 35 min, temperature analysis 105 °C ± 1 °C, flow rate 80 ml/min, one value is based on an average of three measurements
4	18.56	0.59	28-01-2025	22±1	47±7	ambient pressure	the average weight of the sample is around 0,0212 g, time analysis 35 min, temperature analysis 105 °C ± 1 °C, flow rate 80 ml/min, one value is based on an average of three measurements
5	18.94	0.44	29-01-2025	22±1	47±7	ambient pressure	the average weight of the sample is around 0,0194 g, time analysis 35 min, temperature analysis 105 °C ± 1 °C, flow rate 80 ml/min, one value is based on an average of three measurements
6	18.56	0.59	31-01-2025	22±1	47±7	ambient pressure	the average weight of the sample is around 0,0232 g, time analysis 35 min, temperature analysis 105 °C ± 1 °C, flow rate 80 ml/min, one value is based on an average of three measurements
Average	**18.73**	**0.53**					
Max	**19.02**						
Min	**18.45**						
Number of readings	**6**	**6**					
Std	**0.23**						
Std of mean	**0.09**						

CMI Inorganic

Name of participant:	CMI						
Method ID:	LoD						
Date of reporting:	21-03-2025						
MEASUREMENT RESULTS							
Report results for at least 7 samples obtained with a single measurement system.							
	Water mass fraction			Ambient conditions			
Sample number	Estimate [%w]	Expanded unc. (k=2)	Date of measurement	Temperature [°C]	Humidity [%rh]	Pressure [hPa]	Additional information
3	19.44	0.14	04-02-2025	21.9	36		
10	19.36	0.15	04-02-2025	21.9	36		
17	19.36	0.14	04-02-2025	21.9	36		
38	19.22	0.15	04-02-2025	21.9	36		
52	19.58	0.14	04-02-2025	21.9	36		
59	19.36	0.14	04-02-2025	21.9	36		
66	19.34	0.15	04-02-2025	21.9	36		
Average	**19.38**	**0.14**					
Max	**19.58**						
Min	**19.22**						
Number of readings	**7**	**7**					
Std	**0.11**						
Std of mean	**0.04**						

CMI Organic

Name of participant:	CMI						
Method ID:	LoD						
Date of reporting:	21-03-2025						

MEASUREMENT RESULTS

Report results for at least 7 samples obtained with a single measurement system.

	Water mass fraction			Ambient conditions			
Sample number	Estimate [%w]	Expanded unc. (k=2)	Date of measurement	Temperature [°C]	Humidity [%rh]	Pressure [hPa]	Additional information
117	18.67	0.18	04-02-2025	21.9	36		
124	19.06	0.15	04-02-2025	21.9	36		
138	19.37	0.14	04-02-2025	21.9	36		
145	19.11	0.14	04-02-2025	21.9	36		
152	19.24	0.16	04-02-2025	21.9	36		
159	19.19	0.20	04-02-2025	21.9	36		
166	19.24	0.15	04-02-2025	21.9	36		

Average	**19.13**	**0.16**
Max	**19.37**	
Min	**18.67**	
Number of readings	**7**	**7**
Std	**0.22**	
Std of mean	**0.08**	

DTI Inorganic

Name of participant:	DTI
Method ID:	10096
Date of reporting:	21-03-2025

MEASUREMENT RESULTS

Report results for at least 7 samples obtained with a single measurement system.

	Water mass fraction			Ambient conditions			
Sample number	Estimate [%w]	Expanded unc. (k=2)	Date of measurement	Temperature [°C]	Humidity [%rh]	Pressure [hPa]	Additional information
22	19.17	0.56	06-03-2025	22±3	35±6	1015±2	
36	19.35	0.40	13-03-2025	21±1	41±4	1002±6	
50	19.20	0.53	17-03-2025	21±2	33±3	1029±2	
64	19.29	0.52	19-03-2025	22±3	34±5	1023±2	
71	19.16	0.38	20-03-2025	22±2	33±7	1021±3	

Average	**19.23**	**0.48**
Max	**19.35**	
Min	**19.16**	
Number of readings	**5**	**5**
Std	**0.08**	
Std of mean	**0.04**	

DTI Organic

Name of participant:	DTI
Method ID:	10096
Date of reporting:	27-03-2025

MEASUREMENT RESULTS

Report results for at least 7 samples obtained with a single measurement system.

	Water mass fraction			Ambient conditions			
Sample number	Estimate [%w]	Expanded unc. (k=2)	Date of measurement	Temperature [°C]	Humidity [%rh]	Pressure [hPa]	Additional information
101	18.56	0.47	24-02-2025	21±1	41±2	1012±4	
115	18.70	0.44	27-02-2025	21±2	36±5	1026±8	
122	18.72	0.45	03-03-2025	21±1	35±2	1016±7	
129	18.66	0.44	07-03-2025	22±2	36±4	1013±10	
143	19.30	0.47	10-03-2025	21±1	38±2	998±5	
150	18.86	0.44	14-03-2025	21±2	35±4	1021±11	
164	18.58	0.49	21-04-2025	22±3	35±5	1017±9	

Average	18.77	0.46
Max	19.30	
Min	18.56	
Number of readings	7	7
Std	0.25	
Std of mean	0.10	

TUBITAK–UME Inorganic

Name of participant:	TUBITAK
Method ID:	LoD
Date of reporting:	15-04-2025

MEASUREMENT RESULTS

Report results for at least 7 samples obtained with a single measurement system.

	Water mass fraction			Ambient conditions			
Sample number	Estimate [%w]	Expanded unc. (k=2)	Date of measurement	Temperature [°C]	Humidity [%rh]	Pressure [hPa]	Additional information
2	19.72	0.42	31-01-2025	22.48 ±0.52	42.46 ±1.52	1001.56 ±2.56	
9	19.55	0.35	06-02-2025	22.17 ±0.97	36.19 ±2.32	1008.07 ±4.98	
37	19.44	0.42	04-02-2025	23.17±1.30	36.36 ±3.58	1003.84 ±1.49	
44	19.33	0.31	04-02-2025	23.35 ±1.03	36.16 ±3.20	1003.71 ±1.56	
51	19.60	0.53	22-01-2025	22.17 ±1.23	42.16 ±1.35	999.65 ±3.61	
59	19.22	0.36	28-01-2025	22.46 ±0.56	41.04 ±1.03	999.76 ±3.49	
65	19.38	0.32	24-01-2025	22.05 ±0.77	43.44 ±1.70	999.60 ±4.10	

Average	19.46	0.39
Max	19.72	
Min	19.22	
Number of readings	7	7
Std	0.17	
Std of mean	0.06	

TUBITAK-UME Organic

Name of participant:	TUBITAK						
Method ID:	LoD						
Date of reporting:	15-04-2025						
MEASUREMENT RESULTS							
Report results for at least 7 samples obtained with a single measurement system.							
	Water mass fraction			Ambient conditions			
Sample number	Estimate [%w]	Expanded unc. (k=2)	Date of measurement	Temperature [°C]	Humidity [%rh]	Pressure [hPa]	Additional information
102	19.18	0.33	13-02-2025	22.30 ±1.58	39.23 ±7.49	997.99 ±8.09	
109	19.14	0.32	07-02-2025	21.12 ±1.43	37.99 ±4.58	1008.70 ±4.45	
116	19.29	0.33	08-02-2025	21.06 ±1.34	38.88 ±2.16	1006.55 ±3.21	
123	19.27	0.38	13-02-2025	22.37 ±1.54	39.49 ±6.47	998.10 ±7.79	
151	19.27	0.36	08-02-2025	21.10 ±1.46	38.87 ±2.34	1006.12 ±2.56	
158	19.20	0.33	11-02-2025	22.75 ±1.50	36.92 ±1.74	1005.21 ±1.85	
165	19.22	0.30	13-02-2025	22.28 ±0.85	39.54 ±4.37	997.84 ±4.23	
Average	**19.22**	**0.34**					
Max	**19.29**						
Min	**19.14**						
Number of readings	**7**	**7**					
Std	**0.06**						
Std of mean	**0.02**						

Appendix 2 – Assessment of the homogeneity of the samples

Test of homogeneity - inorganic

#	$m_{container}$, g	$m_{wet, cold(container+soil)}$, g	$m_{dry, cold(container+soil)}$, g	$m_{wet\ soil}$, g	$m_{dry\ soil}$, g	m_{change}, g	Water content, g/g	Start	End
4*	5.8	402.89	324.67	397.09	318.870	78.22	19.70%	22-01-2025 08:57	23-01-2025 10:55
11	5.79	403.14	325.7	397.35	319.910	77.44	19.49%	22-01-2025 08:57	23-01-2025 10:55
18	5.8	399.57	323.22	393.77	317.420	76.35	19.39%	22-01-2025 08:57	23-01-2025 10:55
25	5.77	402.15	324.55	396.38	318.780	77.60	19.58%	22-01-2025 08:57	23-01-2025 10:55
32	5.78	410.3	331.25	404.52	325.470	79.05	19.54%	22-01-2025 08:57	23-01-2025 10:55
39	5.78	404.12	327.33	398.34	321.550	76.79	19.28%	22-01-2025 08:57	23-01-2025 10:55
46	5.79	396.88	320.57	391.09	314.780	76.31	19.51%	22-01-2025 08:57	23-01-2025 10:55
53	5.77	411.88	333.23	406.11	327.460	78.65	19.37%	22-01-2025 08:57	23-01-2025 10:55
60	5.79	407.26	330	401.47	324.210	77.26	19.24%	22-01-2025 08:57	23-01-2025 10:55
67	5.8	406.77	329.62	400.97	323.820	77.15	19.24%	22-01-2025 08:57	23-01-2025 10:55

Test of homogeneity - Organic

#	$m_{container}$, g	$m_{wet, cold(container+soil)}$, g	$m_{dry, cold(container+soil)}$, g	$m_{wet\ soil}$, g	$m_{dry\ soil}$, g	m_{change}, g	Water content, g/	Start	End
104	5.79	408.57	331.91	402.78	326.120	76.66	19.03%	11-02-2025 08:28	13-02-2025 08:14
111	5.81	409.43	333.01	403.62	327.200	76.42	18.93%	11-02-2025 08:28	13-02-2025 08:14
118	5.83	407.17	331.13	401.34	325.300	76.04	18.95%	11-02-2025 08:28	13-02-2025 08:14
125	5.81	403.85	328.42	398.04	322.610	75.43	18.95%	11-02-2025 08:28	13-02-2025 08:14
132	5.82	406.58	330.36	400.76	324.540	76.22	19.02%	11-02-2025 08:28	13-02-2025 08:14
139	5.80	404.91	329.06	399.11	323.260	75.85	19.00%	11-02-2025 08:28	13-02-2025 08:14
146	5.79	409.57	333.08	403.78	327.290	76.49	18.94%	11-02-2025 08:28	13-02-2025 08:14
153	5.78	407.23	331.02	401.45	325.240	76.21	18.98%	11-02-2025 08:28	13-02-2025 08:14
160	5.80	407.81	331.42	402.01	325.620	76.39	19.00%	11-02-2025 08:28	13-02-2025 08:14
167	5.81	405.79	329.84	399.98	324.030	75.95	18.99%	11-02-2025 08:28	13-02-2025 08:14

Appendix 3 – Assessment of the stability of the samples

Stability - inorganic

#	Oprindelse	$m_{beholder}$, g	$m_{våd, kold(beholder+jord)}$, g	$m_{tør, kold(beholder+jord)}$, g	$m_{våd\ jord}$, g	$m_{tør\ jord}$, g	m_{tabt}, g	Vandindhold, g/g	Starttid	Sluttid
5	CETIAT	5.90	402.96	326.18	397.06	320.280	76.78	19.34%	02-04-2025 11:32	03-04-2025 13:55
19	CETIAT	5.90	400.45	324.36	394.55	318.460	76.09	19.29%	02-04-2025 11:32	03-04-2025 13:55
68	CETIAT	5.84	401.08	324.88	395.24	319.040	76.20	19.28%	02-04-2025 11:32	03-04-2025 13:55
16	TUBITAK	5.85	389.83	315.57	383.98	309.720	74.26	19.34%	02-04-2025 11:32	03-04-2025 13:55
23	TUBITAK	5.94	402.73	326.05	396.79	320.110	76.68	19.33%	02-04-2025 11:32	03-04-2025 13:55
30	TUBITAK	5.94	400.22	324.47	394.28	318.530	75.75	19.21%	02-04-2025 11:32	03-04-2025 13:55
29	DTI	5.89	404.60	328.09	398.71	322.200	76.51	19.19%	02-04-2025 11:32	03-04-2025 13:55
43	DTI	5.82	403.53	327.21	397.71	321.390	76.32	19.19%	02-04-2025 11:32	03-04-2025 13:55
57	DTI	5.80	404.42	328.14	398.62	322.340	76.28	19.14%	02-04-2025 11:32	03-04-2025 13:55
24	CMI	5.92	401.98	325.27	396.06	319.350	76.71	19.37%	02-04-2025 11:32	03-04-2025 13:55
31	CMI	5.97	404.10	327.77	398.13	321.800	76.33	19.17%	02-04-2025 11:32	03-04-2025 13:55
45	CMI	5.87	399.40	323.64	393.53	317.770	75.76	19.25%	02-04-2025 11:32	03-04-2025 13:55

Stability - organic

#	Origin	$m_{container}$, g	$m_{wet, cold(container+soil)}$, g	$m_{dry, cold(container+soil)}$, g	$m_{wet\ soil}$, g	$m_{dry\ soil}$, g	m_{change}, g	Water content, g/g	Start	End
130	TUBITAK	5.9	403.45	328.27	397.55	322.370	75.18	18.91%	31-03-25 08:49	02-04-25 10:10
144	TUBITAK	5.92	397.54	323.53	391.62	317.610	74.01	18.90%	31-03-25 08:48	02-04-25 10:10
148	TUBITAK	5.92	400.94	326.09	395.02	320.170	74.85	18.95%	31-03-25 08:46	02-04-25 10:10
103	CMI	5.81	399.00	324.36	393.19	318.550	74.64	18.98%	31-03-25 08:45	02-04-25 10:10
110	CMI	5.9	405.36	329.82	399.46	323.920	75.54	18.91%	31-03-25 08:43	02-04-25 10:10
131	CMI	5.85	394.39	320.87	388.54	315.020	73.52	18.92%	31-03-25 08:34	02-04-25 10:10
108	DTI	5.86	407.24	331.01	401.38	325.150	76.23	18.99%	31-03-25 08:50	02-04-25 10:10
136	DTI	5.81	409.72	333.26	403.91	327.450	76.46	18.93%	31-03-25 08:41	02-04-25 10:10
157	DTI	5.86	403.65	326.02	397.79	320.160	77.63	19.52%	31-03-25 08:40	02-04-25 10:10
112	CETIAT	5.92	396.30	322.34	390.38	316.420	73.96	18.95%	31-03-25 08:39	02-04-25 10:10
126	CETIAT	5.84	386.08	314.49	380.24	308.650	71.59	18.83%	31-03-25 08:37	02-04-25 10:10
147	CETIAT	5.88	387.80	315.69	381.92	309.810	72.11	18.88%	31-03-25 08:35	02-04-25 10:10

Appendix 4 – Intercomparison protocol

Instructions for the participants in the interlaboratory comparison

Intercomparison Protocol

Pilot Study of Soil Moisture Measurement

EURAMET Project 1685

Contents

1. Introduction

The intercomparison is conducted as part of the joint research project (JRP) 21GRD08 SoMMet, "Metrology for multi-scale monitoring of soil moisture".

The aim of the intercomparison is to test the measurement standards and methods developed by the partners in the project using soil samples.

The measurand is defined as the water mass fraction on wet basis, w_{water}. That is:

$$w_{water} = m_{water}/m_{sample},$$

where m_{water} is the mass of the water and m_{sample} is the mass of the original wet sample.

The intercomparison is carried out as a pilot study according to EURAMET Guide No. 4 Version 2.0 (04/2021) and DS/EN ISO/IEC 17043:2010

2. Coordinator / pilot laboratory

The intercomparison is coordinated by:

Danish Technological Institute (DTI)

Kongsvang Allé 29

DK – 8000 Aarhus C.

3. Participants

Institute	Delivery address (for shipment of samples)	Contact Person
Danish Technological Institute (DTI)	Kongsvang Allé 29 Building. 14 DK – 8000 Aarhus C.	Emil Andreasen Klahn eak@teknologisk.dk
Český Metrologický Institut (CMI)	Průmyslová 455 530 03 Pardubice Czech Republic	Zuzana Pálková zpalkova@cmi.cz
Turkiye Bilimsel ve Teknolojik Arastirma Kurumu (TUBITAK)	Barış Mah. Dr. Zeki Acar Cad. No:1 41470 Gebze / KOCAELİ TÜRKİYE	Humbet Nasibli humbet.nasibli@tubitak.gov.tr
Centre Technique des Industries Aérauliques et Thermiques (CETIAT)	Domaine Scientifique de la Doua 25, avenue des Arts BP 52042	Bayan TALLAWI Bayan.tallawi@cetiat.fr

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4. Method

The intercomparison is conducted as follows:

- DTI will prepare homogeneous soil samples of two soil types, organic and inorganic
- DTI measures homogeneity using the loss-on-drying (LoD) method on 17 randomly selected samples for each of the two soil types.
- DTI will ship 10 samples of both organic and inorganic soil to each participating laboratory, including 3 samples of both organic and inorganic soil to be returned for testing the stability of the water content during shipping using the loss-on-drying (LoD) method.
- All laboratories measure water mass fraction of the soil samples using a primary measurement standard. In addition, DTI measures the soil samples returned to DTI by the participating laboratories.
- When all measurements have been performed, DTI will analyse the result and submit initial results to partners
- DTI will submit the final report to EURAMET.

Each participant is responsible for the cost related to shipping.

5. Time schedule

DTI will send the samples to the participants by November 2024.

The participants should complete their measurements within 14 days of receiving the samples.

The participants should submit their results using an Excel template provided by DTI.

DTI will analyse the results and send the first draft report to the participants by February 2025.

Handling of samples

Storage and packaging

Soil samples will be packed in sealed aluminium bags. Storage of samples will be at a temperature below 4 °C. and upon receiving the samples, they should be stored at a temperature below 4 °C until being measured.

Transport and customs

Samples will be shipped at a temperature below 4 °C.

6. Measurement

Initial inspection / control measurement

Upon receiving the samples, each participating laboratory much check that

- the sample containers have not been opened or punctured
- the temperature has not exceeded 4 °C, as indicated by a time temperature indicator shipped together with the sample

Measurement points

Soil will be prepared with a target gravimetric water content of 18 %. Each laboratory receives 10 samples, whereof 7 are to be measured, and 3 are to be kept in spare.

Reporting the results

The measurement results should be reported in an Excel-sheet that will be made available by DTI.

Acknowledgement

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or EURAMET. Neither the European Union nor the granting authority can be held responsible for them.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

The project has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.

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