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United Nations

Standard operating procedure for boron determination in soil

Hot water extraction

A decorative graphic consisting of a series of colored dots and squares arranged in a semi-circular arc, transitioning from dark brown to light yellow and green.

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Global Soil Laboratory Network GLOSOLAN	GLOSOLAN-SOP-24	
BORON BY HOT WATER EXTRACTION	Version number: 1	Page 1 of 24
	Effective date: 17 April 2024	

BORON BY HOT WATER EXTRACTION

VERSION HISTORY

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01	17 April 2024	All comments by RESOLANs and reviewers to the draft SOP were addressed	Finalization of the SOP
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Global Soil Laboratory Network GLOSOLAN	GLOSOLAN-SOP-24	
BORON BY HOT WATER EXTRACTION	Version number: 1	Page 2 of 24
	Effective date: 17 April 2024	

Contents

1. Introduction	3
2. Scope and field of application	4
3. Principle.....	5
4. Apparatus.....	6
5. Materials for method A and method B.....	6
5.1. Materials for method A: Berger and Truog extraction method.....	6
5.2. Materials needed for method B: Hot water-soluble boron extraction methods	7
6. Health and safety	8
7. Sample extraction.....	8
7.1. Method A: Berger and Truog reference extraction	8
7.2. Method B: Hot water-soluble boron extraction	9
8. Methods for determining boron concentration	9
8.1. Method A: Berger and Truog extraction reference method.....	10
8.2. Method B: hot water-soluble boron extraction method	11
9. Quality assurance/quality control.....	14
9.1. Accuracy test.....	14
9.2. Precision test.....	14
9.3. Sensitivity requirement.....	15
10. Recommendations	15
11. Interpretation of results	16
References	17
Appendix I: International Chemical Safety Cards (ICSCs) for some risky chemical reagents	20
Appendix II: Acknowledgements	22
Appendix III: List of authors.....	22
Appendix IV: Contributing laboratories	23

Modified by	Revision	Approved date	Validated date
GLOSOLAN SOP Tech. W.G. Global leader: Fassil Kebede, Morocco	By review panel and GLOSOLAN technical committee	17 April 2024	17 April 2024

Global Soil Laboratory Network GLOSOLAN	GLOSOLAN-SOP-24	
BORON BY HOT WATER EXTRACTION	Version number: 1	Page 3 of 24
	Effective date: 17 April 2024	

1. Introduction

Boron (B) is a non-metallic essential nutrient for the healthy growth and yield of higher plants. Plants are extremely variable both in B requirements and in B uptake. The concentration of B in the Earth's crust varies from 1 to 500 mg/kg, depending on the nature of the rock (Aubert and Pinta, 1997), and is released to the soils through weathering. There are more than 200 B compounds in the Earth, but only twelve are commercially significant (Adair, 2007). Some important B-bearing minerals are borax (sodium tetraborate decahydrate $[\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}]$) and colemanite ($\text{Ca}_2\text{B}_6\text{O}_{11} \cdot 5\text{H}_2\text{O}$) (Figure 1). The total content of B in soils ranges usually from about 2 mg/kg to more than 100 mg/kg, averaging about 30–40 mg/kg (Whetstone, Robinson and Blyers 1942; Swaine, 1955). The B concentration in soil interstitial solution is variable, ranging from 0.067 to 3 mg/L (Kabata-Pendias and Pendias 2001). Where soil B levels are less than 0.1 mg/kg, deficiency is likely to occur for most crops. However, where soil B levels are greater than about 6 mg/kg, toxicity may occur (Grieve *et al.*, 2012).

Figure 1. Examples of boron-bearing minerals (borax [left] and colemanite [right])



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The B concentration in soil solution is generally controlled by B adsorption reactions, as is the amount of water-soluble B available for plant uptake. Plants respond only to B activity in soil solution as B adsorbed to soil colloid surfaces is not perceived as being toxic to plants (Keren, Bingham and Roades, 1985; Keren, 1996). Factors that affect B availability and the extent of B adsorption in soils are solution pH, soil texture, soil organic matter, clay mineral types, the presence of secondary calcium carbonate, soil moisture and temperature. Boron in soil can either be present in soil solution or adsorbed onto soil minerals such as clays, aluminium (Al) and iron (Fe) (hydr)oxides and natural organic matter. In neutral or acidic soils (i.e. $\text{pH} \leq 7$), the dominant B form is the neutral molecule H_3BO_3 (boric acid), while in alkaline soils, significant amounts of B occur in the form of borate anions (either $\text{B}(\text{OH})_4^-$ or BO_3^{3-}) (Wimmer, Goldberg and Gupta, 2015; Vaughan and Suarez 2003).

Modified by	Revision	Approved date	Validated date
GLOSOLAN SOP Tech. W.G. Global leader: Fassil Kebede, Morocco	By review panel and GLOSOLAN technical committee	17 April 2024	17 April 2024

Global Soil Laboratory Network GLOSOLAN	GLOSOLAN-SOP-24	
BORON BY HOT WATER EXTRACTION	Version number: 1	Page 4 of 24
	Effective date: 17 April 2024	

The hot water-soluble B procedure is the most commonly used method for predicting the concentration of B that will be available to plants in a soil solution. Hot water-soluble B is commonly used because the water-soluble B extracted by the hot water method correlates positively to plant growth response, as it measures B from the adsorbed, organic, and soluble pools of the soil at boiling temperatures (Offiah and Axley 1993; Sarkar *et al.*, 2008).

2. Scope and field of application

Several techniques are routinely employed to analyse B in biological and geochemical matrices, but only a few are sensitive enough to study B at the trace level (Thellier *et al.*, 2001). The most common methods for determining B concentrations are spectrophotometric and plasma-source spectrometric methods. Although most spectrophotometric methods are based on colorimetric reactions of B with azomethine-H (Wolf, 1971), curcumin, or carmine (Hatcher and Wilcox, 1950) other colorimetric and fluorometric methods have also been used to some extent. In general, these methods suffer from interferences and have low sensitivity and precision. The development of inductively coupled plasma (ICP) revolutionized the determination of several so-called “problem elements” such as B, sulphur (S), molybdenum (Mo), and all hard-to-detect trace elements. This is due to ICP’s low detection limits, large linear range, and multi-element (several elements in the same run) detection capability. Reported detection limits for B are 10 to 15 µg B/L in soil solutions and plant digests by ICP-OES based on a linear self-scanning photodiode array (Spiers *et al.*, 1990).

Plant availability of soil B is closely correlated to the amount of B removed from soil by extraction using hot water (Offiah and Axley, 1993; Sarkar *et al.*, 2008). Extracted B can then be determined by colorimetric methods using azomethine-H. The introduction of plasmas as ionization sources and the development of plasma-source analytical instruments (optical emission spectrometer [ICP-OES], and mass spectrometer, [ICP-MS]) provided higher sensitivity and lower detection capability for B determination than was possible by spectrophotometric, flame atomic emission spectroscopy (AES)/atomic absorption spectrometry (AAS), and time-consuming nuclear methods (Sah and Brown, 1997).

The aim of this SOP is to guide users on the determination of hot water-soluble B in soils through the application of three routine procedures, hereafter known as method B, using: 1) azomethine-H; 2) AAS; and 3) ICP-AES.

The Berger and Truog (1944) extraction method is also presented separately as reference method A, since it is widely accepted and commonly used in literature and many soil laboratories for benchmarking purposes.

Modified by	Revision	Approved date	Validated date
GLOSOLAN SOP Tech. W.G. Global leader: Fassil Kebede, Morocco	By review panel and GLOSOLAN technical committee	17 April 2024	17 April 2024

Global Soil Laboratory Network GLOSOLAN	GLOSOLAN-SOP-24	
BORON BY HOT WATER EXTRACTION	Version number: 1	Page 5 of 24
	Effective date: 17 April 2024	

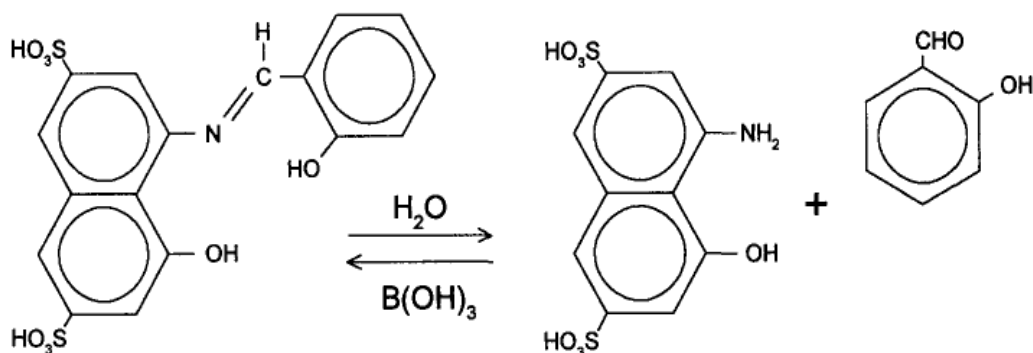
3. Principle

The hot water extraction procedure, introduced by Berger and Truog in 1939 and later modified in 1944 (Berger and Truog, 1939, 1944) is still the most popular method for measuring “available” soil B or the fraction of B related to plant growth in alkaline soils. Water-soluble B, the available form of B, is extracted from the soil by refluxing with hot water. Concentration of B in soil extracts is measured colorimetrically using azomethine-H (Wolf, 1971), by AAS or ICP-OES/ICP-AES.

The principle of the azomethine-H method is based on the reaction of predominantly dissolved H_3BO_3 with an azomethine-H derivative,

1-(2,4-dihydroxybenzylidene-amino)-8-hydroxynaphthalene-3,6-disulphonic acid to form a stable yellow coloured complex (Figure 2) within 15 minutes across a range of 0.5 ppm to 10 ppm with an absorption maximum at 425 nm (the absorbance at 410 nm is measured in the colorimeter).

Figure 2. Hydrolysis of azomethine-H and reverse reaction catalysed by boron in solution



Source: Harp, D.L. 1997. Modifications to the azomethine-H method for determining boron in water. *Analytica Chimica Acta*, 346(3): 373–379. [https://doi.org/10.1016/S0003-2670\(97\)90081-7](https://doi.org/10.1016/S0003-2670(97)90081-7)

The AAS method is based on the principle that free atoms of an element (such as B) in their ground state absorb photons of discrete energy values (a characteristic wavelength, such as 249.7 nm) generated by a hollow cathode lamp containing that element (such as B).

In ICP-OES technology, the B concentration is obtained (**the ICP method**), based on the value of the electromagnetic radiation emitted by the excited B atoms (the wavelength detected for B is 249.773 nm). However, it suffers from some interference (Sah and Brown, 1997) due to the presence of Fe and silicon (Si), which renders low levels of B determination unreliable (Owens, Gladney and Knab, 1982; Din, 1984).

Modified by	Revision	Approved date	Validated date
GLOSOLAN SOP Tech. W.G. Global leader: Fassil Kebede, Morocco	By review panel and GLOSOLAN technical committee	17 April 2024	17 April 2024

Global Soil Laboratory Network GLOSOLAN	GLOSOLAN-SOP-24	
BORON BY HOT WATER EXTRACTION	Version number: 1	Page 6 of 24
	Effective date: 17 April 2024	

4. Apparatus

The following apparatus are required:

- an analytical balance to weigh to the nearest 0.0001 g;
- a 125 mL plastic Erlenmeyer flasks;
- a 250 mL low B flat-bottom flask;
- a 1 L volumetric flask;
- a 100 mL volumetric flask;
- some pipettes;
- a 1 L plastic bottle;
- a 250 mL plastic beaker;
- a 7.5 cm plastic funnel;
- some filter papers;
- a vortex stirrer;
- a double-distilled water dispenser;
- a reciprocal hot water shaking bath;
- a water-cooled reflux condenser;
- a heating mantle;
- an ultraviolet-visible (UV/Vis) spectrophotometer;
- an AA spectrophotometer; and
- an ICP-AES.

5. Materials for method A and method B

Unless otherwise specified, all chemical reagents referred to in this section are analytical grade.

5.1. Materials for method A: Berger and Truog extraction method

The required materials for the Berger and Truog extraction method is as follows:

- Hydrochloric acid (HCl) (0.1 M): Add 8.1 mL of concentrated HCl (reagent grade) to approximately 900 mL of double-distilled water, mix, cool to room temperature, and adjust the solution volume to 1 L with double-distilled water.
- Calcium chloride (CaCl₂) (0.02 M): Dissolve 2.22 g of anhydrous CaCl₂ in approximately 900 mL double-distilled water and adjust the solution volume to 1 L with double-distilled water.

Modified by	Revision	Approved date	Validated date
GLOSOLAN SOP Tech. W.G. Global leader: Fassil Kebede, Morocco	By review panel and GLOSOLAN technical committee	17 April 2024	17 April 2024

Global Soil Laboratory Network GLOSOLAN	GLOSOLAN-SOP-24	
BORON BY HOT WATER EXTRACTION	Version number: 1	Page 7 of 24
	Effective date: 17 April 2024	

- Boron stock solution (1 000 mg/L): Weigh 5.715 g boric acid (H_3BO_3) into a 1 L volumetric flask and dilute to volume with double-distilled water.
- Boron stock solution (20 mg/L): Pipette 20 mL of the 1 000 mg B/L stock solution into a 1 L volumetric flask. Make to volume with double-distilled water.
- Boron working standards: Dilute 0, 1, 2, 3, 4 and 5 mL of the 20 mg B/L stock solution to volume in 100 mL volumetric flasks. This gives a series of working standards with B concentrations of 0, 0.2, 0.4, 0.6, 0.8 and 1 mg B/L.

5.2. Materials needed for method B: Hot water-soluble boron extraction methods

The required materials for the three hot water-soluble B extraction methods are as follows:

1. Azomethine-H:

- Azomethine-H (0.45 percent weight to volume [w/v]) solution: Dissolve 0.45 g azomethine-H in 10 mL double-distilled water containing 1.0 g L-ascorbic acid by gentle heating at 30 °C and make the final volume up to 100 mL with double-distilled water. If the solution is not clear, it should be reheated again till it dissolves. The solution can be kept for seven days under refrigeration.
- Buffer solution: Dissolve 250 g of ammonium acetate in 500 mL of double-distilled water and adjust the pH to about 5.5 by adding dropwise about 100 mL of glacial acetic acid, stirring continuously with a vortex stirrer.
- Na_2 Ethylenediaminetetracetic acid (EDTA) solution (0.025 M): Dissolve 9.3 g of disodium EDTA dihydrate (MW = 372.24) in double-distilled water and make the volume 1 L.
- Calcium chloride dihydrate ($CaCl_2 \cdot 2H_2O$) (0.02 M): Weigh 3.0 g of $CaCl_2 \cdot 2H_2O$ into a 1 L volumetric flask, add 900 mL double-distilled water to dissolve under constant stirring, and dilute to volume with double-distilled water.
- Standard stock solution: Dissolve 0.8819 g of $Na_2B_4O_7 \cdot 10H_2O$ or 0.5717 g of H_3BO_3 in a small volume of double-distilled water and make the volume up to 1000 mL to obtain a stock solution of 100 mg B/L.
- Working standard solution: Put 5 mL of stock solution in a 100 mL volumetric flask and dilute it to the mark with double-distilled water. This solution contains 5 mg B/L.

Modified by	Revision	Approved date	Validated date
GLOSOLAN SOP Tech. W.G. Global leader: Fassil Kebede, Morocco	By review panel and GLOSOLAN technical committee	17 April 2024	17 April 2024

Global Soil Laboratory Network GLOSOLAN	GLOSOLAN-SOP-24	
BORON BY HOT WATER EXTRACTION	Version number: 1	Page 8 of 24
	Effective date: 17 April 2024	

2. AAS:

- Standard B solution: Dissolve 8.819 g of $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$ or 5.717 g of H_3BO_3 in 500 mL warm water and dilute to 1 L to obtain 1000 mg B/L stock solution. Dilute 1 mL of standard to 100 mL to obtain 10 mg B/L.
- Working standards: Take 1, 2, 3, 4, 5, 6, 7 and 10 mL of 10 mg B/L solution and dilute each to 50 mL to obtain 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4 and 2.0 mg B/L.

3. ICP-AES:

- Boron stock solution (1 000 mg/L): Use commercially available single-element plasma grade.
- Boron stock solution (1 000 mg/L): Weigh 5.717 g boric acid (H_3BO_3) into a 1 L volumetric flask and dilute to volume with double-distilled water.
- Boron stock solution (20 mg/L): Pipette 20 mL of the 1 000 mg B/L stock solution into a 1 L volumetric flask. Make to volume with double-distilled water.
- Boron working standards: Dilute either 0, 1, 2, 3, 4 and 5 mL of the 20 mg B/L stock solution to volume in 100 mL volumetric flasks. This gives a series of working standards with B concentrations of 0, 0.2, 0.4, 0.6, 0.8 and 1 mg B/L.

6. Health and safety

As some of the chemicals used in this procedure can pose a safety risk, refer to the International Chemical Safety Cards (ICSCs) in Appendix 1 of this SOP . Moreover, it is also recommended always to wear the appropriate personal protective equipment (PPE) including lab coat, gloves, and safety glasses. Add acid to samples and perform digestions under a fume hood.

7. Sample extraction

7.1. Method A: Berger and Truog reference extraction

To extract B as a reference, use the following process:

1. Place 25 g of air-dried soil into a 250 mL low B flat-bottom flask.
2. Add 50 mL 0.02 M CaCl_2 solution to obtain clear hot water extracts for B determination.

Modified by	Revision	Approved date	Validated date
GLOSOLAN SOP Tech. W.G. Global leader: Fassil Kebede, Morocco	By review panel and GLOSOLAN technical committee	17 April 2024	17 April 2024

Global Soil Laboratory Network GLOSOLAN	GLOSOLAN-SOP-24	
BORON BY HOT WATER EXTRACTION	Version number: 1	Page 9 of 24
	Effective date: 17 April 2024	

3. Attach a water-cooled reflux condenser to the flask. Heat the flask until initiation of boil, reflux the suspension for precisely five minutes, and then cool the flask and filter the suspension through filter paper.
4. Take 5 mL for B determination using the methods described in Section 5.1.

7.2. Method B: Hot water-soluble boron extraction

To initially extract B for B determination, use the following process:

1. Weigh 25 g of air-dried, 2 mm-sieved soil into a 125 mL plastic flask.
2. Add 50 mL of double-distilled water.

Note: where turbidity is expected to be of concern, the double-distilled water in point 2 can be replaced by a 0.02M CaCl₂ extractant, with no significant change in extractable B (Parker and Gardner, 1981).

3. Load the flasks on a reciprocal hot water shaking bath and shake the slurries for 30 minutes at 80 °C.
4. Filter into 125 mL plastic Erlenmeyer flasks, using Whatman No. 42 diameter filter paper. The supernatant may be turbid due to colloidal materials that pass through the filter, check the filtrate for clarity and refilter if necessary. To increase the clarity of the filtrate, 0.5 g of charcoal can be used. Please note that the use of charcoal should be mandatory and not optional for the determination of B in the extract by the azomethine-H method, because the error due to the colour of the extract will be much greater than the error of B loss by sorption to charcoal.

8. Methods for determining boron concentration

Inductively coupled plasma-atomic emission spectrometry is highly correlated with the azomethine-H method ($r = 0.99$) for the measurement of B extracted from many soils (Gestring and Soltanpour, 1981). However, if the hot water extracting solution were to remove organic compounds that contain bound B, then it is likely that the ICP method would result in a higher B concentration value than would other methods which measure only the free B in solution. However, as B is a non-metal, the use of an AAS for its estimation poses some limitations (Sah and Brown, 1997). Besides, this method has poor sensitivity (Papaspyrou *et al.*, 1994), serious memory effects of previous samples, and numerous interferences.

Modified by	Revision	Approved date	Validated date
GLOSOLAN SOP Tech. W.G. Global leader: Fassil Kebede, Morocco	By review panel and GLOSOLAN technical committee	17 April 2024	17 April 2024

Global Soil Laboratory Network GLOSOLAN	GLOSOLAN-SOP-24	
BORON BY HOT WATER EXTRACTION	Version number: 1	Page 10 of 24
	Effective date: 17 April 2024	

8.1. Method A: Berger and Truog extraction reference method

Procedure

The procedure for the Berger and Truog extraction method is as follows:

1. Weigh 20 g of air-dried, sieved soil into a low-B boiling flask capable of use with a water-reflux condensing apparatus.
2. Include at least one blank and one check sample per run.
3. Add 0.6 g of washed charcoal and 2 boiling glass beads to each flask.
4. Add 40 mL of 0.02M CaCl₂ solution into each flask.
5. Attach a water-cooled reflux condenser to the flask. Heat on a prewarmed hot plate.
6. When samples come to a rolling boil, set a timer for five minutes and continue boiling.
7. When the timer goes off, remove samples from hot plate and cool in a pan of cold tap water.
8. Using Whatman No. 42 filter paper, filter into a plastic beaker.
9. Pipette 1 mL of filtrate into a test tube and add 2 mL buffer-masking solution and 2 mL of azomethine-H solution. Thoroughly mix by swirling.
10. Allow the mixture to stand for 30 minutes and read transmittance on a spectrophotometer at a wavelength of 420 nm. Set 100 percent transmittance with a reagent blank 1 mL extracting solution, 2mL buffer-masking solution and 2 mL of azomethine solution.
11. All of the working standards should follow Section 5.1.
12. Prepare a standard curve by adding 1 mL of each of the working standards to a plastic tube or beaker; add the buffer-masking solution and azomethine-H in an identical manner as with soil extracts.
13. Determine the absorbance of standards and compare the results of samples with those from a standard curve.

Calculation

Calculate as follows:

- weight of the soil sample = 20 g;
- volume of the extract = 40 mL; and

Modified by	Revision	Approved date	Validated date
GLOSOLAN SOP Tech. W.G. Global leader: Fassil Kebede, Morocco	By review panel and GLOSOLAN technical committee	17 April 2024	17 April 2024

Global Soil Laboratory Network GLOSOLAN	GLOSOLAN-SOP-24	
BORON BY HOT WATER EXTRACTION	Version number: 1	Page 11 of 24
	Effective date: 17 April 2024	

- available B in the soil (in mg/kg) = B from the standard curve (in mg/kg) × (volume/weight [v/w], i.e. 2).

8.2. Method B: hot water-soluble boron extraction method

8.2.1. Hot water-soluble boron determination by azomethine-H

The extracted B in the filtered extract is determined by the azomethine-H colorimetric method.

Procedure

The procedure for the hot water-soluble B determination method using azomethine-H is as follows:

1. Put 5 mL of the clear filtered extract in a 25 mL volumetric flask and add 2 mL of buffer solution, 2 mL of Na₂-EDTA solution and 2 mL of azomethine-H solution.
2. Mix the contents thoroughly after the addition of each reagent and adjust the volume to 25 mL with distilled water.
3. Let the solution stand for one hour to allow colour development.
4. Measure the intensity of colour using an UV-Vis spectrophotometer at an absorbance of 420 nm (Horneck *et al.*, 1989). The colour solution will be stable for three to four hours.
5. Preparation of the standard curve: Put 0, 0.25, 0.50, 1, 2 and 4 mL of 5 mg B/L solution (working standard) in a series of 25-mL volumetric flasks. Add 2 mL each of buffer reagent, EDTA solution and azomethine-H solution. Mix the contents after each addition and allow to stand at room temperature for 30 minutes. Make the volume up to 25 mL with double-distilled water, and measure absorbance at 420 nm. This will give a reading for standard solution with a B concentration of 0, 0.05, 0.1, 0.2, 0.4 and 0.8 mg B/L. Please note that the calibration curves should be established before running samples.

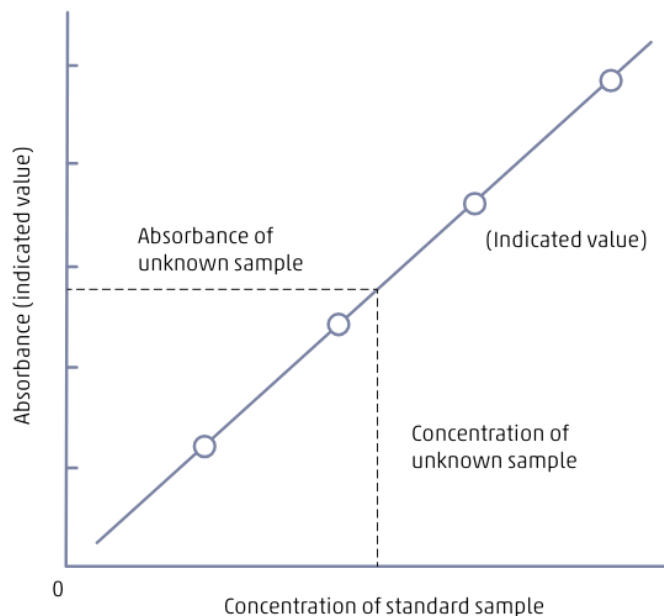
Calculation

The calibration curve of concentration versus absorption is prepared as shown in Figure 3.

Modified by	Revision	Approved date	Validated date
GLOSOLAN SOP Tech. W.G. Global leader: Fassil Kebede, Morocco	By review panel and GLOSOLAN technical committee	17 April 2024	17 April 2024

Global Soil Laboratory Network GLOSOLAN	GLOSOLAN-SOP-24	
BORON BY HOT WATER EXTRACTION	Version number: 1	Page 12 of 24
	Effective date: 17 April 2024	

Figure 3. A calibration curve for determining boron concentration in soils



Source: Authors' own elaboration from the Beer-Lambert Law

The absorbance of unknown samples is measured to obtain the concentration of B in the soil (mg/kg) from the calibration curve by multiplying by a factor of 10 with the following equation:

$$C \text{ (mg/L)} \times DF \text{ (i.e. 10)}$$

where: C (mg/L) = concentration of B as read from the standard curve against the absorbance reading of the soil solution on the spectrophotometer, and the DF = 10, which is calculated as follows:

- weight of the soil sample = 25 g;
- volume of extractant (water) = 50 mL; and
- first dilution = $\times 2$
- volume of the filtrate used = 5 mL;
- final volume of filtrate after colour development = 25 mL;
- second dilution = $\times 5$ times; and
- hence, the total dilution is found to be $5 \times 2 = \times 10$.

Modified by	Revision	Approved date	Validated date
GLOSOLAN SOP Tech. W.G. Global leader: Fassil Kebede, Morocco	By review panel and GLOSOLAN technical committee	17 April 2024	17 April 2024

Global Soil Laboratory Network GLOSOLAN	GLOSOLAN-SOP-24	
BORON BY HOT WATER EXTRACTION	Version number: 1	Page 13 of 24
	Effective date: 17 April 2024	

8.2.2. Hot water-soluble boron determination by atomic absorption spectrometer (AAS)

Procedure

The procedure for the hot water-soluble B determination method using AAS is as follows:

1. Atomize the working standards on an AAS using acetylene nitrous oxide as fuel instead of air acetylene fuel (as used for other micronutrients) at a wavelength of 249.7 nm. Caution: the flame is energetic, unstable and noisy.
2. Prepare a standard curve of known concentration of B by plotting the absorbance values on the y-axis against their respective B concentration on the x-axis. Measure the absorbance of the soil sample extract and determine the B content in the soil from the standard curve. Remember to prepare the calibration curve and check for linearity.

Calculation

To calculate the concentration of B in the soil sample (mg/kg), the following equation should be used:

$$C \text{ (mg/L)} \times 2 \text{ (DF)}$$

where: C = concentration of B in the sample, as read from the standard curve for the given absorbance; and DF = 2 (i.e. 50 mL solution to 25 g soil = 2).

8.2.3. Hot water-soluble boron extraction by inductively coupled plasma-atomic emission spectrometry (ICP-AES)

Signal suppression caused by other dissolved materials in the sample is termed matrix effects (Olivares and Houk, 1986). Hence, a matrix correction is needed when a salt-affected soil sample is analysed. Potassium chloride (KCl) – a salt typically used to demonstrate matrix effects – and calcium chloride (CaCl₂), can be chosen for the purpose because calcium is known to interact with B and has shown signal enhancement matrix effects (Jarvus *et al.*, 1992).

Procedure

The procedure for hot water-soluble extraction by ICP-AES is as follows:

1. Use the 0.10 mg/L standard as a curve verification check. Analyse this standard immediately after calibration and after the last soil sample.
2. Analyse the filtrate by ICP-AES.
3. Prepare one duplicate sample and one quality control sample with each set of samples analysed.

Modified by	Revision	Approved date	Validated date
GLOSOLAN SOP Tech. W.G. Global leader: Fassil Kebede, Morocco	By review panel and GLOSOLAN technical committee	17 April 2024	17 April 2024

Global Soil Laboratory Network GLOSOLAN	GLOSOLAN-SOP-24	
BORON BY HOT WATER EXTRACTION	Version number: 1	Page 14 of 24
	Effective date: 17 April 2024	

- With the ICP-OES or ICP-AES at a wavelength of 249.773 nm, measure the B concentration in the standard series, the blank, and the sample extracts. At this wavelength, a (fitted) background correction is needed.

Please note that beryllium (Be) (5 mg/L) at a wavelength of 234.861 nm is used in some laboratories as an internal standard to compensate for matrix effects (Erwin and Victor, 2004). Moreover, the detection limit for B using ICP-AES (27 MHz plasma) at a wavelength of 249.773 nm is about 5 mg/L (APHA, 1992). Lastly, care must be taken to filter samples properly as colloidal-free extracts are recommended for ICP-AES to avoid nebulizer-clogging problems.

- For the calibration curve, the emission counts are plot on y-axis versus B concentrations of 0, 0.2, 0.4, 0.6, 0.8 and 1 mg B/L on the x-axis. Please note that the computers and software used with the ICP-AES/ICP-OES instruments represent these calibration curves mathematically within the computer's memory.

Calculation

To calculate the concentration of B in the soil sample (mg/kg), the following equation should be used:

ICP extract B reading \times 2.

The DF of 50/25 is the volume of double-distilled water added, divided by the weight of soil used (= 2).

9. Quality assurance/quality control

Analytical method options selected for this analysis must meet or exceed the performance requirements specified below (see Table 1 for the quality control requirements summary). Accuracy and precision requirements apply to measures of long-term method performance (averages and standard deviations).

9.1. Accuracy test

Laboratories must demonstrate method accuracy (measured as average recovery) of 80 to 120 percent or better for clean matrix spikes or certified reference materials at concentrations above ten times the method detection limit (MDL).

9.2. Precision test

Laboratories must demonstrate method precision equal to or better than 15 percent relative standard deviation for clean matrix spikes at concentrations above ten times the MDL. If the precision test fails, the cause of the failure must be identified, and corrective or preventive actions must be developed.

Modified by	Revision	Approved date	Validated date
GLOSOLAN SOP Tech. W.G. Global leader: Fassil Kebede, Morocco	By review panel and GLOSOLAN technical committee	17 April 2024	17 April 2024

Global Soil Laboratory Network GLOSOLAN	GLOSOLAN-SOP-24	
BORON BY HOT WATER EXTRACTION	Version number: 1	Page 15 of 24
	Effective date: 17 April 2024	

9.3. Sensitivity requirement

Where possible, the method should generate MDLs that are less than one fifth of applicable numerical standards. The method is not fit-for-purpose if an MDL exceeds a guideline, standard, or regulatory criteria against which it will be used for evaluation of compliance.

Table 1. Summary of quality control requirements

Method quality control component	Minimum frequency	Minimum data quality objectives (DQOs)*
Method blank	1 per batch (max 20 samples)	Less than reported detection limit
Laboratory control sample or reference material	1 per batch (max 20 samples)	60–140%
Lab duplicate	1 per batch (max 20 samples)	≤40% relative percentage difference (RPD)**

* Minimum DQOs apply to individual QC samples, not averages, and only at levels above 10 × MDL. Laboratories must report qualified data when DQOs are not met.

**An RPD analysis of primary and duplicate/triplicate samples is used to measure the representativeness and/or precision of duplicate samples. The RPD is calculated from the absolute difference between results of the duplicate pair divided by the mean value of the duplicate pair.

10. Recommendations

Recommendations for this process are as follows:

- If glassware is used, it should be washed with a 1:1 mixture of boiling HCl and deionized water before use. It is also advisable to run replicate analysis of all samples when using glassware, to isolate random contamination errors due to insufficient leaching
- The use of azomethine-H is an improvement over that of carmine, quinalizarin and curcumin, since the procedure involving this chemical does not require the use of concentrated acid.
- Care must be taken to filter samples properly to avoid clogging of the nebulizer by colloids in the extract.
- Heating acid solutions containing B to temperatures above 5 °C may result in loss of B if calcium hydroxide (Ca(OH)₂) has not been added.

Modified by	Revision	Approved date	Validated date
GLOSOLAN SOP Tech. W.G. Global leader: Fassil Kebede, Morocco	By review panel and GLOSOLAN technical committee	17 April 2024	17 April 2024

Global Soil Laboratory Network GLOSOLAN	GLOSOLAN-SOP-24	
BORON BY HOT WATER EXTRACTION	Version number: 1	Page 16 of 24
	Effective date: 17 April 2024	

- Soils containing higher organic matter may require additional amounts of charcoal to obtain a colourless extract, but the addition of excessive amounts of charcoal can reduce the amount of B in the extract.
- If it is necessary to use charcoal, it should be washed several times with dilute HCl to remove possible B contamination. It is important that the solutions be mixed thoroughly.

11. Interpretation of results

Boron is unique among the trace elements because very small quantities are necessary for optimal crop production. However, a slightly high concentration may become toxic for the plant, as the range between B deficiency and toxicity is very narrow (Gupta, 1993). Hot water-soluble B generally follows the classes given in Table 2.

Table 2. Hot water-soluble boron class

Category	mg B/kg soil
Insufficient	<1
For normal growth	1–2
High	2.1–5
Excessive	>5

Source: **Benton Jones, J.** 2001. *Laboratory guide for conducting soil tests and plant analysis*. Boca Raton, USA, CRC Press.

Boron is routinely recommended for alfalfa, cotton, peanuts and all commercial vegetable crops that reseed with clover or where clover seed is to be harvested. It is not advisable to exceed the rates recommended for the specific crops, as B toxicity can occur from excessive applications.

Crops differ in the amount of B they can tolerate. Sensitive crops are soybeans, peaches, and strawberries. Some of the tolerant crops are alfalfa, clovers, cole crops, and root crops. Maize, cotton, tobacco, tomatoes and small grains are intermediate.

Modified by	Revision	Approved date	Validated date
GLOSOLAN SOP Tech. W.G. Global leader: Fassil Kebede, Morocco	By review panel and GLOSOLAN technical committee	17 April 2024	17 April 2024

Global Soil Laboratory Network GLOSOLAN	GLOSOLAN-SOP-24	
BORON BY HOT WATER EXTRACTION	Version number: 1	Page 17 of 24
	Effective date: 17 April 2024	

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Modified by	Revision	Approved date	Validated date
GLOSOLAN SOP Tech. W.G. Global leader: Fassil Kebede, Morocco	By review panel and GLOSOLAN technical committee	17 April 2024	17 April 2024

Global Soil Laboratory Network GLOSOLAN	GLOSOLAN-SOP-24	
BORON BY HOT WATER EXTRACTION	Version number: 1	Page 18 of 24
	Effective date: 17 April 2024	

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Modified by	Revision	Approved date	Validated date
GLOSOLAN SOP Tech. W.G. Global leader: Fassil Kebede, Morocco	By review panel and GLOSOLAN technical committee	17 April 2024	17 April 2024

Global Soil Laboratory Network GLOSOLAN	GLOSOLAN-SOP-24	
BORON BY HOT WATER EXTRACTION	Version number: 1	Page 19 of 24
	Effective date: 17 April 2024	

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Modified by	Revision	Approved date	Validated date
GLOSOLAN SOP Tech. W.G. Global leader: Fassil Kebede, Morocco	By review panel and GLOSOLAN technical committee	17 April 2024	17 April 2024

Global Soil Laboratory Network GLOSOLAN	GLOSOLAN-SOP-24	
BORON BY HOT WATER EXTRACTION	Version number: 1	Page 20 of 24
	Effective date: 17 April 2024	

Appendix I: International Chemical Safety Cards (ICSCs) for some risky chemical reagents

ASCORBIC ACID				ICSC: 0379 (June 1997)
Vitamin C L-Ascorbic acid L-Xyloascorbic acid 3-Oxo-L-gulofuranolactone (enol form)				
CAS #: 50-81-7 EC Number: 200-066-2				

FIRE & EXPLOSION	ACUTE HAZARDS	PREVENTION	FIRE FIGHTING
	Combustible.	NO open flames.	Use water spray, powder.

PREVENT DISPERSION OF DUST!			
SYMPTOMS	PREVENTION	FIRST AID	
Inhalation	Cough, Sore throat.	Use local exhaust or breathing protection.	Fresh air, rest.
Skin	Redness.	Protective gloves.	Remove contaminated clothes. Rinse skin with plenty of water or shower.
Eyes	Redness, Pain.	Wear safety spectacles.	First rinse with plenty of water for several minutes (remove contact lenses if easily possible), then refer for medical attention.
Ingestion			Rinse mouth.

SPILLAGE DISPOSAL	CLASSIFICATION & LABELLING
Personal protection: particulate filter respirator adapted to the airborne concentration of the substance. Sweep spilled substance into covered containers. If appropriate, moisten first to prevent dusting. Wash away remainder with plenty of water.	According to UN GHS Criteria
STORAGE	
Separated from strong oxidants and strong bases.	
PACKAGING	Transportation UN Classification

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ASCORBIC ACID	ICSC: 0379
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SODIUM BORATE, DECAHYDRATE				ICSC: 0567 (April 2014)
Disodium tetraborate decahydrate Sodium tetraborate decahydrate Sodium pyroborate decahydrate Borax				
CAS #: 1303-96-4 EC Number: 215-540-4				

FIRE & EXPLOSION	ACUTE HAZARDS	PREVENTION	FIRE FIGHTING
	Not combustible.		In case of fire in the surroundings, use appropriate extinguishing media.




PREVENT DISPERSION OF DUST! STRICT HYGIENE!			
SYMPTOMS	PREVENTION	FIRST AID	
Inhalation	Cough, Sore throat.	Use local exhaust or breathing protection.	Fresh air, rest.
Skin	Redness.	Protective gloves. Protective clothing.	Rinse and then wash skin with water and soap.
Eyes	Redness, Pain.	Wear safety spectacles or eye protection in combination with breathing protection.	Rinse with plenty of water (remove contact lenses if easily possible).
Ingestion	Nausea, Vomiting, Diarrhoea, Headache, Weakness, Drowsiness, Convulsions.	Do not eat, drink, or smoke during work.	Rinse mouth. Do NOT induce vomiting. Refer for medical attention.





SPILLAGE DISPOSAL	CLASSIFICATION & LABELLING
Personal protection: particulate filter respirator adapted to the airborne concentration of the substance. Sweep spilled substance into covered containers. If appropriate, moisten first to prevent dusting. Carefully collect remainder. Then store and dispose of according to local regulations.	According to UN GHS Criteria <div style="text-align: center;"> DANGER </div>
STORAGE	
Well closed. Dry.	
PACKAGING	Causes eye irritation May damage fertility or the unborn child Transportation UN Classification

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Modified by	Revision	Approved date	Validated date
GLOSOLAN SOP Tech. W.G. Global leader: Fassil Kebede, Morocco	By review panel and GLOSOLAN technical committee	17 April 2024	17 April 2024

Global Soil Laboratory Network GLOSOLAN	GLOSOLAN-SOP-24	
BORON BY HOT WATER EXTRACTION	Version number: 1	Page 21 of 24
	Effective date: 17 April 2024	

CALCIUM HYDROXIDE			ICSC: 0408 (September 1997)
Calcium dihydroxide Calcium hydrate Hydrated lime Slaked lime			
CAS #: 1305-62-0			
EC Number: 215-137-3			
FIRE & EXPLOSION	ACUTE HAZARDS	PREVENTION	FIRE FIGHTING
	Not combustible.		In case of fire in the surroundings, use appropriate extinguishing media.
PREVENT DISPERSION OF DUST!			
	SYMPTOMS	PREVENTION	FIRST AID
Inhalation	Sore throat. Cough. Burning sensation.	Use local exhaust or breathing protection.	Fresh air, rest. Refer for medical attention.
Skin	Redness. Roughness. Pain. Dry skin. Skin burns. Blisters.	Protective gloves. Protective clothing.	Remove contaminated clothes. Rinse skin with plenty of water or shower. Refer for medical attention.
Eyes	Redness. Pain. Severe deep burns.	Wear safety goggles, face shield or eye protection in combination with breathing protection.	First rinse with plenty of water for several minutes (remove contact lenses if easily possible), then refer for medical attention.
Ingestion	Burning sensation. Abdominal pain. Abdominal cramps. Vomiting.	Do not eat, drink, or smoke during work.	Rinse mouth. Do NOT induce vomiting. Give nothing to drink. Refer for medical attention.
SPILLAGE DISPOSAL		CLASSIFICATION & LABELLING	
Personal protection: particulate filter respirator adapted to the airborne concentration of the substance. Sweep spilled substance into covered containers. Then store and dispose of according to local regulations.		According to UN GHS Criteria	
STORAGE		Transportation UN Classification	
Separated from strong acids.			
PACKAGING			
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CALCIUM CHLORIDE (ANHYDROUS)			ICSC: 1184 (June 2012)
CAS #: 10043-62-4			
EC Number: 233-140-8			
FIRE & EXPLOSION	ACUTE HAZARDS	PREVENTION	FIRE FIGHTING
	Not combustible. Gives off irritating or toxic fumes (or gases) in a fire.		In case of fire in the surroundings, use appropriate extinguishing media.
PREVENT DISPERSION OF DUST! IN ALL CASES CONSULT A DOCTOR!			
	SYMPTOMS	PREVENTION	FIRST AID
Inhalation	Cough. Sore throat. Burning sensation.	Use local exhaust or breathing protection.	Fresh air, rest. Refer for medical attention.
Skin	Redness. Dry skin. Skin burns.	Protective gloves.	Remove contaminated clothes. Rinse skin with plenty of water or shower. Refer immediately for medical attention.
Eyes	Redness. Pain. Burns.	Wear safety goggles in combination with breathing protection.	Rinse with plenty of water for several minutes (remove contact lenses if easily possible). Refer immediately for medical attention.
Ingestion	Burns in mouth and throat. Nausea. Vomiting.	Do not eat, drink, or smoke during work.	Rinse mouth. Do NOT induce vomiting. Give one or two glasses of water to drink. Refer immediately for medical attention.
SPILLAGE DISPOSAL		CLASSIFICATION & LABELLING	
Personal protection: complete protective clothing including self-contained breathing apparatus. Sweep spilled substance into covered containers. If appropriate, moisten first to prevent dusting. Wash away remainder with plenty of water.		According to UN GHS Criteria	
STORAGE		 Causes severe skin burns and eye damage May cause respiratory irritation May be harmful if swallowed	
Separated from zinc. Dry. Well closed.			
PACKAGING		Transportation UN Classification	
Airtight.			
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Modified by	Revision	Approved date	Validated date
GLOSOLAN SOP Tech. W.G. Global leader: Fassil Kebede, Morocco	By review panel and GLOSOLAN technical committee	17 April 2024	17 April 2024

Global Soil Laboratory Network GLOSOLAN	GLOSOLAN-SOP-24	
BORON BY HOT WATER EXTRACTION	Version number: 1	Page 22 of 24
	Effective date: 17 April 2024	

Appendix II: Acknowledgements

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Appendix III: List of authors

Lead author:

- Fasil Kebede, Soil Spectroscopy Laboratory, Center for Soil and Fertilizer Research in Africa (CESFRA), Mohammed VI Polytechnic University (UM6P), **Morocco**.

Main authors (in alphabetical order):

- Muhammad Ansar Farooq, National University of Science & Technology (NUST), **Pakistan**; and
- Mopmanee Suvannang, Land Development Department, Ministry of Agriculture and Cooperatives, **Thailand**.

Members of the review panel (from the International Network on Salt-Affected Soils):

- Jason Reynolds, School of Science, Western Sydney University, **Australia**;
- Georges K. Kome, University of Dschang, **Cameroon**;
- Magdi Abdelhamid, Botany Department, National Research Centre, **Egypt**;
- Shiveshwar Pratap Singh, Rajendra Prasad Central Agricultural University, **India**;
- Karim Shahbazi, Laboratories Department, Soil and Water Research Institute (SWRI), **Islamic Republic of Iran**;
- Jorge Battle-Sales, University of Valencia, **Spain**;
- Mike Schmidt, Agricultural Water Efficiency and Salinity Research Unit, USDA Agricultural Research Service, **United States of America**; and
- Todd Skaggs, Agricultural Water Efficiency and Salinity Research Unit - U.S. Salinity Laboratory, USDA Agricultural Research Service, **United States**

Modified by	Revision	Approved date	Validated date
GLOSOLAN SOP Tech. W.G. Global leader: Fasil Kebede, Morocco	By review panel and GLOSOLAN technical committee	17 April 2024	17 April 2024

Global Soil Laboratory Network GLOSOLAN	GLOSOLAN-SOP-24	
BORON BY HOT WATER EXTRACTION	Version number: 1	Page 23 of 24
	Effective date: 17 April 2024	

Appendix IV: Contributing laboratories

GLOSOLAN would like to thank the following laboratories for completing the GLOSOLAN form on the method and providing information on their SOP for boron determination in soil. This information was used as a baseline for the global harmonization.

From the African region:

- Farming and Engineering Services, Agrilab, **Malawi**; and
- Central Services Laboratory National Cereals Research Institute, **Nigeria**.

From the Asian region:

- Central Laboratory, Soil Resource Development Institute, **Bangladesh**;
- Soil Resource Development Institute, **Bangladesh**;
- Agri Biochem Research Lab, **India**;
- Laboratorium Pengujian, Balittanah, Soil Test Laboratory, Indonesian Soil Research Institute (ISRI), **Indonesia**;
- Soil Science Research Section, Department of Agricultural Research, **Myanmar**;
- Soil and Plants Nutrition Laboratory, Land Resources Research Institute (LRRI), National Agricultural Research Centre (NARC), **Pakistan**; and
- Regional Soils Laboratory, Department of Agriculture Regional Field Office 12, **Philippines**.

From the European region:

- Soil and Water Laboratory, Centre of Agriculture Technology Transfer (QTTB), **Albania**;
- Laboratório de Solos e Fertilidade da Escola Superior Agrária de Castelo Branco, **Portugal**;
- Laboratorio Quimico Agricola Rebelo da Silva, INIAV/SAFSV/LQARS, **Portugal**;
- SGS Portugal, **Portugal**;
- International Agricultural Research And Training Center, IARTC-UTAEM, **Türkiye**;
- Ankara University, Faculty of Agriculture, Department of Soil Science and Plant Nutrition, **Türkiye**; and
- Ministry of Agriculture and Forestry - Soil, Fertilizer And Water Resources Central Research Institute, **Türkiye**.

From the Latin American region:

- Laboratorio de Suelos, Instituto de Investigaciones Agropecuarias (INIA), **Chile**;
- Instituto Geográfico Agustín Codazzi (IGAC), **Colombia**;

Modified by	Revision	Approved date	Validated date
GLOSOLAN SOP Tech. W.G. Global leader: Fassil Kebede, Morocco	By review panel and GLOSOLAN technical committee	17 April 2024	17 April 2024

Global Soil Laboratory Network GLOSOLAN	GLOSOLAN-SOP-24	
BORON BY HOT WATER EXTRACTION	Version number: 1	Page 24 of 24
	Effective date: 17 April 2024	

- Laboratorio de Suelos Foliare y Aguas, Agencia de Regulación y Control Fito y Zoonosanitario – Agrocalidad, **Ecuador**; and
- Laboratorio de Suelos y Agua comandante Fidel Castro Ruz, Nicaraguan Institute of Agricultural Technology (INTA), **Nicaragua**.

From the Near East and North Africa region:

- Soil, Water and Environment Research Institute, **Egypt**;
- KIMIA AB Environmental and Agricultural Consulting Laboratory, **Islamic Republic of Iran**;
- Soil and Water Research Institute Laboratory, Soil and Water Research Institute, **Islamic Republic of Iran**;
- LABOMAG, **Morocco**; and
- National Center for Research Agriculture and Livestock, Ministry of Environment, Water and Agriculture, **Saudi Arabia**.

From the Pacific region:

- SWEP Analytical Laboratories, **Australia**;
- Fiji Agricultural Chemistry Laboratory, **Fiji**; and
- School of Agriculture and Food Technology - The University of the South Pacific, **Samoa**.

Modified by	Revision	Approved date	Validated date
GLOSOLAN SOP Tech. W.G. Global leader: Fassil Kebede, Morocco	By review panel and GLOSOLAN technical committee	17 April 2024	17 April 2024



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.

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