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**Soil quality — Determination of soil  
microbial diversity —**

Part 1:

**Method by phospholipid fatty acid  
analysis (PLFA) and phospholipid ether  
lipids (PLEL) analysis**

*Qualité du sol — Détermination de la diversité microbienne du sol —*

*Partie 1: Méthode par analyse des acides gras phospholipidiques  
(PLFA) et par analyse des lipides éther phospholipidiques (PLEL)*

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Case postale 56 • CH-1211 Geneva 20  
Tel. + 41 22 749 01 11  
Fax + 41 22 749 09 47  
E-mail [copyright@iso.org](mailto:copyright@iso.org)  
Web [www.iso.org](http://www.iso.org)

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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In other circumstances, particularly when there is an urgent market requirement for such documents, a technical committee may decide to publish other types of document:

- an ISO Publicly Available Specification (ISO/PAS) represents an agreement between technical experts in an ISO working group and is accepted for publication if it is approved by more than 50 % of the members of the parent committee casting a vote;
- an ISO Technical Specification (ISO/TS) represents an agreement between the members of a technical committee and is accepted for publication if it is approved by 2/3 of the members of the committee casting a vote.

An ISO/PAS or ISO/TS is reviewed after three years in order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn. If the ISO/PAS or ISO/TS is confirmed, it is reviewed again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TS 29843-1 was prepared by Technical Committee ISO/TC 190, *Soil quality*, Subcommittee SC 4, *Biological methods*.

ISO/TS 29843 consists of the following parts, under the general title *Soil quality — Determination of soil microbial diversity*:

- *Part 1: Method by phospholipid fatty acid analysis (PLFA) and phospholipid ether lipids (PLEL) analysis*
- *Part 2: Method by phospholipid fatty acid analysis (PLFA) using the “simple PLFA extraction method”*

## Introduction

Phospholipids are essential components of membranes of all living cells, and their fatty acid (PLFA: phospholipid fatty acids) or ether-linked isoprenoid side chains (PLEL: phospholipid ether lipid) allow for taxonomic differentiation within complex microbial communities (References [5] and [7]). This approach is now well established in soil ecology and serves as a phenotypic and thus complementary tool to genotypic (molecular genetic) approaches for determining microbial diversity.

Different methodologies for determination of soil fatty acids are available. These methodologies present different levels of complexity when applied and provide different levels of resolution in the description of soil microbial communities.

The determination of total PLFA and PLEL provides a quantitative measure of the viable biomass of soil: microorganisms of all three domains of the biosphere (bacteria, fungi and archaeobacteria). Viable microbes have an intact membrane, which contains phospholipids. Cellular enzymes hydrolyze and release the phosphate group within minutes or hours following cell death (Reference [6]).

Apart from taxonomic descriptions, the PLFA technique enables the determination of physiological changes within microbial consortia. For instance, the monoenic PLFA 16:1  $\omega$ 7c and 18:1  $\omega$ 7c are increasingly converted to the cyclopropyl fatty acids cy17:0 and cy19:0 in Gram-negative bacteria in response to environmental stress (Reference [2]).

Besides the method described in this part of ISO/TS 29843, other methods for the determination of PLFA are available (References [3] and [6]). With these methods, only bacterial and fungal PLFA can be estimated; the determination of hydroxy-substituted fatty acids (PLOH), non-ester-linked (NEL) fatty acids and PLEL is not possible.

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# Soil quality — Determination of soil microbial diversity —

## Part 1: Method by phospholipid fatty acid analysis (PLFA) and phospholipid ether lipids (PLEL) analysis

### 1 Scope

This part of ISO/TS 29843 specifies an extended method for the extraction and determination of both phospholipid fatty acids (PLFA) and phospholipid ether lipids (PLEL) from soils.

ISO/TS 29843-2 specifies a simple method for the extraction of only PLFA from soils.

### 2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 10381-6, *Soil quality — Sampling — Part 6: Guidance on the collection, handling and storage of soil under aerobic conditions for the assessment of microbiological processes, biomass and diversity in the laboratory*

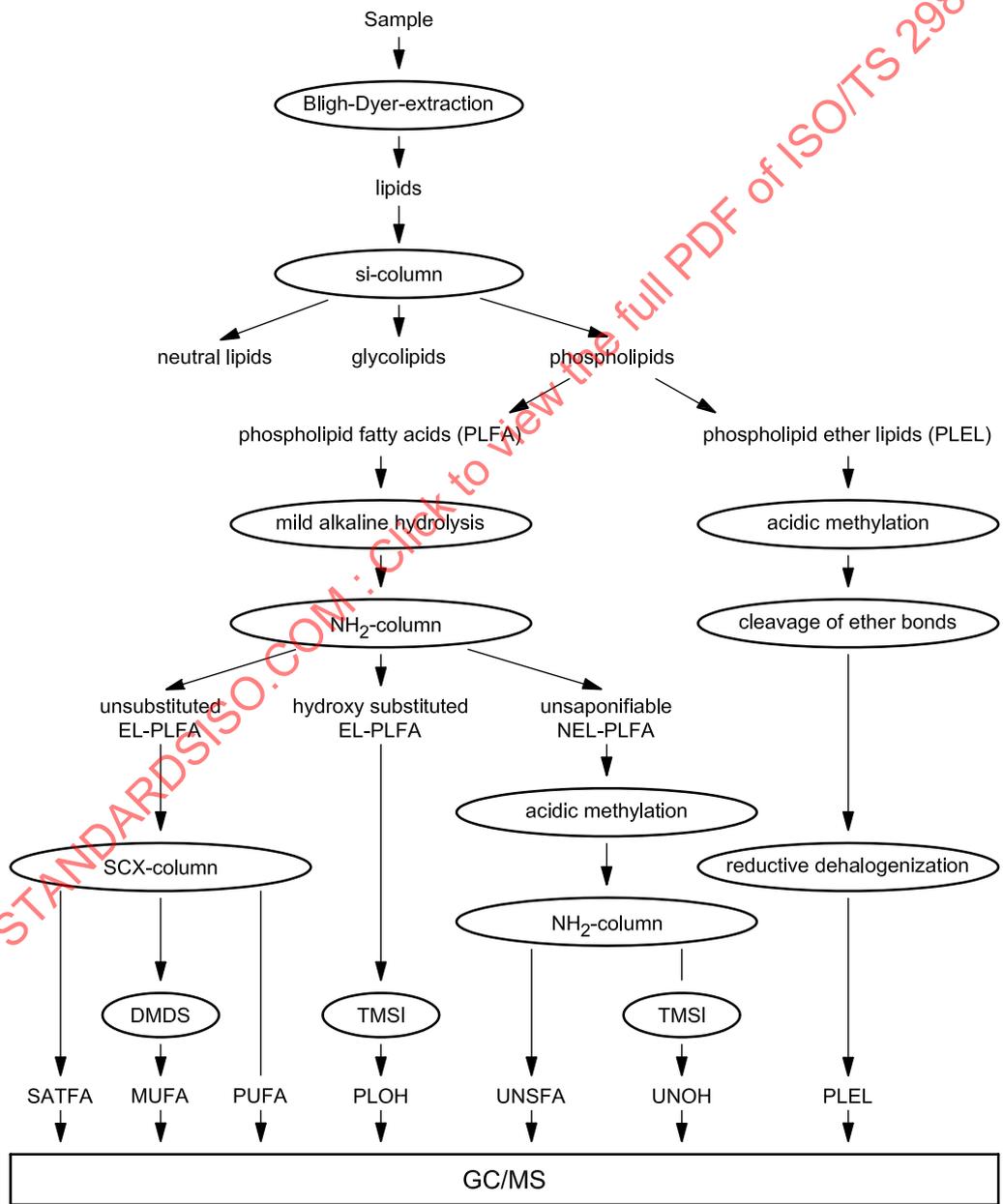
### 3 Abbreviated terms

<b>FAME</b>	fatty acid methyl ester(s)
<b>(EL-)PLFA</b>	(ester-linked) phospholipid fatty acid(s)
<b>PLEL</b>	phospholipid ether lipid(s)
<b>SATFA</b>	saturated fatty acid(s)
<b>MUFA</b>	mono-unsaturated fatty acid(s)
<b>PUFA</b>	poly-unsaturated fatty acid(s)
<b>PLOH</b>	hydroxy-substituted fatty acid(s)
<b>NEL-PLFA</b>	non-ester-linked phospholipid fatty acid(s)
<b>UNSFA</b>	unsubstituted fatty acid(s)
<b>UNOH</b>	hydroxy-substituted fatty acid(s)
<b>GC/MS</b>	gas chromatography/mass spectrometry

**SCX** strong cation exchange  
**HPLC** high-performance liquid chromatography

**4 Principle**

Lipids are extracted using the Bligh and Dyer<sup>[9]</sup> extraction procedure. Lipid extracts are separated by liquid chromatography using a silica column (si-column). Phospholipids are transformed into fatty acid methyl esters (FAME) by mild alkaline hydrolysis and into phospholipid ether lipids (PLEL) by acid hydrolysis and methylation. Separation of FAME into saturated (SATFA), mono-unsaturated (MUFA), poly-unsaturated (PUFA), hydroxy-substituted (PLOH), non-ester-linked unsubstituted (NEL-UNSFA) and non-ester-linked hydroxy-substituted (NEL-UNOH) fatty acids is achieved on solid-phase extraction columns. The different FAME are measured using gas chromatography/mass spectrometry (GC/MS). A schematic overview of the procedures is given in Figure 1.



**Figure 1 — Schematic overview of PLFA and PLEL analysis**

## 5 Reagents and materials

### 5.1 Soil

Take soil samples and prepare them as specified in ISO 10381-6. If samples which have been sieved in the fresh state are not analysed immediately, they may be kept at  $-20\text{ }^{\circ}\text{C}$  or stored in chloroform after lipid extraction (see 6.1).

### 5.2 Reagents

During the analysis, unless otherwise stated, use only reagents of recognized analytical grade.

- 5.2.1 Acetone**,  $\text{C}_3\text{H}_6\text{O}$ , residue analysis.
- 5.2.2 Acetonitrile**,  $\text{CH}_3\text{CN}$ , for high-performance liquid chromatography (HPLC).
- 5.2.3 Bis(trimethylsilyl)trifluoroacetamide (BSTFA)**.
- 5.2.4 Celite 545<sup>1)</sup>**, particle size 0,02 mm to 0,10 mm.
- 5.2.5 Chloroform**,  $\text{CHCl}_3$ .
- 5.2.6 Dichloromethane**,  $\text{CH}_2\text{Cl}_2$ , for residue analysis.
- 5.2.7 Diethyl ether**,  $(\text{C}_2\text{H}_5)_2\text{O}$ .
- 5.2.8 Dimethyl disulfide (DMDS)**,  $(\text{CH}_3\text{S})_2$ .
- 5.2.9 Acetic acid**,  $\text{CH}_3\text{COOH}$ .
- 5.2.10 Ethyl acetate**,  $\text{C}_4\text{H}_8\text{O}$ .
- 5.2.11 Hexamethyldisilane (HMDS)**.
- 5.2.12 Hexane**,  $\text{C}_6\text{H}_{14}$ , for residue analysis.
- 5.2.13 Potassium hydroxide**, KOH.
- 5.2.14 Methanol**,  $\text{CH}_3\text{OH}$ , for residue analysis.
- 5.2.15 Sodium sulfate**,  $\text{Na}_2\text{SO}_4$ .
- 5.2.16 Sodium thiosulfate**,  $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$ .
- 5.2.17 Aminopropyl-column [Chromabond<sup>2)</sup>] NH<sub>2</sub>-column**.
- 5.2.18 Pyridine**, dried, maximum 0,01 %  $\text{H}_2\text{O}$ .
- 5.2.19 Hydrochloric acid**, HCl.
- 5.2.20 Silver nitrate**,  $\text{AgNO}_3$ .

1) Celite 545 is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

2) Chromabond is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

5.2.21 Toluene, C<sub>7</sub>H<sub>8</sub>, scintillation grade.

5.2.22 Trimethylchlorosilane (TMSI).

5.2.23 Potassium hydrogenphosphate, K<sub>2</sub>HPO<sub>4</sub>.

5.2.24 Nonadecanoic acid methyl ester, C<sub>20</sub>H<sub>40</sub>O<sub>2</sub>.

5.2.25 Hydriodic acid, HI, 57 % stabilized with hydrophosphorous acid.

5.2.26 Isooctane, C<sub>8</sub>H<sub>18</sub>.

5.2.27 Iodine, I<sub>2</sub>, 6 % in diethyl ether.

5.2.28 Sodium carbonate, Na<sub>2</sub>CO<sub>3</sub>.

5.2.29 Zinc powder, GR quality for analyses, particle size 45 µm.

### 5.3 Buffers and standards

5.3.1 Phosphate buffer, 0,05 mol/l, 17,42 g of K<sub>2</sub>HPO<sub>4</sub> in 2 000 ml H<sub>2</sub>O, adjusting with 4 mol/l HCl to pH 7,4.

5.3.2 Methanolic KOH solution, 0,2 mol/l, 0,11 g of KOH in 10 ml of methanol.

5.3.3 Acetic acid, 1 mol/l, 6,0 g of acetic acid (100 %) in 100 g of water.

5.3.4 Sodium carbonate solution, 0,1 mol/l, 5,3 g of Na<sub>2</sub>CO<sub>3</sub> in 500 ml of water.

5.3.5 Sodium carbonate solution, 10 %, 40 g of Na<sub>2</sub>CO<sub>3</sub>·5H<sub>2</sub>O in 360 g of water.

5.3.6 Sodium thiosulfate solution, 50 %, 272,5 g of Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub>·5H<sub>2</sub>O in 200 g of water.

5.3.7 Standard (C<sub>19:0</sub> FAME), 25,0 mg nonadecanoic acid methyl ester in 25,0 ml of *i*-octane = stock solution => dilution 1:10 with *i*-octane [2,5 ml of stock solution (using a 5 ml pipette) adjusting to 25,0 ml with *i*-octane]; final concentration 32,05 nmol/100 µl<sup>-1</sup>.

### 5.4 Apparatus

Usual laboratory equipment and the following.

5.4.1 SCX-column, strong-cation-exchange column, 0,5 g/3 ml, Bond Elut 1210-2040<sup>3)</sup>.

5.4.2 SI-column, 2 g/12 ml, Mega Bond Elut 1225-6018<sup>4)</sup>.

5.4.3 Gas chromatograph, with mass-selective detector equipped with a capillary column (length = 50 m, internal diameter = 0,2 mm, coated with a cross-linked 5 % phenylmethyl rubber phase with a film thickness of 0,3 µm).

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3) Bond Elut 1210-2040 is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

4) Mega Bond Elut 1225-6018 is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

## 6 Procedures

### 6.1 Lipid extraction (Bligh-Dyer-extraction)

About 10 g to 25 g of soil (dry weight) are put in a 500 ml volumetric flask; 125 ml of methanol (5.2.14), 62,5 ml chloroform (5.2.5), 0,05 mol/l phosphate buffer (pH 7,4; 50 ml minus the water content in soil, 5.3.1) are added. After shaking for 2 h, 62,5 ml of water and 62,5 ml of chloroform (5.2.5) are added. The mixture is kept for 24 h, then the water phase is removed and discarded. The organic phase and slurry are passed through a filtration funnel containing 2 cm of Celite 545 (5.2.4). The chloroform phase is transferred to a separating funnel, dried over anhydrous sodium sulfate (5.2.15) and reduced to a small volume (about 10 ml).

### 6.2 Separation of lipids by si-column

Column size:	2 g/12 ml (reservoir volume, <i>V</i> ).
Conditioning:	1 <i>V</i> of chloroform (5.2.5).
Sample application:	sample dissolved in chloroform (5.2.5); sample volume: < 12 ml.
Elution:	1 <i>V</i> of chloroform (5.2.5) for neutral lipids, 1 <i>V</i> of acetone (5.2.1) for glycolipids and 4 <i>V</i> of methanol (5.2.14) for phospholipids. The last fraction is reduced to almost dryness.

The following protocol is divided into two parts: the analysis of the phospholipids, PLFA (6.3) and the ether lipids, PLEL (6.4).

### 6.3 PLFA analysis

#### 6.3.1 Mild alkaline hydrolysis

During this step, ester bonds between the glycerol backbone and the fatty acid side chains are cleaved and fatty acid methyl esters (FAME) are formed from the released fatty acids.

The residue of phospholipids is dissolved in 1 ml of methanol (5.2.14):toluene (5.2.21) (1:1, volume fraction), then 5 ml of 0,2 mol/l KOH (5.2.13) in methanol (freshly prepared, 5.3.2) are added. This mixture is incubated for 15 min at 37 °C. Afterwards, the pH of this mixture is adjusted to approximately pH 6 with 1 mol/l acetic acid (5.3.3). 10 ml of chloroform (5.2.5) and 10 ml of water are added and transferred to a centrifugation tube. This tube is mixed for 1 min and centrifuged at 2 000 *g* for 10 min. After removing the chloroform phase (lower phase), the water phase is extracted once more with 5 ml of chloroform (5.2.5). The combined chloroform phases are dried over sodium sulfate (5.2.15) and reduced to a small volume.

#### 6.3.2 NH<sub>2</sub> column: Separation of FAME from OH-substituted FAME (PLOH) and unsaponifiable lipids

FAME generated during step 6.3.1 are separated on the NH<sub>2</sub> column.

Column size:	0,5 g/3 ml.
Conditioning:	1 <i>V</i> of hexane (5.2.12):dichloromethane (5.2.6) (3:1, volume fraction).
Sample application:	sample dissolved in hexane (5.2.12):dichloromethane (5.2.6) (3:1, volume fraction), sample volume < 1,5 ml.
Elution:	1 <i>V</i> of hexane (5.2.12):dichloromethane (5.2.6) (3:1, volume fraction) for unsubstituted FAME; 1 <i>V</i> of dichloromethane (5.2.6):ethyl acetate (5.2.10) (9:1, volume fraction) for PLOH and 2 <i>V</i> of 2 % acetic acid in methanol for unsaponifiable lipids.

### 6.3.3 SCX column: Separation of unsubstituted ester-linked PLFA (EL-PLFA)

Unsubstituted ester-linked PLFA obtained during step 6.3.2 are separated via a silver-impregnated SCX column.

Column size:	0,5 g/3 ml.
Conditioning:	0,1 g of silver nitrate (5.2.20) in 1,5 ml of acetonitrile (5.2.2):water (10:1, volume fraction), followed by 2V of acetonitrile (5.2.2), 2V of acetone (5.2.1) and 4V of dichloromethane (5.2.6).
Sample application:	sample is dissolved in dichloromethane (5.2.6):hexane (5.2.12) (7:3, volume fraction); sample volume < 3,0 ml.
Elution:	2V of dichloromethane (5.2.6):hexane (5.2.12) (7:3, volume fraction) to elute the SATFA; 2V of dichloromethane (5.2.6):acetone (5.2.1) (9:1, volume fraction) to obtain the MUFA and 4V of acetone (5.2.1):acetonitrile (5.2.2) (9:1, volume fraction) to elute the PUFA. All liquids should pass the column without pressure.

### 6.3.4 Acidic methylation of unsaponifiable lipids and separation into UNOH and UNSFA

NEL-PLFA are generated through the hydrolysis and methylation of the unsaponifiable lipid fraction obtained during step 6.3.2.

After solvent removal, the residue of the unsaponifiables is redissolved in 2 ml of methanol:chloroform:hydrochloric acid (37 %) (10:1:1, volume fraction) in a centrifugation tube, and is kept at 60 °C overnight. Then, 2 ml of 2 % sodium chloride are added. The extraction is done three times with 4 ml of hexane (5.2.12):toluene (5.2.21) (1:1, volume fraction). The sample is dried with sodium sulfate (5.2.15) (sodium sulfate is washed with hexane). The resulting NEL-PLFA are separated into UNOH and UNSFA using the procedure of step 6.3.2.

### 6.3.5 TMSI derivatization of PLOH and UNOH (see 5.2.22)

PLOH and UNOH obtained during steps 6.3.2 and 6.3.4, respectively, are derivatized prior to gas chromatography (GC) injection:

0,5 ml of a mixture of pyridine (5.2.18):BSTFA (5.2.3):hexamethyldisilane (5.2.11):trimethylchlorosilane (5.2.22) (0,2:1:2:1, volume fraction) are added to the sample. This mixture is kept at 60 °C for 15 min, then evaporated by a stream of nitrogen.

### 6.3.6 DMDS derivatization of MUFA (see 5.2.8)

MUFA obtained during step 6.3.3 are derivatized prior to GC injection:

The sample is dissolved in 0,05 ml of hexane (5.2.12), 0,1 ml of DMDS (5.2.8), and three to five drops of iodine (6 % in diethyl ether, 5.2.27) are added. This mixture is kept at 60 °C for 72 h. The excess iodine is removed by addition of 1 ml of 5 % sodium thiosulfate (5.2.16) and the adduct is extracted three times with 1,5 ml of hexane (5.2.12). The hexane phases are combined, dried with sodium sulfate (5.2.15) and evaporated until nearly dry.