Global Soil Laboratory Assessment
2018 ONLINE SURVEY

GLOBAL SOIL LABORATORY NETWORK
Global Soil Laboratory Assessment
ONLINE SURVEY 2018

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Abbreviations

CRM: Certified reference material
EC: Electrical conductivity
FAO: Food and Agriculture Organization of the United Nations
GLOSOLAN: Global Soil Laboratory Network
GLP: Good laboratory practice
GSOCmap: Global Soil Organic Carbon map
GSP: Global Soil Partnership
IPNI: International Plant Nutrition Institute
IPPI: International Public Policy Institute
IRM: Internal reference material
ISO: International Organization for Standardization
LATSOLAN: Red Latinoamericana de Laboratorios de Suelos
NENA: Near East and North Africa Soil Partnership
NGO: Non-governmental Organization
OECD: Organisation for Economic Co-operation and Development
QA: Quality assurance
QC: Quality control
RESOLAN: Regional soil laboratory network
SEALNET: South-East Asia Soil Laboratory Network
SOP: Standard operating procedure
WEPAL: Wageningen Evaluating Programmes for Analytical Laboratories
Executive summary

The analysis of the first worldwide survey of laboratories undertaking soil analyses:
(i) demonstrates the motivation of these laboratories to join an international network;
(ii) confirms the need for the implementation of global harmonization and standardization of analytical procedures;
(iii) shows the need for improving the knowledge and competence of laboratory staff; and
(iv) suggests that addressing the existing quality assurance/quality control issues between laboratories should start at the regional level.

Key findings

- The questionnaire was viewed more than 700 times in 8 weeks, demonstrating a large worldwide interest in an initiative concerning soil laboratories. However, either the questionnaire or the platform used to launch the online survey was probably not well enough designed as only 111 complete questionnaires could be assessed. Moreover, the low number of answers to some questions suggested a lack of clarity or an excess of complexity.

- At the global scale, most of the responding laboratories were not affiliated with a laboratory network. Laboratories already involved in networks were generally affiliated with a national network and rarely with an international network. This suggests that international inter-comparability of data is probably not currently possible.

- Formal education of laboratory staff varies highly between regions. This indicates a need for targeted capacity building (especially in small-sized laboratories) through regional soil laboratory networks (RESOLANs).

- Some laboratories have a large percentage of temporary staff. This suggests that staff turnover may be high and the retention of experienced staff may be low. Moreover, the absence of regular staff training exacerbates the apparent lack of succession planning and mentoring.
• In most cases, laboratory infrastructure, facilities and equipment were appropriate and did not appear as a limiting factor for obtaining reproducible results.

• Methodologies and procedures varied highly for a set of basic soil analyses between laboratories, even if the laboratories were in the same region. This suggests difficulties for comparing results at the global level, the regional level, or even between different laboratories located in a single country.

• Standard operating procedures are generally available in the local language and seem to be well established. Maintenance and results log books are less common.

• Quality control and quality assurance are established in the majority of laboratories. However, in many laboratories, the frequency with which the controls are applied is too low to guarantee the quality of the results.

• Laboratory certification and accreditation are not yet sufficiently established either regionally or internationally.
Recommended action for GLOSOLAN

• GLOSOLAN should propose draft standard operating procedures (SOPs) for a suite of the most common or important soil parameters. This action would stimulate development and adoption of SOPs. At present, the operating procedures are so diverse that worldwide implementation would be difficult for even a single SOP for each parameter. Consequently, it seems necessary to first identify which procedures are most likely to affect results obtained for a particular soil parameter and then design an SOP that can accommodate regional and local practices. This topic should be addressed during the GLOSOLAN second meeting.

• GLOSOLAN should develop e-books and videos to disseminate knowledge concerning good laboratory practices (GLPs) and to provide information on specific aspects related to soil analysis. This action would improve staff qualifications. GLOSOLAN should also propose a training programme that would increase staff competence and could be adopted at regional scale and updated on a regular basis.
• **GLOSOLAN should stimulate the development of new regional soil laboratory networks (RESOLANs).** This action would facilitate the dissemination of e-books and videos and the adoption of training programmes.

• **GLOSOLAN should motivate laboratories to more frequently analyse internal control soils and thereby improve internal quality control.** By increasing the number of internal quality control analyses, laboratories can better assess, monitor and benchmark their precision and can also better detect systemic problems.

• **GLOSOLAN should organize a proficiency testing programme, or ring test, to benchmark the results of each method across laboratories.** Ring tests could be organized on a regular basis at two levels: regional and global. These tests would: 1) evaluate and monitor the performance of existing laboratories (certified or not), 2) validate standard methods, and 3) help set up new laboratories and train staff.

• **GLOSOLAN should establish one or two soil reference laboratories in each region to provide technical advice, training and capacity building.**

• **GLOSOLAN should set up a communication platform to share information and experience among laboratories.** This platform could host a database to gather, collect and review available literature (FAO/WEPAL/IPNI/IPPI/OECD).

• **GLOSOLAN should develop and promote a certified soil laboratory quality assurance system and provide a GLOSOLAN accreditation scheme.**
1 Introduction

The Global Soil Partnership (GSP) of the Food and Agriculture Organization of the United Nations (FAO) was established in 2012 for the purpose of promoting sustainable soil management and strengthening soil governance at all levels. The GSP operates through five Pillars of Action and nine Regional Soil Partnerships.

In the framework of implementing Pillar 5 activities concerning the harmonization of methods, measurements, and indicators for the sustainable management and protection of soil resources, the Global Soil Laboratory Network (GLOSOLAN) was established in November 2017.

GLOSOLAN aims to (1) make soil information comparable and interpretable across laboratories, countries and regions, (2) build a set of agreed upon harmonization principles, (3) improve quality assurance (QA) and quality control (QC) of soil analyses, and (4) promote exchange of information and experience and thereby develop capacities wherever needed. The establishment of the GLOSOLAN and the definition of Pillar 5 activities assume that soils can only be managed sustainably at the global level if sufficient, reliable and comparable information becomes available. Additionally, reliable and comparable soil information can only result from laboratories following standards and norms.

This report presents and discusses the results of the first GLOSOLAN online survey at the global and regional level. This is the first soil laboratory survey ever made at such a large and international scale.

When the survey was launched, no information existed concerning the practices of soil laboratories around the world. Such information was necessary to determine a roadmap for GLOSOLAN and a list of priority actions.

The survey was intended to identify post-2018 activities of the global and the several Regional Soil Laboratory Networks (RESOLANs). It was developed by the GLOSOLAN Working Group using the questionnaire developed by the Asian RESOLAN (SEALNET) as a baseline.

The survey was created and hosted on the “SurveyHero” website (www.surveyhero.com). The GSP Secretariat made it accessible from 4 February to 30 March, 2018. Any interested laboratory manager could participate. To maximise the number of answers, the GSP focal points and the participants in the first GLOSOLAN meeting were asked to forward the survey invitation to their national laboratories and contacts.

The results of the individual questionnaires were and are stored in the server of the GSP Secretariat. They are accessible by only a limited number of authorised FAO staff and are treated according to the GSP Soil Data Policy. Individual questionnaires are non-public.

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To ensure data confidentiality, survey replies were made anonymous before being forwarded to the GLOSOLAN working group. The name of each laboratory was changed to a single code number, and the results of each lab were aggregated with results of the laboratories for the same region.
2 Structure, dissemination and evaluation of the survey

2.1 Structure of the survey

The survey was organized in 11 Sections. A short justification and list of objectives for each section is herewith provided:

- **General information about the soil laboratory**: this section identifies the responding laboratory and provides a unique code to avoid duplicate answers and to make future monitoring possible.

- **Affiliation to an existing soil laboratory network**: this section identifies potential collaboration with existing networks during the establishment and implementation of RESOLANs and GLOSOLAN.

- **Staff qualification and performance**: this section (1) estimates the size and capacity of the soil laboratory, (2) identifies the employee expertise, educational gaps or training needs, and (3) assesses the internal QA/QC of a laboratory and the overall laboratory performance in terms of good laboratory practices (GLP).

- **Infrastructure of the laboratory**: this section identifies the current status of soil laboratories and checks for the infrastructure characteristics required to perform good quality data according to international standards.

- **Clients of the soil laboratory**: this section (1) identifies the types of institutions and citizens interested in collecting data about soils, (2) identifies the local role of each laboratory in the network, and (3) sets a basis for more standard interpretation of laboratory results.

- **Analysis performed by the laboratory**: laboratories were asked about the methods used to assess a set of 40 soil chemical, physical and biological parameters. This huge dataset has provided a first overview of the analytical procedures currently performed by the laboratories in the different world regions. It could be used to assess the needs and possibilities for worldwide standardization and harmonization of these soil analyses.

- **Special focus on pH in water**: this section is a detailed investigation of the procedures for this analysis. Not only is pH one of the most basic soil characteristics, determination of pH is also one of the simplest and cheapest soil analyses. Consequently, setting up a standard method for soil pH can have an immediate impact (i) for improving global soil management and (ii) for developing procedures of standardization and harmonization inside RESOLANs and GLOSOLAN.

- **Special focus on organic carbon**: this section is a detailed investigation of the procedures for this analysis and an assessment of the role of analytical procedures in explaining worldwide differences in the results. In the near future, harmonization of analytical procedures will improve the Global Soil Organic Carbon Map (GSOCmap). The map was prepared and launched by the Global Soil Partnership in December 2017 and is highly needed by many international institutions.

- **Quality Assurance and Quality Control (QA/QC)**: this section included questions on the use of control samples and reference materials. Identifying the current practices can help to determine the
quality of results currently provided by the laboratories and to identify the actions needed to reach a minimum level of worldwide quality.

- **Soil laboratory certification and accreditation**: this section assesses the extent to which individual laboratory quality has been previously evaluated and certified. Ultimately, this information would serve GLOSOLAN to integrate in and complement the work of already established systems.

- **Expectations on GLOSOLAN**: this section was an open question that allowed respondents to make any suggestion they found useful.

The first 10 sections contained questions numbered from 1 to 73 (the survey is available in Annex 1). Most of the questions were in a closed format but also gave space for answers that deviated from prescribed options. Some questions were designed to cross-check information that concerned critical aspects of soil laboratory functioning.

Note that question 38 requested a detailed description of the laboratory procedures for 40 different parameters. Consequently, the survey contained a total of 113 questions, including a final question about expectations for GLOSOLAN. The final question did not receive a specific number in the questionnaire.

### 2.2 Outreach and participation in the survey

Statistics about the outreach and participation in the survey include:

- 732 views.

- 293 forms were started (40 percent of the views); but, several respondents did not finalise the survey during the first visit and tried to complete it during a second visit. This was not, however, possible. Therefore, they had to start again from the beginning, which seemingly discouraged a large number of people from answering all questions.

- 111 forms were finally completed and were used to realize this survey interpretation.

Results came from 66 countries. The top 10 responding countries were: Thailand (6 respondents); Philippines, Portugal, Germany and Belgium (5 respondents each); Croatia (4 respondents); and UK, Pakistan, France and Mozambique (3 respondents each).

### Preliminary comments

When analysing a survey such as this, two main concerns must be taken into consideration:

- Firstly, the quality of the answers. Some questions could be unclear or qualitative in such a manner that different people interpret them in differently. Also, people might be tempted to provide the answer they think the investigator expects, making the answer generally different from or nicer than the reality.

- Secondly, the representativeness of the sample. The survey was completed on a voluntary basis and, consequently, the laboratory sample is not representative of all the soil laboratories existing worldwide. The hypothesis was used that responding laboratories were those having the highest motivation to participate in GLOSOLAN and a RESOLAN. Because these laboratories have the highest probability to participate, it is worthwhile to have a detailed picture of them.
Despite any limitations, this survey is the first ever made about soil laboratories at such a large scale. The data compiled through this survey has inestimable value for the international community and for GLOSOLAN to set its work plan. In this regard, the decision was made to focus the data analysis on the identification of priority activities to propose at the 2nd GLOSOLAN meeting (28–30 November 2018). The authors hope that the readers can forgive them for analysing and interpreting some data only preliminarily at this stage and would like to thank all lab managers completing the survey for their time and contribution to GLOSOLAN and RESOLANs.

### 2.3 Survey evaluation

Responding laboratories were grouped by geographical regions (Africa, Asia, Europe, America, Near East and North Africa) as showed in Figure 1. Note that:

- Because only one survey was completed by North America and the Pacific, these two regions are not mentioned in this report and their answers are associated to America and Asia, respectively.

- Because of the interest of the European Soil Partnership and the Eurasian Soil Partnership to work together in GLOSOLAN, their contribution to the survey is compiled under Europe.

- Because the Central America, Caribbean and Mexico Soil Partnership and the South America Soil Partnership work together in GLOSOLAN as “Red Latinoamericana de Laboratorios de Suelos” (LATSOLAN), their contribution to the survey is compiled under America.

A summary of the replies to the survey provided by each region in the Global Soil Partnership and their geographical classification for this report are provided in Table 1.

![Figure 1. Geographical regions considered in the survey analysis](image-url)
Table 1. Participation in the survey by region

<table>
<thead>
<tr>
<th>GSP REGIONS</th>
<th>NUMBER OF COUNTRIES THAT ANSWERED THE SURVEY</th>
<th>TOTAL NUMBER OF RESPONSES PER IDENTIFIED REGION</th>
<th>CLASSIFICATION OF THE REGIONS IN THIS REPORT</th>
</tr>
</thead>
<tbody>
<tr>
<td>NORTH AMERICA SOIL PARTNERSHIP</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>CENTRAL AMERICA, CARIBBEAN AND MEXICO SOIL PARTNERSHIP</td>
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<td>17</td>
<td>America</td>
</tr>
<tr>
<td>SOUTH AMERICA SOIL PARTNERSHIP</td>
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<td></td>
<td></td>
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<td>17</td>
<td>Africa</td>
</tr>
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<td>9</td>
<td>NENA</td>
</tr>
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</tr>
<tr>
<td>PACIFIC SOIL PARTNERSHIP</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3 Results and discussion

3.1 Section 1: General information about the soil laboratory (questions 1–8)

The answers to these questions are confidential and cannot be presented or commented on.

3.2 Section 2: Affiliation to an existing soil laboratory network (questions 9–10)

At a global scale, most of the laboratories (59 percent) reported not yet being affiliated with an existing soil laboratory network. The remaining 41 percent were affiliated with an existing network. Of these, two out of three were affiliated with a national soil laboratory network. Only one out of three reported being affiliated with an international network.

Some regional variability was observed. Of the respondent laboratories:

- NENA: none were affiliated with a soil laboratory network.
- Asia: 5 were affiliated with an existing network.
- America: 8 were affiliated with an existing network.
- Europe: 25 were affiliated with an existing network.
- Africa: 10 were affiliated with an existing network.

To conclude, this section enquired whether laboratories collected national data on agricultural or forest soils. Most of the laboratories (46 percent) collected national data on agricultural soils, 27 percent collected data on both agricultural and forest soils, and only 5 percent, mainly in America and Europe, worked on forest soils only. Surprisingly, 21 percent of the laboratories reported not collecting data on either agricultural or forest soils.

3.3 Section 3: Staff qualification and performance (questions 11–16)

Number of employees (question 11) & Employee contract type (question 12)

Based on the number of employees (both permanent and temporary contracts), the laboratories are classified as small, medium and large; i.e., <=10, 11–50, and >50 employees. Over half (53 percent) of the laboratories completing the survey were small, 41 percent were medium and only 6 percent of them were large and located in America and Europe.

If large laboratories are taken out from the calculation, the average number of permanent employees is 9.1 (+/- 7.6 as the standard deviation, n= 104). The average number of temporary contract employees is 2.6 (+/- 2.5 as the standard deviation, n= 94). It appeared that nearly all the laboratories were employing temporary
staff, and the temporary staff represented a significant proportion of total staff in some laboratories. On average, temporary staff made up around 20 percent of employees in Africa and Europe, 25 percent in NENA, 35 percent in America and up to 70 percent in Asia.

Regional differences also existed in the total number of staff members: in America, the average number of staff members was 9; in Africa, Europe and Asia, the average number ranged from 11 to 15; and in NENA countries, the average was 23 (see annex 2).

**Formal education, training and experience of laboratory staff (questions 13, 14, 15)**

In 72 percent of the laboratories completing the survey, half or more of all employees received a formal education. In 24 percent of the labs, the majority of the staff did not. The remaining 4 percent did not answer this question. Significant differences were noticed in Africa (low educational level concerned 42 percent of the laboratories) and in NENA (low educational level was never mentioned).

Regarding the percentage of employees trained to perform analytical work (question 14), 75 percent of respondent laboratories counted half or more of their employees as being trained to perform analytical work. A major lack of training to perform analytical work was identified in America (in one out of three laboratories, the majority of the staff was not trained). When looking collectively at the percentage of employees educated, trained or having experience specifically in “soil” analyses (question 15), the results show that most laboratories (82 percent) have such employees.

**Existence of a training programme for the laboratory staff (question 16)**

One third (36 percent) of respondents did not have a training programme to regularly improve the skills of their employees. A particularly high need for the establishment of a regular training programme could be identified in Africa and America, where half of the surveyed laboratories did not offer regular training for their staffs.

**Discussion and suggestions**

The assessment of the number of employees with either a permanent or a temporary contract provides information on the general staff qualification in the laboratories. It can be assumed that a high percentage of temporary staff increases the risk of inconsistent practices when performing analytical procedures. Data showed the existence of a significant number of laboratories with a high ratio of either temporary, low education or untrained staff on soil analysis or any analytical work.

During the assessment of educational programmes to maintain or increase analytical expertise, it was observed that a large number of laboratories did not provide routine, organized professional training. For those laboratories where training is organized, it is unclear how the respondents understood the word “training”, which may have been misconstrued to mean the provision of basic information to new staff. In the near future, it will be important to define “training” and to identify those laboratories that could be available to train other laboratories.
As a conclusion, the current staff qualifications are probably not high enough to guarantee good quality analytical results. Thus, complementary information should be collected to get a better picture of the current situation. A complementary survey could be conducted by the RESOLANs because of their better understanding of national diversity. This complementary survey must be made under the coordination of GLOSOLAN in order to ensure that the data can be compared between regions. Moreover, training programmes should be developed by GLOSOLAN (to have a worldwide standard) and regularly conducted at the regional level. The most qualified laboratories could organize and host such training for the other laboratories in their region. Such training could also be a good way to promote technical and scientific cooperation between the most qualified laboratories in GLOSOLAN.

3.4 Section 4: Infrastructure situation (questions 17–29)

Soil sample reception and storage (questions 17–20)

Almost all surveyed laboratories (92 percent) reported having a sample reception area. The majority of the laboratories (86 percent) stored dried, sieved soil samples at room temperature in a proper storage room on a laboratory cupboard, tray, soil bank or other container at an average room temperature of 25°C. Most laboratories (71 percent) stored soil samples in plastic containers, very few (5 percent) stored in sealed glass, and the rest of respondents stored in both or in other storage materials, such as paper bags and zip bags. Only 38 percent of the laboratories had a cold room with a constant storage temperature of 4°C. Cold rooms were mainly found in Europe (62 percent). Twenty-one per cent of laboratories in Europe stored their samples in a dark room. The number was very low elsewhere.

Laboratory safety (questions 21–23)

The survey indicated a general adoption of storage and labelling procedures for reagents. Eighty-six percent of laboratories have one or more rooms that are dedicated to the storage of reagents and in which the reagents are labelled and organized by groups (acids, bases, flammable, highly toxic compounds and compressed gases). Additionally, 74 percent of all laboratories have labels indicating the dates of receipt, opening, and disposal of all chemicals and reagents. Laboratories generally (67 percent) have a system to check the receipt and opening dates of chemicals and reagents. One out of three laboratories, however, did not have such a system yet. Those systems were particularly missing in laboratories in America and Africa.

Facility monitoring (question 24)

Temperature and humidity in sensitive areas (e.g., balance room, analytical room) are monitored hourly or daily by only 39 percent of the responding laboratories. This situation is similar in all regions.

Laboratory facilities (questions 25–27)

A large majority of laboratories (93 percent) have a room dedicated to the preparation of soil samples, 75 percent have a room dedicated to the storage and use of balances, and 80 percent have a specific area dedicated to glassware cleaning.
Water in the laboratories (questions 28–29)

Most of the respondents (46 percent) used deionized water. Next most common was distilled water (29 percent) and then double distilled water (8 percent). Tap water is used by 6 percent of laboratories in Africa.

In addition, 36 percent of the laboratories did not check the quality of water used in the laboratories (i.e. electrical conductivity, EC).

Discussion and suggestions

It appears that infrastructures and organization inside soil laboratories match the minimal requirements. These factors, therefore, do not seem to be limiting the quality of the analytical results. However, in case of further investigation, it could be useful to enquire on how good laboratory practices (GLP) are implemented and used on a regular basis.

3.5 Section 5: Clients of the soil laboratory (questions 30–34)

Main client type (questions 30–31)

The labs reported having as clients: farmers and major public entities, such as research institutes and government departments (over 70 to 80 percent each); NGOs and the fertilizer industry (over 40 percent each); and other clients, such as industries and private companies (12 percent each).

A majority of clients (83 percent) requested advice on the interpretation of their soil tests.

Data reporting and interpretation (questions 32–34)

The results of soil tests were commonly provided in both hard copy and electronically (59 percent). Some respondent laboratories provide results either in hard copy form (21 percent) or in electronic form (15 percent). In most cases, soil laboratory reports were signed by the laboratory manager (42 percent) or by multiple signers (24 percent). Alternatively, the head of the department (12 percent) or the technical staff (6 percent) signed the report.

For the majority of soil laboratory reports (51 percent), an interpretation of data results was included in the analysis as a standard. At 33 percent of the laboratories, an interpretation was given upon request of the client. Only 15 percent of respondent soil laboratories indicated that no interpretation was provided.

Discussion and suggestions

Nowadays, most information about soils is derived from analytical results (direct profile observations are no longer common, and remote sensing observations from satellites or drones are not yet common). Thus, it was necessary to have a global view on the human resources and institutions that are investing in soil analysis. Because the majority of the clients were public entities (e.g., research institutes, NGOs and governmental departments), the quality of soil analysis is expected to have a large impact on decision making, science or both. It is important to consider that some of these institutions might need to provide financial or technical support to GLOSOLAN, a RESOLAN or both.
Interpretation of the results was requested for a large number of analyses and should consequently be included in the standardization and harmonization that GLOSOLAN would like to achieve.

3.6 Section 6: Analyses performed by the laboratory (questions 35–42)

Purpose of the analyses (questions 35–37)

Most of the laboratories reported performing analyses related to soil chemistry (98 percent) and soil physics (76 percent). A minority performed analyses in relation to soil biology (23 percent) and “other” characteristics (15 percent).

At global scale, analyses were used firstly for fertilizer recommendations (76 percent) and secondly for soil classification (65 percent). At the regional scale, 56 percent of Asian laboratories did not perform analyses for soil classification and a majority of Latin-American and European laboratories did not perform analyses for fertilizer recommendations.

The average annual number of samples can be considered an indicator of the level of laboratory activity.

According to the number of samples, laboratories were classified into small, medium and large; i.e., <=1,000; 1,000–6,000; and >6,000 samples annually. Sixty-six percent and 42 percent of respondent laboratories reported analysing fewer than 1,000 samples for soil classification and fertilizer recommendations, respectively. Large numbers of samples (>6,000/year) for fertilizer recommendations were more commonly reported (18 percent) compared to the sample numbers analysed for soil classification (7 percent).

The distribution of small, medium and large laboratories varied amongst the regions. One in four laboratories in Africa and Asia and one in three in Latin-America were classified as large (>6,000 samples/year for fertilizer recommendations).

The results generally were in accordance with the estimated laboratory size based on the number of employees. See Section 3: Staff qualification and performance

Discussion and suggestions

The RESOLANs will need to consider the diversity in lab characteristics when developing their work plan.

Soil pre-treatment (questions 39–42)

Five types of sample pre-treatment are generally considered: drying, crushing, sieving, dividing and milling as reported in ISO 11464. This international standard was the most common method of soil pre-treatment reported globally. Seventeen per cent of the other respondent laboratories reported using a mix of established protocols from literature, further international standards (ISO 9000, ISO 11465), and inter-organizational standards. The lack of standard soil pre-treatment was 36 percent at the global level. It was particularly high in laboratories affiliated with Asia, America and Africa, where no soil pre-treatment was applied in 83 percent, 50 percent and 47 percent of the laboratories, respectively. This high rate is very surprising and could result from a misinterpretation of the question.
Respondent laboratories reported drying their soil samples as follows: 55 percent air dry, 32 percent oven dry and 8 percent both approaches. Very few laboratories (3 percent) reported using chemical dry, freeze dry, or flat heater approaches. Oven dried samples are mainly used for analyses in laboratories in Europe (42 percent) and America (38 percent). Those using “oven dry” reported a range of temperature conditions from 30°C to 105°C. Most of the respondents (46 percent) who use “oven dry” did so at 40°C. This procedure was especially well established amongst laboratories in Europe (57 percent). Temperatures ranged broadly between laboratories in other regions.

Sample grinding was mainly done manually (50 percent), by machines (29 percent) or both (12 percent). Grinding methods were found to be most diverse amongst laboratories in Europe, where 12 percent of laboratories reported using other methods; e.g., agate ball mill, colloid mill and jaw crusher.

The most common sieve was the 2 mm sieve (79 percent); 0.5 and 0.2 mm sieves were used by only 4 percent and 2 percent of the laboratories, respectively. As for the grinding method, laboratories in Europe reported a bigger variety for sieves in the category “Others”. For example, several different sieves, ranging from an 8 mm to 53 µm, were used, depending on the type of analysis, the type of the soil sample (mineral or organic soil), and the amount or weight of sample to be analysed.

**Discussion and suggestions**

The high rate of absence of soil pre-treatment in some regions was very surprising. This suggested a misinterpretation of the survey question; most probably, many laboratories had to prepare and process the samples before analysis but did not call it a “pre-treatment”. From the analysis of the results, a lack of standard soil pre-treatments may also explain the variability in the results.

**The analyses performed by the laboratories (questions 38)**

A list of 40 parameters was provided. Respondents were asked if these were analysed; how many analyses were performed annually; what the general procedure was and, if that was a standard method, for which purpose it was used; and if the method was accredited, certified, or both. Even with a limited list of basic questions, a large diversity of answers was obtained. This diversity documents the existence of a large diversity of situations. In this report, the only aspects presented are those that are most important to discuss at the second GLOSOLAN meeting. More detailed analysis will be performed and provided as soon as possible.

Points for consideration are: (i) the parameters that were analysed by the largest number of responding laboratories and (ii) the parameters that were analysed more frequently worldwide. The “top 10” analyses identified using these two criteria are presented in Table 2.
Table 2. Soil parameters analysed by the largest number of responding laboratories (list on the left side) or analysed more frequently (list on the right side).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Number of laboratories</th>
<th>Parameter</th>
<th>Number of analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH in H₂O</td>
<td>88</td>
<td>Available P₂ other</td>
<td>335 480</td>
</tr>
<tr>
<td>Electrical conductivity (EC)</td>
<td>83</td>
<td>Organic matter</td>
<td>272 927</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>81</td>
<td>pH in H₂O</td>
<td>239 293</td>
</tr>
<tr>
<td>Texture analysis</td>
<td>80</td>
<td>pH in KCl</td>
<td>224 857</td>
</tr>
<tr>
<td>Organic carbon</td>
<td>78</td>
<td>Exch. K – NH₄0-Ac</td>
<td>221 608</td>
</tr>
<tr>
<td>Organic matter</td>
<td>72</td>
<td>Exchangeable acidity</td>
<td>214 755</td>
</tr>
<tr>
<td>Micro elements</td>
<td>67</td>
<td>Organic carbon</td>
<td>189 948</td>
</tr>
<tr>
<td>N-NO3 and N-NH4</td>
<td>63</td>
<td>Texture analysis</td>
<td>180 213</td>
</tr>
<tr>
<td>pH in KCl</td>
<td>61</td>
<td>Micro elements</td>
<td>174 230</td>
</tr>
<tr>
<td>Trace elements</td>
<td>60</td>
<td>Electrical conductivity (EC)</td>
<td>160 600</td>
</tr>
</tbody>
</table>

As shown in Table 2, the most frequently and widely analysed parameters are pH in H₂O and in KCl, organic carbon, organic matter, electrical conductivity (EC) and texture.

Unfortunately, the large set of analysis and procedure information collected through the survey could not be reported in this document. However, the information will be analysed in the near future in collaboration with RESOLANs.

**Discussion and suggestions**

It was very surprising not to see phosphorous and potassium in the list of the most frequently and widely analysed parameters. These two parameters are indeed quite important when assessing soil fertility. Similarly, it was also surprising not to see cation exchange capacity (CEC), which is necessary to estimate fertilizer application rates or fertility potential/capacity. This could result from mistakes when answering the survey. Perhaps wrong answers increased the importance of some parameters (that consequently appeared in the “top 10”) and simultaneously decreased the importance of other parameters. It could be useful to organize region-specific surveys to gain a better estimation of the number of analysis performed by a larger sample of laboratories and thereby confirm or correct the list of the “top 10” parameters.
Moreover, it seems necessary to include these parameters in the effort of standardization and harmonization. The laboratory managers that have the highest motivation to join GLOSOLAN and their clients would be interested to get higher quality, standard results.

3.7 Section 7: pH in water (questions 43–46)

Soil: water ratio for preparing the soil suspension

A large majority (82 percent) of laboratories reported using a weight to weight ratio (g soil/g water). The others (18 percent) used a volume/volume approach. The later were more frequent in Europe (29 percent).

Laboratories reported soil to solution ratios ranging from 1:1 to 1:10. In the majority, ratios of 1:2.5 (32.1 percent), 1:5 (35.7 percent), and 1:1 (14.3 percent) were reported.

At the regional level, 1:2.5 was preferred in Africa and America (53 percent and 38 percent respectively), 1:1 was preferred in Asia (56 percent) and 1:5 was preferred in Europe (42 percent).

Stirring and settling times

Respondent laboratories also reported a very broad range of stirring times: from 1 to 120 minutes. The most frequent stirring times were 30 minutes (20 percent) and 60 minutes (19 percent) followed by 5 minutes (14 percent) and 10 minutes (8 percent).

The largest regional variation was in America, where 5 minutes was most common (38 percent).

An even larger range was reported for the sample settling times after stirring time: from 0 to 20 hours. The most frequent settling time was 60 minutes (19 percent) followed by 10, 30 and 120 minutes (11 percent each). The largest regional deviation from average was found in Europe, where 60 and 120 minutes were the most frequent (21 percent each).

pH reading

When reading the value of pH, the electrode was located in the clear supernatant for 48 percent of the respondents and in the soil settled at the bottom for 16 percent. One out of four laboratories reported using other procedures; e.g., measuring the pH while stirring (6 percent), in the stirred soil suspension (16 percent), and in the soil pulp (1 percent).

Comment: even for measuring a parameter as simple (from a technical point of view) as the pH, a large variability was observed in executing four compulsory steps in the analysis. This variability resulted in a very large variability between the laboratories, even where the laboratories were located in the same region.
3.8 Section 8: Carbon content (questions 47–50)

**Removal of living roots**

Complete removal of roots from soil samples before measurement of soil organic carbon is a prerequisite. The removal of living roots, however, was reported by only 65 percent of the laboratories. All the regions had a very similar answer to that question. Removal was done either manually (37 percent), by sieving (16 percent) or by both methods (4 percent). Living roots were not removed in 38 percent of the laboratories in America, 29 percent of the laboratories in Africa and 21 percent of the laboratories affiliated in Europe. Standardization of sample pre-treatment seems necessary.

**Soil fraction and mass**

Sieving size is a critical factor. Reported sieves were mainly 2 mm, which was the size used by half of the laboratories (47 percent). The other half used 0.5 mm (20 percent) or sieves other than one mentioned in the questionnaire. Other sizes ranged from 0.25 mm to 25 µm, depending on the type of analysis, the type of soil sample and the sample weight.

A broad range of soil masses was reported for carbon analyses, ranging from 0.0025 g to over 500 g. The most common (36 percent) soil mass range was between 0.2 g to 5 g, and nearly the same proportion of laboratories (28 percent) used a range of soil masses depending on the soil type.

**Analytical methods**

Walkley-Black was the most common method. It was used by 62 percent of laboratories. Dry combustion was used by 26 percent of the laboratories, and other methods (Tyurin, Heanes, etc.) were used by 12 percent.

If the regions are considered, Europe is the only region where the Walkley-Black method was used by a minority of labs (15 percent) and dry combustion method was more frequent (26 percent).

**Details on procedures for the Walkley and Black method**

Another critical factor is the ratio of potassium dichromate to sulfuric acid. This ratio was 10:20 for 34 percent of total number of laboratories and 10:25 for only 5 percent of them. Note that a 10:10 ratio was used by the 19 percent of laboratories who also replaced K-dichromate by K-permanganate. This change could have a significant impact on the analytical results because no sulfuric acid is used with K-permanganate, making the reaction temperature lower.

**Comment:** Even though procedural variations were small for measuring carbon content compared to those for measuring soil pH, the variability can have large consequences on the final result. Absence or presence of root removal probably has the largest affect, but even differences in fraction sizes and ratio of potassium dichromate to sulfuric acid could have important affects.
3.9 Section 9: Quality control and quality assurance (questions 51–65)

Standard operating procedures (SOPs) and log books

Most soil laboratories (91 percent) reported having and using SOPs; however, 4 percent reported they did not and 3 percent reported having SOPs but not using them. About 39 percent of the laboratories from Asia did not have SOPs. This high rate is surprising and could result from a misinterpretation of the question. Mostly, analytical SOPs are available in the rooms where analytical tests are carried out. However, in 11 percent of all surveyed laboratories and 39 percent of surveyed laboratories in Asia, SOPs were not available in that room. SOPs were written in the national language for 39 percent of the laboratories, in English for 24 percent, in other official UN languages (English, French, Spanish, Chinese, Russian and Arabic) for 19 percent, and in both national and a UN official language in 10 percent. At the regional level, laboratories in Europe most commonly used SOPs written in the national language (65 percent). English written SOPs were rarely used. Laboratories in Africa and NENA, for the majority, reported using SOPs written in English. In America, 63 percent of laboratories used SOPs written in other UN official languages (mostly Spanish).

Survey responses for investigating the existence of maintenance log books for instruments (balance, spectrometer, etc.) found that only 68 percent of laboratories used such books yet. “Result log books” near each instrument were available in only 59 percent of the laboratories.

Instrument calibration

Survey participants also reported frequencies of calibration for the balances differing from yearly to daily. In this regard, the results showed that good laboratory practices (GLP) still need to be implemented as a standard. Generally, it is assumed that the higher the calibration frequency for the balances, the better the performance of the laboratory. However, only 25 percent of all surveyed laboratories reported daily calibration. On the contrary, another 25 percent reported calibrating the balances only once per year. Calibration of balances was best established in European laboratories, which had a high percentage of daily (29 percent) and weekly (13 percent) calibration and internal calibration before each use/set of measurements (10 percent). The majority of laboratories in Africa, Asia and America reported yearly calibration. Laboratories in NENA reported monthly (50 percent) and quarterly (50 percent) calibration.

Analytical batches

Thirty-three per cent of the respondents reported that the average number of samples per analytical batch was dependent on the analytical method, the analysed parameter, and the rate at which samples were received in the laboratory. They did not give an explicit of number of samples (3 percent) or gave an explicit variable range (33 percent). A very small portion of respondent laboratories (5 percent) did not include a “blank” sample of the extracting solution in each analytical batch.

Internal/quality control samples

Internal control samples were also widely used in laboratories (85 percent). Only 15 percent of participants reported not using them. At the regional level, however, insufficient use of internal control samples was observed in Asia and Africa, where 39 percent and 24 percent, respectively, did not use such samples.
number of internal control samples per analytical batch ranged from 1 to 10 (70 percent), with the majority of laboratories using less than 6.

Most laboratories (83 percent) included quality control samples. Only 17 percent of the laboratories did not. At the regional level, however, internal quality control samples were not commonly used in Africa and Asia, where 29 percent and 28 percent of the laboratories, respectively, used such samples in an analytical batch. The majority of quality control samples were internal reference material (IRM) and standard reagents, each representing about a third of the reported answers. Certified reference material (CRM) is used overall less commonly in laboratories (25 percent), particularly in Asia. Internal control samples were used track performance in 34 percent of the responding labs. There was a wide range of responses for how frequently laboratory performance is checked, ranging from daily to yearly. More than half of the laboratories used internal standards to check performance at least once per week.

The acceptance limits used to consider the analysis of an “internal control sample” or “quality control sample” as reproducible were reported as follows: 5 percent acceptance limit (25 percent of responses), 10 percent acceptance limit (32 percent of responses), and 15 percent acceptance limit (3 percent of responses). A large majority (80 percent) of respondent laboratories would reanalyse the batch of samples when results from “internal control samples” or “quality control samples” fall out of the acceptance limits. Some laboratories (9 percent) indicated they would only reanalyse the analytical data near the control. Five per cent of laboratories reported taking no action, and 1 percent reported that the analytical data would be corrected. No conclusions can be drawn regarding reanalysis in Africa, Asia, and America. Acceptance limits for reproducibility in these regions were 6 percent, 11 percent and 6 percent, respectively.

3.10 Section 10: Soil laboratory certification and accreditation (questions 66–70)

Participation in proficiency tests/inter-laboratory comparisons

Most of the laboratories (81 percent) reported that they participated in proficiency tests or inter-laboratory comparisons. Only 19 percent did not participate. Generally, the survey results showed that the participation in those activities was highest for laboratories in Europe (92 percent). In Africa, Asia, America and NENA, approximately one third of surveyed laboratories did not participate in proficiency tests or inter-laboratory comparisons. Those laboratories that answered “yes” reported participation at the international (37 percent) or national (33 percent) level; only 13 percent of them participated at both levels. A majority of laboratories in Africa (59 percent) and Europe (48 percent) participated at the international level. Laboratories in Asia, America and NENA mostly participated at the national level. A few laboratories reported being in the planning phase towards participation in proficiency tests/inter-laboratory comparisons. Twenty three per cent of laboratories indicated that they participated in proficiency tests or inter-laboratory comparisons at least once a year. Fourteen per cent of all surveyed laboratories, and one in four laboratories in America, reported participating less frequently (every 2 to 5 years).
Accreditation/Certification

More than half of all participants in the survey were not accredited or certified (54 percent). The accredited/certified labs were mostly certified by ISO 17025 (28 percent) and to a much lesser extent by ISO 9000 (3 percent). Other responses included further accreditation/certification by, for example, ISO 9001, ISO 10012, ISO 17026 or national standards. A few laboratories from Africa, Asia and America reported being in the process of accreditation/certification. Regarding the status of accreditation/certification of analytical procedures used in the laboratories (see Table 3), only one in three laboratories was accredited/certified. Twenty-three per cent of all surveyed laboratories did not use certified analytical procedures yet. For the majority of laboratories, no information at all was available on the status of accreditation/certification. These results indicate an urgent need for the implementation of a certification system as well as a QA/QC system using ring tests or inter-laboratory comparisons.

Table 3. Status of certification/accreditation of analytical procedures used in the laboratories

<table>
<thead>
<tr>
<th>Answer option</th>
<th>AFRICA</th>
<th>ASIA</th>
<th>AMERICA</th>
<th>EUROPE</th>
<th>NENA</th>
<th>GLOBAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accreditation</td>
<td>29%</td>
<td>33%</td>
<td>17%</td>
<td>50%</td>
<td>44%</td>
<td>33%</td>
</tr>
<tr>
<td>Non certified</td>
<td>24%</td>
<td>20%</td>
<td>33%</td>
<td>27%</td>
<td>12%</td>
<td>23%</td>
</tr>
<tr>
<td>NA</td>
<td>47%</td>
<td>47%</td>
<td>50%</td>
<td>23%</td>
<td>44%</td>
<td>44%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

A good majority of laboratories taking the survey (71 percent) reported maintaining a data library. However, about half of the laboratories in Africa and Asia did not collect their data using a data library yet.

3.11 General comments on expectations for GLOSOLAN

Overall, respondent laboratories expect GLOSOLAN to work on the following:

- Establishment of a training programme for laboratory staff (technical staff/management staff);
- Improvement/enhancement of laboratory infrastructure, equipment and facilities;
- Support for laboratories in accreditation/certification process for used instruments, laboratory procedures, and other activities following international standards (e.g., ISO); and
- Development and promotion of a certified GLOSOLAN soil laboratory QA/QC system that includes staff training to improve QA/QC.

In addition to general expectations on GLOSOLAN, the needs of soil laboratories were different from one region to another, see Table 4.
Table 4. Summarized specific laboratory needs in the RESOLANs

<table>
<thead>
<tr>
<th>Region</th>
<th>Specific laboratory needs</th>
</tr>
</thead>
</table>
| Africa | • Guidance for managing the disposal of laboratory waste properly  
• Methodology catalogue that includes methods that are not harmful to the environment and pose no health risk for staff  
• Participation in inter-laboratory tests/proficiency tests on national/international level  
• Regular maintenance/calibration of instruments  
• Innovative analytical methods  
• Improvement of the internal laboratory control and enhancement of the use of logs |
| Asia   | • Data management system  
• Enhanced collaborations with academia, industries, governmental institutions  
• Innovative analytical methods  
• Capacity building (e.g., resource mobilization to hire trained and qualified soil analysts)  
• Acquisition of internal quality control samples (for batch analyses) |
| America| • Innovative analytical methods  
• International cooperation  
• Training and capacity building |
| Europe | • Improvement of the experience exchange on national/international level  
• Participation in international ring tests  
• Certification of used instruments and procedures that follow ISO  
• Participation in inter-laboratory comparisons  
• Reference materials  
• Acquisition of certified materials as reference standards in analytical procedures  
• Standardized data repository |
| NENA   | • Improvement of the experience exchange on national/international level  
• Revision and adaption of existing analytical methods following ISO standards  
• Acquisition of internal quality control samples (for batch analyses) |
4 General discussion

Most knowledge concerning soils and the impact of human management comes from laboratory analysis. To achieve global management of the limited soil resource, the data collected from any laboratory in the world will need to be comparable with data collected from any other laboratory. In other words: for a given sample, every laboratory should provide the same analytical results within the range of uncertainty for the analysis.

From everyday laboratory experience, it is known that reaching such a goal cannot happen by chance but requires constant effort. If laboratory managers and their staff do not make this effort, different results are likely for the same soil samples. Differences in analytical results can be monitored during a ring test (also called "proficiency test"). Conducting such a test at a worldwide scale, however, is challenging because of (i) customs and quarantine rules concerning soil exportation and (ii) difficulties in obtaining sufficiently large quantities of control samples (reference material, etc.).

As organizing a global ring test was neither possible in the timeframe nor resourced, GLOSOLAN launched a survey to document the current procedures and practices of soil laboratories. The survey was intended to identify: (i) possible sources of analytical result variations and (ii) efforts that could be undertaken to achieve the desired objective (i.e., send one sample to many labs and get one result +/- known uncertainty).

To achieve standardized and harmonized analyses, the following factors need to be controlled: standard operating procedures (SOPs), equipment, staff qualifications, internal quality control, external quality assessment and certification.

Based on the results of the survey, milestones could be suggested for each of these six factors on the GLOSOLAN roadmap to advance excellence in soil laboratories and thereby facilitate more efficient and effective worldwide soil management.

4.1 Standard operating procedures (SOPs)

When working with laboratories, the first factor that explains differences between analytical results is the differences in analytical procedures. Question 38, which concerned 40 parameters, demonstrates that these differences in analytical procedures can be very large not only for complex procedures (such as phosphorous), but even for simpler procedures (such as pH). Consequently, the first priority of GLOSOLAN should be the development of SOPs that could be adopted worldwide. But worldwide adoption seems difficult, if not impossible.

The existing barriers to the adoption include resistance from:

- laboratory owners/managers, who would have to buy, maintain and calibrated new equipment (glassware, chemicals, etc.);
- laboratory staff, who would have to change working habits and increase their competences; and
- clients, who might not want to get data obtained with different methods, as these data can hardly be compared with older ones.
Given that all laboratories will not adopt a single SOP (at least during this first round of discussions), it is necessary to select for each parameter a SOP that fulfils one or more of the following criteria.

The SOP:
- is already used by the highest number of laboratories,
- already represents the highest number of analysis done worldwide,
- is already a validated international SOP,
- could be adopted by nearly all the participating laboratories in a given region,
- could be adopted by at least the reference laboratories of each country,
- has other characteristics that make it uniquely appropriate.

Note that for different SOPs, different criteria could be necessary or more efficient.

If all laboratories do not adopt a single SOP, different procedures will be used to characterise a given soil characteristic. **Consequently, the selection of a SOP should necessarily consider harmonization of results with other methods; i.e., consideration should be given to ways of converting results to make them comparable.**

As a conclusion, for each SOP it will be necessary to answer at least these questions:

1. What is important to standardize for this particular method?
2. At what level can decisions be made: RESOLAN or GLOSO-LAN?
3. What is an achievable objective?
4. What can be the drivers or facilitators to reaching this objective?
5. What are the barriers to reaching the objective?
6. What must be controlled to reach a sufficient level of standardization?

In the context of this report, it is not possible to answer these questions because direct discussion is needed between laboratory managers.

### 4.2 Equipment and infrastructure

The topic of equipment and infrastructure concerns the environment in which the analyses are performed. See Section 4, questions 17 to 29. As for the SOPs, this topic can be examined by trying to answer some simple questions:

**What needs to be improved?**

According to the answers to the survey, most of the laboratories have generally good quality equipment and the infrastructures: they have special rooms for soil preparation and storage, good conditions for storage of soil and chemicals, special rooms for specific equipment, and, in most cases, the quality of water seems correct. Consequently, in most of the laboratories the equipment and infrastructure did not appear to limit the quality of the analytical results.

**At what level can decisions be made?**

If improvement is necessary or recommended, decisions can be made and organized only at the laboratory level or national level.
What is an achievable objective?

An achievable objective could be to get equipment and infrastructure that follow the general recommendations from RESOLAN and GLOSOLAN. The equipment and infrastructure would thereby have similar influences on the analytical results and their variability and on the safety and working conditions of the staff. For example, if pH is considered, an achievable objective is to have all laboratories using equipment and infrastructures that have similar characteristics (pH meter, probes, controlled room temperature, etc.). This example was selected because pH is one of the most commonly analysed parameters.

What can be the drivers or facilitators to reaching this objective?

Reaching the objective would be facilitated by the existence of a platform of discussion for laboratory managers to exchange information. Topics of discussion could include instrument qualities (reliability, cost of running the instruments, specific need, etc.), building organization, sample storage, etc. It is also recommended that a database be set up to record technical information that could be used by any interested laboratory.

What are the barriers to reaching the objective?

One of the main barriers is the cost of some equipment and building improvements. In some cases, country/city infrastructure might also be a problem. Insufficient or low quality water or an unreliable electricity supply can become a major barrier to running a laboratory.

What are the criteria for evaluating success?

A laboratory can consider an investment in equipment or infrastructure successful if the investment has a positive effect on precision or accuracy. It is necessary to get a certification or accreditation, or improves the safety or working conditions of the staff members.

4.3 Staff qualification and performance

The staff is the most valuable element in a laboratory. A trained (and motivated) staff is an absolutely necessary ingredient to a successful laboratory; i.e., a laboratory able to deliver good quality results and follow all standard procedures during its everyday activities. The best equipment and infrastructure can deliver good quality results only if trained staff members and qualified managers are able to correctly run such equipment and correctly collect and interpret the results.

To run a laboratory and obtain good results, not only is a sufficient number of staff necessary, but the staff also needs to have appropriate qualifications. The staff needs training to ensure that all laboratory operations are correctly executed and needs adequate supervision by a qualified laboratory manager. Although a large budget can help to get expensive instruments, much more than only budget is necessary to hire and retain qualified staff and laboratory managers.

The survey collected some basic information about staff qualifications and performance (see Section 3, questions 11 to 16) that will now be examined to provide recommendations for GLOSOLAN to consider when defining its roadmap.
What needs to be improved?

The survey highlighted that many laboratories have: (i) a high number of temporary staff, (ii) a lack of education and specific training for soil analysis, and (iii) a lack of regular training even for permanent staff.

The current situation could be improved by organizing initial or regular training on general qualifications firstly for chemical analyses work.

Secondly, training should be conducted specifically concerning soil analysis (that even people having experience in chemistry should receive). Examples include handling and preparing soil samples, calibrating and running analytical instruments used for soils (texture for example), presenting and explaining the specific SOP for each soil parameter, reporting results correctly in standard units for soil science and agronomy, and assessing and solving certain elementary daily problems concerning soil samples.

Training should also concern good laboratory practices, in particular: using a maintenance log book, reporting troubles on written documents, reviewing the results of the internal control samples, running the analysis for external proficiency testing samples, and understanding the safety rules.

At what level can decisions be made?

Countries need to make staff training mandatory for accreditation. The laboratory managers can test the competence of the staff and organize regular training to improve or maintain these competences.

GLOSOLAN, in agreement with RESOLANs, can provide some manuals that present the knowledge and skills that soil laboratory staff should have. The manuals should (i) help develop training programmes concerning the different aspects of soil analysis laboratories and (ii) suggesting the minimal level of skills and competency for different aspects of soil analysis laboratories and then develop tests for these skills and competencies.

What is an achievable objective?

GLOSOLAN should make available free videos, e-books and other instructional materials for all categories of soil laboratory staff.

Each laboratory should organize initial training for new staff and should annually test performance with the support from GLOSOLAN recommendations.

What can be the drivers or facilitators to reaching this objective?

If the most advanced laboratories volunteer to organize training for less advanced ones, it would be much easier to reach the objectives.

It will also be necessary to identify who will cover the costs associated with such training (travel, accommodation, etc.) and the production of manuals and video.

What are the barriers to reaching the objective?

Because of the differences in languages, e-books, videos and trainings that can be understood by laboratory staff from all countries should be developed.
What are the criteria for evaluating success?

Success can be estimated from:

- Number of e-books and videos that are downloaded;
- Number of qualified laboratories that volunteer to train other labs or host training;
- Number of staff that participate in the training;
- Number of staff that can pass the competency test;
- Number of countries that make the initial training and competency testing mandatory for the soil analysis laboratories;
- Number of countries and regions where staff has been trained.

Note that even laboratories that do not use standard operating procedures should have trained staff and can join the RESOLANs and GLOSOLAN to get support on these aspects.

4.4 Internal quality control

One of the objectives of GLOSOLAN is to standardize the analytical procedures in soil laboratories around the world so that the laboratories provide similar results when receiving the same soil sample. This objective requires that multiple analyses of a sample provide the same result (within a defined range of uncertainty). This requirement can be controlled by the laboratory itself by running internal quality control. The survey provided some information on these aspects. See Section 9, questions 59 to 65.

What needs to be improved?

The use of internal control samples is already very high (85 percent of the responding laboratories). In one third of the laboratories, however, these quality controls are used only once a week or less frequently. Consequently, it seems necessary to increase the frequency at which the results are used to track performance.

No question was asked about how these data are recorded, used and shown to customers for quality assurance purposes. This aspect should be considered for improving the performance of the laboratory and fulfilling the customer’s need for good quality results.

At what level can decisions be made?

The laboratory managers must implement internal quality control on a regular basis.

For each analytical parameter, GLOSOLAN and RESOLANs should provide clear recommendations on the best procedures of internal control. The recommendations must comply with the general rules for good laboratory practices.

What is an achievable objective?

Each laboratory should prepare a stock of at least two or three soils to be used as control samples. The soils should have different characteristics. These samples would be used at least daily in routine laboratories (or in each batch for research laboratories) to track the quality of the results. The data on the control samples should be recorded in a local database, used to plot quality charts, and used to calculate the quality of the laboratory for each of the parameters.
What can be the drivers or facilitators to reaching this objective?

Each institute should provide budget to collect, prepare and store internal control samples. A platform of discussion should be established between laboratory managers to exchange information on how to organize the internal quality control and how to solve problems.

What are the barriers to reaching the objective?

The highest barrier will be the human tendency to keep the same habits and a reluctance to analyse samples that are considered as additional work, useless or a waste of time.

Another barrier is that the cost and time required for additional analysis reduce budget and time dedicated to client’s samples.

What are the criteria for evaluating success?

Success can be evaluated from the quality charts for the different analysis done by the laboratory.

Note that even laboratories that do not use the SOPs recommended by GLOSOLAN need to implement internal quality control and can thus join the RESOLANs and GLOSOLAN to get support and recommendations on implementation.

4.5 External quality assessment

Internal quality control helps to evaluate and improve the precision of a laboratory (whatever the parameters analysed and the procedure that is used). External quality assessment helps to evaluate the accuracy of the results that is the closeness of the results to the “true” or “consensus” value. To make soil data comparable and exchangeable worldwide, sound and harmonized data should be produced. Such data could thereafter be used for monitoring, reporting and mapping as well as in decision making. Participation in external quality assessment was examined in the survey. See Section 10, questions 66 to 69.

What needs to be improved?

A large majority (81 percent) of the laboratories is already involved in external quality control and would probably be ready to participate in a global proficiency test, or ring test.

It is possible (i) to increase the participation in a ring test by involving as many as possible of the remaining laboratories and (ii) to provide the same material to all the laboratories interested in joining a global ring test.

At what level can decisions be made?

The GLOSOLAN and the RESOLANs should organize global and regional ring tests.

What is an achievable objective?

It should be achievable to involve at least the reference laboratory of each country in such ring tests and to establish international connections among the laboratories.
What can be the drivers or facilitators to reaching this objective?

A need exists for financial support to collect, prepare and send the samples in the different laboratories. Also needed are volunteer experts to perform statistical analyses, interpret the results, and write reports.

What are the barriers to reaching the objective?

Due to custom regulations, it can be very difficult to send soil samples to some countries. These regulations make it very difficult to conduct a ring test that is really international. As a first step, it would be possible to organize a ring test at the level of the RESOLANs and include as many countries as possible. Customs problems exist even at the regional level.

What are the criteria for evaluating success?

Criteria for success could include the number of participating regions, laboratories, reference laboratories, and countries and measurements of global or regional improvement in laboratory accuracy.

Note that laboratories that do not use the GLOSOLAN’s SOPs should be motivated to join the GLOSOLAN and RESOLANs ring test to facilitate the harmonization of analytical results received from all laboratories and countries.

4.6 Certification/accreditation

Certification represents a written assurance by a third party of the conformity of a product, process or service to specified requirements. Accreditation is the formal recognition by an authoritative body of competence to work to specified standards. Both accreditation and certification prove that a laboratory provides accurate and reliable results. The difference is that each country can host multiple certification bodies (ISO is the most famous one) but each country has only one recognized source for national accreditation (ministries, special institutions, etc.).

What needs to be improved?

Half of the responding laboratories did not get certification or accreditation. The number without certification or accreditation should be reduced.

At what level can decisions be made?

GLOSOLAN should set up its own certificate. Laboratory managers could then decide to join the certification process.

What is an achievable objective?

GLOSOLAN can launch a certificate of quality for soil analysis results.
What can be the drivers or facilitators to reaching this objective?

The objective needs experts who are ready to contribute in setting up such a certificate and are willing to join the auditing and evaluation of the laboratories.

What are the barriers to reaching the objective?

Budget is needed to cover the cost of organizing meetings to set up the certificate. Labour time is needed to develop such a system and to organize the audit. Experts in this field are rare.

What are the criteria for evaluating success?

Criteria for success could include the number of laboratories that get a certificate and the number of countries and institutions that request GLOSOLAN certificates for soil analysis laboratories.
5 Conclusions

Recommended actions for GLOSOLAN
Towards the GLOSOLAN Roadmap for 2019

• GLOSOLAN should propose draft standard operating procedures (SOPs) for a most common or important soil parameters. This action would stimulate the development and adoption of SOPs. At present, the operating procedures are so diverse that worldwide implementation would be difficult for even a single SOP for each parameter. Consequently, it seems necessary to first identify which procedures are most likely to affect results for a particular soil parameter and then design an SOP that can accommodate regional and local practices. This should be addressed during the GLOSOLAN second meeting.

• GLOSOLAN should develop e-books and videos to disseminate knowledge concerning good laboratory practices (GLPs) and to provide information on specific aspects related to soil analysis. This action would improve staff qualifications. GLOSOLAN should also propose a training programme that would increase staff competence and could be adopted at regional scale and updated on a regular basis.

• GLOSOLAN should stimulate the development of new RESOLANs. This action would facilitate the dissemination of e-books and videos and the adoption of training programmes.

• GLOSOLAN should motivate laboratories to more frequently analyse internal control soils and thereby implement internal quality control. By increasing the number of internal quality control analyses, laboratories can better assess, monitor and benchmark their precision and also can detect systemic problems.

• GLOSOLAN should organize a proficiency testing programme, or ring test, to benchmark the results of each method across laboratories. Ring tests could be organized on a regular basis at two levels: regional and global. These tests would: (1) evaluate and monitor the performance of existing laboratories (accredited or not), (2) validate standard methods, and (3) help set up new laboratories and train staff.

• GLOSOLAN should establish one or two soil reference laboratories in each region to provide technical advice, training and capacity building.

• GLOSOLAN should set up a communication platform to share information and experience among laboratories. This platform could host a database to gather, collect and review available literature (FAO/WEPAL/IPNI/IPPI/OECD).

• GLOSOLAN should develop and promote a certified soil laboratory quality assurance system and provide a GLOSOLAN accreditation scheme.
Annex 1 First GLOSOLAN Survey

Briefly describe how the survey is organized (mention the sections)

First block of questions were on general information to identify the responding laboratory like

1. Email address * ________________________________
2. Your name * __________________________________
3. Official soil laboratory name * _______________________
4. Soil laboratory short name or acronym ___________________
5. Full address of the soil laboratory* _________________
6. Country of the soil laboratory * ______________________
7. Head of the soil laboratory - last name, name ______________________
8. Head of the soil laboratory - e-mail _______________________

The analysis showed that respondents were …regions

A question (question 9) was asked to know if the lab belonged to any network (this information is useful too identify potential collaboration hubs with existing networks), results for this question are herewith reported:

[You can keep question 9 and 9a as in the survey]
Results for question 9 and 9a

10. Does your laboratory collect national data on agricultural or forest soils?
Single answer
   o Yes, on agricultural soils
   o Yes, on forest soils
   o Yes, on agricultural and forest soils
   o No

GLOBAL AND REGIONAL OVERVIEW (WITH THE GRAPHS)

Staff of the soil laboratory
11. Number of employees with a permanent contract ______
12. Number of employees with a temporary contract ______
13. Percentage of employees who received a formal education on analytical work
   Mark only one oval. 0 1 2 3 4 5 6 7 8 9 10 0 percent 100 percent
14. Percentage of employees who were trained to perform analytical work
   Mark only one oval. 0 1 2 3 4 5 6 7 8 9 10 0 percent 100 percent
15. Percentage of employees who were educated, trained or having experience in "SOIL" analyses
   Mark only one oval. 0 1 2 3 4 5 6 7 8 9 10 0 percent 100 percent
16. Does your lab have a training program to regularly improve the skills of the employees?
   o Yes
   o No

Infrastructure of the soil laboratory
17. Do you have a sample reception area?
   o Yes
   o No
18. Do you have a cold room (constant temperature of 4 ° C) to store samples?
   o Yes
18a. If no, please specify where you store samples and the approximate temperature of the storing place.

19. How do you store samples?
   o sealed glass
   o plastic containers
   o other, please specify

20. Do you store the dried, sieved soil samples
   o at room temperature.
   o in a dark room

20a. Please specify the temperature of the room.

21. Does the soil laboratory have one or more rooms that are dedicated to the storage of reagents, are the latter organized by groups (acids, bases, flammable, highly toxic compounds and compressed gases) and are these sections labeled accordingly and properly?
   o Yes
   o No

22. Do all chemicals/reagents have labels indicating the receipt, and the opening/disposal dates?
   o Yes
   o No

23. Does the soil laboratory have a system to check the receipt and opening dates of chemicals/reagents?
   o Yes
   o No

24. Are the temperature and humidity monitored and recorded in the sensitive areas (balance room, analytical room) of soil laboratory?
   Single answer
   o Hourly
   o Daily
   o Not regularly
   o Never
   o Other (please specify)

25. Does the soil laboratory have a room dedicated to the preparation of soil samples?
   o Yes
   o No

26. Does the soil laboratory have an analytical room dedicated to the storage and use of balances?
   o Yes
   o No

27. Does the soil laboratory have a specific area dedicated to glassware cleaning?
   o Yes
   o No

28. What is the quality of the water used in the soil laboratory?
   o De-ionized water
   o Distilled water
   o Double distilled water
   o Other (please specify)

28a. Please specify the resistivity or electrical conductivity of the water used: ____________

29. How often is the EC of the de-ionised/distilled water tested?
   o Hourly
Clients of the soil laboratory
Which institutions or organisms send their samples to your laboratory for analysis?
30. Who are the main clients of the soil laboratory? [Tick all that apply]
   o Government departments
   o Research institutions [e.g., universities, governmental research centers]
   o NGOs
   o Fertiliser companies
   o Land users (farmers)
   o Other, please specify ______________________

31. Do the clients request advice on which soil tests to use?
   o Yes
   o No

32. How are results reported to the clients?
   o Hard copy
   o Electronically
   o Both
   o Other (please specify)

33. Who signs the result reports? ______________________

34. Does the soil laboratory provide an interpretation of the analyses?
   o Yes
   o No
   o Upon request of the client

Analyses performed by the laboratory
35. Which type of soil analyses does your laboratory provide?
   o Tick all that apply
   o Soil chemistry
   o Soil physics
   o Soil biology
   o Other (please specify)

36. Does the laboratory perform analyses that are useful for soil classification?
   o Yes
   o No

36a. If you choose "Yes", please answer the average number per year.

37. Does the laboratory perform analyses useful for fertilizer recommendations?
   o Yes
   o No

37a. If you choose "Yes", please answer the average number per year.

38. Specify the analyses performed in the next table.
In column USE:
1=For soil classification or national inventory;
2=For fertilizer recommendation
<table>
<thead>
<tr>
<th>YES/NO</th>
<th># SAMPLES PER YEAR (on average)</th>
<th>GENERAL PROCEDURE / METHOD (please describe)</th>
<th>Is the method STANDARD, e.g. ISO? (Yes/no, please specify)</th>
<th>Please specify what this data is USED for</th>
<th>Is the method used ACCREDITED/ CERTIFIED? (please provide details)</th>
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<td>pH in H₂O</td>
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<td>pH in KCl</td>
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<td>pH in CaCl₂</td>
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<td>Organic carbon</td>
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<td>Inorganic carbon (CO₃)</td>
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<td>N-NO₃ and N-NH₄</td>
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<td>Available P by Olsen</td>
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<td>Available P by Bray and Kurtz</td>
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<td>Available P by other method</td>
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<td>CEC in NH₄O-Ac</td>
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<td>Exchangeable Mg by other methods</td>
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<td>Exchangeable Na in NH₄O-Ac</td>
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<td>Water retention Curve</td>
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<td>-Dry bulk density</td>
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<td>-Hydraulic conductivity</td>
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<td>-Microbial biomass</td>
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<td>Other microbiology analysis</td>
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<td>Other, please specify</td>
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</tbody>
</table>
39. Do you follow a standard in soil pretreatment?
   o ISO 11464
   o None
   o Other, please specify

40. How do you dry the samples?
   o Air dry
   o Oven dry
   o Other, please specify

40a. If you choose “Oven dry”, which temperature? [No more than]

41. How do you grind the sample?
   o Manual method (e.g. mallet or mortar)
   o Automated method (e.g. mill)
   o Other, please specify

42. What type of sieve do you use?
   o 2 mm sieve
   o 0.5 mm sieve
   o 0.2 mm sieve
   o Other, please specify

pH in water
43. The soil to solution ratio used to determine the pH in water is:
   in mass/volume, please specify____g soil /___mL water
   or
   in volume/volumen, please specify __mL soil/___mL water

44. How long are the samples stirred for (in minutes): ____

45. After stirring, for how long are the samples left to settle (in minutes): ____

46. When measuring the pH, is the electrode submerged in:
   o The clear supernate (clear liquid after leaving suspension unstirred and soil has settled at the bottom)
   o The soil settled at the bottom of the vessel
   o Other, please specify

Carbon
47. Which fraction of the soil is analyzed?
   o Sieved through a 5 mm sieve
   o Sieved through a 0.5 mm sieve
   o Sieved through a 2 mm sieve
   o Other, please specify

48. Specify the soil mass used for the measurements (in g): ____________

49. In case of using the Walkey and Black method, what is the ratio of the potassium permanganate and sulfuric acid?
   o 10 : 20
   o 10 : 25
   o Other, please specify____

50. For soil Organic carbon measurements, are living roots removed from the sample prior to analysis?
   o No
   o Yes

50a. If you choose "yes", please describe "how" living roots are removed from the sample prior to analysis.

Analytical Procedures
51. Does the soil laboratory have and use any Standard operating procedures (SOPs)?
i.e. Standard operating procedures are WRITTEN documents that present the details of analytical or administrative procedures)?
  o Yes
  o No
  o Existing but not used
52. Are the analytical SOPs available in the rooms where the analytical tests are conducted?
  o Yes
  o No
53. In which language are the SOPs written? ______________
54. Does a "Maintenance Log Book" exist for each instrument (balance, spectrometer, etc.)?
A maintenance log book is a record of all the maintenance operations done by the laboratory personnel or by private companies on a given instrument
  o Yes
  o No
55. Is a "Result Log Book" available near each instrument (balance, spectrometer, etc.)
A result log book is a record of all the results obtained on a given instrument.
  o Yes
  o No
56. How often are the balances in the soil laboratory calibrated?
  o Every day
  o Every week
  o Every month
  o Every 3 months
  o Every 6 months
  o Every year
  o Other, please specify

Quality control
57. How many samples do you usually have in an analytical batch?
A batch is a set of samples which are processed/analysed at the same time. ______________
58. Are "blank" samples of the extracting solution included in each analytical batch?*
A blank solution is the solution that contains all extracting reagents, but was not used for any extraction; it is usually used to calibrate instruments and to check for instrument stability during analysis.
  o Yes
  o No
59. Are "internal control" samples used in the soil laboratory?*
An internal control is a reference soil sample, of known analytical characteristics, available in large quantities (several kilos), and which is analysed in each 'batch' of samples, to check the quality of the results.
  o Yes
  o No
60. If used, how many internal control samples are used for each analytical batch? ____________
61. Are "quality control samples" used in the soil laboratory?*
  o Yes
  o No
62. If used, which material is used as "quality control samples"?
Certified Reference Materials (CRMs): A reference material whose property values (purity, concentration, etc.) are established and certified in accordance with metrological principles using established, international best practice protocols. CRMs are used to calibrate the measurement process and they all have common
characteristics: 1) Assigned values are accompanied by an uncertainty statement, and 2) Information is given on the methods used to assign values

**Internal Reference Material (IRM):** A reference material prepared in the respective laboratory to use as an internal control sample for monitoring precision of the lab results in each batch of analysis

**Standard Reagent:** It can be a certified material if they have certificate that shows the purity, concentration, and traceability
  - Certified Reference Material (CRM)
  - Internal Reference Material (IRM)
  - Standard reagent
  - Other, please specify

63. Are the data obtained from internal control used to track the soil laboratory performance?
  - Yes, performance is tracked every day
  - Yes, performance is tracked every week
  - Yes, performance is tracked every month
  - Yes, performance is tracked every 3 months
  - Yes, performance is tracked every 6 months
  - Yes, performance is tracked every year
  - No
  - Other, please specify

64. What are the acceptance limits used to consider the analysis of an "internal control sample" or "quality control sample" reproducible?
  - 5 percent
  - 10 percent
  - 15 percent
  - Other, please specify

65. When results from "internal control samples" or "quality control samples" fall out of the acceptance limits:
  - The batch of samples is reanalyzed
  - The analytical data near the control are reanalyzed
  - The analytical data is corrected
  - No consequence is drawn

**Soil laboratory certification**

66. Does the soil laboratory participate in proficiency tests or inter-laboratory comparisons?*Proficiency testing or inter-laboratory comparison compares the measured results obtained by different laboratories. Hereby, soil samples are sent to different laboratories. The results reported by each laboratory are compared to a reference value.
  - Yes
  - No

67. If yes, at which level does the proficiency test / inter-laboratory comparison occur?
  - National
  - International
  - Other, please specify

68. If applicable, how often does the soil laboratory participate in proficiency tests / inter-laboratory comparisons?
  - Once every 2-5 years
  - 1 time per year
  - 2-4 times per year
  - Over 5 times per year
69. Is the soil laboratory certified?
   - Yes, under ISO 17025
   - Yes, under ISO 9000
   - No
   - Other, please specify

70. Do you have a data library?
   - Yes
   - No

71. General comments.
   Please provide any further relevant information or details from the soil laboratory, methods

72. What could other soil laboratories learn from your laboratory?

73. What could your laboratory do to improve?

[Closing remarks]
Thanks for taking the survey.


Please address your questions to GSP-Secretariat@fao.org
The Global Soil Partnership (GSP) is a globally recognized mechanism established in 2012. Our mission is to position soils in the Global Agenda through collective action. Our key objectives are to promote Sustainable Soil Management (SSM) and improve soil governance to guarantee healthy and productive soils, and support the provision of essential ecosystem services towards food security and improved nutrition, climate change adaptation and mitigation, and sustainable development.

GLOSOLAN
GLOBAL SOIL LABORATORY NETWORK

GLOSOLAN is a Global Soil Laboratory Network which aims to harmonize soil analysis methods and data so that soil information is comparable and interpretable across laboratories, countries and regions. Established in 2017, it facilitates networking and capacity development through cooperation and information sharing between soil laboratories with different levels of experience. Joining GLOSOLAN is a unique opportunity to invest in quality soil laboratory data for a sustainable and food secure world.

Thanks to the financial support of